Updates Decoherence and Tuning Simulations for FCC-ee

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FCC-ee tuning meeting

10th February 2022

FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

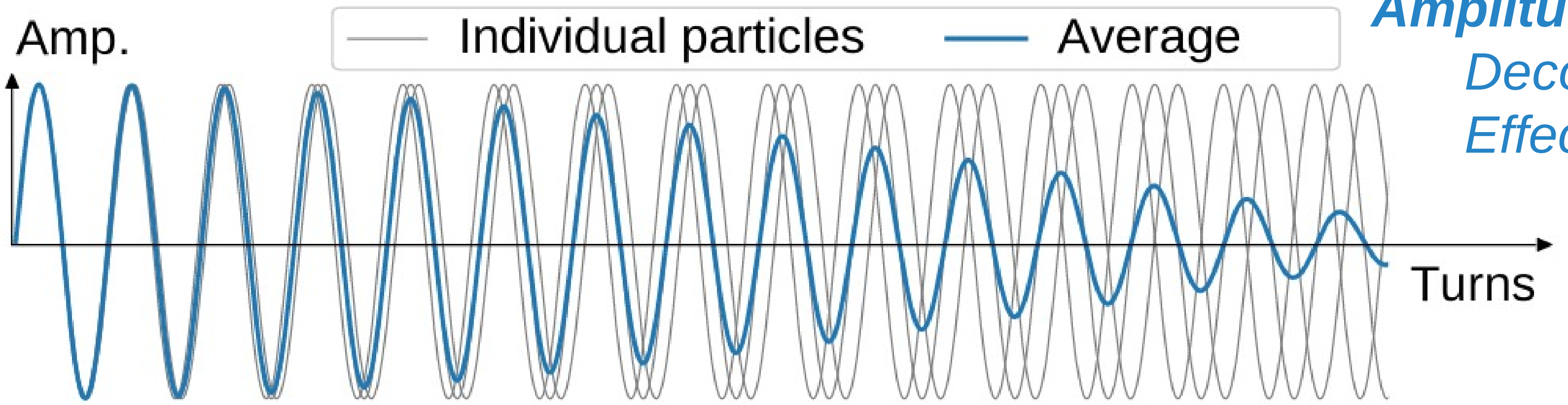
Decoherence

- Originates from finite tune spread
- Particles do not oscillate synchronously
- After applying a kick particles start to decohere
- Not observable for AC-dipole excitation

Linear chromatictiy
Decoherence and recoherence

Second-order chromaticity
Decoherence

Amplitude detuning
Decoherence
Effect different for hadrons and leptons



Decoherence illustrated for hadrons
Individual amplitudes remain constant over time

Strong synchrotron radiation damps amplitude of each particle

Decoherence from Chromaticity

Linear chromatictiy

Decoherence and recoherence

$$A_{\text{lin.chr.}}(N) = \exp\left\{-\frac{2\sigma_\delta^2 Q'^2}{Q_s^2}\sin^2(\pi N Q_s)\right\}$$

R.E. Meller, SSC-N-360, 1987.

Second-order chromaticity

Decoherence

$$A_{\text{so.chr.}}(N) = \frac{1}{\sqrt{\left|1 - 2i\xi N + \xi^2\left(\left(\frac{\sin(2\pi Q_s N)}{2\pi Q_s}\right)^2 - N^2\right)\right|}}$$

$$\xi = \pi Q'' \sigma_\delta^2$$

G. Rumolo and R. Tomas, NIM-A 528, pp. 670-676, 2004.

σ_δ … energy spread

Q' … linear chromaticity

Q" … second-order chromaticity

Q_s … synchrotron tune

N … turn

Decoherence from Nonlinearity

$$A_{\mathrm{Dec}} = \frac{1}{1+\theta^2}\,\exp\left\{-\frac{Z^2}{2}\frac{\theta^2}{1+\theta^2}\right\}$$

R.E. Meller, SSC-N-360, 1987.

Hadrons:

