Spin Tracking Simulations towards EDM Measurements at COSY

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Introduction

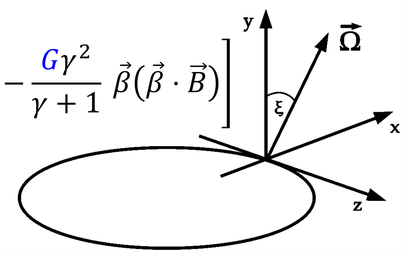
- Spin motion in electromagnetic fields is described by T-BMT equation.
- Electric Dipole Moments (EDMs) couple to (motional) electric fields.
- Radiofrequency fields are used to induce spin resonances in storage ring COSY.
- Excitation of an EDM related spin resonance is proposed.
- Transfer maps to allow particle and spin tracking in time-varying fields have been implemented into an extension of the simulation framework COSY INFINITY.
- Benchmarking of these simulations has been performed.

$$\vec{\mu} = 2(G+1)\cdot\frac{e}{2m}\vec{S} \qquad \vec{d} = \eta\cdot\frac{e}{2mc}\vec{S}$$

$$\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \vec{S}\times\vec{\Omega}_{\mathrm{MDM}} + \vec{S}\times\vec{\Omega}_{\mathrm{EDM}}$$

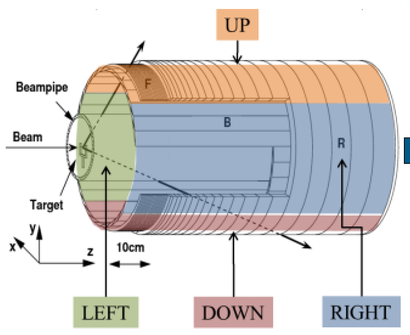
$$\vec{\Omega}_{\mathrm{MDM}} = \frac{e}{\gamma m}\left[(1+G\gamma)\vec{B} + \left(G\gamma + \frac{\gamma}{1+\gamma}\right)\frac{\vec{E}\times\vec{\beta}}{c} - \frac{G\gamma^2}{\gamma+1}\vec{\beta}(\vec{\beta}\cdot\vec{B})\right]$$

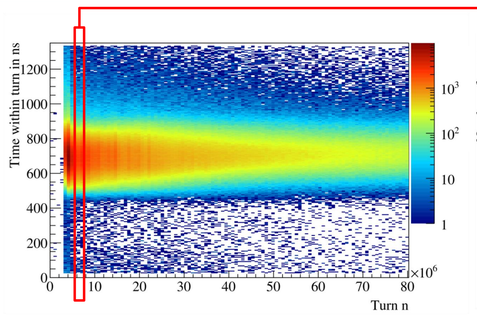
$$\vec{\Omega}_{\mathrm{EDM}} = \frac{e}{m}\frac{\eta}{2}\left[\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B} - \frac{\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\cdot\frac{\vec{E}}{c}\right)\right]$$



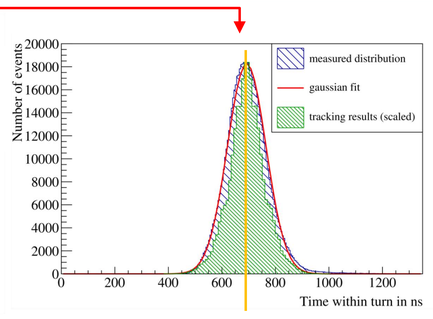
Benchmarking using RF-B Solenoid Driven Polarization Oscillations

Beam setup
- Pol. deuterons
- 970 MeV/c
- Electron cooled
- Bunched
- Optimized Spin Coherence Time





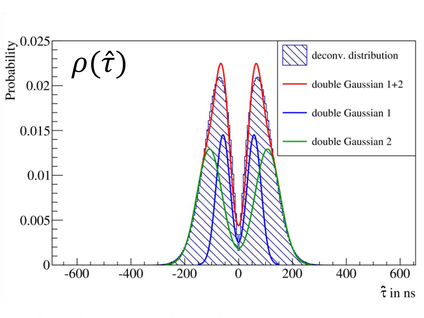
Time marking system allows for determination of event time within turn.



