Beam-beam simulations for FCC-ee (tt) - Preliminary results

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Acknowledgements: K. Ohmi and K. Oide

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Outline

- **Introduction**
  - Lattice designed by K. Oide
  - Lattice version: FCCee_t_25_4_cw_DZ.sad
  - Crab waist achieved by reducing chromaticity correction sextupoles
- **Motivations**
  - Beam-beam issues
  - Interplay of beam-beam and lattice nonlinearity
- **Dynamic aperture by SAD**
- **Beam-beam simulations by BBWS**
  - Crab waist
  - Beamstrahlung
  - Specific luminosity and tune scan
- **Summary and future work**

1. Parameters for half ring

C (km)	50810.8
E (GeV)	175
Number of IPs	1
N_b	51
$N_p(10^{11})$	2.6
Full crossing angle	0.06
ε_x (nm)	2
ε_y (pm)	2
β_x^* (m)	0.5
β_y^* (mm)	1
σ_z (mm)^{SR} [BS[1)]]	2.36 [3.66]
$\sigma_\delta(10^{-3})^{SR}$ [BS[1)]]	0.00136 [0.00211]
Betatron tune ν_x/ν_y	178.56/183.53
Synch. tune ν_s	0.0457
Damping rate/turn (10^{-2}) [x/y/z]	0.954/0.954/1.882
Geometric Lum./IP($10^{34}cm^{-2}s^{-1}$) [No BS]	2

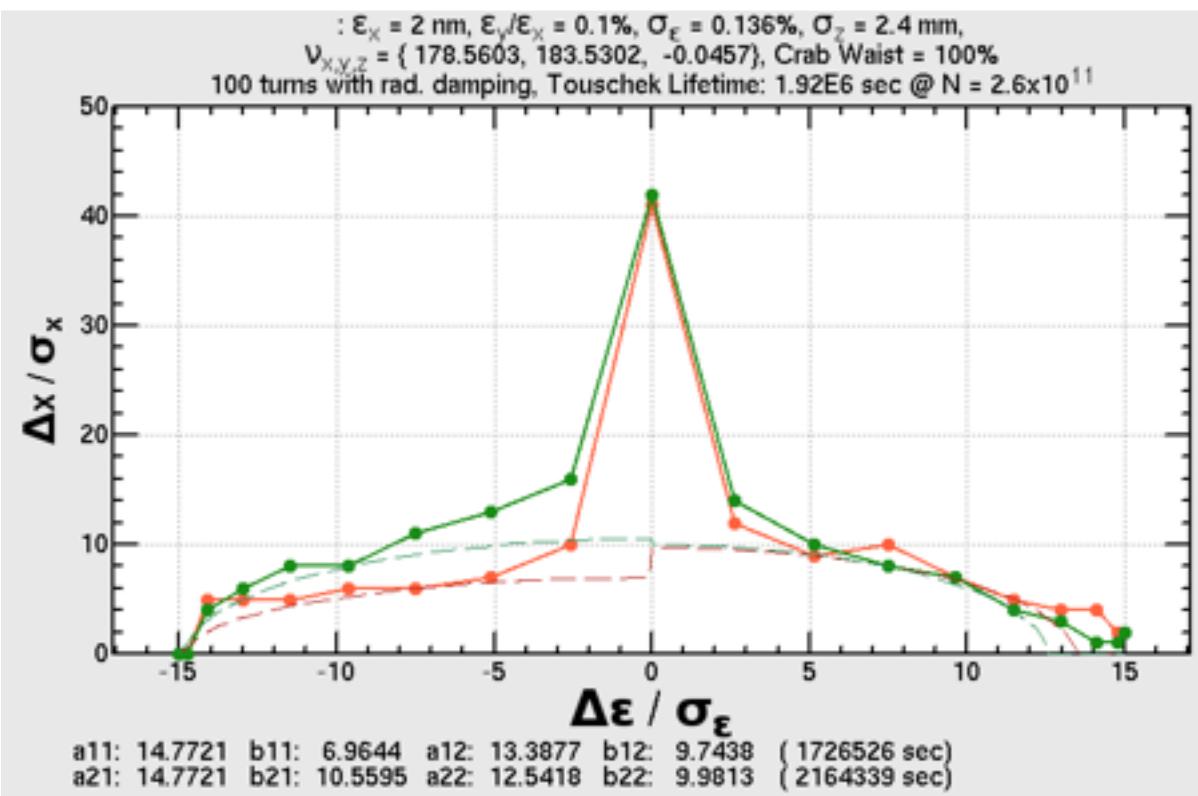
[1)]Ref. K. Ohmi, THPRI004, IPAC'14 (Eq. (5))