$$\theta = 4\pi\mu N$$

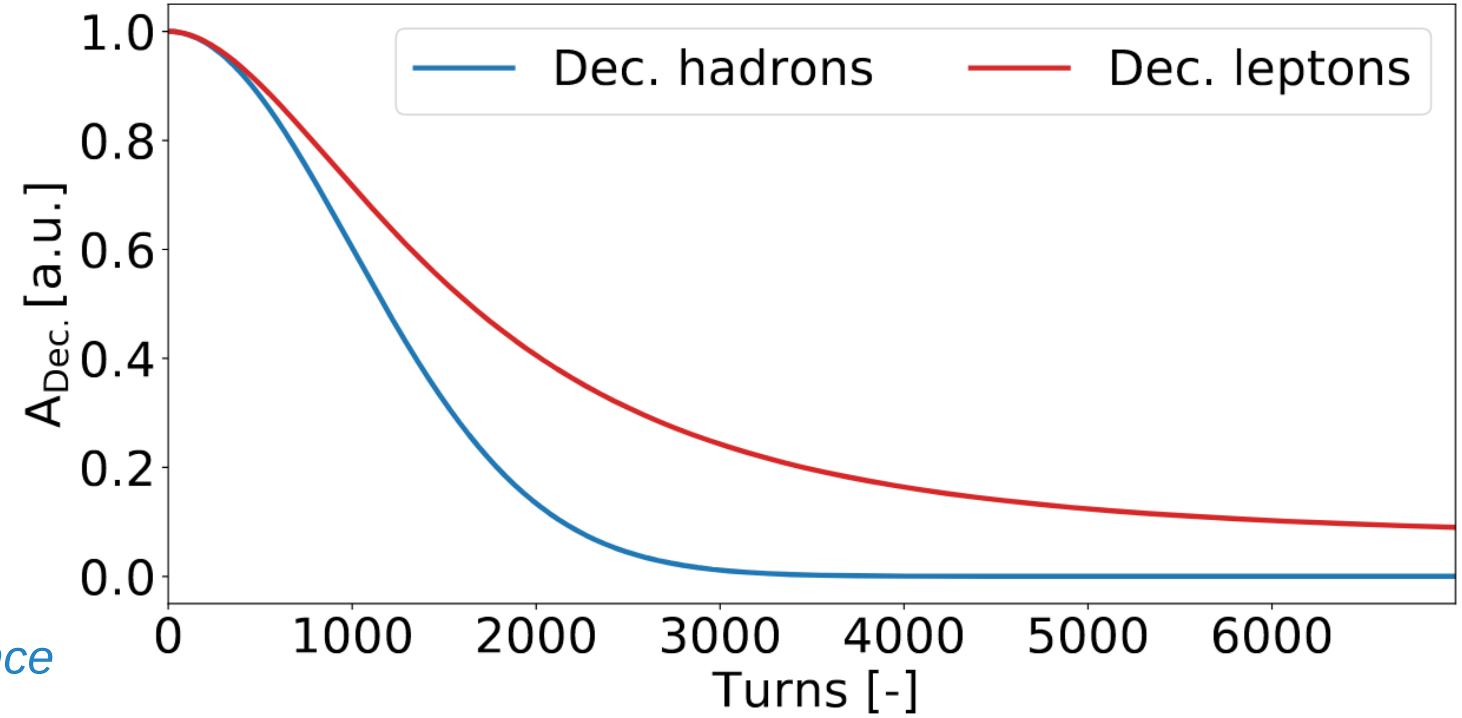
R.E. Meller, SSC-N-360, 1987.

Leptons:

$$\theta = 2\pi\mu\,\tau_{\mathrm{SR}}\left(1 - e^{-2N/\tau_{\mathrm{SR}}}\right)$$

N … Turns
Z … Initial kick
μ … Amplitude detuning normalized by emittance

Decoherence factor over estimated when synchrotron radiation damping is not included



Simulation Parameters

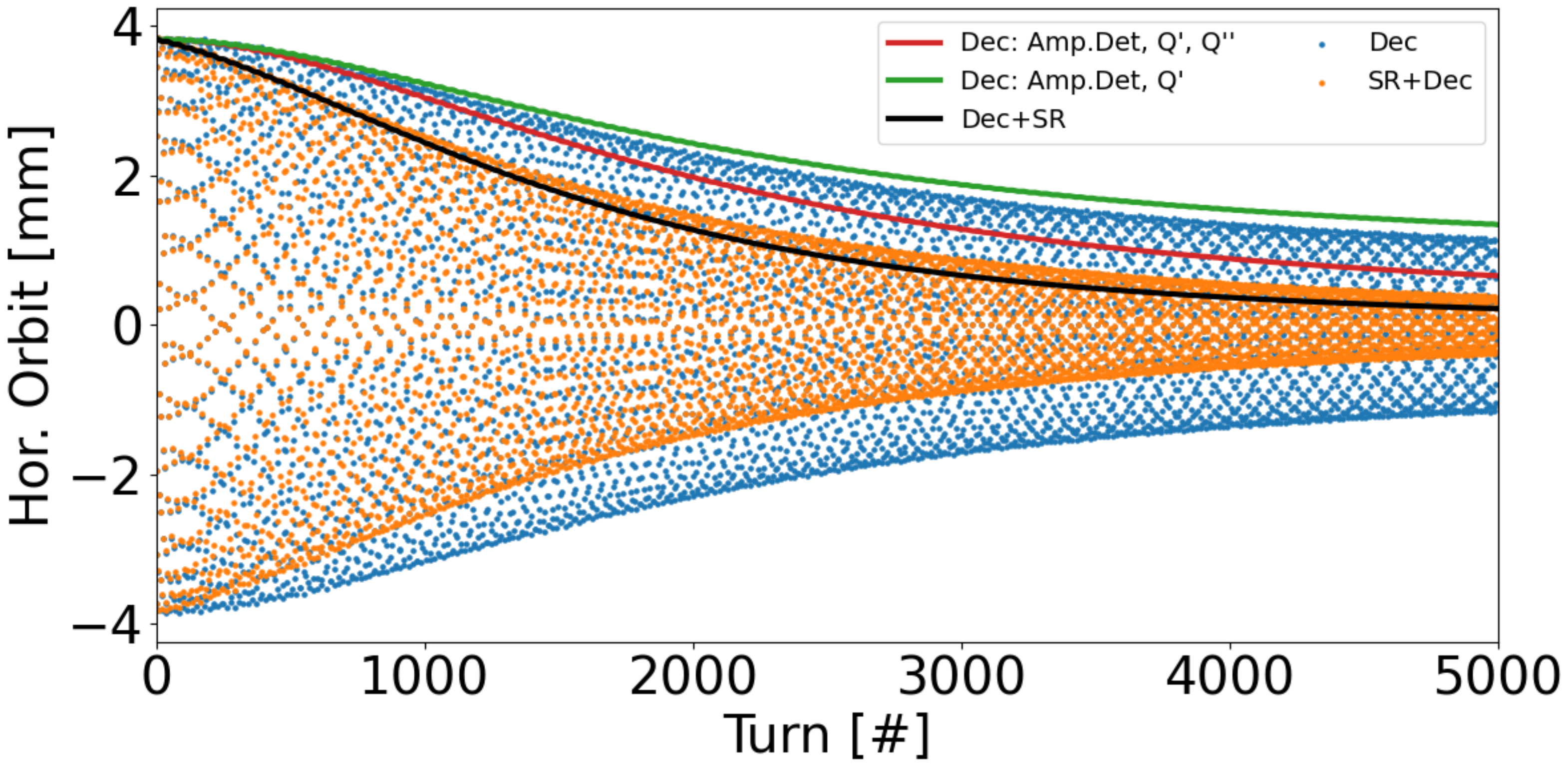
- Performed for SuperKEKB positron ring (LER)
- Amplitude detuning
  - $dQ_x/d2J_x = 1.76 \times 10^3\ m^{-1}$
  - $dQ_y/d2J_x = 1.28 \times 10^4\ m^{-1}$
- Off-momentum amplitude detuning smaller than on-momentum

