Beam-beam simulations with lattice for FCC-ee

Demin Zhou

Acknowledgements:

K. Ohmi, K. Oide, D. Shatilov

39th FCC-ee Optics design meeting, CERN

Sep. 16, 2016

Outline

- **Lattices for $t\bar{t}$ (by K. Oide)**
  - Compare two versions
    - FCCee_t_82_by2_1a_nosol_DS_2
    - FCCee_t_65_26_1_2
  - Error seeds in vertical offsets of S{DF}* [sextupoles in arc sections) to generate vertical emittance
- **FMA**
  - DA, beam-beam and lattice resonances
- **Luminosity**
  - BBWS
  - SAD: beam-beam + lattice
- **Summary**

1. Machine parameters (for half ring)

Lattice version	82_by2*	65_26_1_2
C (km)	49988.8	49990.9
E (GeV)	175	175
Number of IPs	1	1
N_b	81	78
$N_p(10^{11})$	1.7	1.7
Full crossing angle(rad)	0.03	0.03
ε_x (nm)	1.26	1.3
ε_y (pm)	2.52	2.5
β_x^* (m) [optional]	1	1
β_y^* (mm) [optional]	2	2
σ_z (mm)^{SR}	2.4	2.1
$\sigma_\delta(10^{-3})^{SR}$	1.4	1.4
Fractional betatron tune ν_x/ν_y	.56/.61	.54/.57
Synch. tune ν_s	0.0329	0.0375
Damping rate/turn (10^{-2}) [x/y/z]	1.06/1.06/2.09	1.1/1.1/2.2
Lum./IP($10^{34}cm^{-2}s^{-1}$)	1.3	1.3

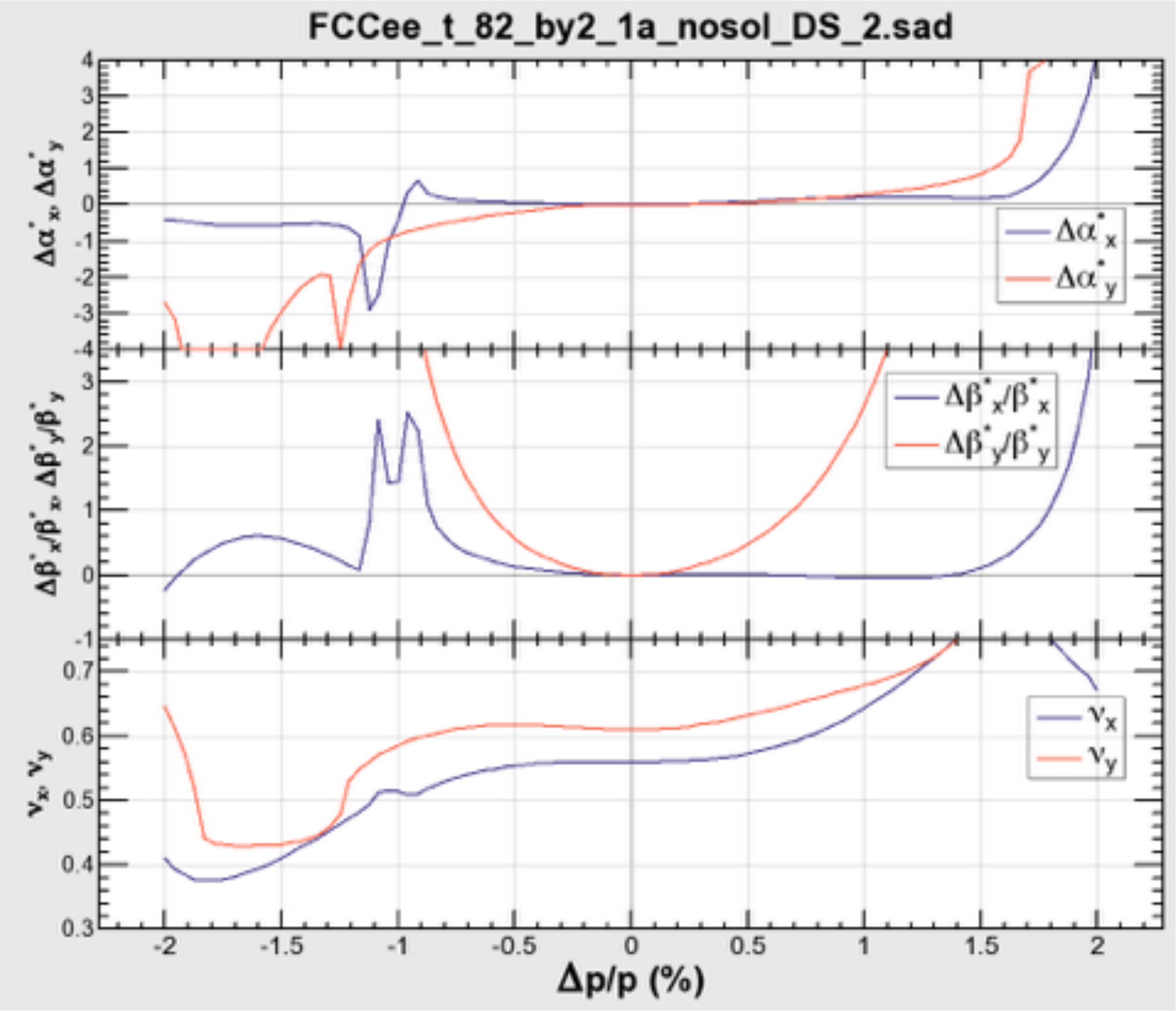
*Ref. K. Oide et al., “Design of beam optics for the FCC-ee collider ring”, Submitted to PRAB.

