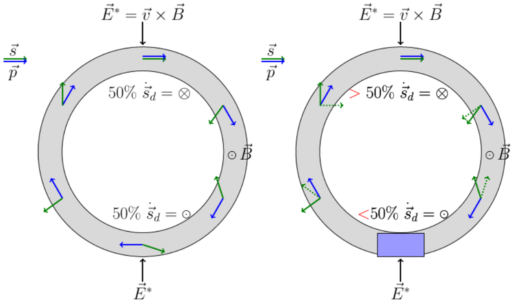
# Stabilization of the Deuteron Spin Tune in a Storage Ring Using Active Feedback

27.9.2016 | Nils Hempelmann, on behalf of the JEDI-Collaboration |

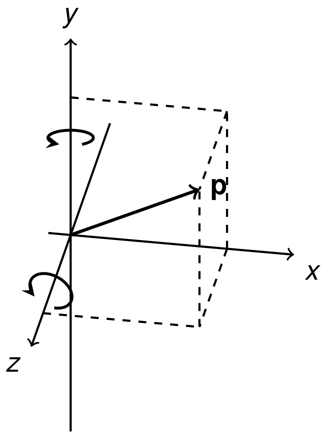
# Introduction




- Precursor experiment needs Wien filter to measure electric dipole moment (EDM)
- Currently no Wien filter in COSY ring, use solenoid as substitute

# Solenoid and Wien Filter

- Spin precesses around y-axis in the ring
- Solenoid rotates spin around beam axis (z), Wien filter around y-axis
- Slow build-up of vertical polarization from horizontally polarized beam



# Feedback System

- Feedback system fixes phase between spin precession and solenoid frequency

1. Measure polarimeter events, COSY frequency and solenoid frequency using one time reference
2. Readjust COSY rf frequency to change the relative phase between spin frequency and solenoid
3. Repeat to keep phase stable

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# Phase Difference and Spin Tune

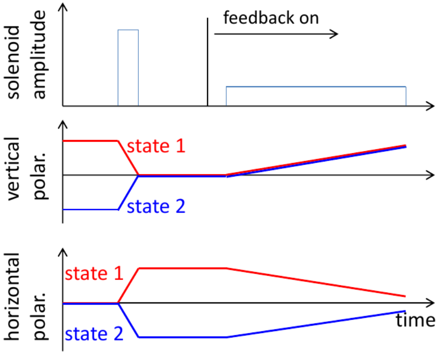
- Relative phase:
  $\phi = 2\pi f_{\mathrm{sol}} T - 2\pi \nu_s f_{\mathrm{COSY}} T = 2\pi n \left( \frac{f_{\mathrm{sol}}}{f_{\mathrm{COSY}}} - \nu_s \right)$
- COSY frequency change has two effects for phase:
  - Spin tune changes
  - Particles arrive at the detector at a different time

## Phase Difference and Spin Tune

- $$\frac{d\phi}{df_{\mathrm{COSY}}} = 2\pi n \left( \underbrace{-\frac{f_{\mathrm{sol}}}{f_{\mathrm{COSY}}^2}}_{\text{timing}} \underbrace{-\frac{d\nu_s}{df_{\mathrm{COSY}}}}_{\text{tune}} \right)$$
- Spin tune effect: $\frac{\Delta\nu_s}{\nu_s} = \frac{\Delta\gamma}{\gamma} = \beta^2 \frac{\Delta p}{p} = \frac{\beta^2}{\eta} \frac{\Delta f}{f}$
- At $f_{\mathrm{COSY}} \approx 750\,\mathrm{kHz}$ and $f_{\mathrm{sol}} \approx 871\,\mathrm{kHz}$:
- $\frac{|\Delta\phi|}{\Delta T} = \left(7.3\,\frac{\mathrm{rad}}{\mathrm{Hz\,s}} + 0.36\,\frac{\mathrm{rad}}{\mathrm{Hz\,s}}\right) \Delta f_{\mathrm{COSY}}$
- Frequency can be adjusted in steps of 3.7 mHz corresponding to $\Delta\phi/\Delta T \approx \pm 30\,\mathrm{mrad/s}$