2. Dynamic aperture

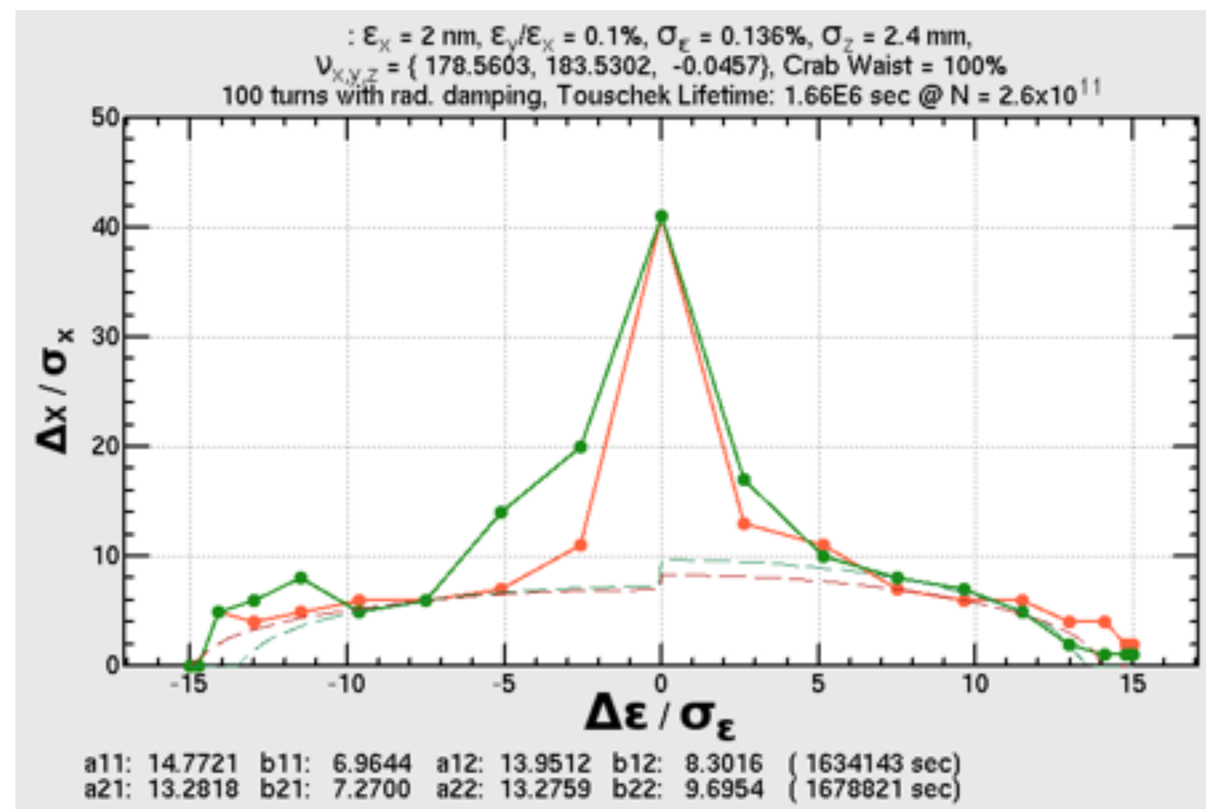
➤ **By SAD**

- **No beamstrahlung**
- **w/ crab waist**
- **No significant loss of DA from beam-beam**

Bare lattice



w/ beam-beam



3. BBWS simulations

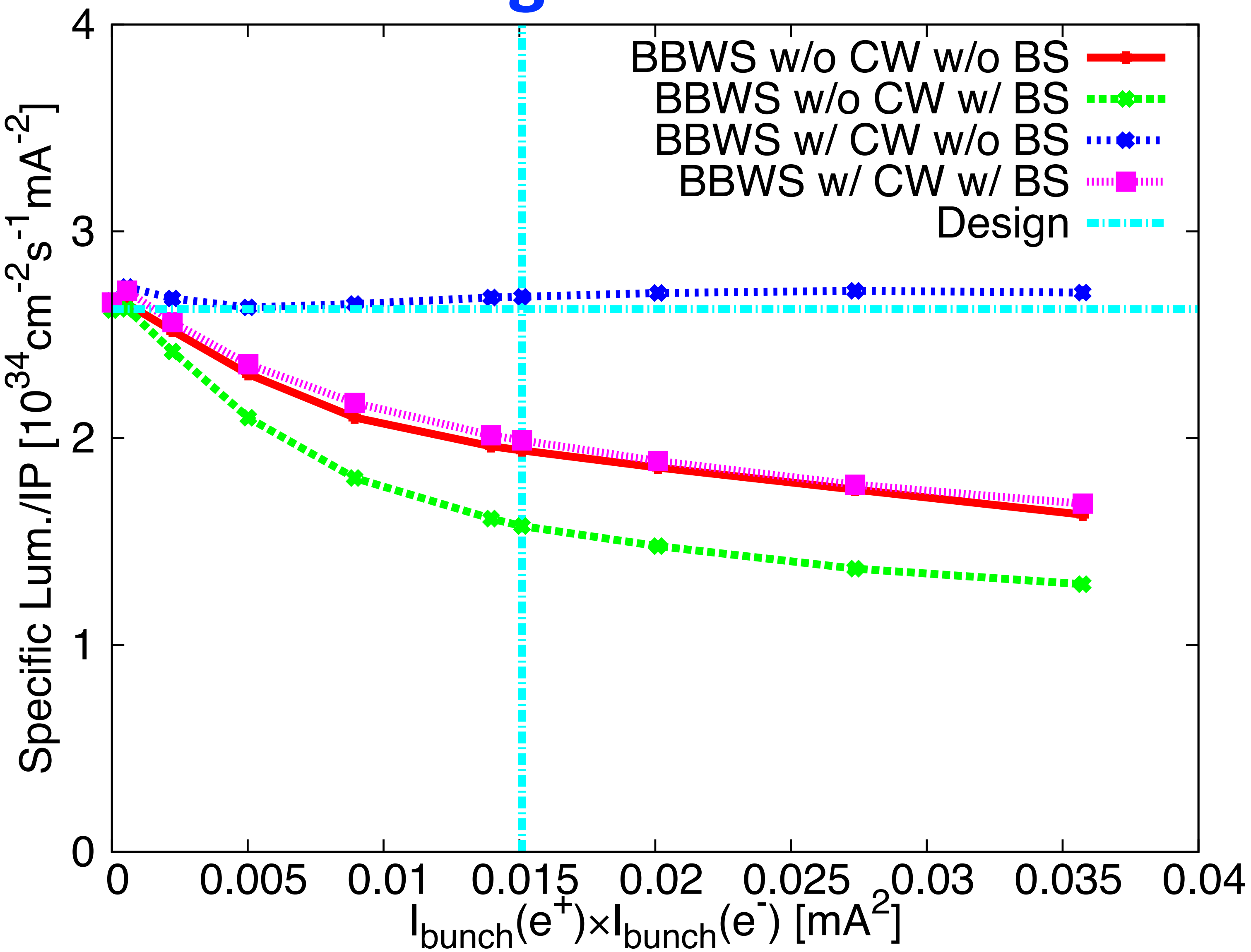
➤ **BBWS developed by K. Ohmi**

- **Crab waist (CW) transform for weak beam**
- **No CW for strong beam**
- **Beamstrahlung included. For symmetric beams, the bunch length is updated every 100 turns(?) for the strong beam, but transverse beam sizes not updated.**

3. BBWS simulations: Specific luminosity

➤ **Conditions:**

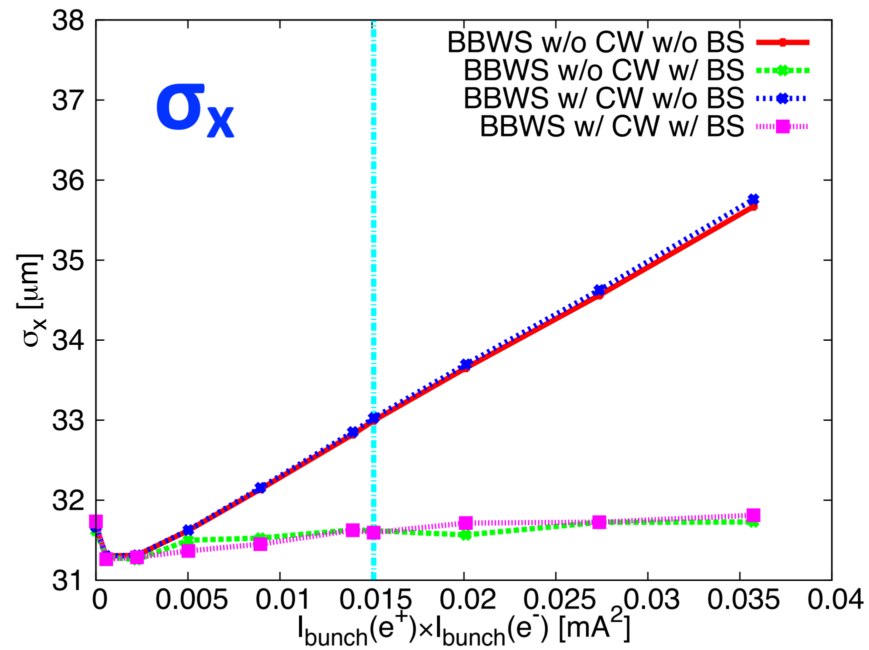
- **w/ and w/o crab waist (CW)**
- **w/ and w/o beamstrahlung (BS)**
- **Working point: [.56, .53]**
- **Cyan line indicates design values**