Parameter	Value
Beam Energy [GeV]	4
Synchr. rad. damp. time τ_{SR} [ms]	46
Revolution time [µs]	10
Momentum spread σ_p $[10^{-4}]$	7.53
Synchrotron tune Q_s [-]	0.0235
β_x^*/β_y^* [mm]	80 / 1
Emittances ϵ_x/ϵ_y [nm/pm]	1.56 / 29.14
Betatron tunes Q_x/Q_y [-]	44.53 / 46.58
Linear chroma. Q'_x/Q'_y [-]	1.5 / 1.5
Second-order chroma. Q''_x/Q''_y [-]	-199 / 196

Note:
Horizontal second-order chromaticity and amplitude detuning opposite signs

Simulations for Leptons (w. SR)

- 2000 particles tracked with SAD (scatter plot)
- Compared with theoretical equations



Green line:
Decoherence from linear chromaticity and nonlinearitiy

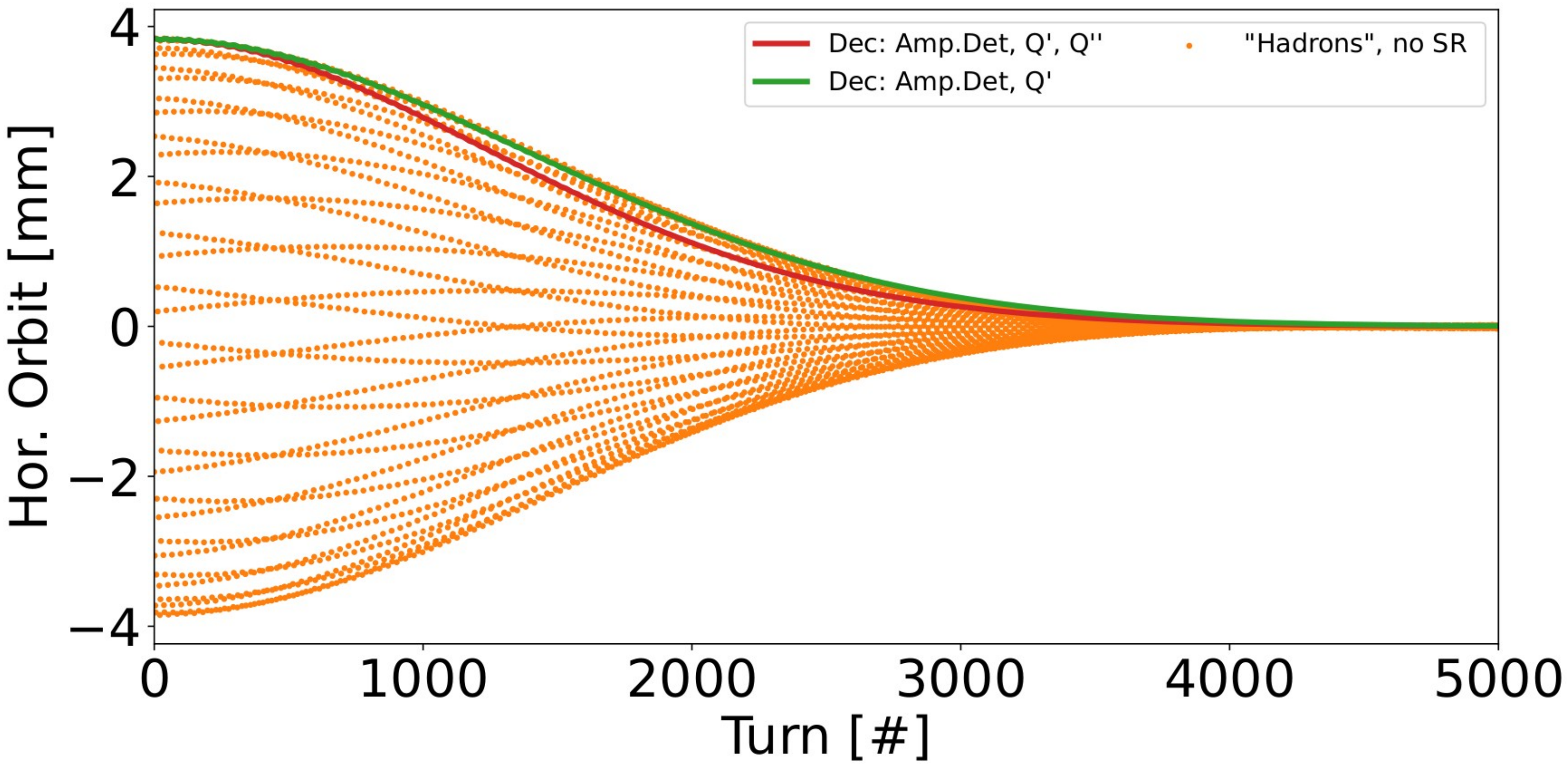
Red line:
+ second-order chromaticity

Black line:
+ synchrotron radiation damping

Equations over-estimate tracked damping for leptons Why?

Simulations for Hadrons (no SR)

- 2000 particles tracked with SAD (scatter plot)
- Compared with theoretical equations



