Spin Motion Perturbation Effect on the EDM Statistic in the Frequency Domain Method

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INTRODUCTION

The Frequency Domain method of search for the EDM of a particle consists in measuring the combined MDM+EDM spin precession frequency in two situations: beam circulating clockwise (direct), and counter-clockwise (time-reversed). When these frequencies are added up, the MDM effect cancels, leaving only the EDM in the final statistic.

The frequency in question is estimated by fitting a sine function to polarimetry data. However, variation of the spin precession angular velocity vector introduces a mismatch between the constant-parameter sinusioidal model and measurement data.

Model specification errors are prone to introducing biases into parameter estimates. The purpose of this work is to analyze the effect of spin motion perturbation on the EDM statistic.

PROBLEM STATEMENT

Solution of the T-BMT equation for the vertical spin-vector component:

$$s_y(n_{turn}) = \sqrt{(\bar{n}_y\bar{n}_z)^2 + \bar{n}_x^2} \cdot \sin(2\pi\nu_s \cdot n_{turn} + \delta)\,. \tag{1}$$

Here

- the *invariant spin axis* $\bar{n}$ defines the orientation of the spin precession angular velocity vector;
- *spin tune* ν_s defines the magnitude of the vector.

Data is fitted by model

$$f(t) = a \cdot \sin(\omega \cdot t + \delta),$$

$(a, \omega, \delta) = \text{const}$.

Therefore, significant variation of $\bar{n}$ and/or ν_s can lead to model specification error.

