

# Modeling of CW/CCW calibration in a FS-type lattice

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# Overview

- ▶ Optimization of sextupole strengths for reducing decoherence;
  - ▶ problem with simultaneous suppression of x- and d-offset decoherence.
- ▶ Modeling of the CW/CCW calibration procedure;
  - ▶ spin freeze problem.

# Optimization of sextupole strengths

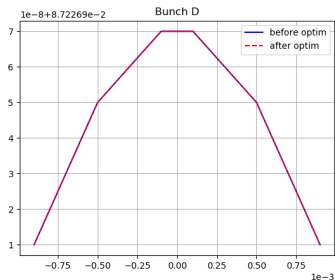
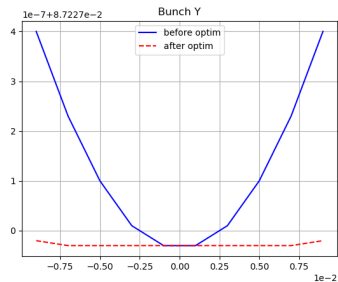
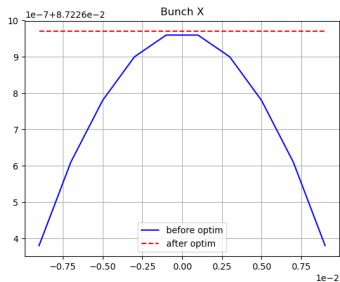
for the reduction of decoherence

- ▶ Three sextupole families (GSX, GSY, GSD), each expected to suppress decoherence, resp., in X-,Y-,D-planes;
- ▶ spin tune Taylor expansion (COSY Infinity) assumes the form (some terms omitted):

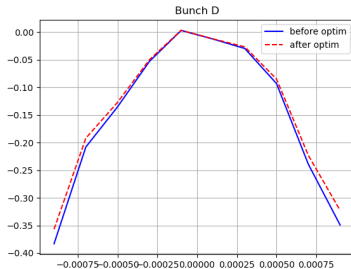
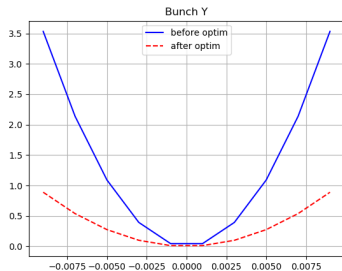
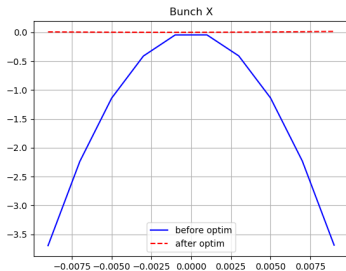
$$\mu(x, y, d) = \mu_0 + a_{xx} \cdot x^2 + a_{yy} \cdot y^2 + a_{dd} \cdot d^2 + a_{xd} \cdot x \cdot d + a_{yd} \cdot y \cdot d;$$

- ▶ parabolic dependence of spin tune on the  $x, y, d$  variables (confirmed by spin tracking)  $\Rightarrow$  objective function  $f = a_{xx}^2 + a_{yy}^2 + a_{dd}^2$ ;
- ▶ the reason  $a_{dd}$ ,  $a_{xd}$  are not involved in  $f$ :  $a_{xx}$ ,  $a_{dd}$  couldn't be minimized simultaneously (analysis below).

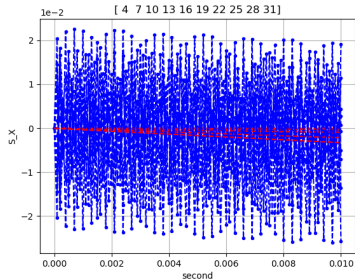
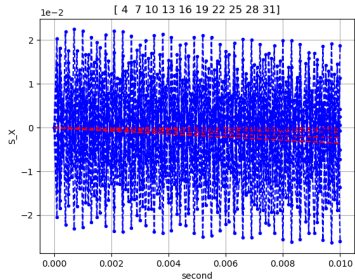
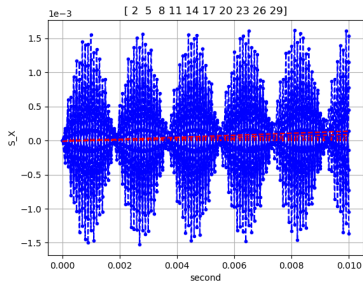
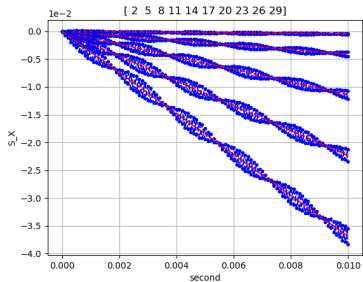
Computed as  $\mu_i = \mu(x_0^i, y_0^i, d_0^i)$



