Spin-Tracking simulations in an idealized COSY model using Bmad

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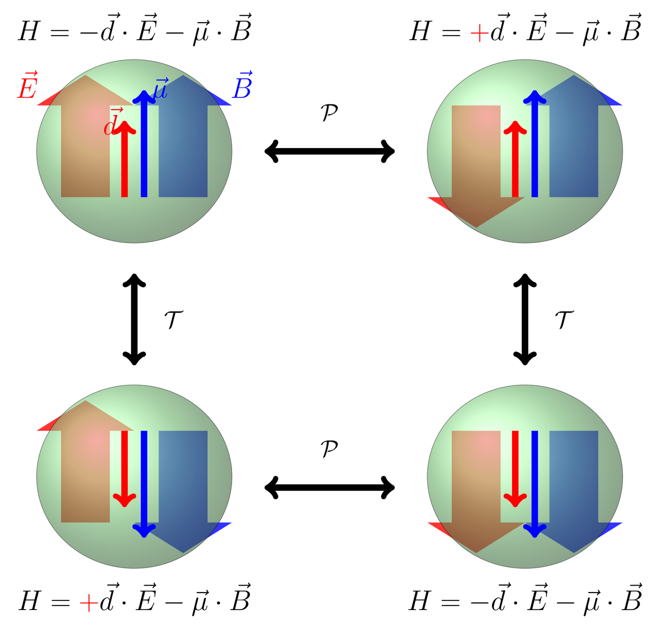
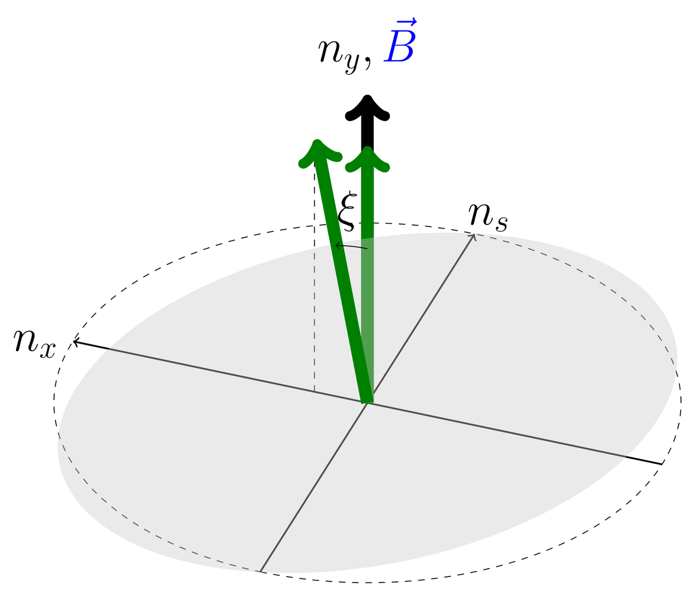
Motivation

- Electric Dipole Moment (EDM) is a fundamental property of a subatomic particle, similar to the Magnetic Dipole Moment (MDM).
- Source of $\mathcal{P}$ and $\mathcal{T}$ violation ($\overset{\mathcal{CPT}}{=}$ $\mathcal{CP}$ violation) and therefore closely connected to matter antimatter asymmetry.



- EDM of charged particles can be measured in a storage ring as spin rotation is defined by EDM and MDM contribution [1].
- Vertical spin build-up is used to estimate the EDMs magnitude but also EDM-like systematic effects occur.
- Spin tracking simulations with Bmad Software Library are used to disentangle systematic effects from a real EDM signal [2].