SIMULATION

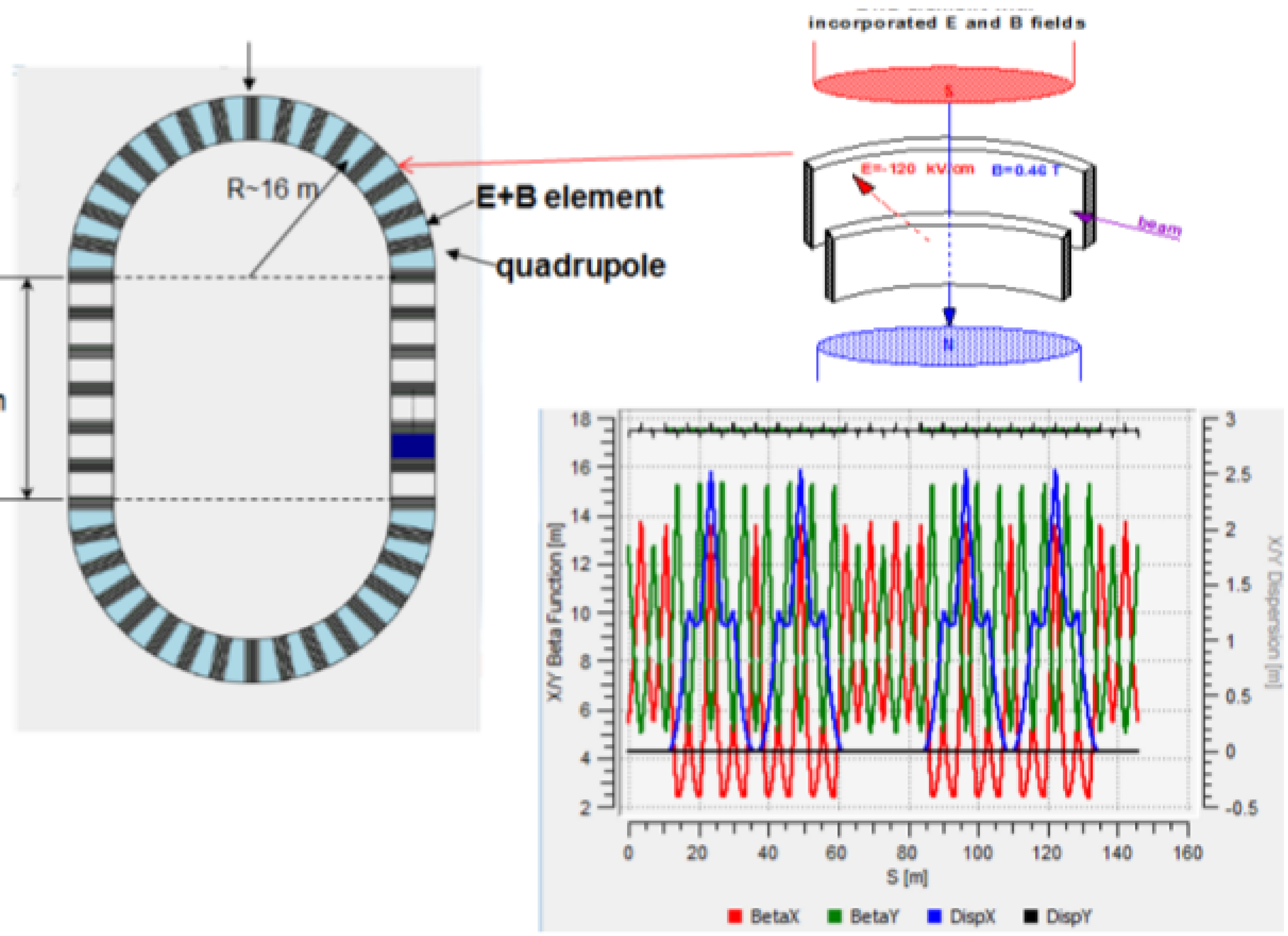

Figure 1: Imperfect Frozen Spin lattice in which sextupole spin decoherence suppression is implemented

Machine imperfections

- rotations of E+B spin rotator elements about the optic axis by $\alpha \sim N(\mu_i, 3\cdot 10^{-4})$ degrees;;
- $\mu_i \in [-1.5\cdot 10^{-4}, +2.5\cdot 10^{-4}]$ degrees
- μ_i simulates the application of a Spin Wheel.

Particle

- 0.3 mm offset from the reference orbit — vertical plane betatron oscillations;
- injection kinetic energy slightly off Frozen Spin;
- small $\bar{n}_x$ value — increased sensitivity to perturbations.

ANALYSIS

Three data series

- TRK spin data generated by the COSY INFINITY TR command (closest to measurement data);
- GEN data computed from equation (1) with $\bar{n}$, ν_s the TSS command output (accounts for parameter variation remaining within the confines of the sinusoidal model);
- IDL as in GEN, but $\bar{n} = \langle\bar{n}(t)\rangle$, $\nu_s = \langle\nu_s(t)\rangle$ (closest to the model).

Two comparator statistics

- $\epsilon_1(t) = s_y^{gen}(t) - s_y^{idl}(t)$;
- $\epsilon_2(t) = s_y^{trk}(t) - s_y^{idl}(t)$.

What was done

- Compared model (1)'s goodness-of-fit with respect to S_y^{trk}, S_y^{gen}, S_y^{idl};
- checked ϵ_1 and ϵ_2's standard deviation behavior against $\sigma[\bar{n}]$ behavior.