# Linear fit of tracking data



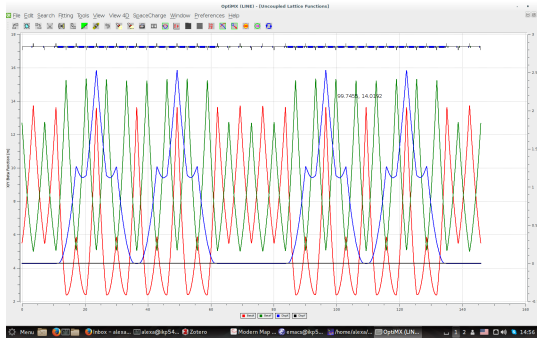
# Example fits (X-,D-bunch)



# Gradient sweep analysis

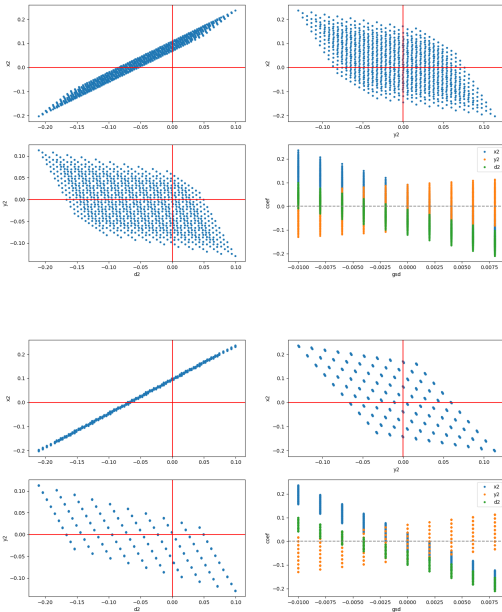
## FS-type lattice beta functions

- ▶ Sextupoles are placed in the maximums of the corresponding beta functions;
- ▶ because DispX, BetaX maxima coincide, considered 3 cases:  
1) GSD only in big DispX maxima, 2) GSD only in smaller maxima not coinciding with BetaX maxima, 3) GSD in both types DispX maxima.



# Gradsweep cases 4&12

- ▶ Took a grid GSX, GSY, GSD:  $\pm 10^{-2}$  T/cm<sup>2</sup> (10 points each axis);
- ▶ computed the spin tune, and extracted the  $a_{xx}$ ,  $a_{yy}$ ,  $a_{dd}$  coefs (plotted);
- ▶ observe that  $a_{xx}$ , and  $a_{dd}$  cannot be simultaneously set to 0.





# CW/CCW B-field calibration procedure

## Rationale

- ▶ The core idea of the procedure is to use the x-z plane spin precession frequency as a measure of the B-field;
- ▶ an element tilt  $\theta$  introduces a  $B_x$  field component, which induces a  $\Omega_x^{\text{MDM}} \propto B_x$ ;
- ▶  $\Omega_y^{\text{MDM}} \propto B_y$ , and  $B_y$  and  $B_x$  are strictly related via  $\theta$ ;
- ▶  $\theta$  doesn't change going from CW to CCW, hence by reproducing  $\Omega_y^{\text{MDM}}$  we can be sure to reproduce  $B_y$ , and also  $B_x$  and  $\Omega_x^{\text{MDM}}$ .