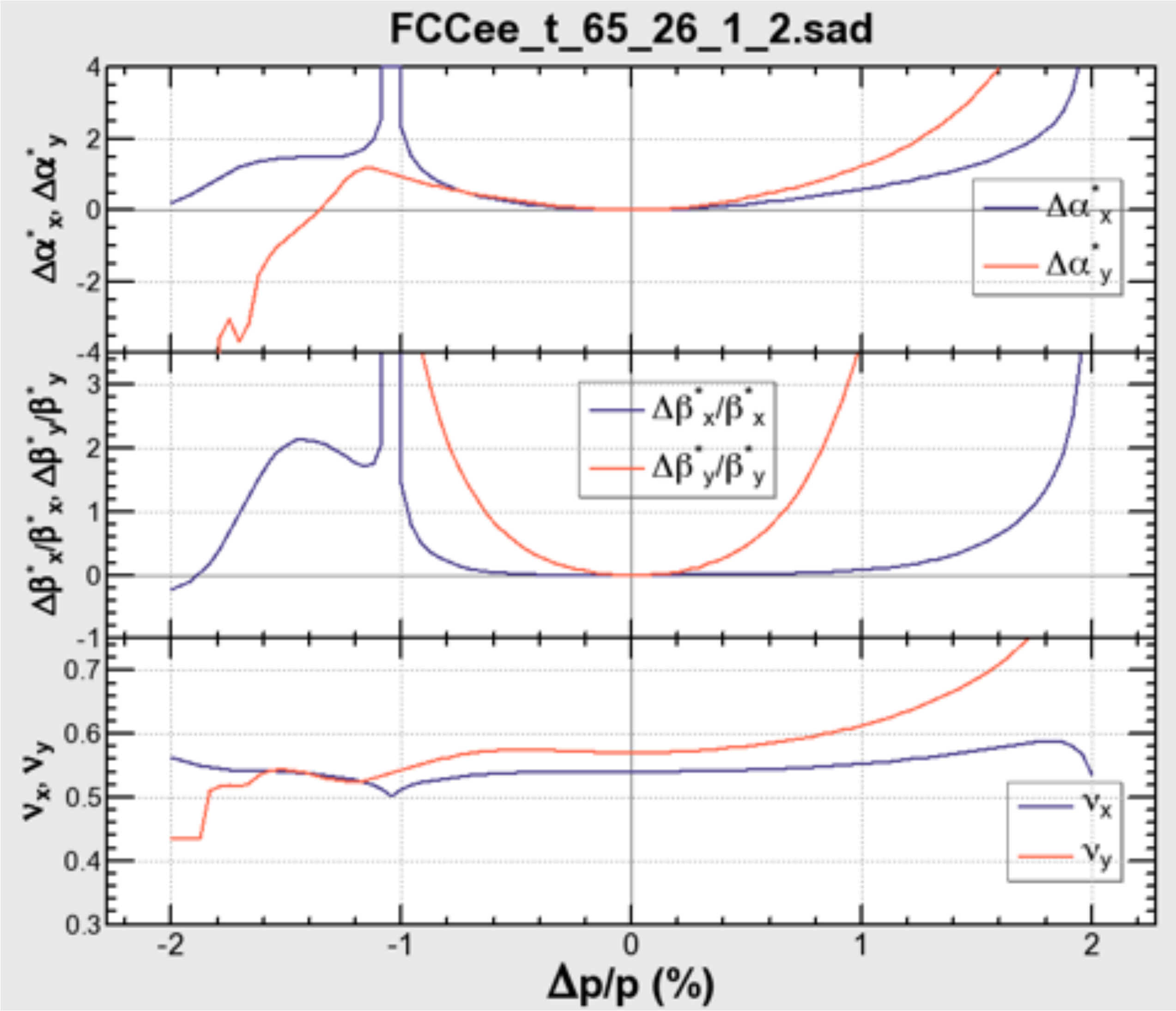
1. Lattice properties

➤ Chromatic nonlinearity

- Similar except higher 3rd chromaticity in Ver. 82_by2

From K. Oide



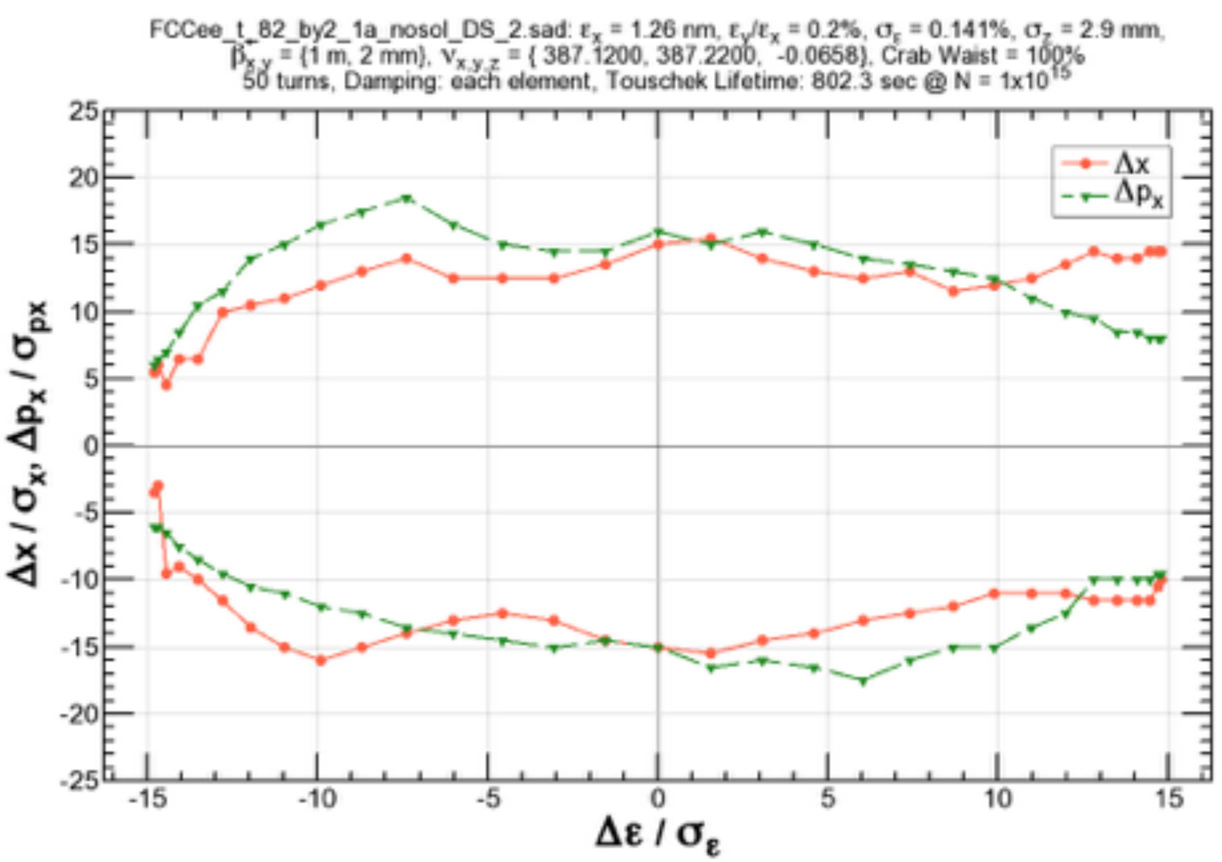


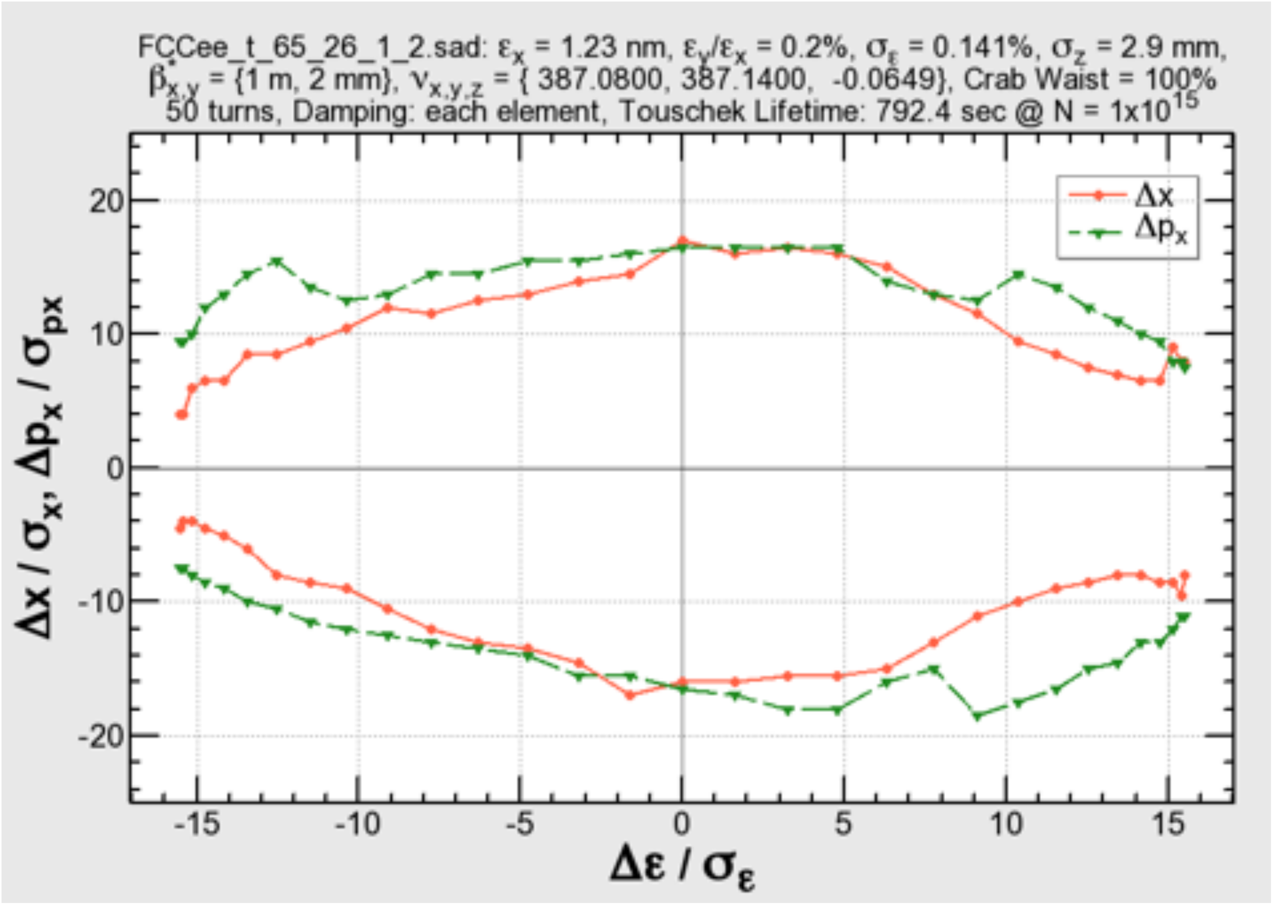
1. Lattice properties

➤ Dynamic aperture

- 6D Tracking: 50 turns
- Element-by-element rad. damping

From K. Oide



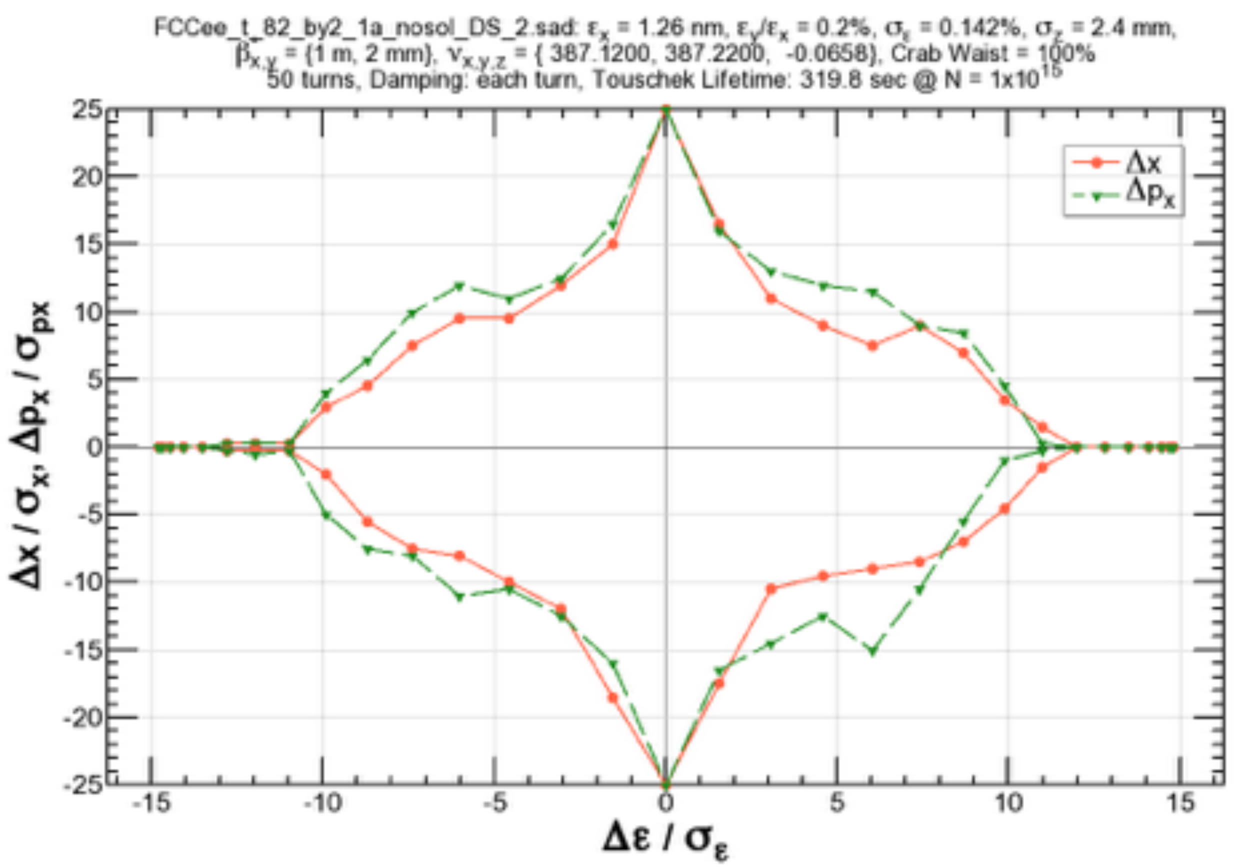


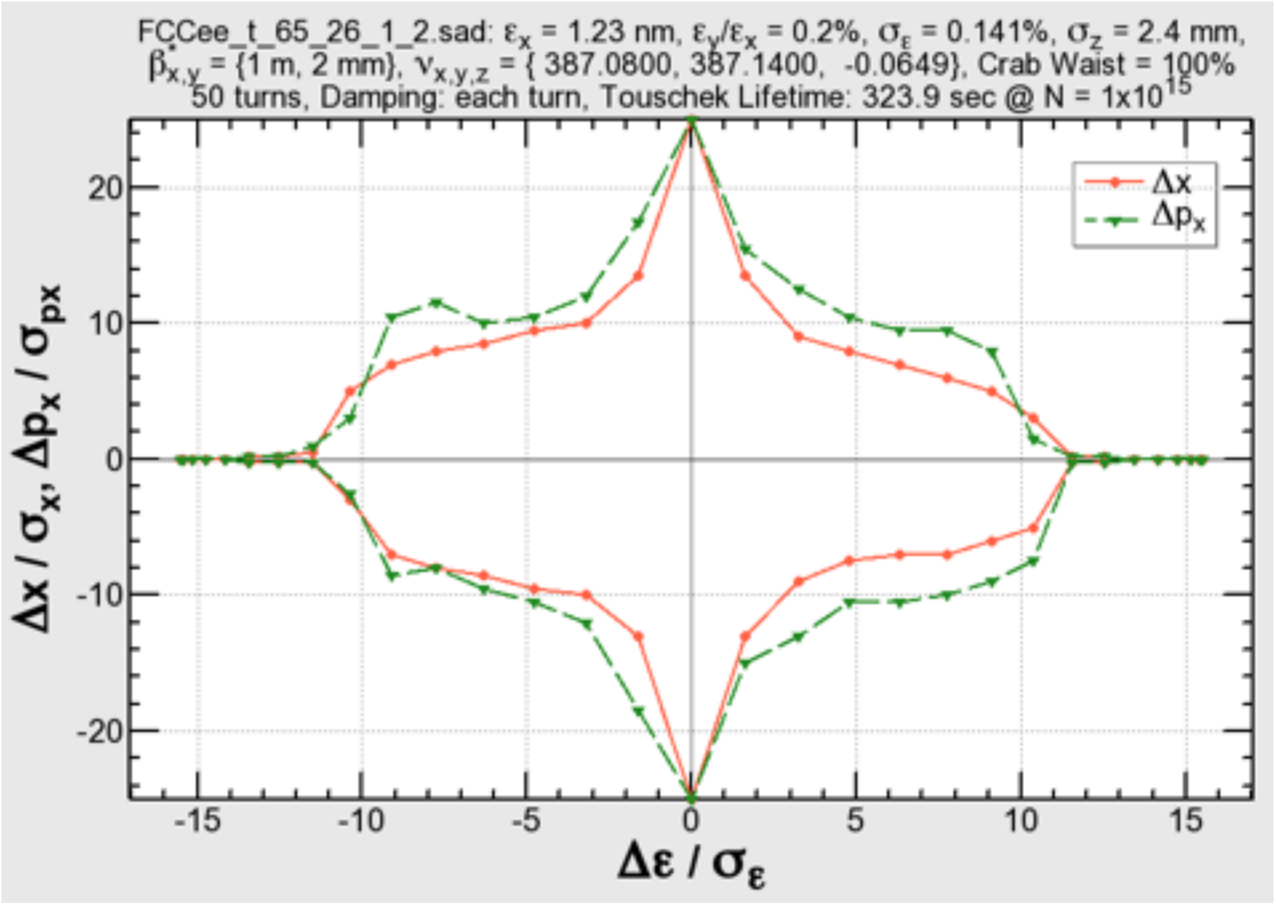
1. Lattice properties

➤ Dynamic aperture

- **6D Tracking: 50 turns**