Green line:
Decoherence from linear chromaticity and nonlinearitiy

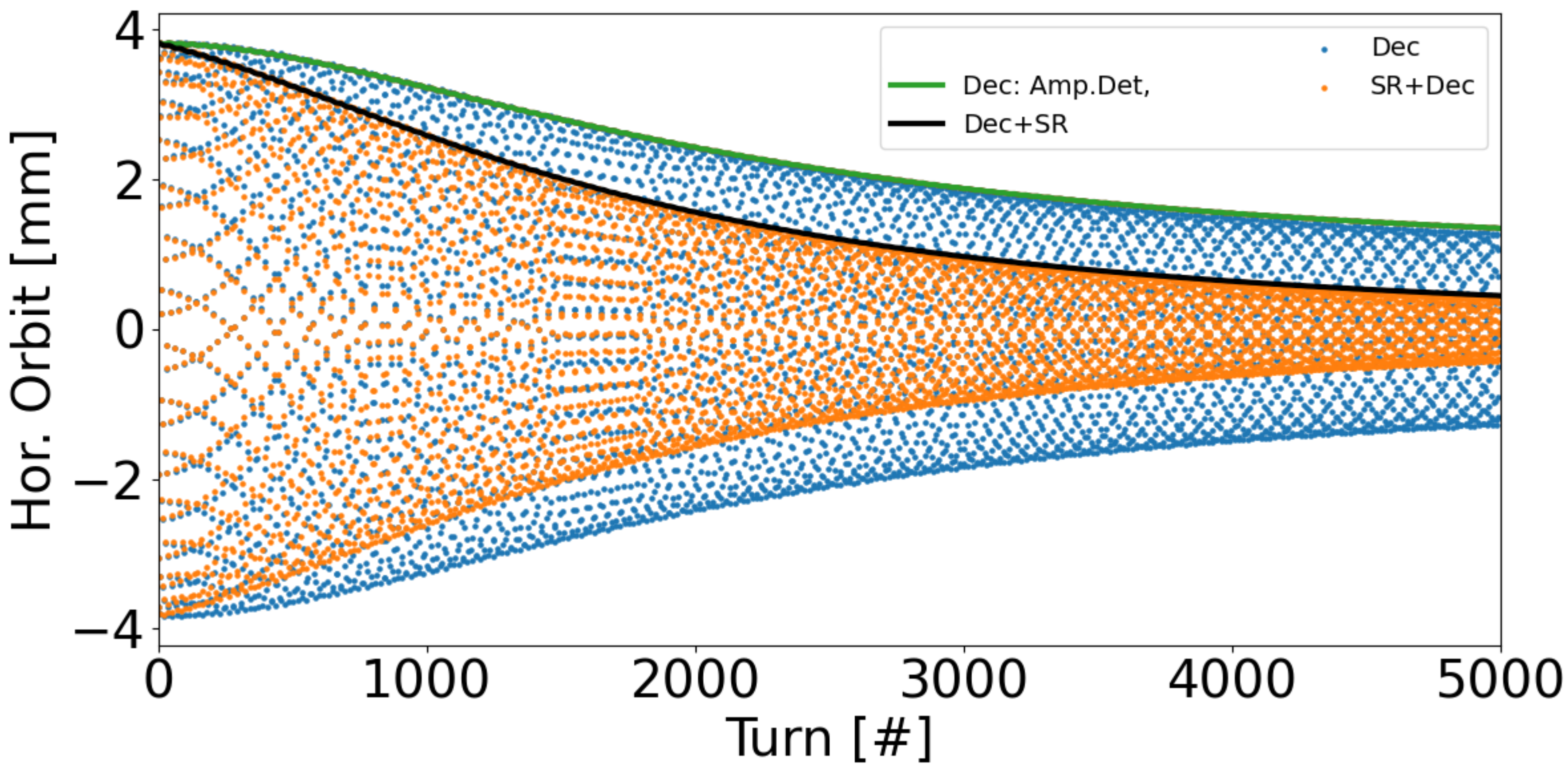
Red line:
+ second-order chromaticity

Equations over-estimate tracked data also for hadrons

Results probably from interplay between tune spread from second-order chroma and amplitude detuning

No Second-Order Chromaticity

- 2000 particles tracked with SAD (scatter plot) including synchrotron radiation