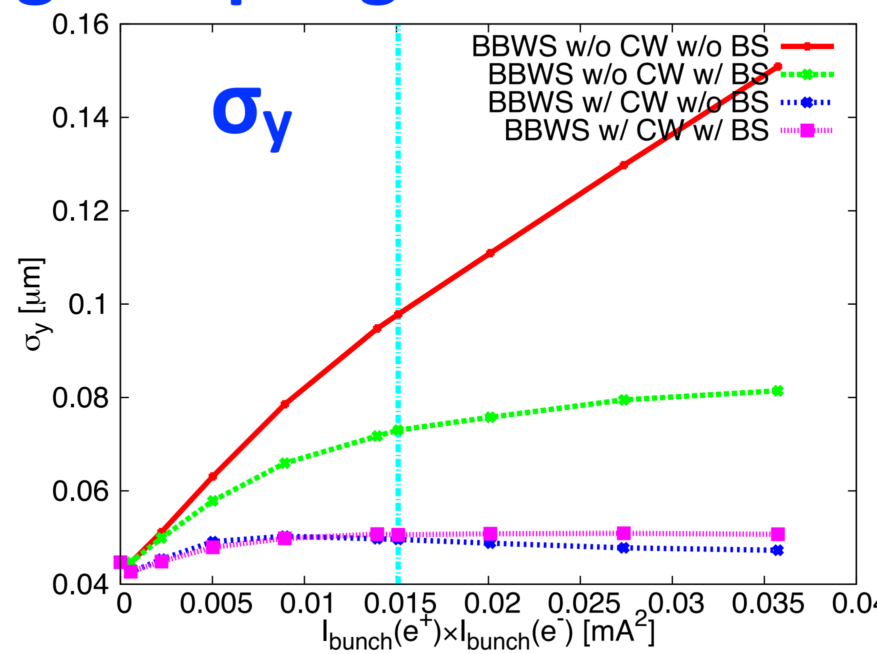


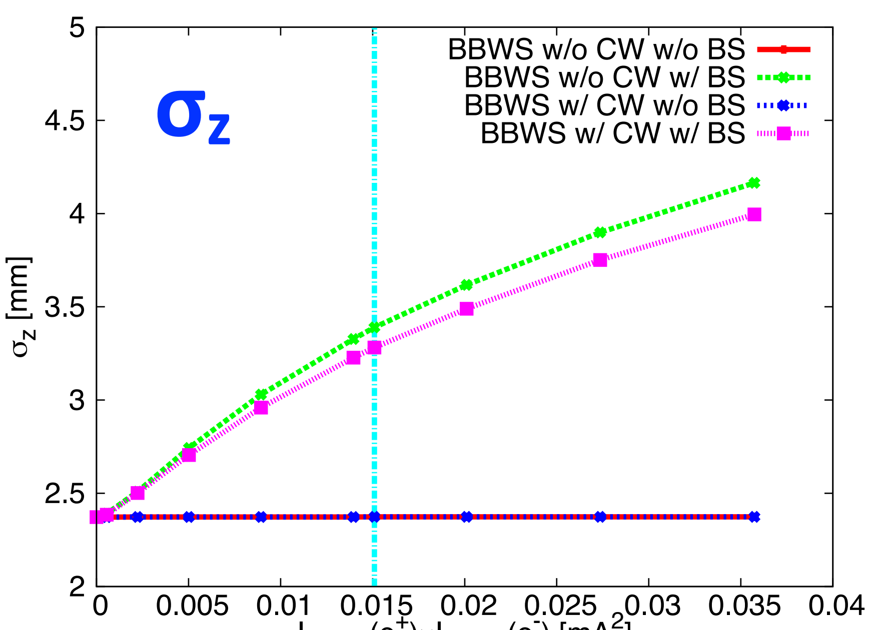
3. BBWS simulations: Specific luminosity (cont.)

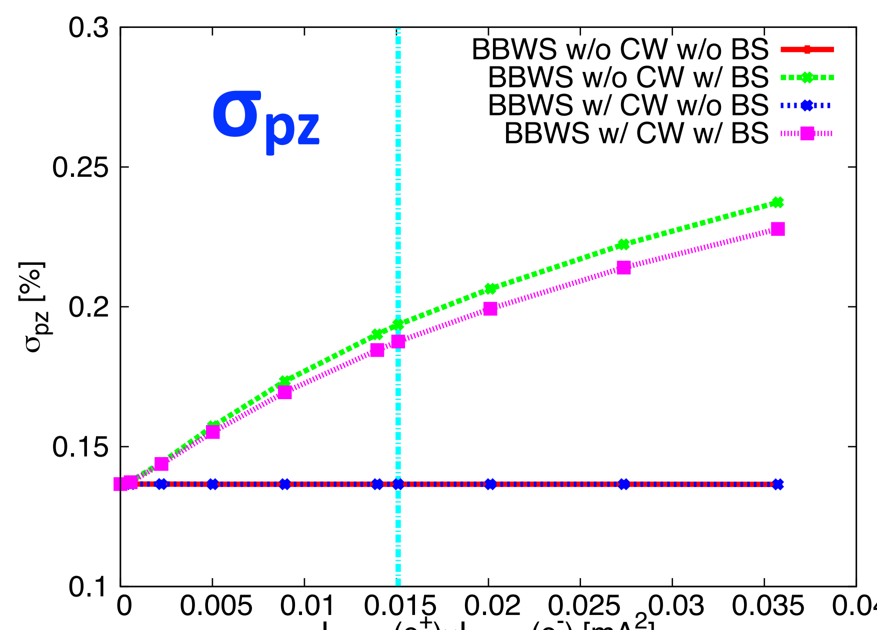
➤ Corresponding beam parameters [rms values]

- **Worst case of bunch lengthening: w/o CW w/ BS**
- **BS correlates trans. and long. emittances**
- **BB resonances enhance trans.-long. coupling**