- **Turn-by-turn lumped rad. damping**

From K. Oide



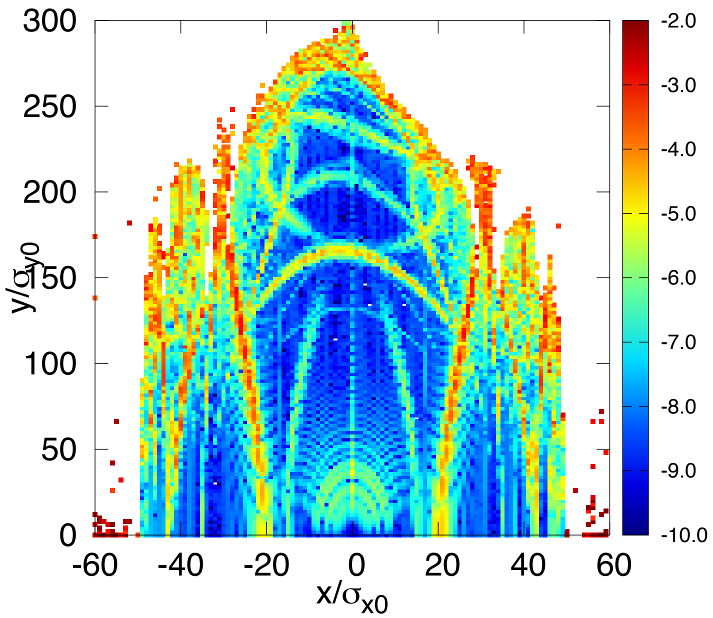


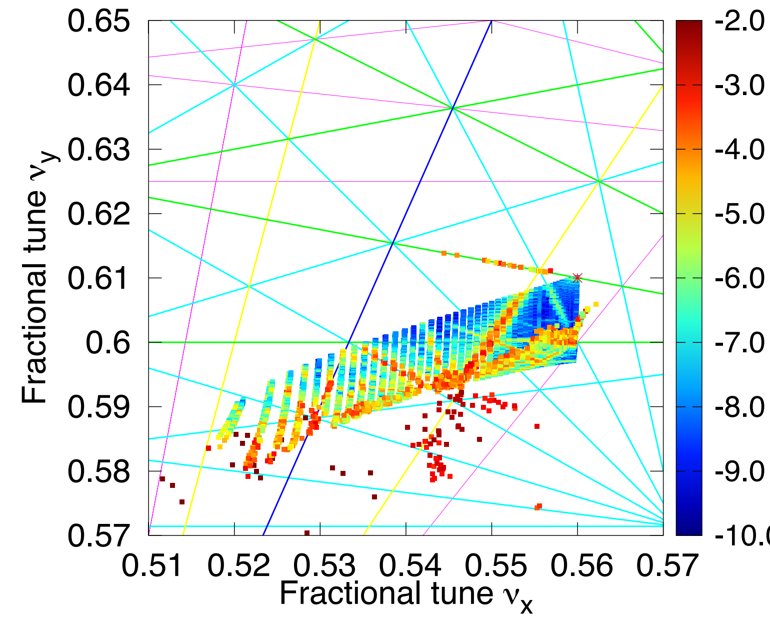
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of RF

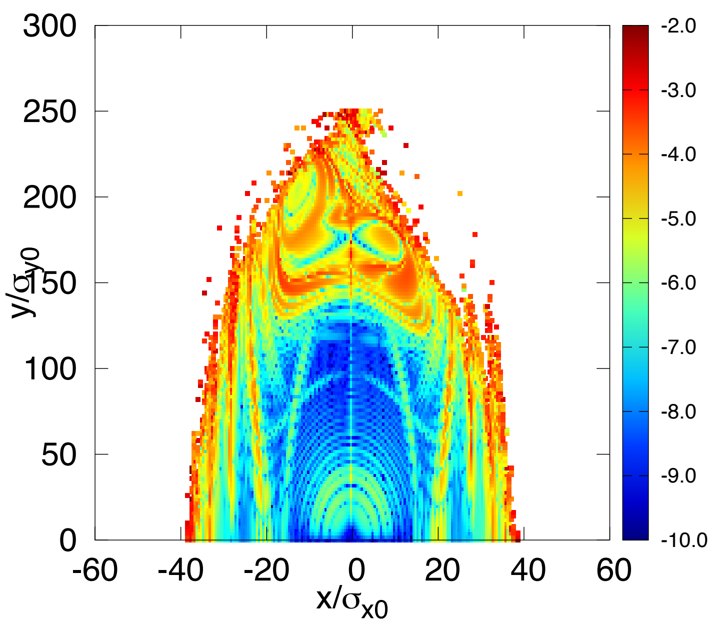
- Strong X-Y to Z coupling
- Strong impact of synch. motion on FMA
- On-momentum DA decrease significantly due to SR

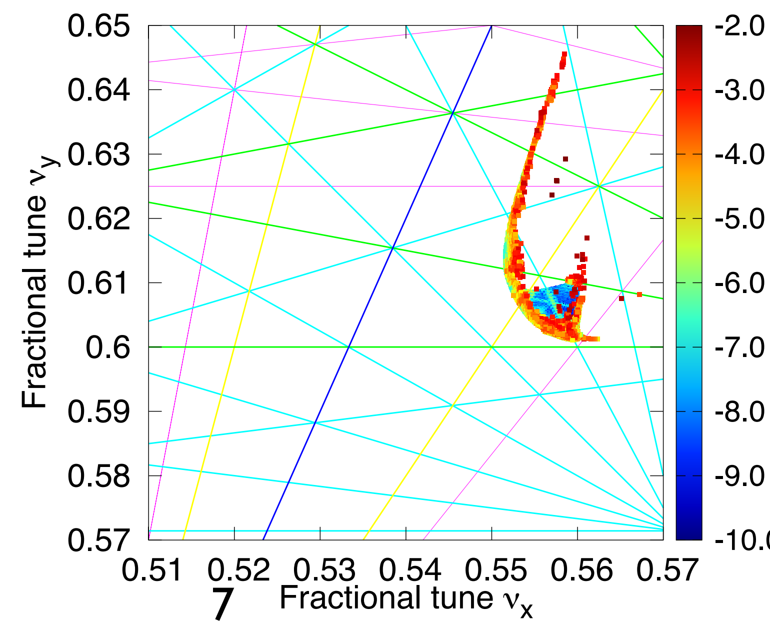
RF OFF:





RF ON:





Conditions:

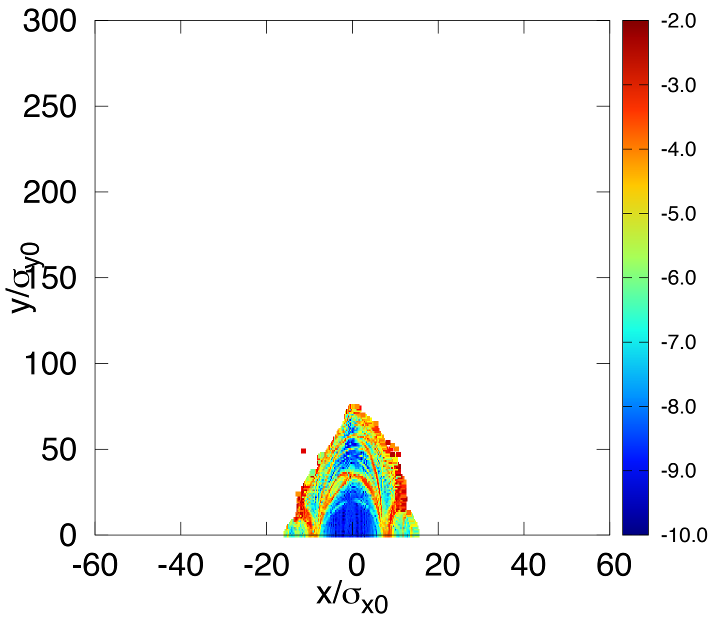
1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) BB OFF
7) $\delta=0$