Invariant Spin Axis

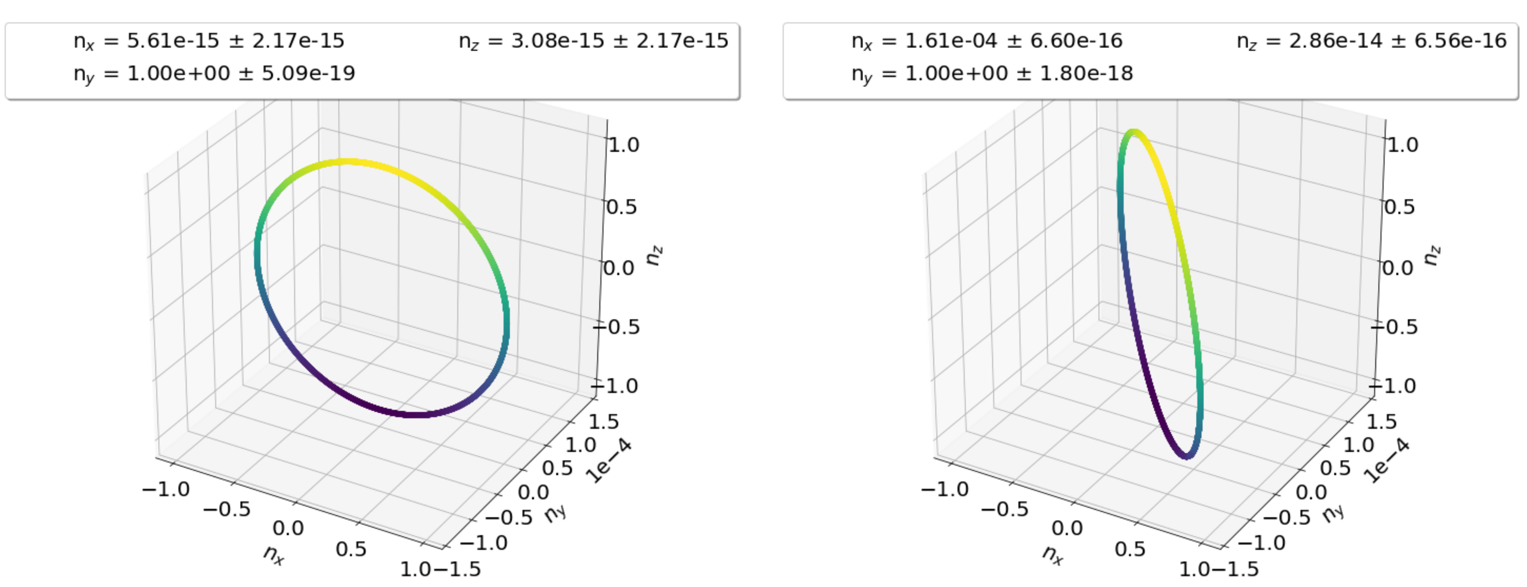


- Expected horizontal tilt n_x due to the EDM strength η is described via:

$$\tan \xi_{EDM} = \frac{\eta\beta}{2G}$$

- Proof of principle was performed using the Bmad COSY model and tracking the reference particle for some thousand turns.

$$<\vec{n}> = \frac{1}{n-1}\sum_{i=1}^{n-1}\left(\frac{\vec{s}_i \times \vec{s}_{i+1}}{|\vec{s}_i \times \vec{s}_{i+1}|}\right)$$