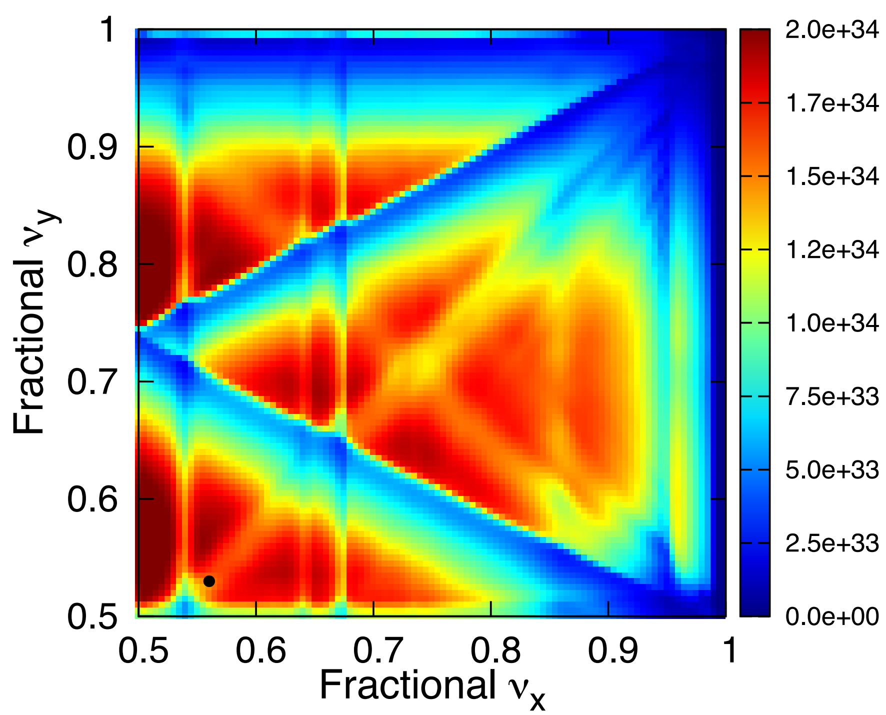


3. BBWS simulations: Lum. tune scan

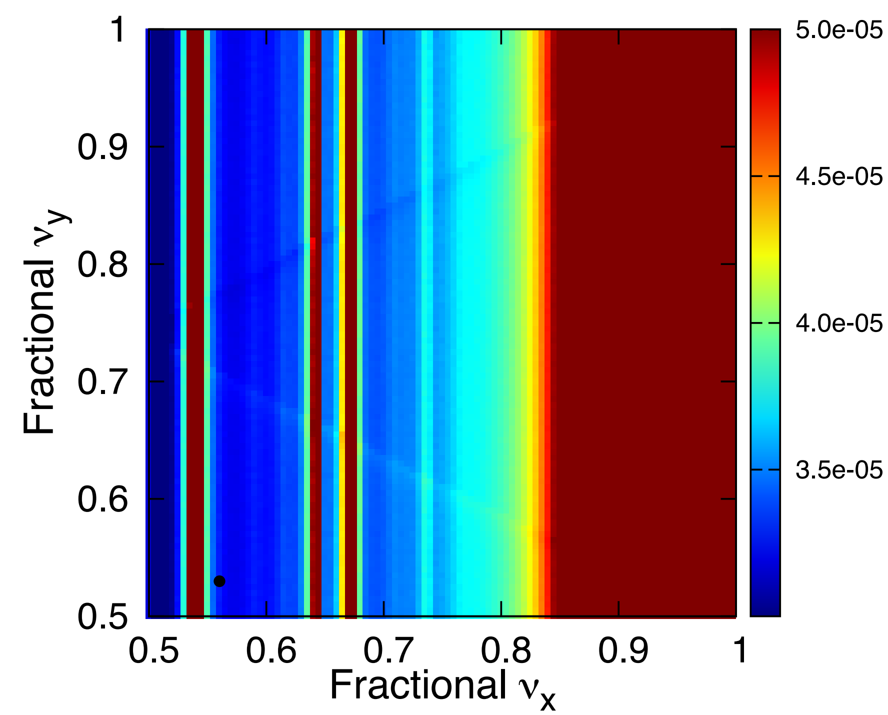
➤ **w/o CW w/o BS (Black dot indicates [.56,.53])**

- **Large crossing angle => BB resonances**

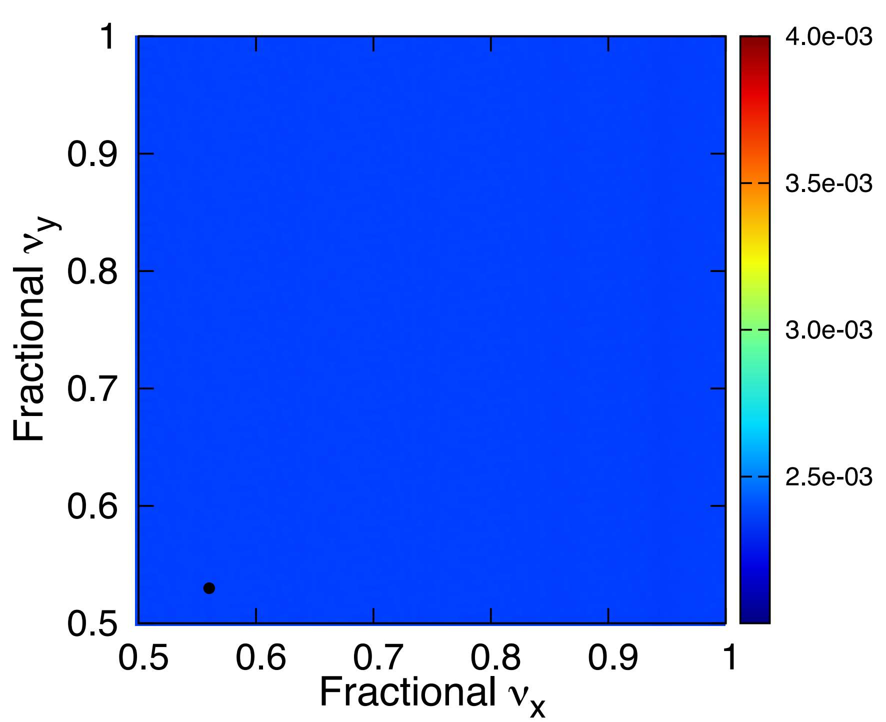
Lum.