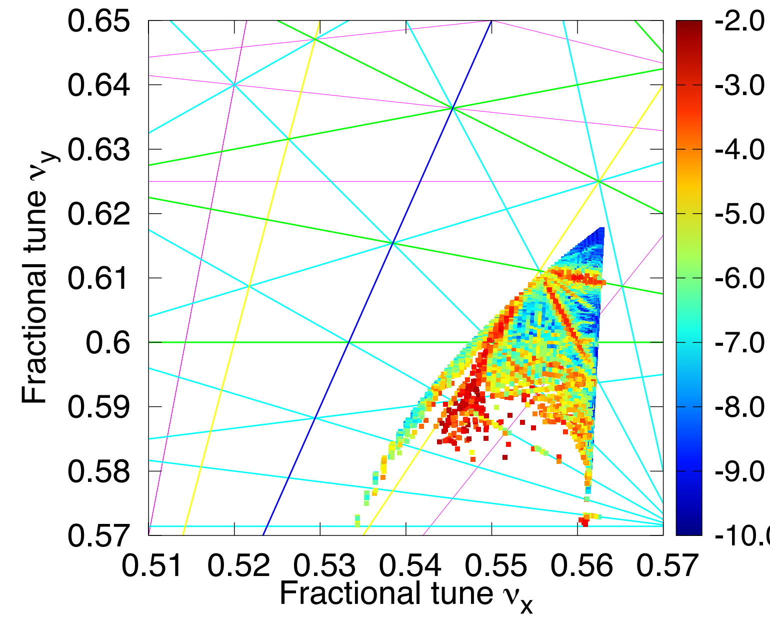
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of RF

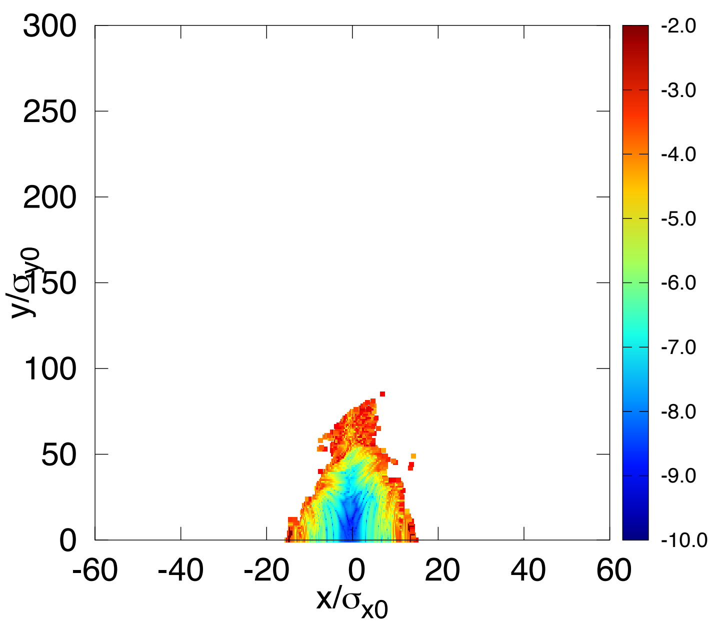
- **Strong X-Y to Z coupling**
- **Strong impact of synch. motion on FMA**

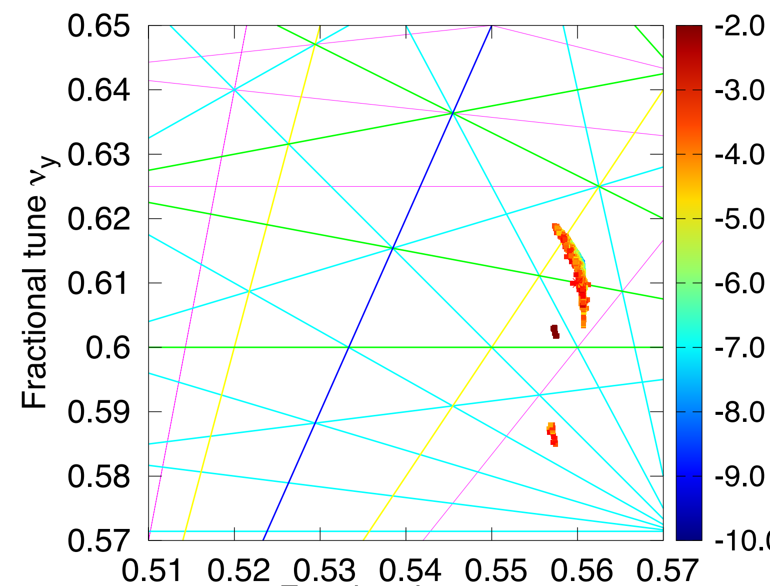
RF OFF:





RF ON:





Conditions:

1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) BB OFF
7) $\delta=2\sigma_p$

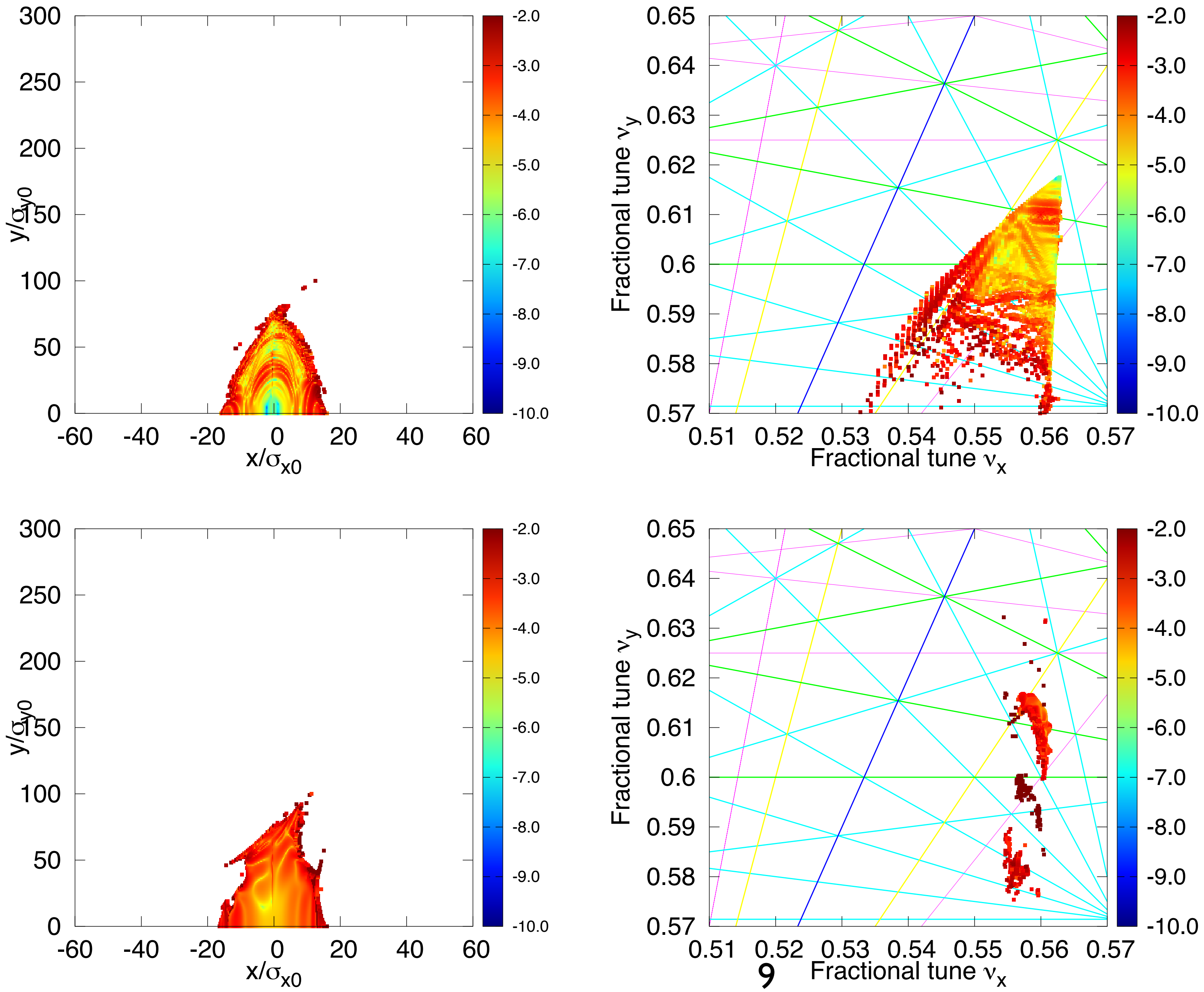
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of tracking turns

- Poor resolution of diffusion in FMA
- Weak impact on size of DA w/o BB

RF OFF:

RF ON:



Conditions:

1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 128 half turns
6) BB OFF
7) $\delta=2\sigma_p$

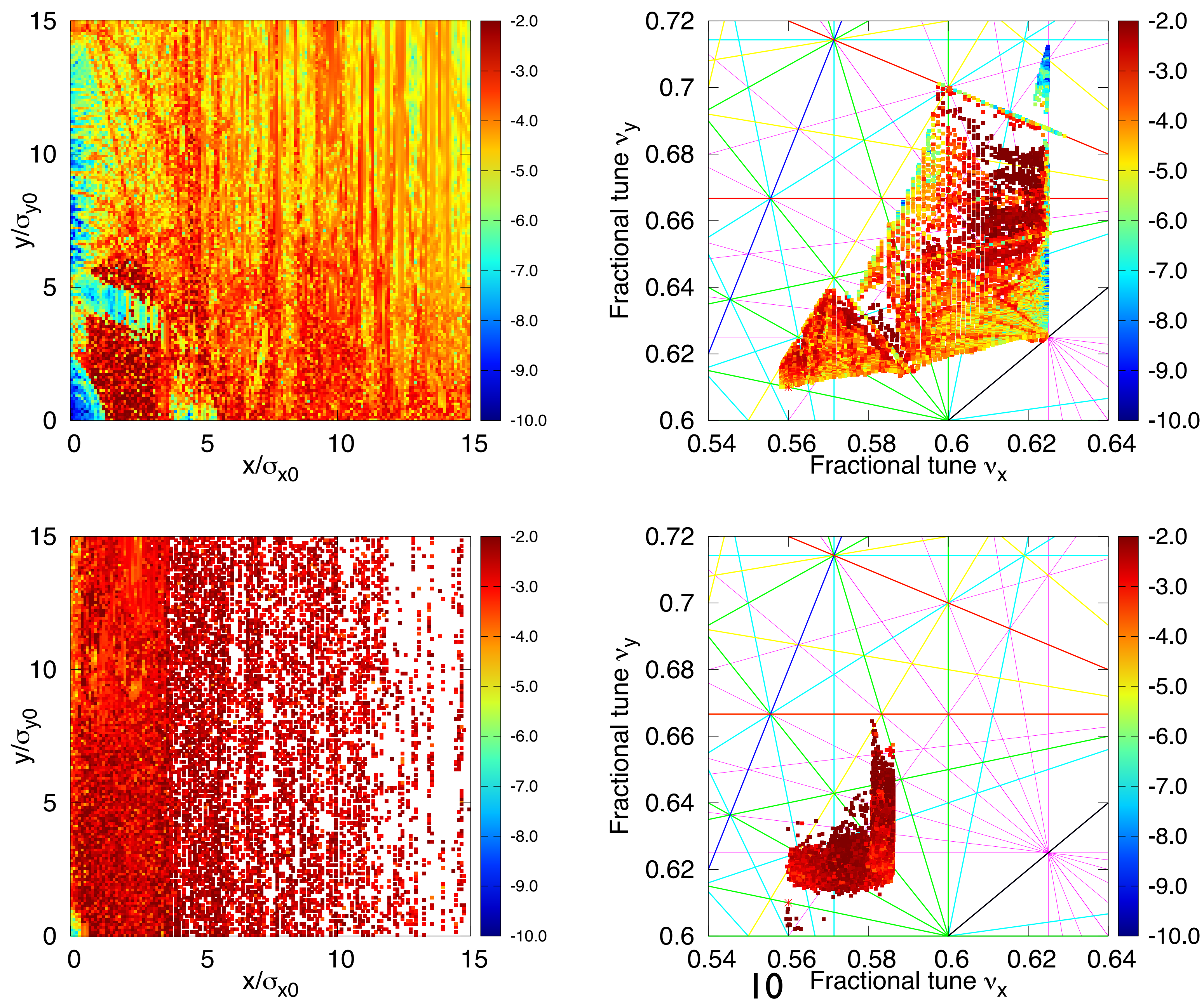
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Beam-beam effects