- Longitudinal emittance = 0 –> no decoherence from second-order chroma

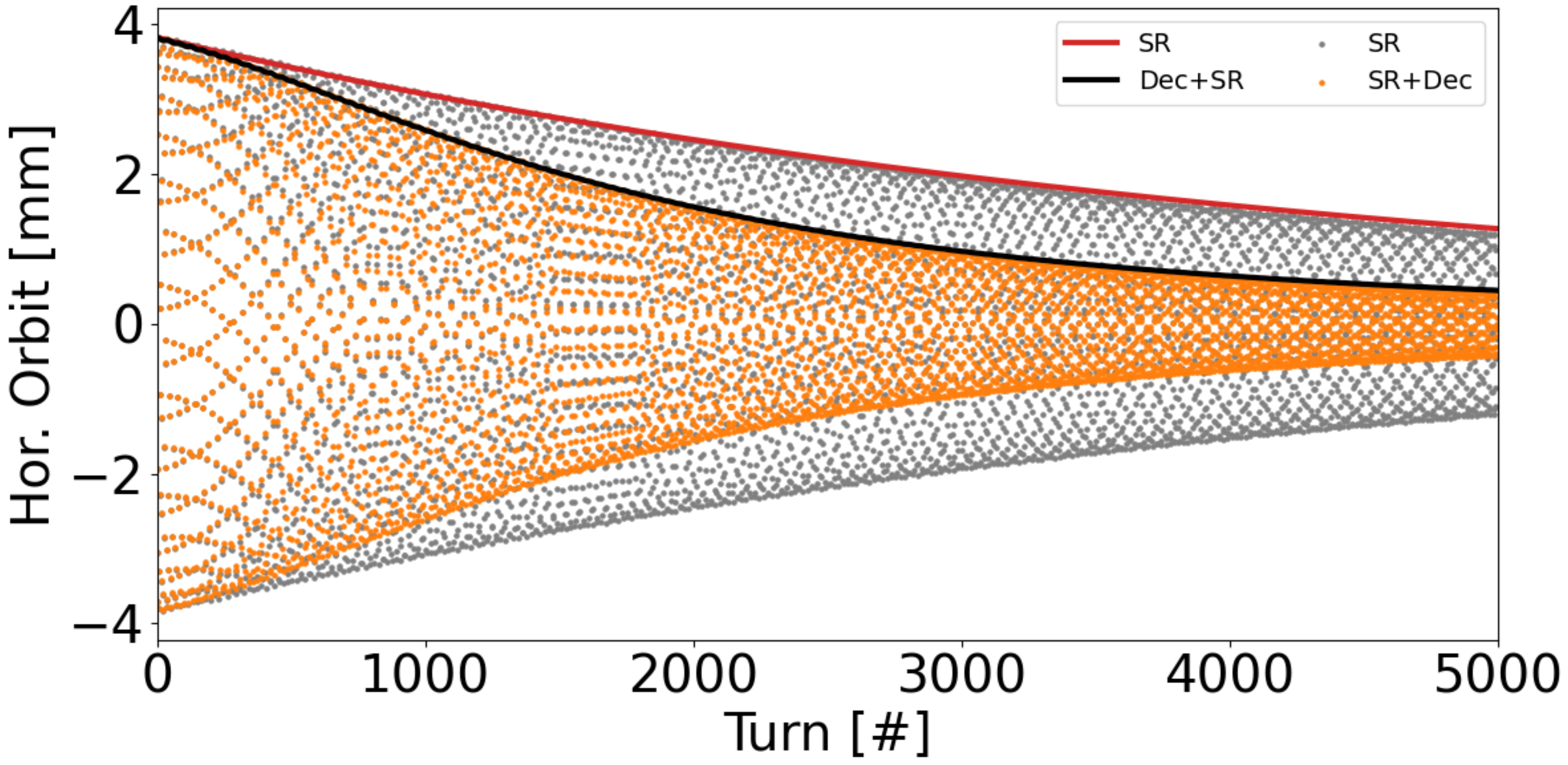


Decoherence only from nonlinearity gives very good agreement with tracking simulations with 0 longitudinal emittance

Over-estimate results from combination of decoherence from non-linearity and second-order chromaticity!