Bunch center: $\tau = 0$

deconvolution assuming harm. oscillator

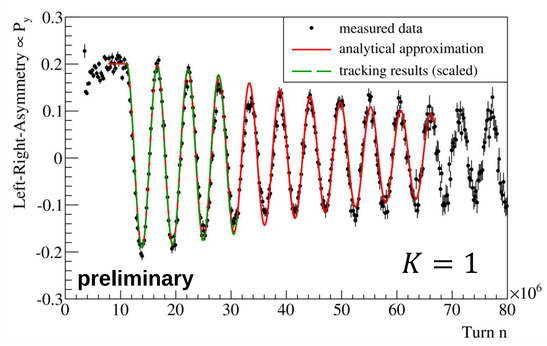
averaging τ in tracking

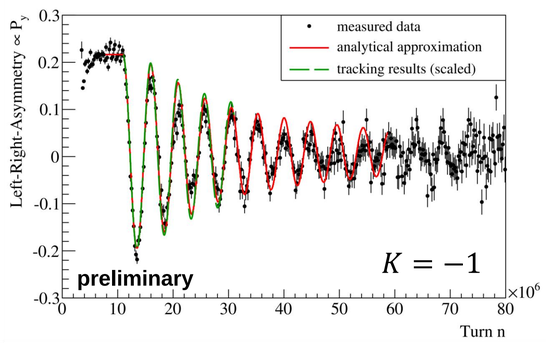


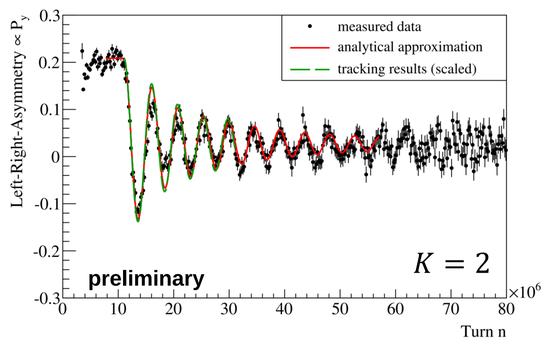
Initial longitudinal amplitude distribution for tracking simulations

$\tau \approx \hat{\tau}\cdot\cos(2\pi\nu_{\mathrm{sync}}n + \phi_{\mathrm{sync}})$

- rf-B solenoid induced spin resonance generates polarization oscillations.
- Radiofrequency field: $B_{\mathrm{sol}} = \hat{B}_{\mathrm{sol}}\cdot\cos(2\pi\nu_{\mathrm{sol}}\cdot n + \phi_{\mathrm{sol}})$, resonance condition: $\nu_{\mathrm{sol}} = G\gamma + K,\ K\in\mathbb{Z}$







Analytical estimation:

$$P_y(n) = \int_{-\infty}^{\infty}\rho(\hat{\tau})S_y(n,\hat{\tau})\,d\tau$$

$$S_y(n,\hat{\tau}) = \cos\left(\frac{\alpha_0}{2}\cdot J_0(C\cdot\hat{\tau})\cdot n\right)$$

$$\alpha_0 = (1+G)\frac{q}{p}\left(\hat{B}\cdot L\right)_{\mathrm{sol}}$$

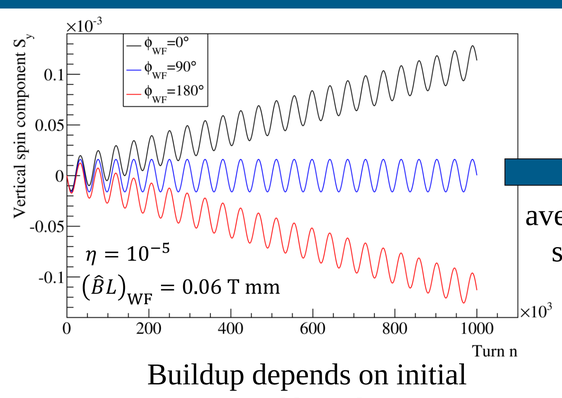
$$C = \omega_{\mathrm{rev}}\left(\nu_{\mathrm{sol}} - \frac{G\gamma\beta^2}{\eta_{\mathrm{ts}}}\right)$$

and tracking results

Systematic Limitations of EDM Measurement Method using rf-E×B Wien filter

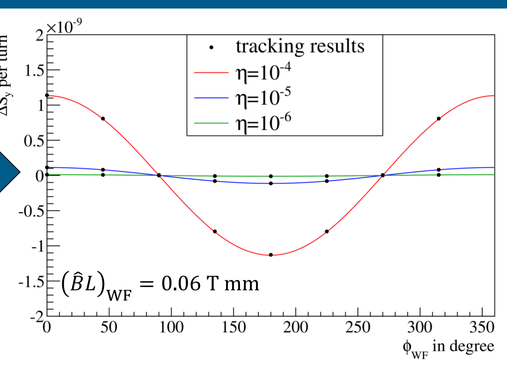
Idea:
- rf-E×B Wien filter with $\vec{B}\parallel\vec{e}_y$ on resonance induces buildup of vertical spin component for non-vanishing EDM.