- **Extend footprint in tune space and drive resonances**
- **Reduce DA**

δ=0:

$\delta=2\sigma_p$:



Conditions:

1) Bare lattice
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) RF & BB ON
7) Np=0.85E11

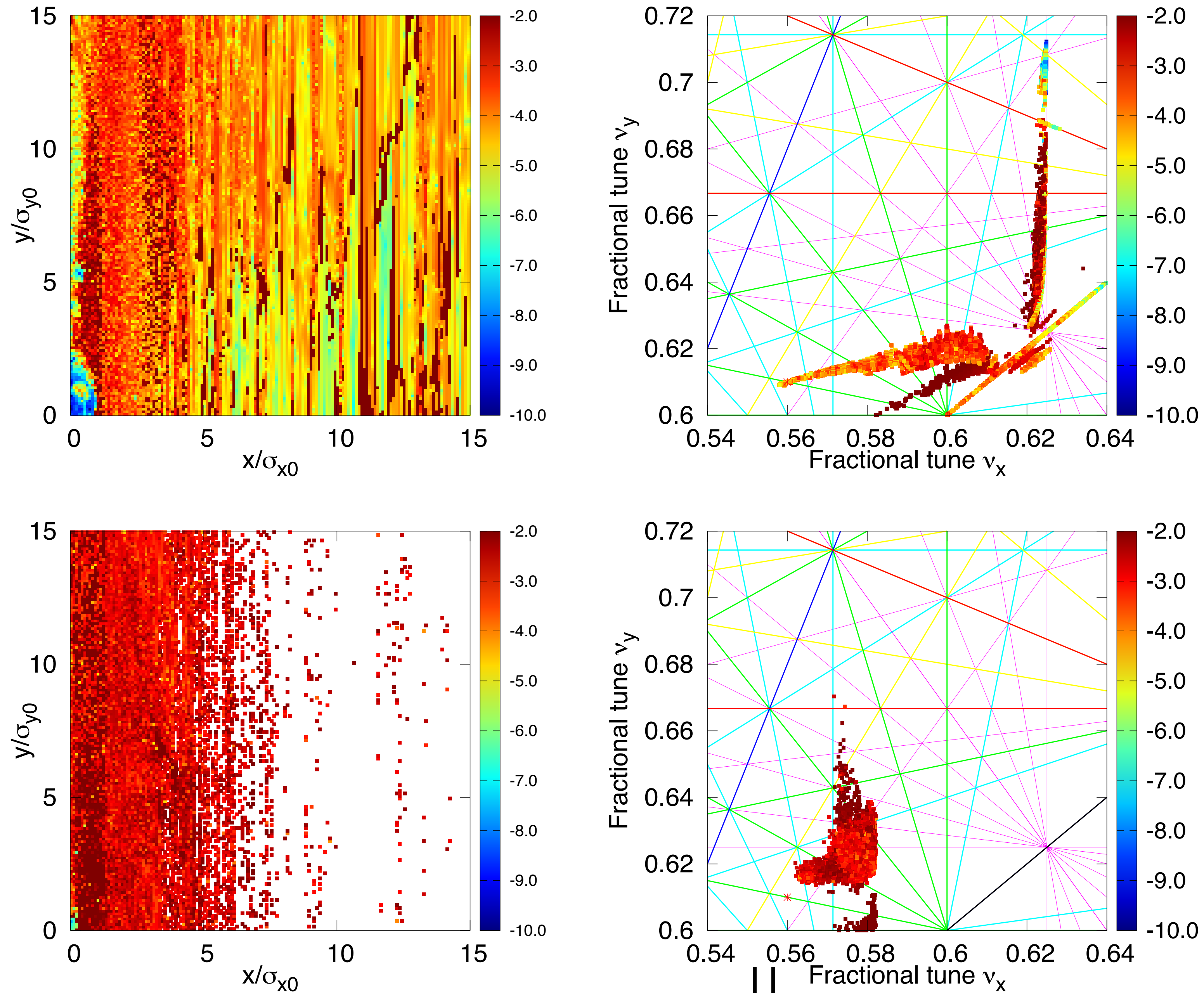
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ Effects of errors in vertical offsets of S{DF}*

- **Modify footprint in tune space**
- **Reduce DA**

$\delta=0$:

$\delta=2\sigma_p$:



Conditions:

1) Error seed #25
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 1024 half turns
6) RF & BB ON
7) Np=0.85E11

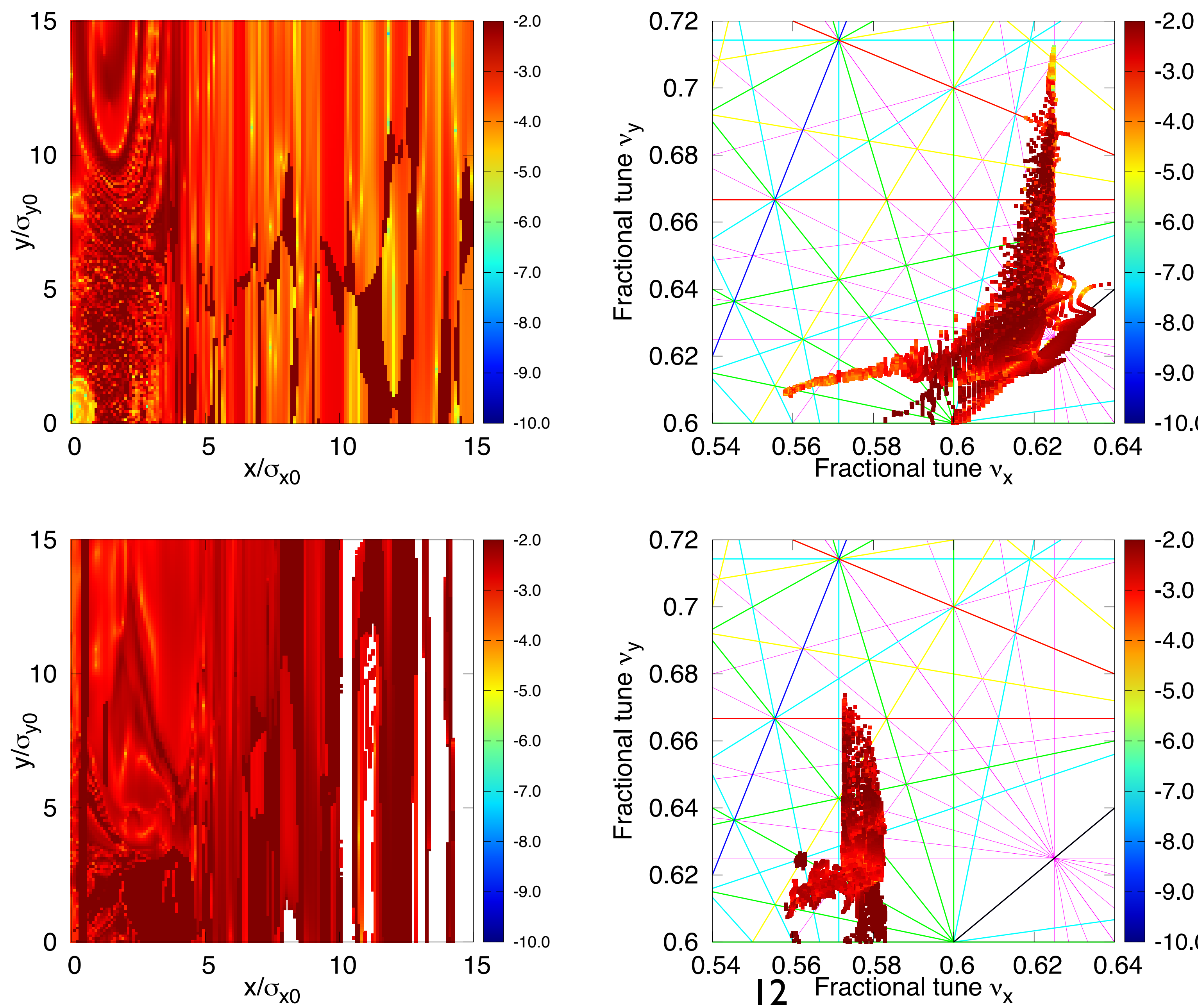
2. FMA: Ver. FCCee_t_82_by2_1a_nosol_DS_2

➤ **Effects of errors in vertical offsets of S{DF}***

- Modify footprint in tune space
- Reduce DA
- Tracking in the order of damping time: Better surviving rate

δ=0:

δ=2σ_p:



Conditions:

1) Error seed #25
2) 6D tracking
3) SAD + NAFF
4) No rad. damping
5) 128 half turns
6) RF & BB ON
7) Np=0.85E11