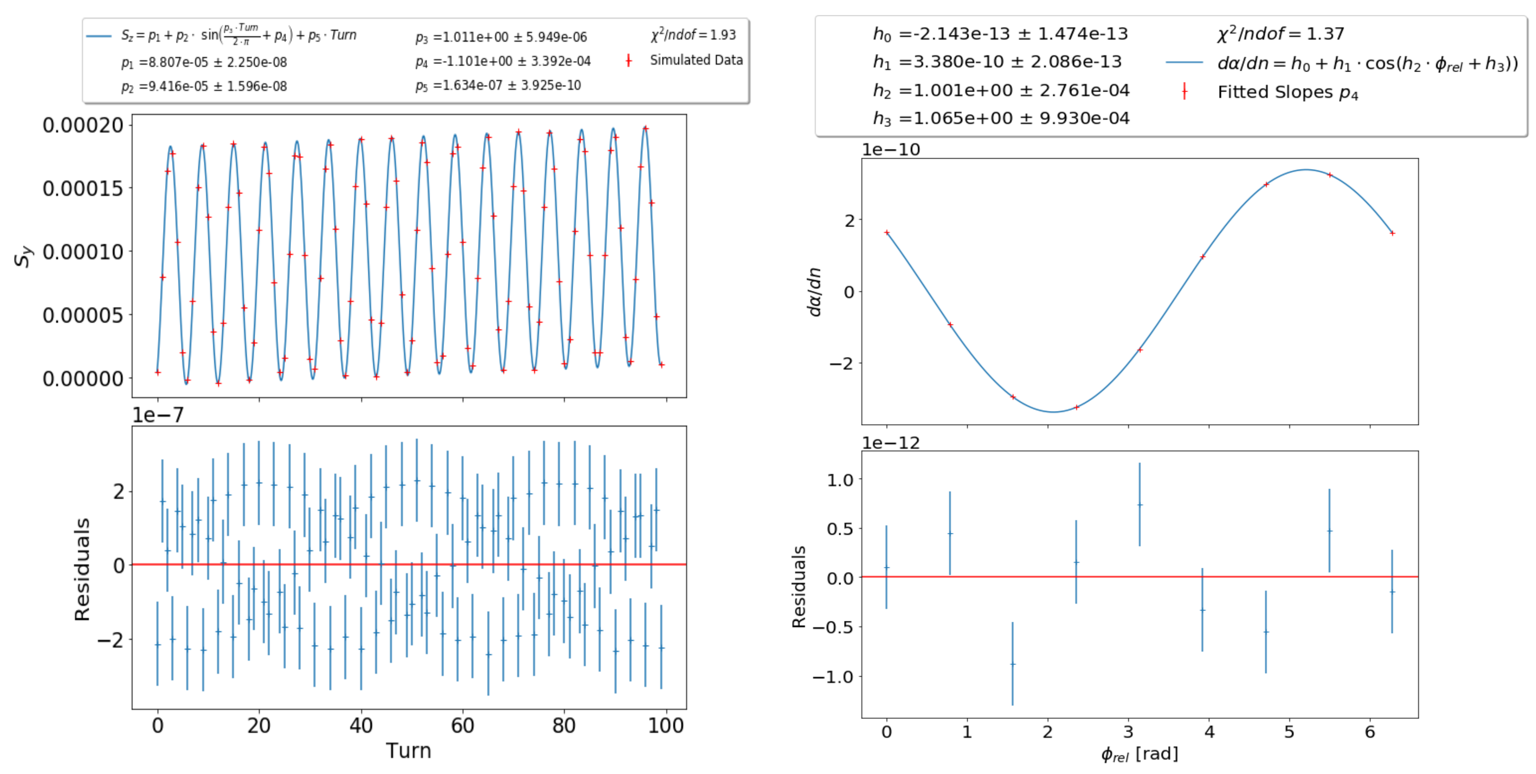


- Simulation result n_x in an idealized COSY model is in agreement with the expected tilt of the invariant spin axis ξ_{EDM}.
- As one cannot apply this method to an experiment a different approach to measure the EDM signal has to be used.

Experiment at COSY

- The experiment measures the EDM using a Wien-Filter and a solenoid $\Rightarrow$ **Resonant Wien Filter Method**
- Wien Filter gives the beam a phase dependent kick for vertical spin build-up:

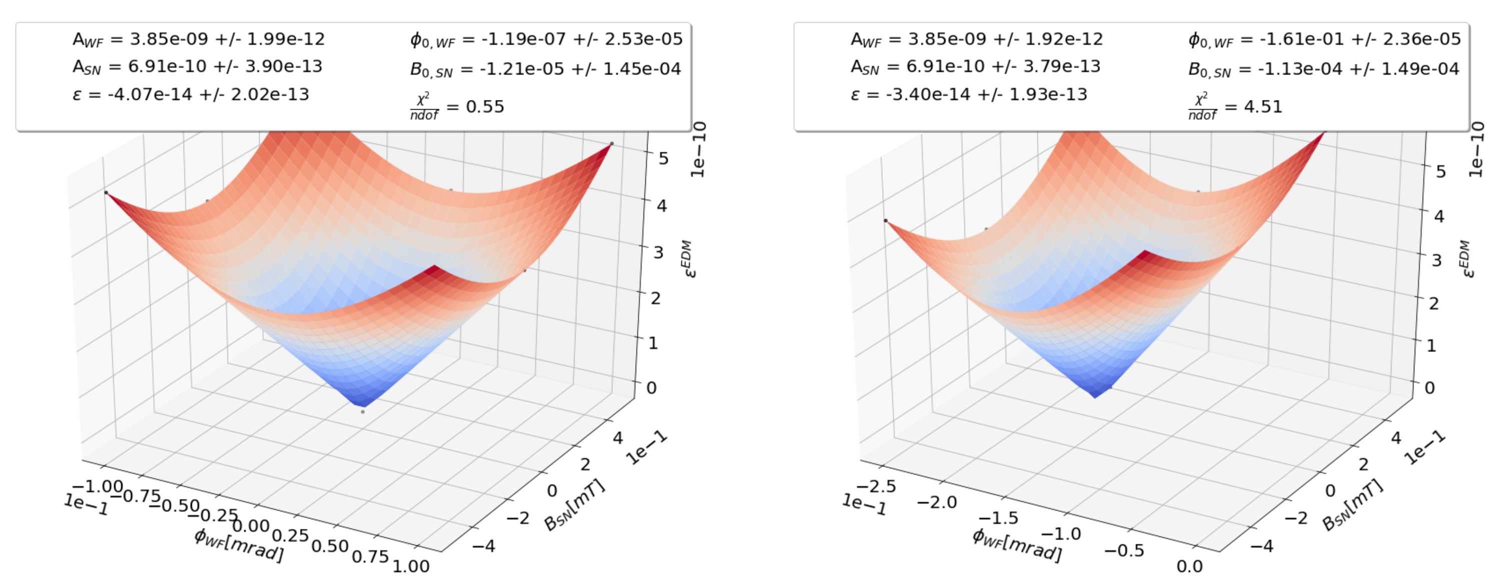
$$E_x = E_0 \cdot \cos(2\pi f_{rev}|k+\nu_s| + \phi_{rel})$$
$$B_y = B_0 \cdot \cos(2\pi f_{rev}|k+\nu_s| + \phi_{rel})$$



- Amplitude of oscillation displays the EDM resonance strength [3].

$$\epsilon_{EDM} = \left(A_{WF}^2(\phi_{WF} - \phi_{WF,0})^2 + A_{SN}^2\left(\frac{\xi_{SN} - \xi_{SN,0}}{2\sin(\pi\nu_{s,0})}\right)^2\right)^{1/2} + \epsilon_0$$

- Find the fit point of **minimal resonance strength** $(\phi_{WF,0}, \xi_{SN,0}) \Rightarrow \phi_{WF,0}$ is measured EDM plus systematic effects.



- Shift in $\phi_{WF,0}$ is observed as soon as an EDM signal is included in the simulation $\Rightarrow$ $\phi_{WF,0}$ in an idealized COSY lattice with EDM signal simulated fits the expectation.
- Ring imperfections as magnet misalignments, higher order multipole components etc. are influencing the map minimum $\Rightarrow$ Their effect must be systematically build in and understood!

References

[1] T. Fukuyama and A. J. Silenko, Derivation of Generalized Thomas-Bargmann-Michel-Telegdi Equation for a Particle with Electric Dipole Moment, Int. J. Mod. Phys A28, 1350147, 2013.

[2] D. C. Sagan, Bmad: A relativistic charged particle simulation library, Nuclear Instruments and Methods in Physics Research A, vol.558, pp.356-359, 2006.

[3] F. Rathmann, N. N. Nikolaev and J. Slim, Spin dynamics investigations for the electric dipole moment experiment, Physical Review Accelerators and Beams 23, 024601, 2020.

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