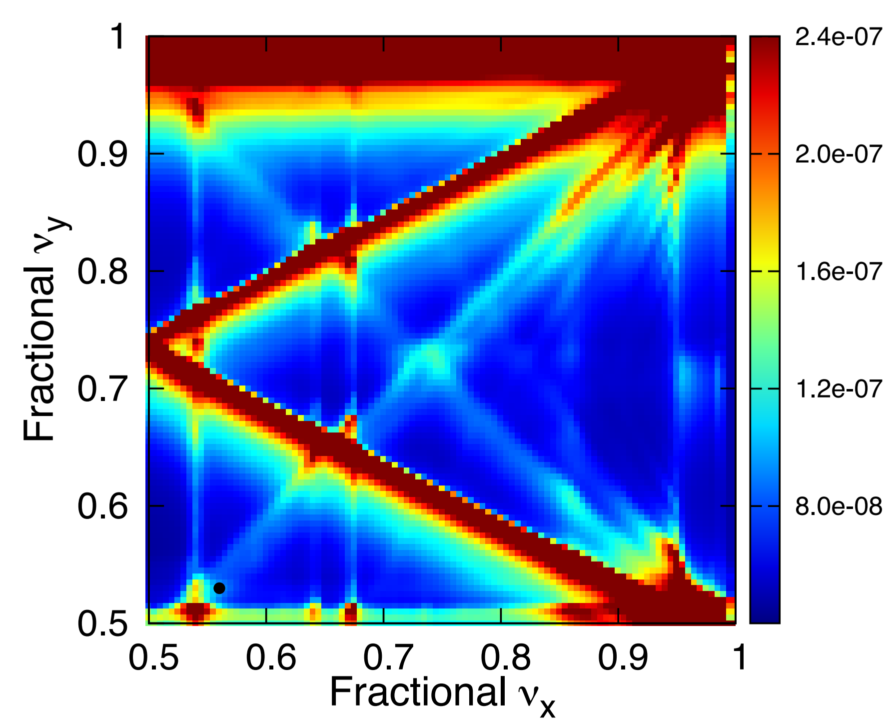
σ_x



σ_z



σ_y

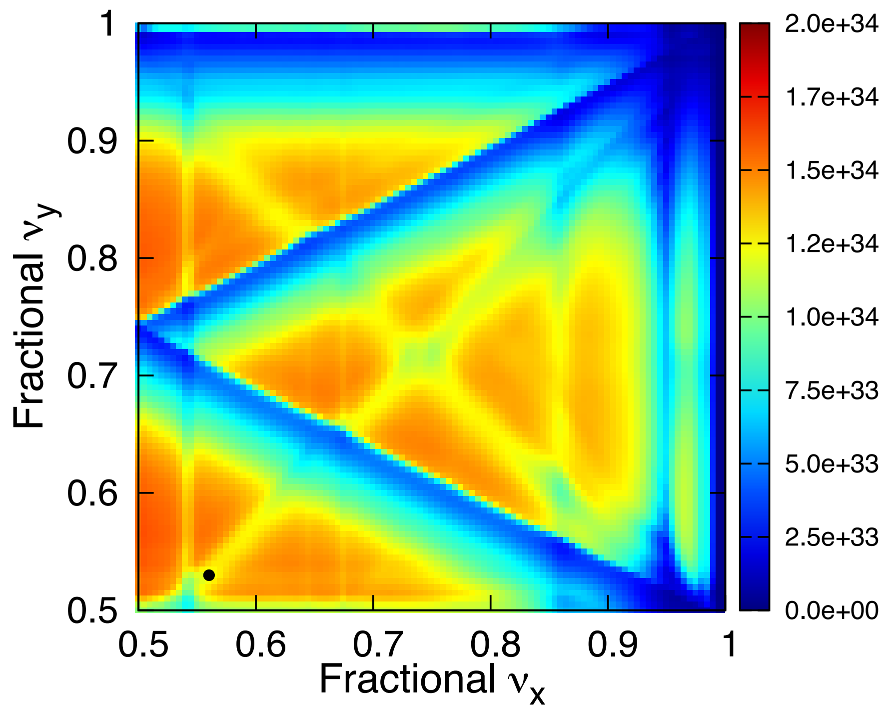


3. BBWS simulations: Lum. tune scan (cont.)

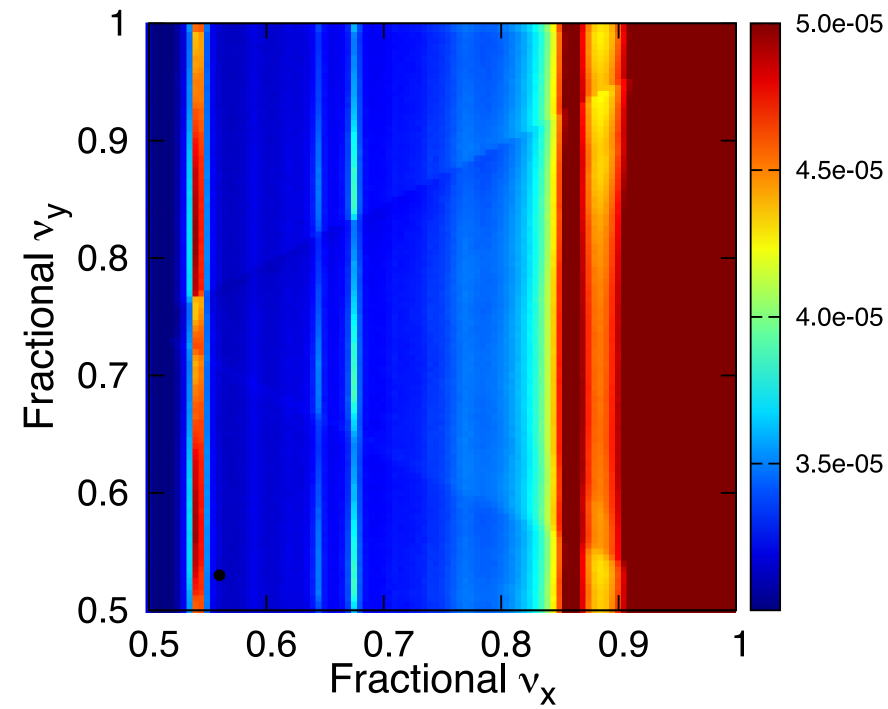
➤ **w/o CW w/ BS (Black dot indicates [.56,.53])**