3. Luminosity

➤ Weak-strong simulation w/ and w/o lattice

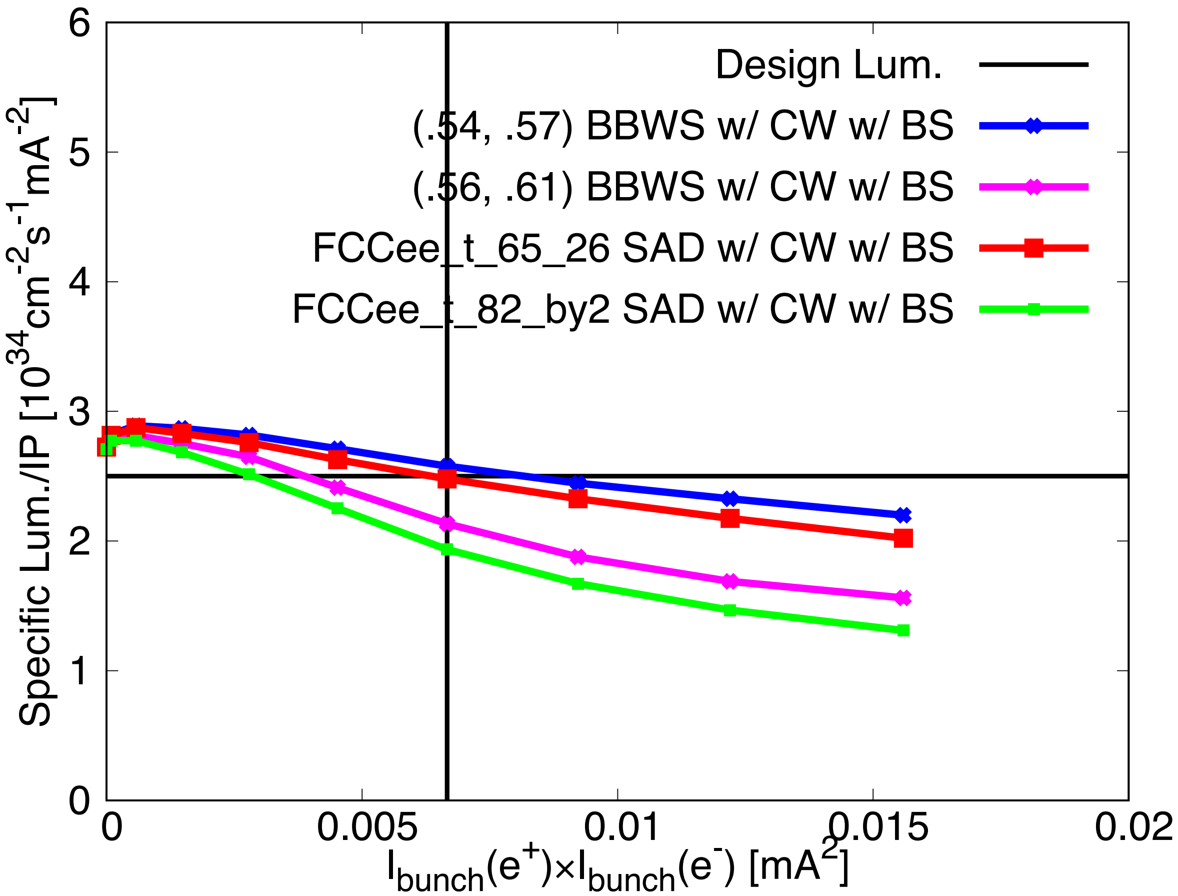
- Lum. loss due to interplay of BB+Lattice => a few per cent
- Lum. is sensitive to working point

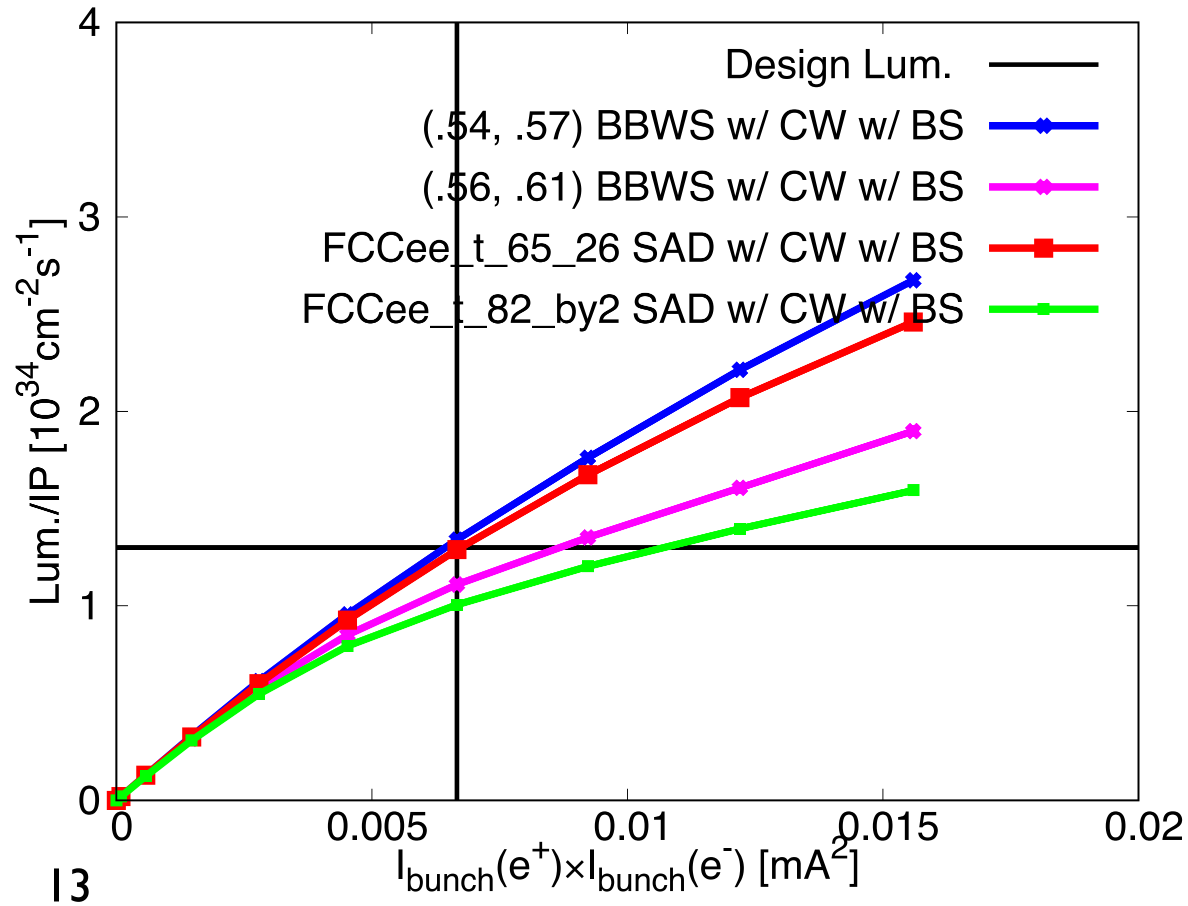
Conditions:

1) Bare lattice

2) Lumped rad. damping/excitation, CW & BS ON

3) # of bunches: 78, σ_{z0}=2.1mm





3. Luminosity

➤ Weak-strong simulation w/ and w/o lattice

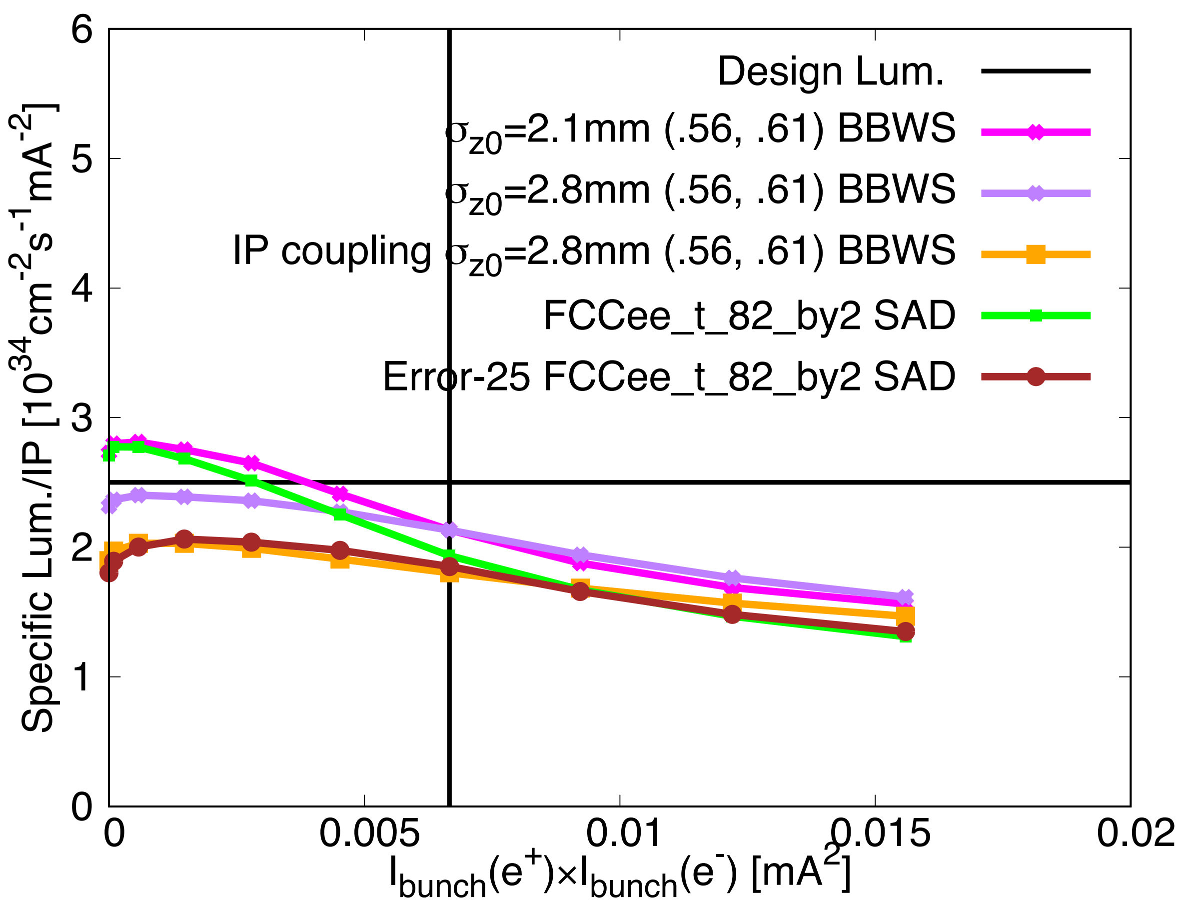
- Errors in S{DF}* also generate dispersion at RF (longer bunch), and dispersion/linear coupling at IP
- Lum. loss with errors in S{DF}* is not due to lattice nonlinearity
- Local linear coupling at IP => Additional lum. loss