# CW/CCW B-field calibration procedure

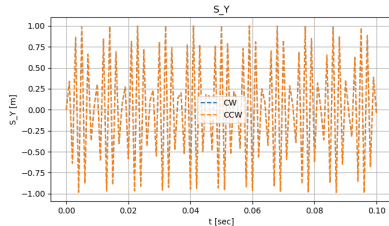
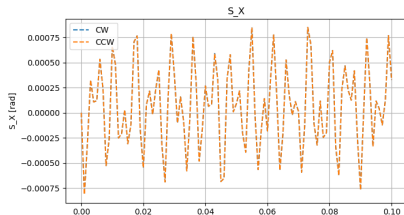
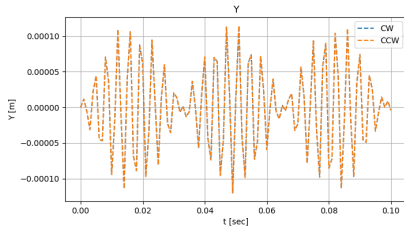
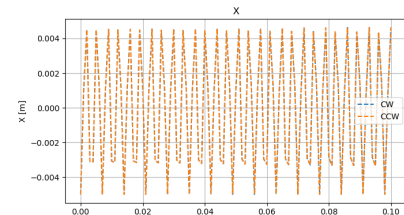
## Modeling

1. distribute element tilt errors  $\theta \sim N(\mu_j, \sigma_j), j \in J$ ;
2. for an ensemble of initial conditions  $\{(x^i, a^i, y^i, b^i, t^i, d^i)\}_{i \in I}$   
compute array of  $\{(\Omega_x^i, \Omega_y^i)\}_{i \in I}$ ;
3. compute statistics:  
 $S_1 \equiv |\Omega_x^{\text{CW}}| - |\Omega_x^{\text{CCW}}|, S_2 \equiv |\Omega_y^{\text{CW}}| - |\Omega_y^{\text{CCW}}|$ ;
4. repeat for  $j \in J$ .

# Spin freeze

$$\theta = \theta_0$$

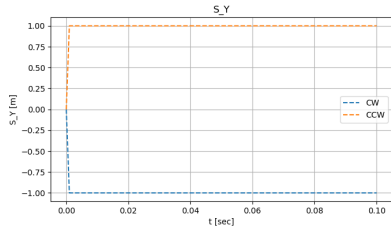
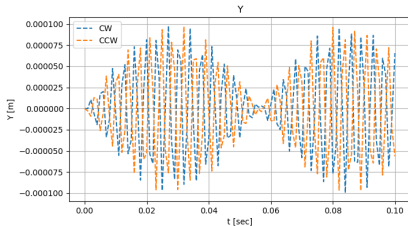
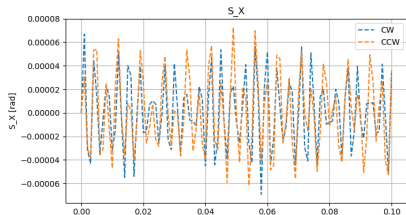
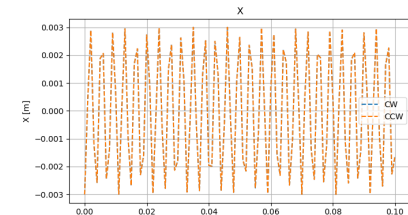
All WF are tilted by the same angle  $\theta_0$ ;  $S_y$  oscillates as expected.



# Spin freeze

$$\theta \sim N(0, \sigma)$$

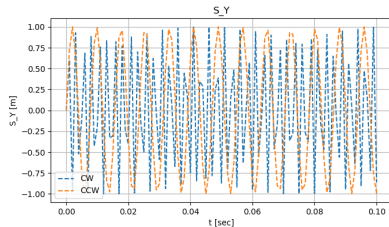
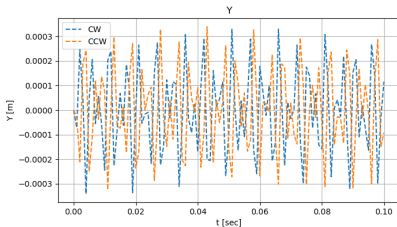
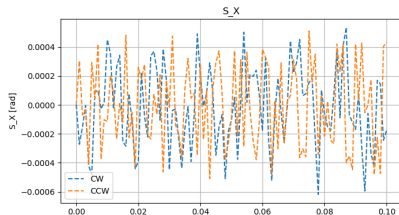
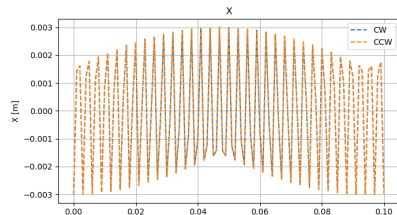
Reaching the apex, spin freezes at  $(S_y, S_z) = (1, 0)$ .