- **BS correlates trans. and long. emittances**

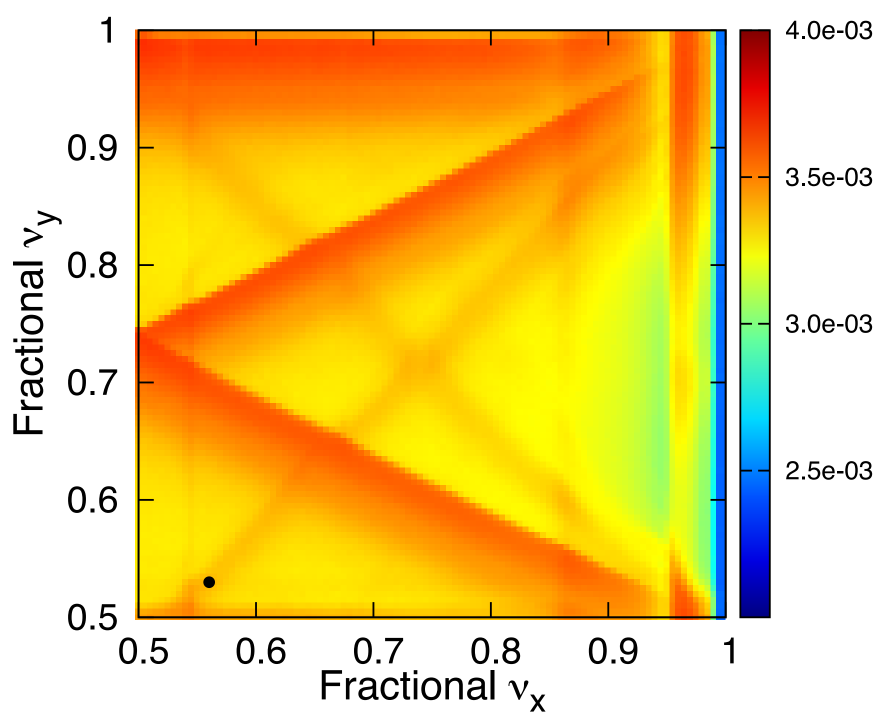
Lum.



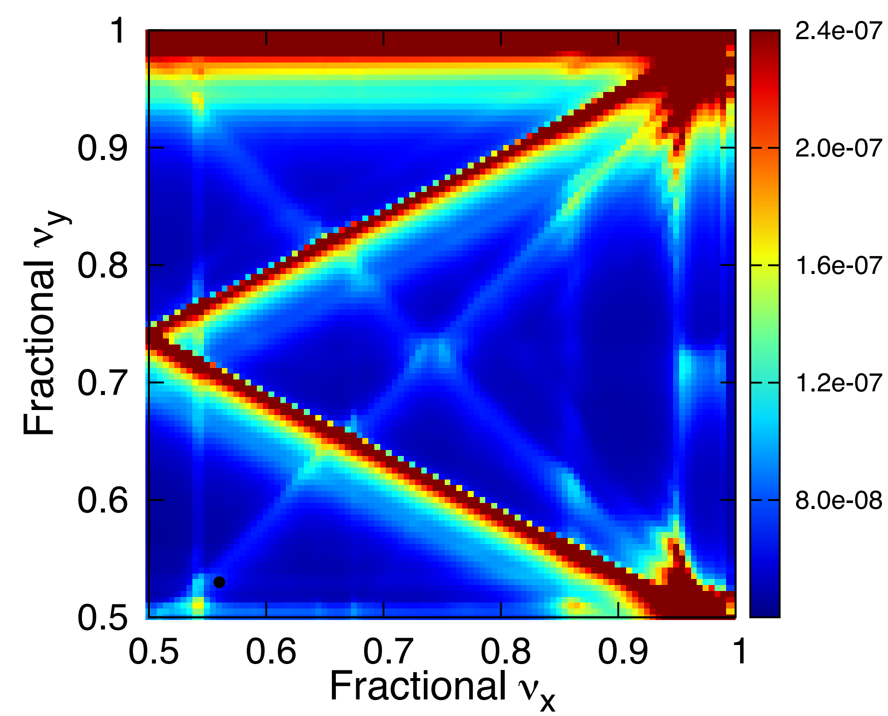
σ_x



σ_z



σ_y

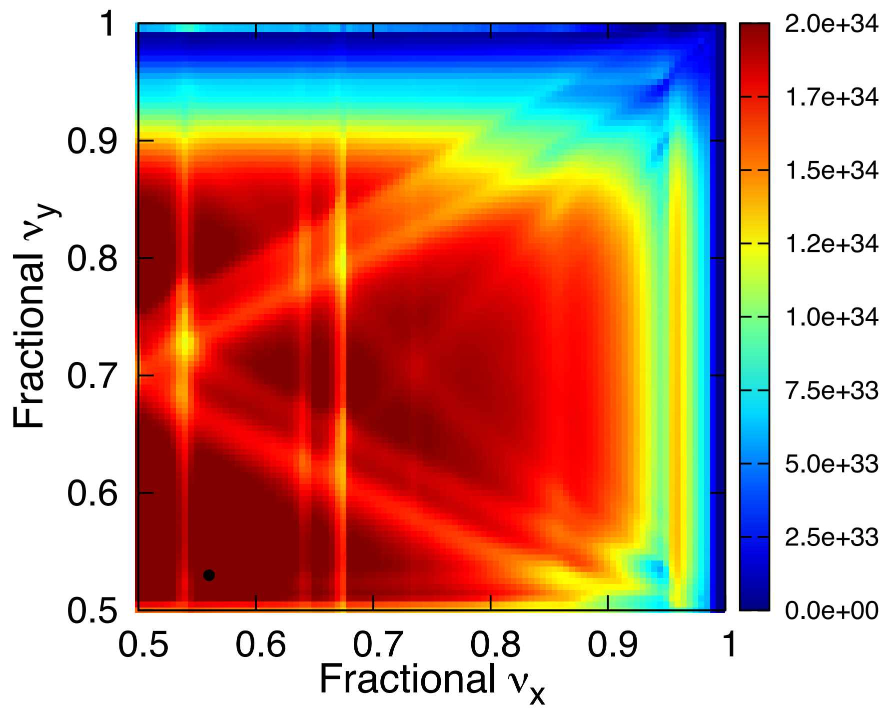


3. BBWS simulations: Lum. tune scan (cont.)

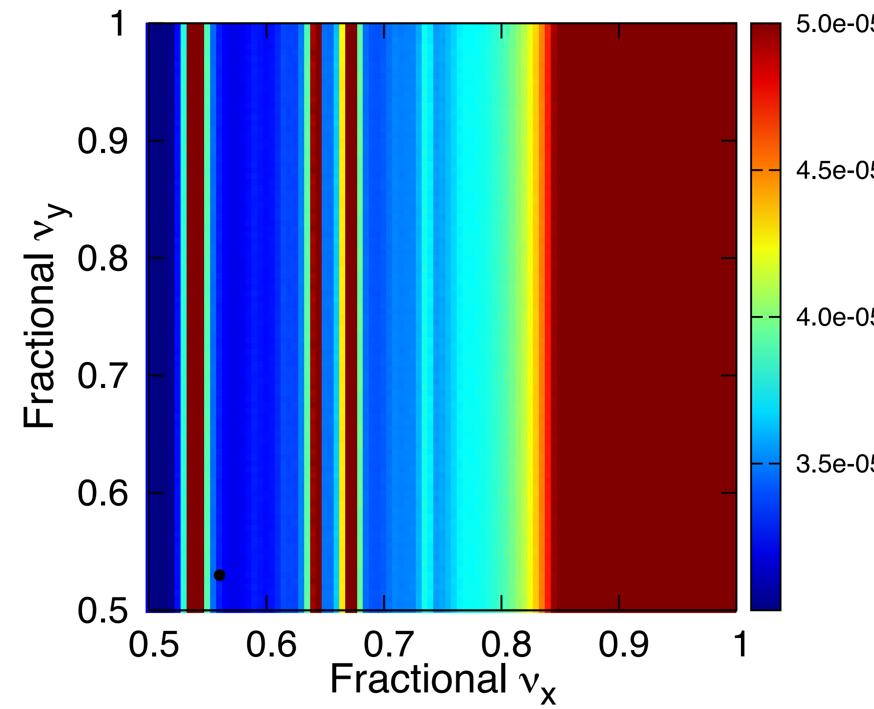
➤ **w/ CW w/o BS (Black dot indicates [.56,.53])**