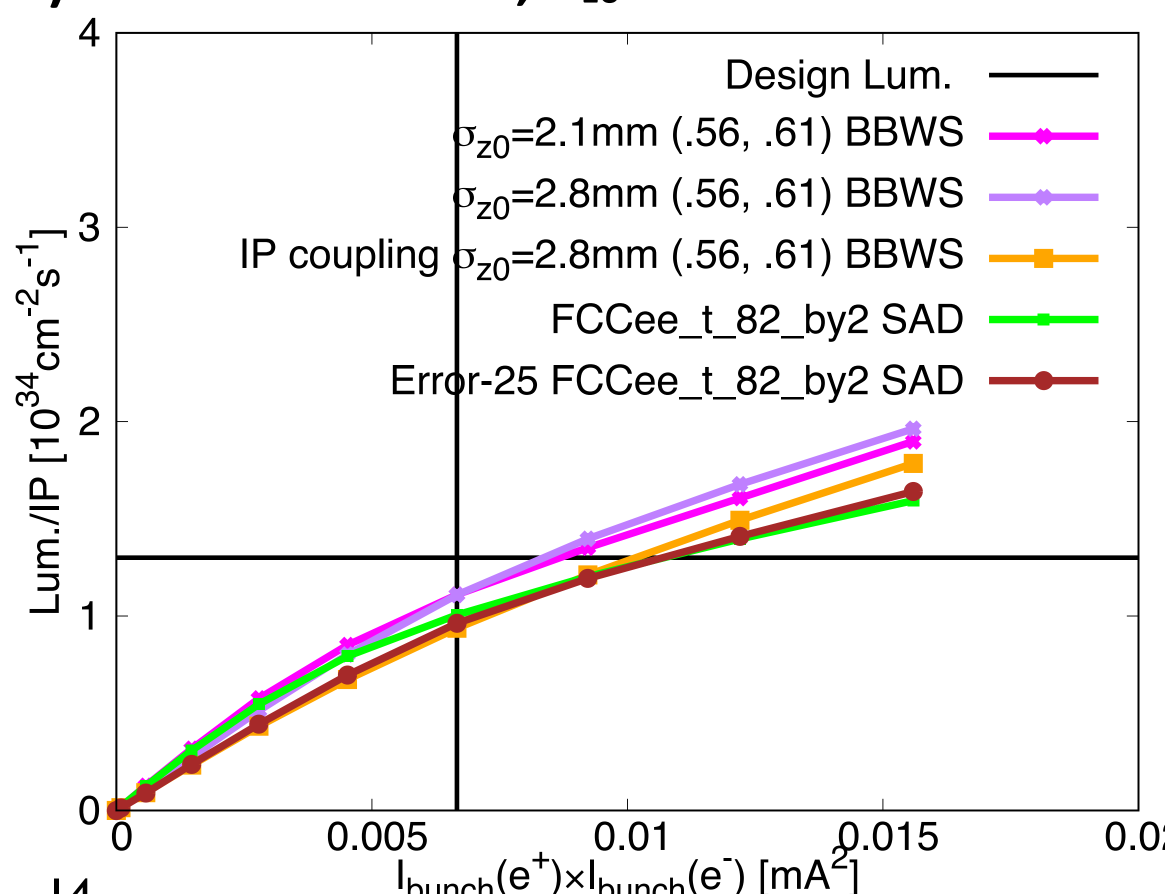
Conditions:

1) Bare lattice + Errors

2) Lumped rad. damping/excitation, CW & BS ON

3) # of bunches: 78, σ_{z0}=2.8mm



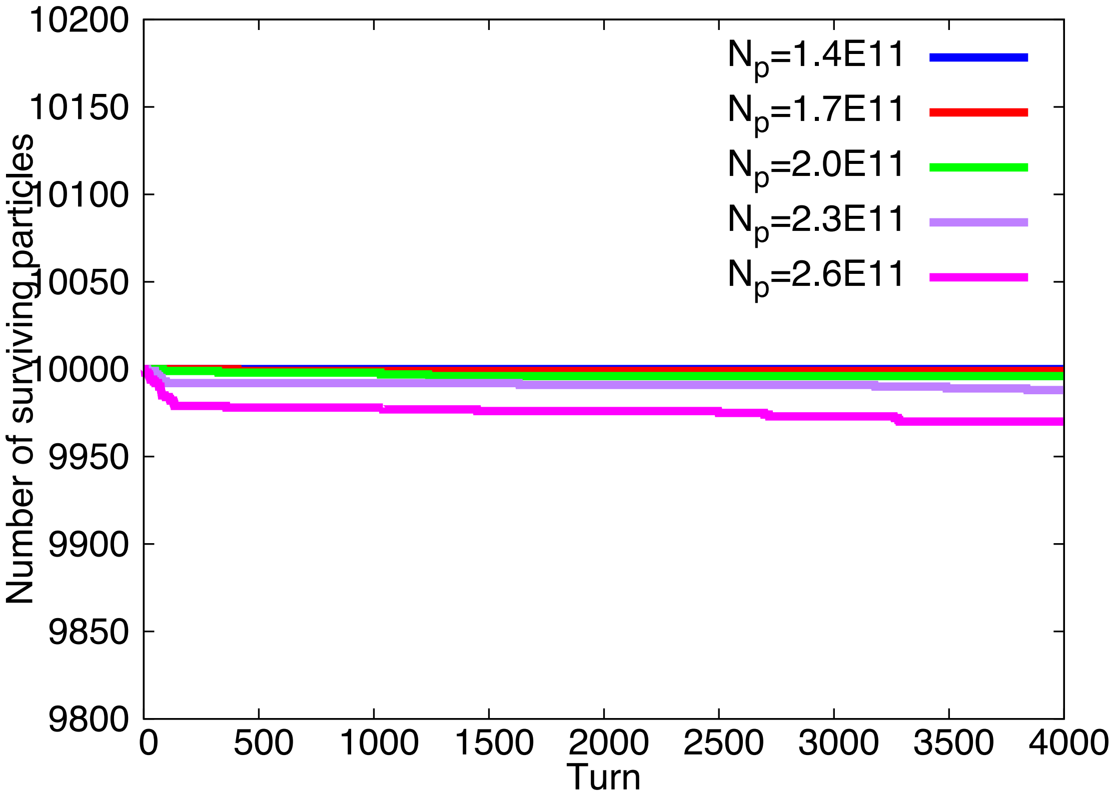


4. Lifetime

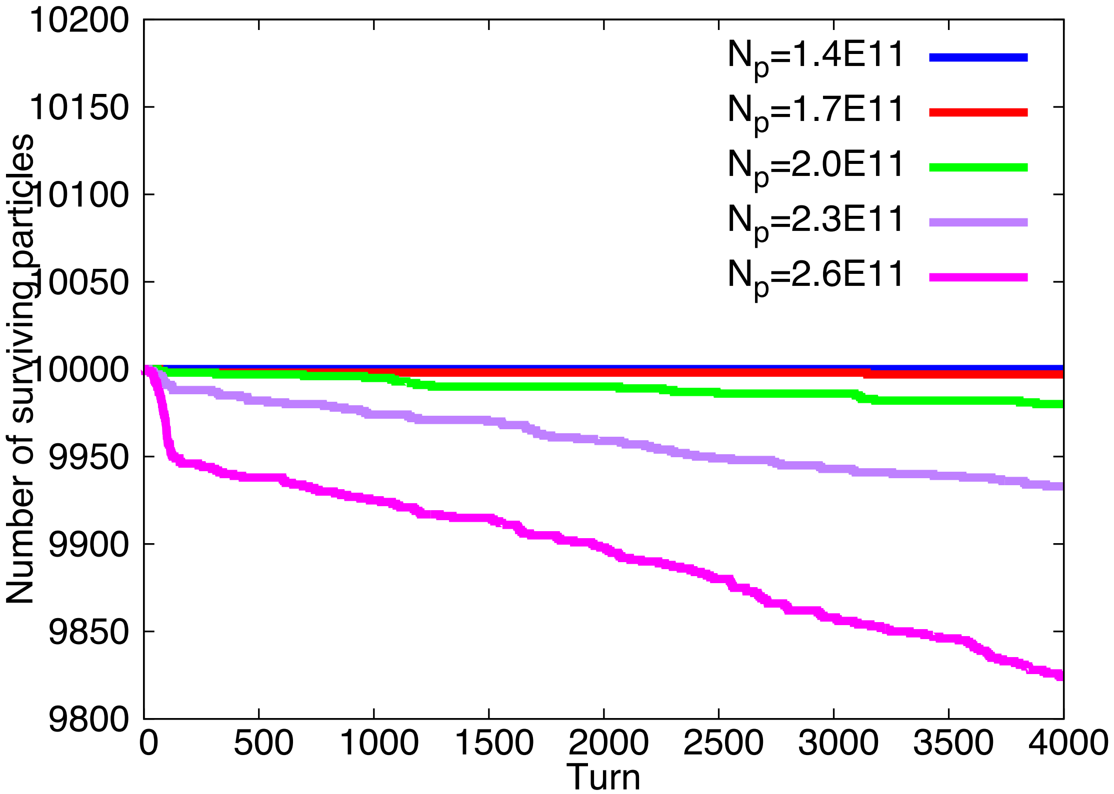
➤ Particle losses in tracking

- **Mechanism: Beamstrahlung effects + Finite DA**
- **DA is determined by rad. damping/excitation, Lattice nonlinearity and BB**