Scaling to Damping from SR

- Damping explained fully by decoherence and synchrotron radiation
- Data scaled to compensate for decoherence –> get only synchrotron radiation damping



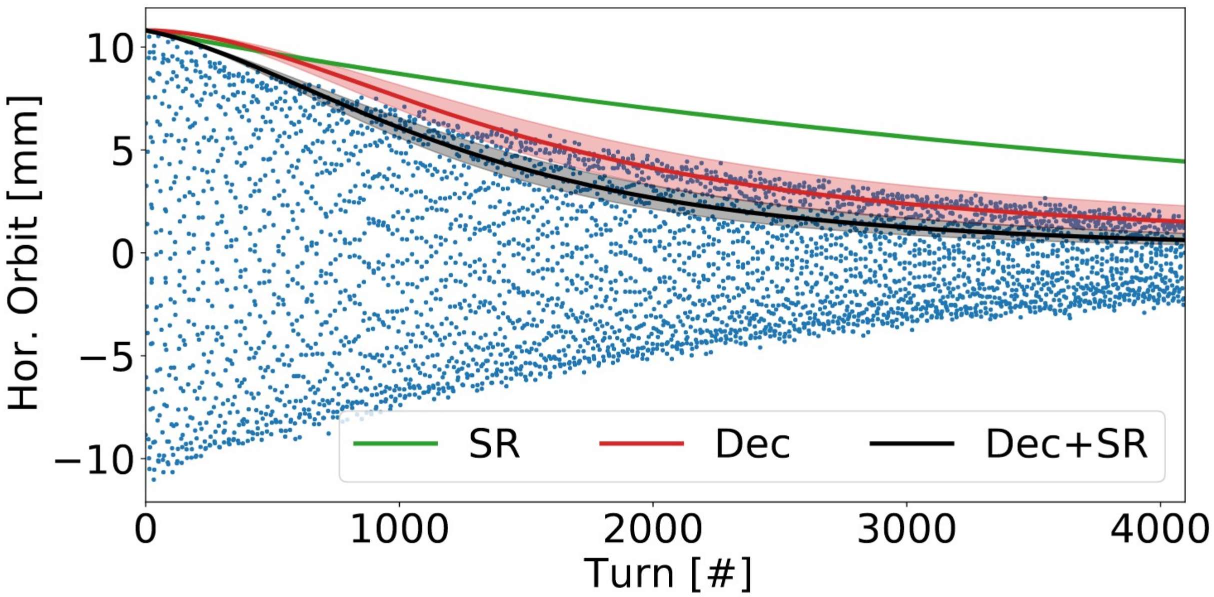
Amplitude detuning measured by using slices of 500 turns gives

$dQ_x/d2J_x = 1.81 \times 10^3\ m^{-1}$

–> error of +3% with respect to correct amplitude detuning for this lattice ($1.76 \times 10^3\ m^{-1}$)

Decoherence Summary

- Interplay between decoherence from second-order chromatictiy and non-linearity
- Equations can be used for either
  - Small amplitude detuning → G. Rumolo and R. Tomas, NIM-A 528, pp. 670-676, 2004
  - Small second-order chromaticity → To be finalized and then submitted
- Are suitable for measurements in SuperKEKB
  - $Q_x' = 1.7 \pm 0.04$ (model 0.04)
  - $Q_x'' = -22 \pm 18$ (model -199)



Outlook:
Understand interplay of both effects

First Look into Optics Tuning

- Framework created by Tessa Charles
- Created as indidual modules for corrections
  - Beta-beat, coupling and dfs
- Can be run for 1 seed or multiple seeds in htcondor
- Various requirements for python3
  - Different packages required for 1 seed vs htcondor
  - Different versions required for 1 seed vs htcondor
- Existing omc-python3 distribution not compatible
  - /afs/cern.ch/eng/sl/lintrack/omc_python3/bin/python

Requirements htcondor

```
attrs==21.2.0
click==8.0.1
in-place==0.5.0
iniconfig==1.1.1
Jinja2==3.0.1
MarkupSafe==2.0.1
numpy==1.21.1
packaging==21.0
pandas==1.3.1
pluggy==0.13.1
py==1.10.0
pyparsing==2.4.7
pytest==6.2.4
pytest-warnings==0.3.1
python-dateutil==2.8.2
pytz==2021.1
random2==1.0.1
scipy==1.7.0
six==1.16.0
tfs-pandas==2.1.0
toml==0.10.2
PyYAML==6.0
```