# Principle of the Experiment

- Tilt vertically polarized beam to horizontal plane
- Start feedback
- Start solenoid again at lower amplitude
- Feedback fails when polarization is vertical again, phase undefined
- Slow tilt from horizontal to vertical is similar to the effect of EDM

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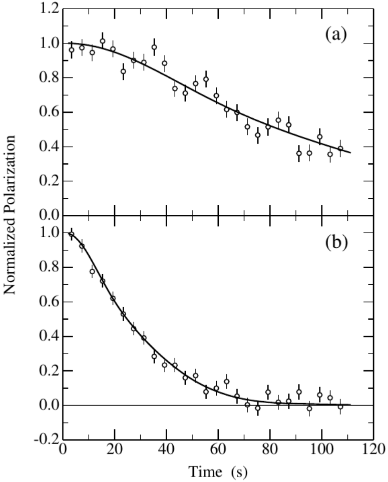
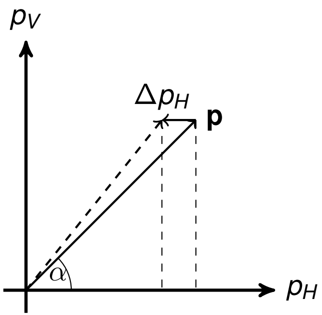
# Effect of Decoherence

- Vertical polarization is stable, horizontal polarization decays
- Causes deviation from ideal tilt
- Same effect expected in EDM measurements

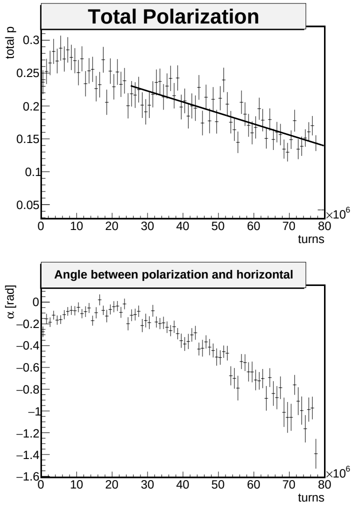


# Analysis

- Aims for analysis
  - Independent from initial polarization
  - Distinguish between effects of solenoid/EDM and decoherence
- Solution: look at angle $\alpha = \arctan\left(\frac{p_H}{p_V}\right)$ and magnitude $p = \sqrt{p_H^2 + p_V^2}$
- Decoherence changes magnitude, spin tilts do not



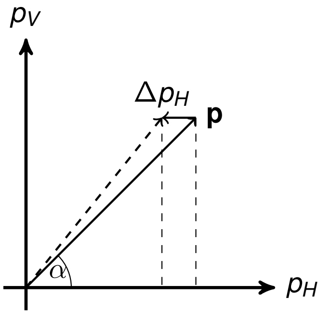
# Angle and Magnitude




- Magnitude decreases at approximately constant rate
- Angle changes at slightly faster than constant rate

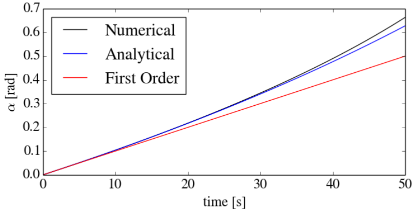
# Model

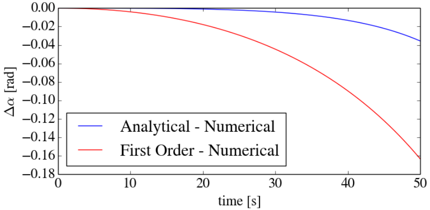
- $\frac{d\alpha}{dt} = \underbrace{k \sin(\phi)}_{\text{solenoid}} + \frac{\partial \alpha}{\partial p_H} \frac{\partial p_H}{\partial p} \underbrace{\frac{\partial p}{\partial t}}_{\approx \text{const}}$
- Some geometry:
  - $\frac{\partial \alpha}{\partial p_H} = \frac{-p_V}{p^2}$
  - $\frac{\partial p_H}{\partial p} = \frac{p}{p_H}$
- $\frac{\partial p}{\partial t} = p'$ from fit
- Resulting equation $p_H$ and $p_V$ using $\alpha$ and $p$:
  $\frac{d\alpha}{dt} = k \sin(\phi) - \frac{\tan \alpha}{p_0 + p' t} p'$