FCCee_t_65_26_1_2
w/ CW



FCCee_t_65_26_1_2_nocw
w/o CW



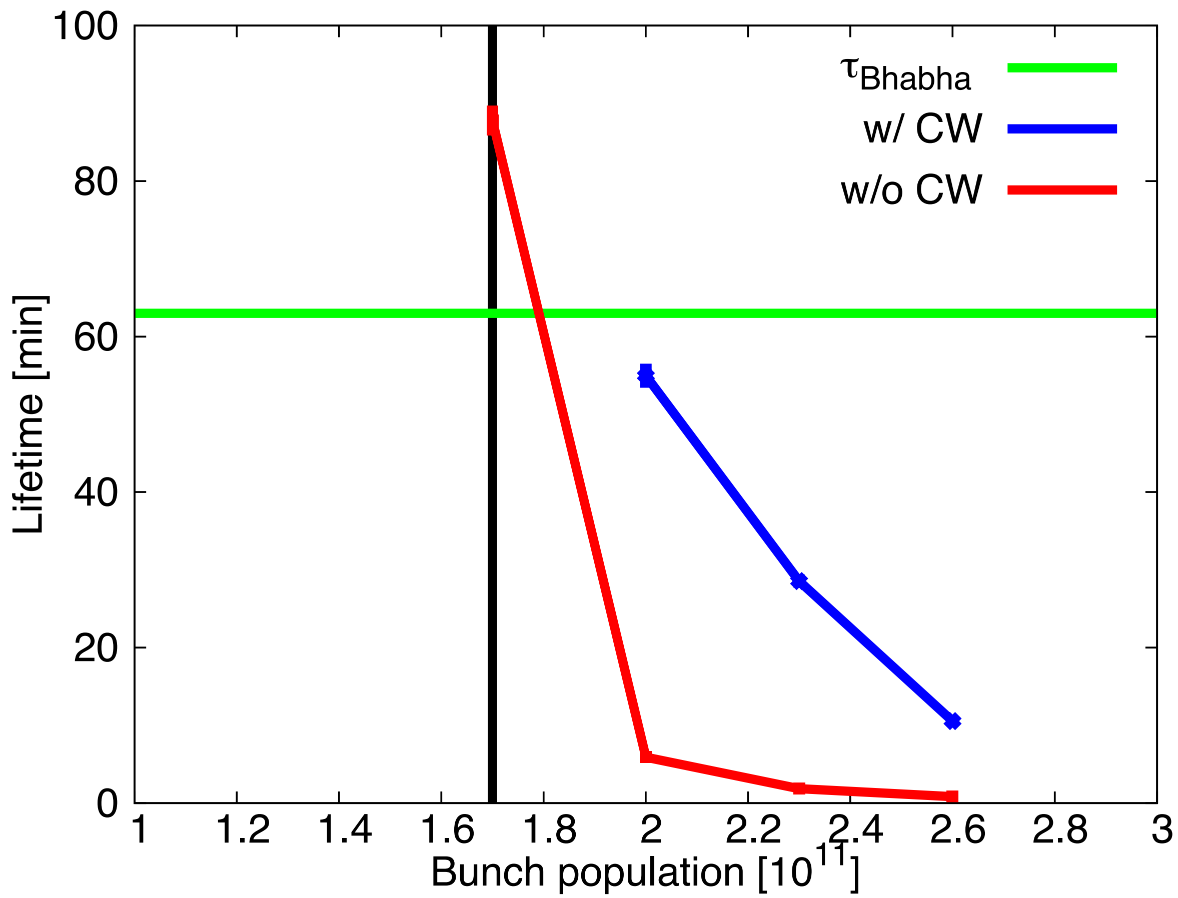
Ref. D. Zhou, Talk at FCC week 2016, Rome.

4. Lifetime

➤ Particle losses in tracking

- Translate loss rate into lifetime
- CW improves lifetime via suppressing beam-beam tail
- Need more careful simulations: Larger number of macro-particles and tracking turns

FCCee_t_65_26_1_2

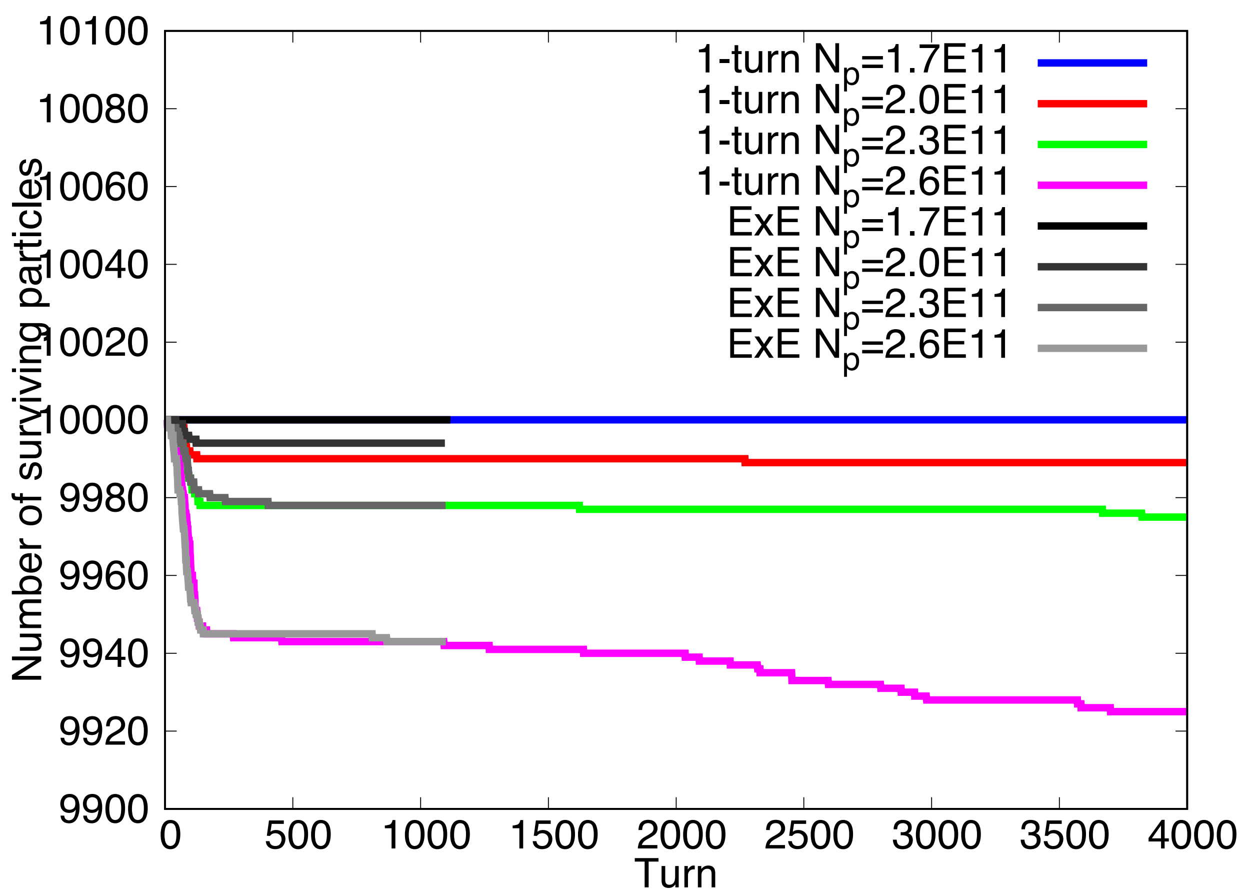


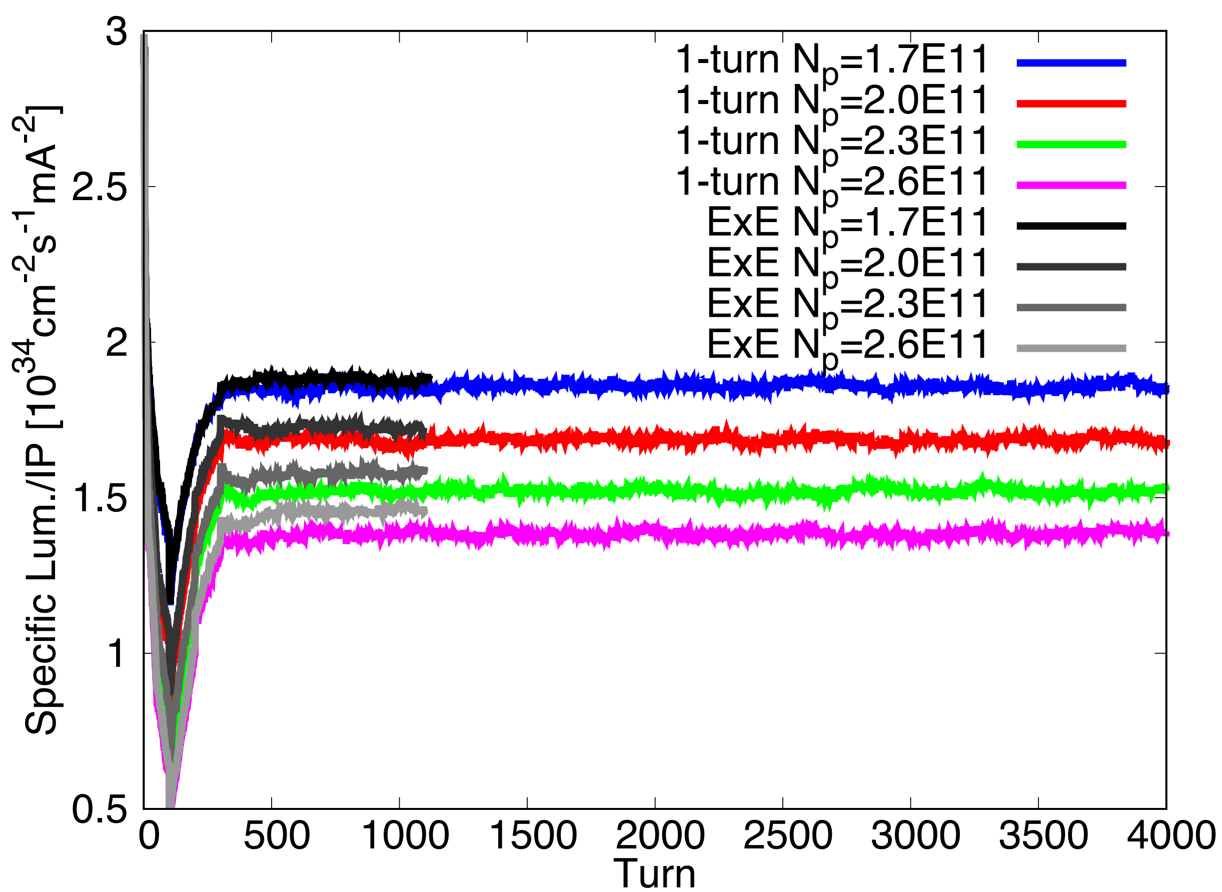
Ref. D. Zhou, Talk at FCC week 2016, Rome.

4. Lifetime

➤ Effects of rad. damping/excitation

- **Distributed (element-by-element) vs. Lumped (one-turn, to speed up simulation)**
- **Case: FCCee_t_82_by2_1a_nosol_DS_2 with Error seed #25**
- **Small effect if BB dominates DA (?)**





5. Summary

➤ FMA

- Rad. damping/excitation: not considered in FMA but very important at FCC-ee
- SAD+NAFF+BB almost agree with D. Shatilov’s results except much worse resolution in my simulations
- Synch. motion (X-Y to Z coupling) is very important at FCC-ee
- Beam-beam is an important factor in determining DA
- Errors in vert. offsets of S{DF}* affect DA (w/ BB) [likely tolerable?]

➤ Luminosity and lifetime

- BB+Lattice causes lum. loss in the order of a few per cent
- Errors in vert. offsets of S{DF}*: almost no lum. loss, might affect lifetime with BB
- BS+DA defines lifetime, likely not serious