# Spin freeze

$$\theta \sim N(0, \sigma)$$

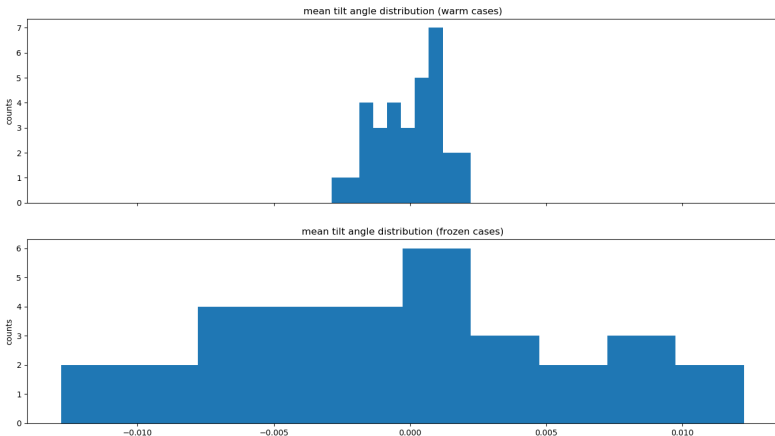
Another realization of the same distribution; this time there's no spin freeze.



# Look at the lattice as a whole

Hypothesis: something's wrong with the mean  $B_x$  value.

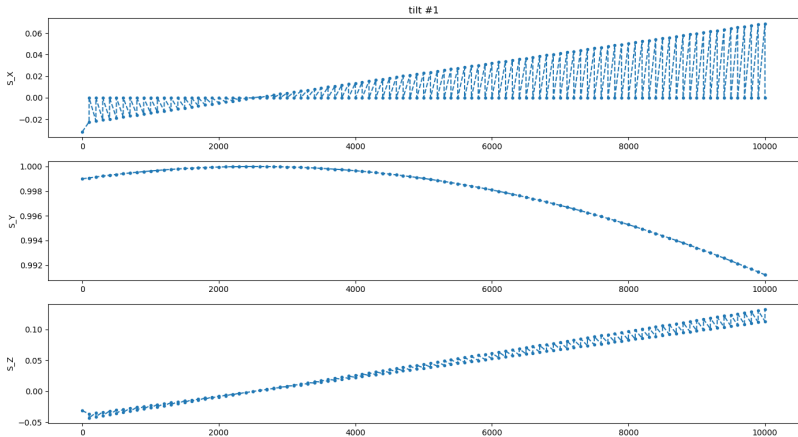
Simulation: Three values of  $\sigma \in [1, 2, 3] \cdot 10^{-4}$  rad; 30 trials/value.



# Look at particular WFs

Tilted WF #1 by  $10^{-4}$  rad

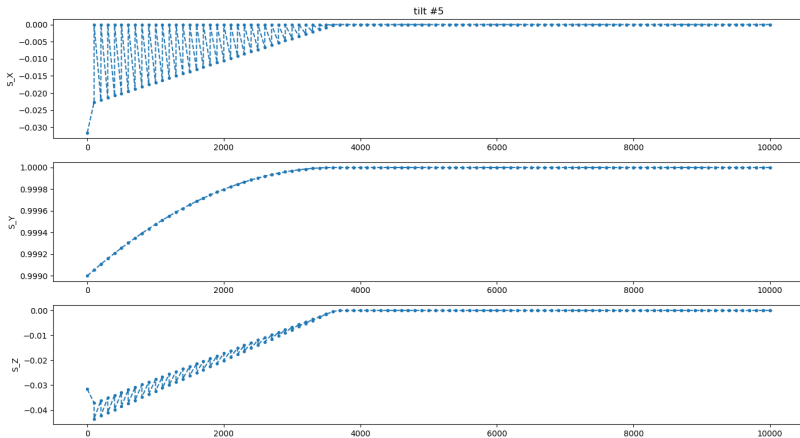
Spin doesn't have a problem crossing the apex.



# Look at particular WFs

Tilted WF #5 by  $10^{-4}$  rad

Spin freeze at the top.





# Probable causes

There's evidence that spin freeze is not caused by my crooked hands; Eremey also encountered that problem:

- ▶ Spin freeze is not a computational artifact; it's a resonance implicit in the mathematical model;
- ▶ it occurs whenever the spin vector gets into a certain, fairly wide altitude range close to  $S_y = 1$ .

And it looks like that range is dangerous in some places along the beamline, and not the others, seeing as tilting of WF ##1, 32, some others, doesn't cause freezing, whereas ##5, 8 does.