Setup:
- Pol. Deuterons on closed orbit
- 970 MeV/c
- $S_z(0) = 1$ @ rf Wien filter location



Buildup depends on initial Wien filter phase.

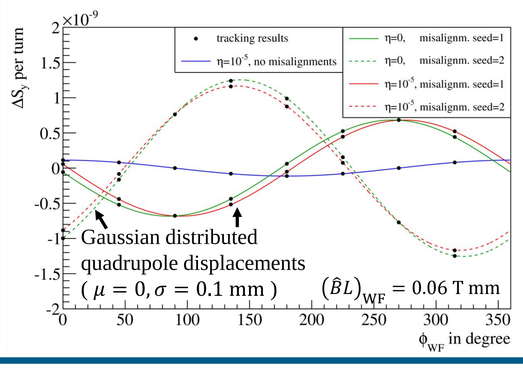
averaged slope

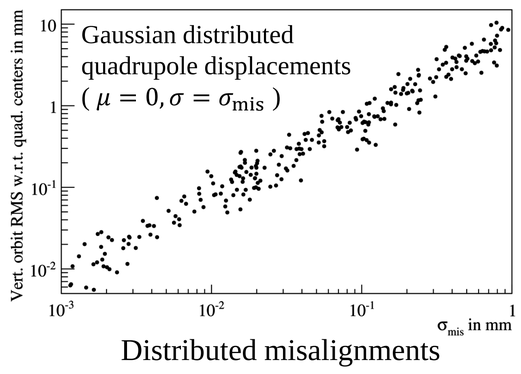


Buildup in ideal ring scales with EDM.

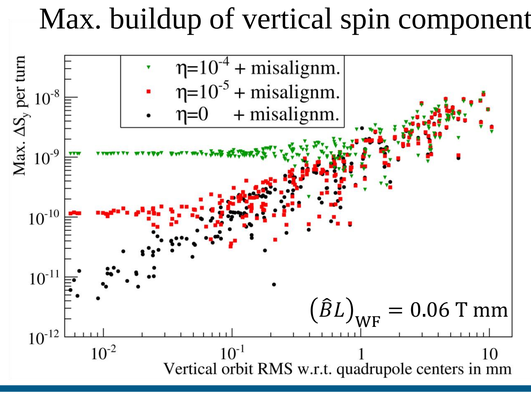
Misalignments spoil vertical buildup.

colored lines





Distributed misalignments
↔
RMS of vertical orbit displacements
↔
Max. buildup of vertical spin component



Analytical estimation:

$$\frac{\mathrm{d}S_y}{\mathrm{d}n} \approx -\frac{\alpha_0}{2}\left(n_y^2\cdot n_z\cdot\sin(\phi_{\mathrm{WF}}) + n_y\cdot n_x\cdot\cos(\phi_{\mathrm{WF}})\right) + \text{fast osc. terms}$$

$$\alpha_0 = \frac{(1+G)}{\gamma}\frac{q}{p}\left(\hat{B}\cdot L\right)_{\mathrm{WF}}$$

$$B_{\mathrm{WF}}(n) = \hat{B}_{\mathrm{WF}}\cdot\cos(2\pi\nu_{\mathrm{WF}}\cdot n + \phi_{\mathrm{WF}})$$

$$E_{\mathrm{WF}}(n) = -v\cdot B_{\mathrm{WF}}(n)$$

(n_x, n_y, n_z): spin closed orbit of static ring @ rf Wien filter location

Summary

- Dependence of oscillation damping on solenoid frequency could be reproduced, good agreement with analytical estimates and data.
- Tracking results for EDM related buildup of vertical spin component match with analytical calculations.
- Gaussian distributed quadrupole displacements with $\sigma_{\mathrm{mis}} = 0.1$ mm lead to a buildup similar to an EDM with $\eta = 10^{-4}$ for closed orbit deuterons. This corresponds to $d \approx 5\cdot 10^{-19}$ e cm.

References

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