Requirements one seed

```
attrs==21.4.0
click==8.0.3
contextlib2==21.6.0
execnet==1.9.0
iniconfig==1.1.1
Jinja2==3.0.3
MarkupSafe==2.0.1
mock==4.0.3
numpy==1.22.0
packaging==21.3
pandas==1.3.5
path==16.2.0
path.py==12.5.0
pluggy==1.0.0
py==1.11.0
pyparsing==3.0.6
pytest==6.2.5
pytest-shutil==1.7.0
pytest-warnings==0.3.1
python-dateutil==2.8.2
pytz==2021.3
PyYAML==6.0
random2==1.0.1
scipy==1.7.3
six==1.16.0
termcolor==1.1.0
tfs-pandas==3.0.2
toml==0.10.2
```

Single Seed – First Experiences

- Started by running the test case for one seed

- Path needed to be changed in correction scripts (correct_betabeat_c.py, etc.)
- *{{path}} not recognized* → for now hard coded changed in variable “response_mat_path”

- Found one hard coded path in dfs_c.py
- project_root = "/afs/cern.ch/work/t/techarle/public/FCCee_tolerance_study/"

- Script went halfway through then stopped with error
- Correctors strengths, orbits, tunes exact zero

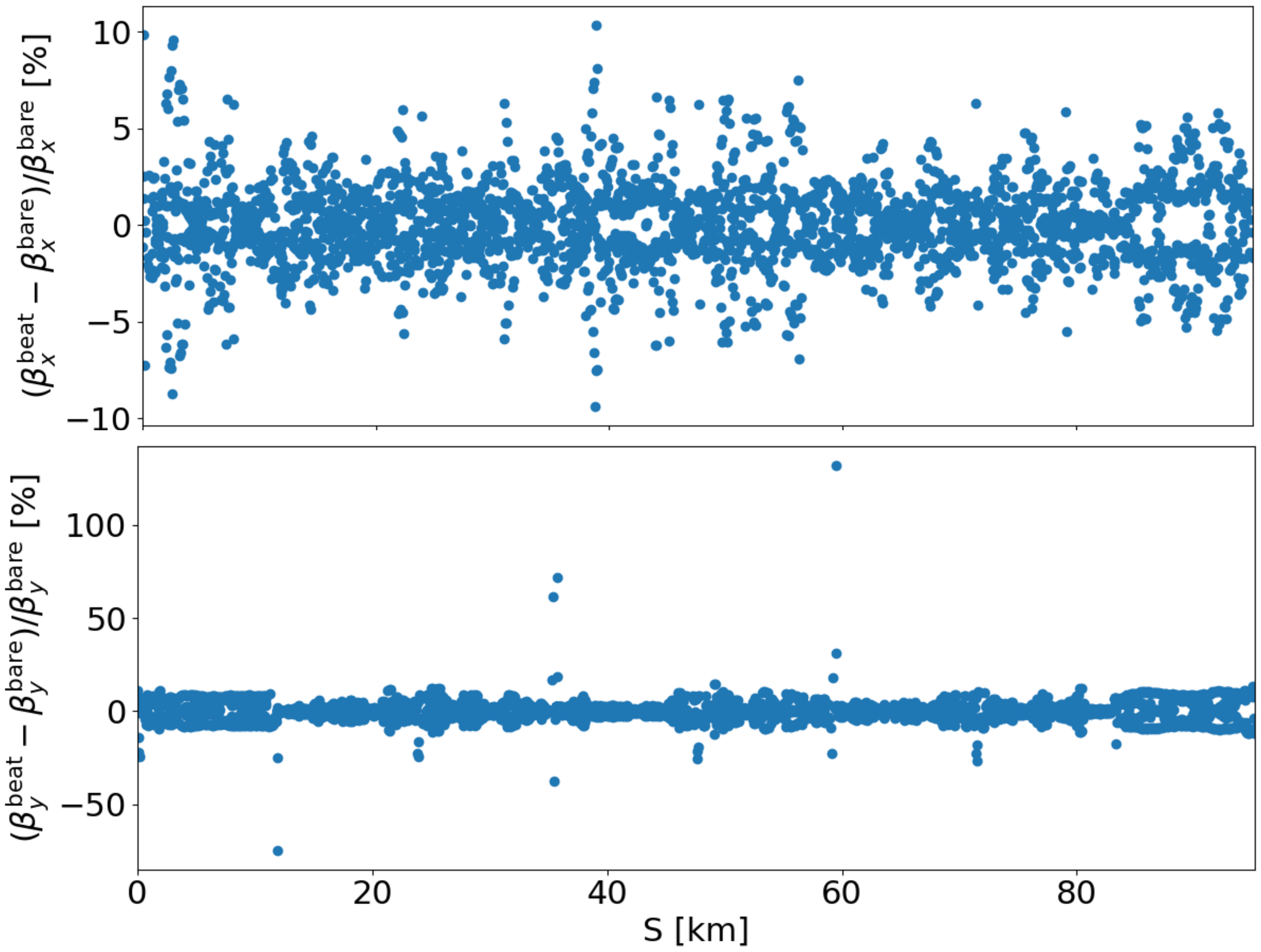
To be understood
Only for test case?

```
++++++ Error: seterrorflag : Errorcode: 1   Reported from pro_twiss:
++++++ Error: seterrorflag : Description: TWISS failed
++++++ warning: Twiss failed:  MAD-X continues
-------checking (inside orbit marco 3 y)-------
vycomax            =   0.00000000000000e+00 ;
vxcomax            =   0.00000000000000e+00 ;
vbetymax           =   0.00000000000000e+00 ;
tuneq1             =   0.00000000000000e+00 ;
tuneq2             =   0.00000000000000e+00 ;
----------------------
testing tune q1
scheme_tunes macro
90                 =   9.00000000000000e+01 ;
----------------------
tuneq1             =   0.00000000000000e+00 ;
tuneq2             =   0.00000000000000e+00 ;
----------------------
```