- **CW suppresses BB resonances**

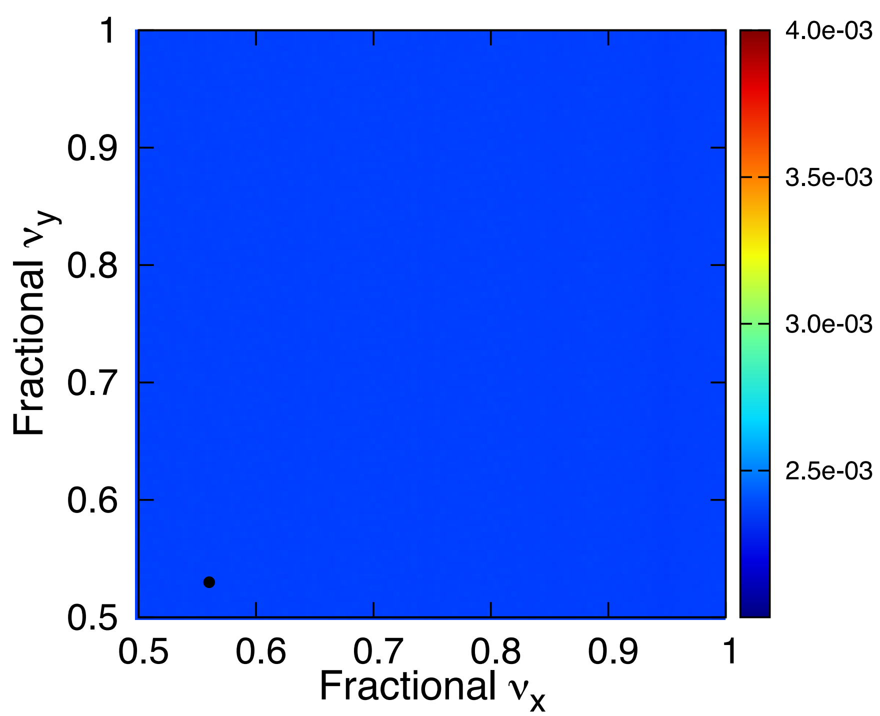
Lum.