RESULTS

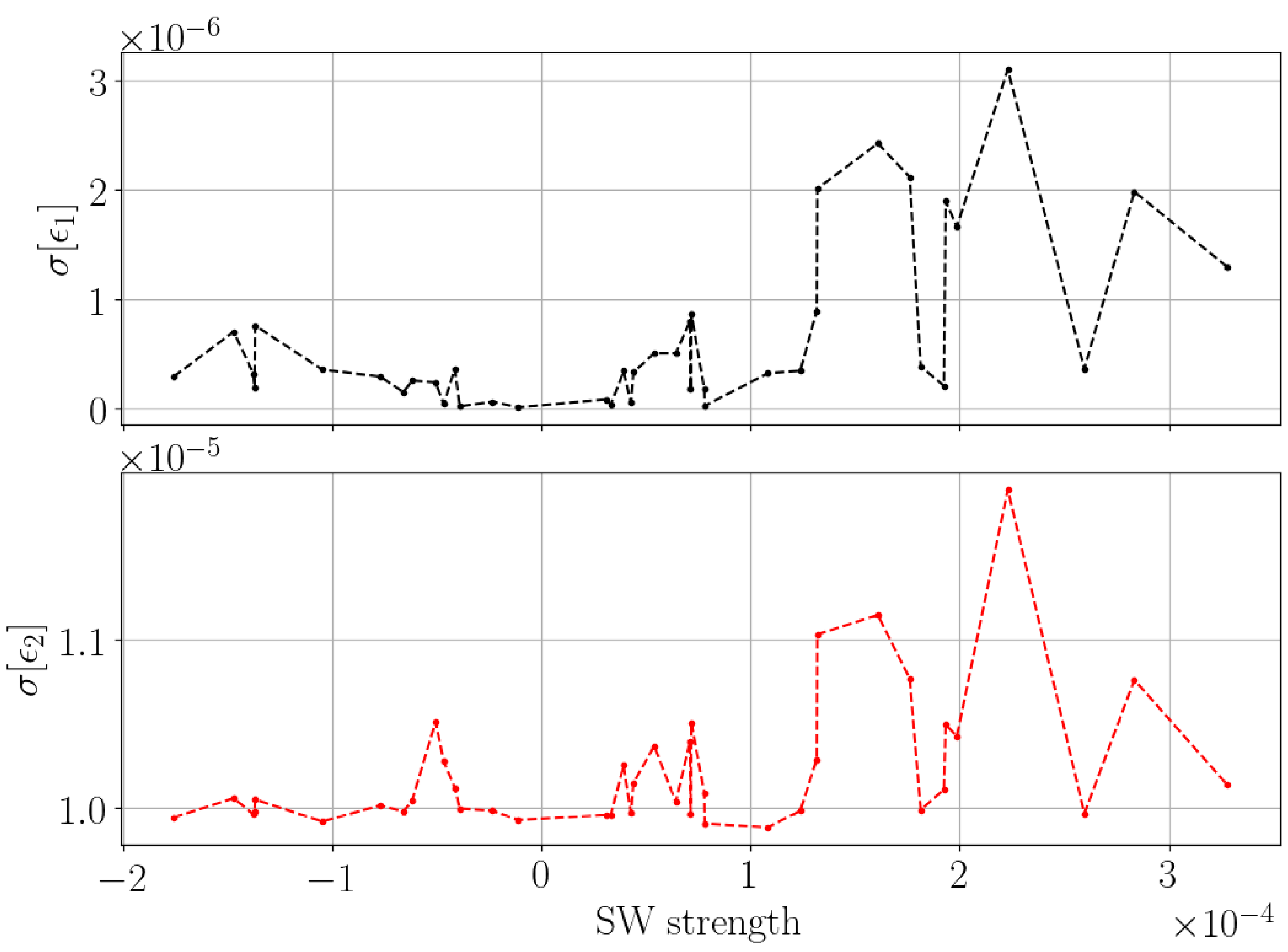

Figure 2: Residual standard deviations versus Spin Wheel roll rate

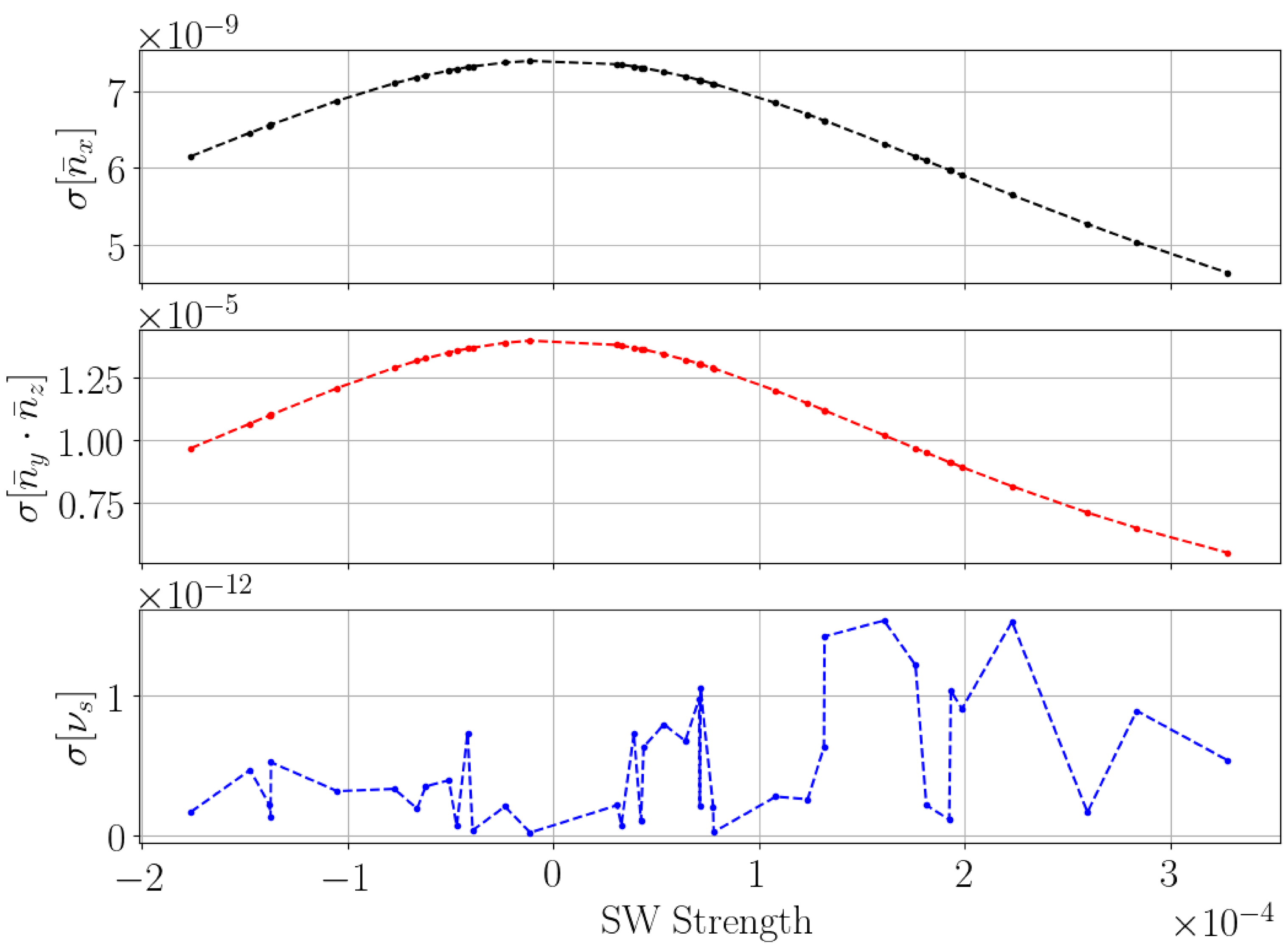

Figure 3: $\bar{n}$ components' standard deviations versus Spin Wheel roll rate

CONCLUSIONS

Three circumstances of the betatron motion effect on the EDM statistic:

1. $\bar{n}$ variation is insignificant compared to ν_s variation.
2. $\sigma[\epsilon_2] \ll \sigma[P_y]$. Therefore, the superposition of this systematic error with random measurement error will exhibit no statistically-significant systematicity.
3. $\sigma[\hat{a}, \hat{\omega}] < 10\%$. Even if $\bar{n}$ variation happens to be sufficiently strong to affect $\hat{a}$-estimate, its effect on $\hat{\omega}$ will be reduced by at least a factor of 10.
4. This systematic effect is controllable. The advantage of Frequency Domain versus Space Domain is that by increasing the SW roll rate the $\bar{n}$ oscillations can be continuously minimized.