# Solution

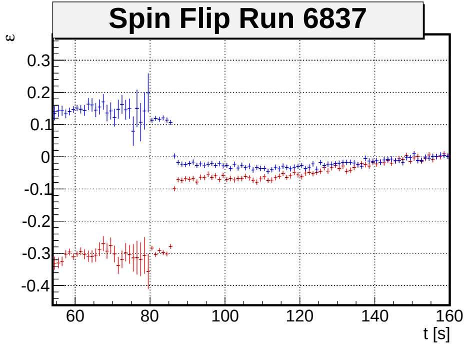
- First order perturbation theory: $\alpha(t) = At - \frac{ABt^2}{2} + \frac{AB^2t^3}{3} + \mathcal{O}(t^4)$, for $\alpha(0) = 0$
- With $A = k\sin(\phi)$, $B = \frac{p'}{p_0}$
- Difference $< 2^\circ$ between approximation model and numerical integration



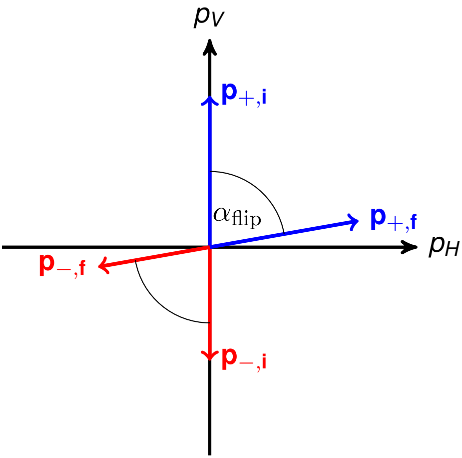
# Systematic Effects

- Two sources for systematic errors
  - Detector asymmetry shifts both spin states
  - Incomplete flip: states do not match



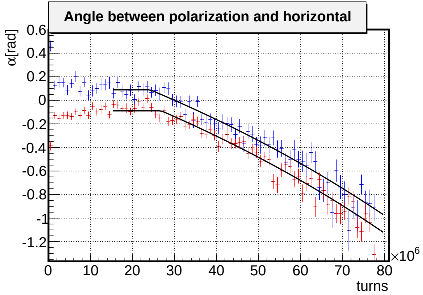
# Separating Spin Flip and Detector Asymmetry

- Both states see the same flip:
- Measure vertical asymmetry $\epsilon = \frac{N_L - N_R}{N_L + N_R} \propto p_V$ before and after flip for positive and negative state
- Solve for initial angle and detector asymmetry
  - $\cos(\alpha_{\text{flip}}) = \frac{\epsilon_+^f - \epsilon_-^f}{\epsilon_+^i - \epsilon_-^i}$
  - $\epsilon^{\text{det}} = \frac{\epsilon_+^i \cdot \epsilon_-^f - \epsilon_+^f \cdot \epsilon_-^i}{\epsilon_+^i + \epsilon_+^f - \epsilon_+^f - \epsilon_-^i}$
  - Index denotes initial (i) and final (f) value for positive (+) and negative (-) initial polarization



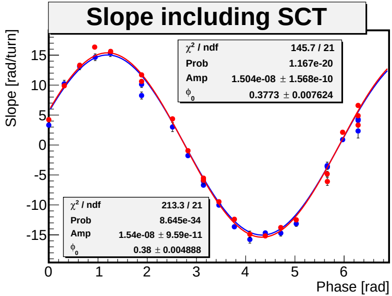
# Fits

- Positive (blue) and negative (red) initial polarizations
- Fit magnitude to find $p'$
- Fit approximate solution to angle
- Difference to simple linear approximation ≈ 10% despite similar shape



# Final Result

- Found expected sine dependency of the build-up speed on the spin phase
- Good agreement between positive (blue) and negative (red) initial polarization



# Conclusion

- Feedback system can fix phase between spin precession and rf-solenoid
- Spin decoherence can influence the apparent build up of vertical polarization
  - Developed scheme for correction
  - Basic idea applicable to EDM-measurement as well