Single Seed – First Experiences

- Twiss bare: generated before applying errors –> error free twiss
- Twiss beat: generated after applying errors and updated after running corrections
- Hor. rms beta beat: 2.07 %
- Ver. rms beta beat: 5.66 %

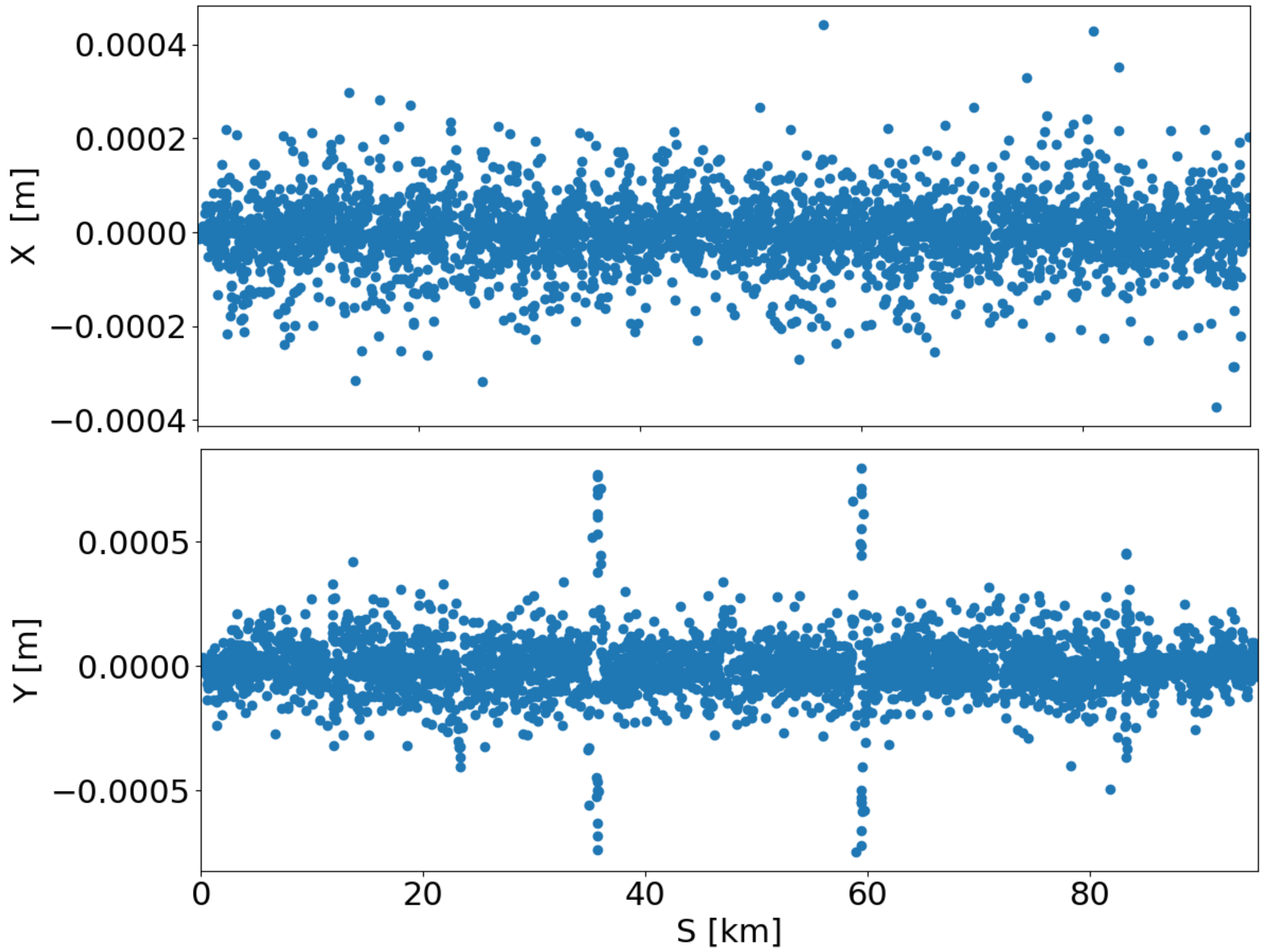
To be understood which correction steps have already been performed



Single Seed – First Experiences

- Twiss bare: generated before applying errors –> error free twiss
- Twiss beat: generated after applying errors and updated after running corrections
- Hor. rms orbit: 7.3 x 10^{-5} m
- Ver. rms orbit: 1.2 x 10^{-4} m

To be understood which correction steps have already been performed



Thank you!

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