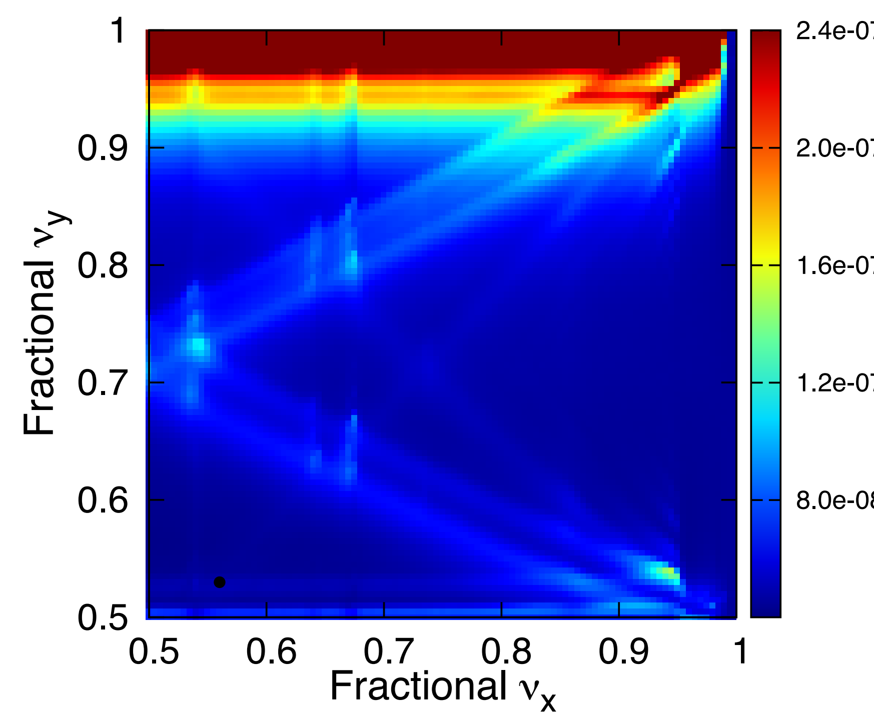
σ_x



σ_z



σ_y

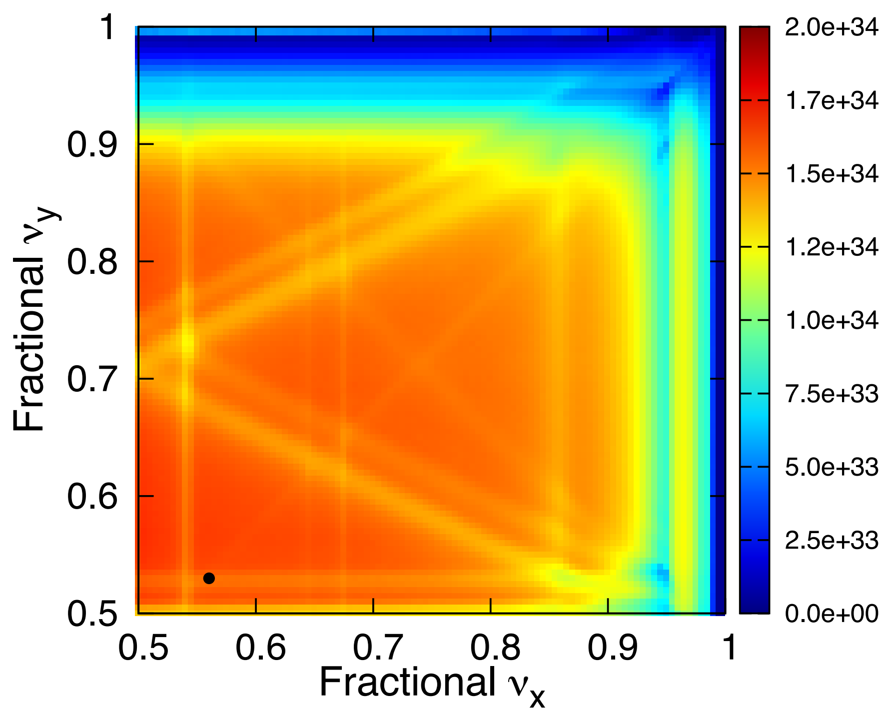


3. BBWS simulations: Lum. tune scan (cont.)

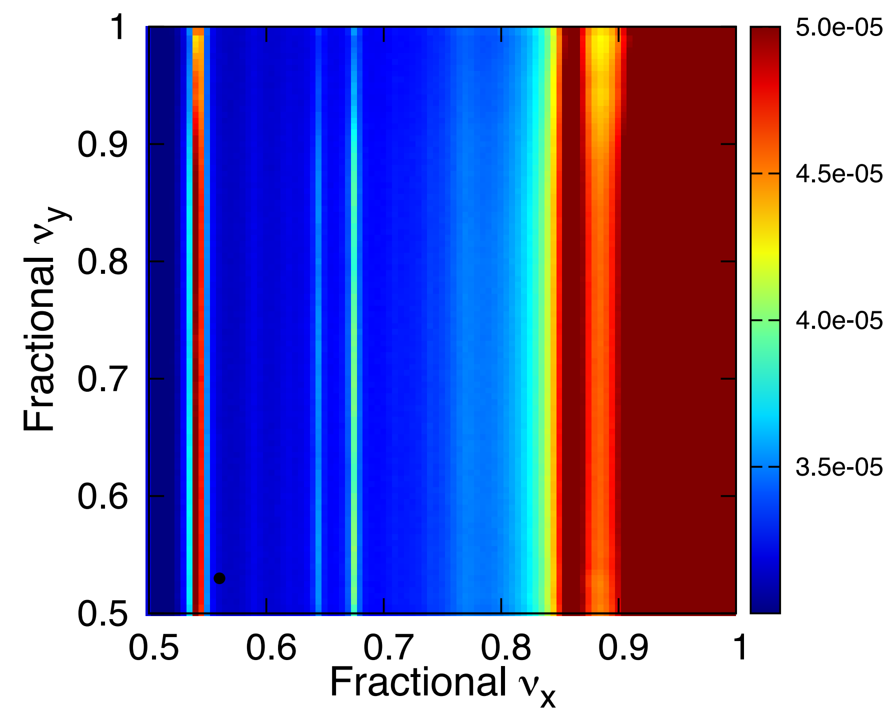
➤ w/ CW w/ BS (WP [.56,.53] not the best?)

- BS => Bunch lengthening => Lum. loss but relax BB effects

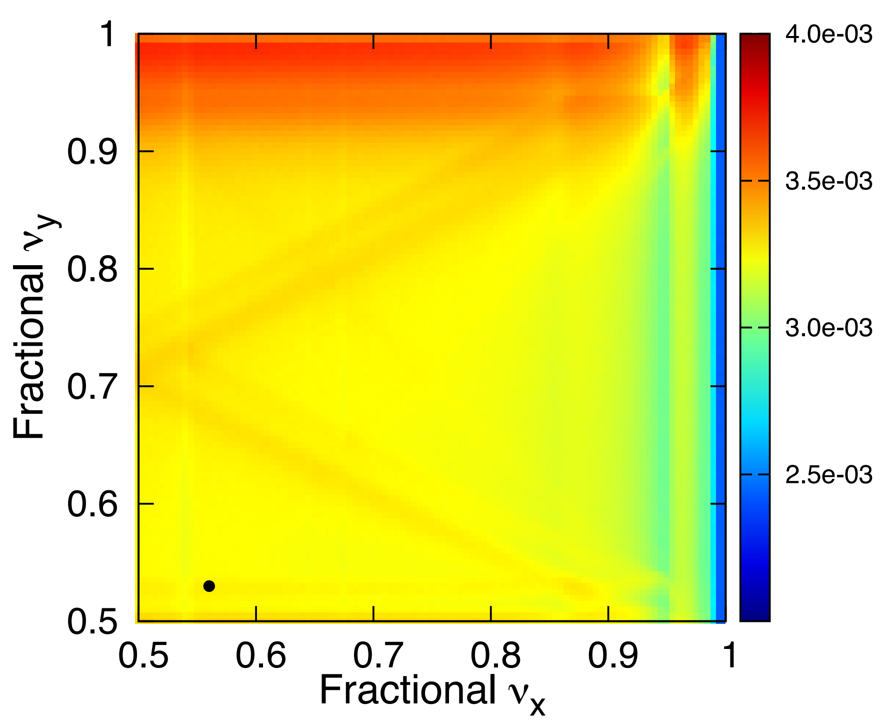
Lum.



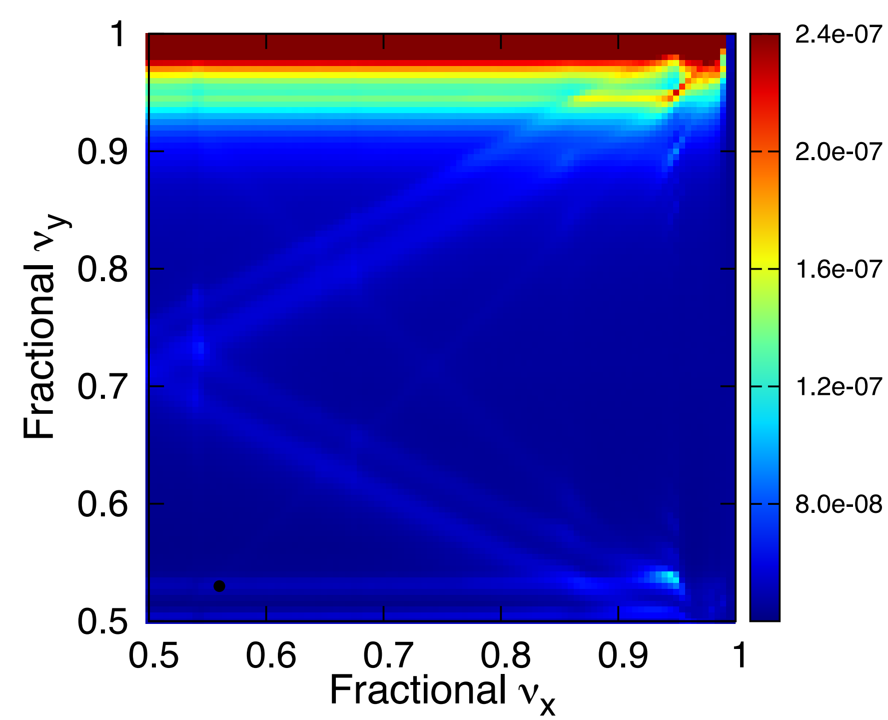
σ_x



σ_z



σ_y



4. Interplay of BB and latt. nonlin.

- **SAD script set-up done**
  - **Method demonstrated in D. Zhou et al, TUPE016, IPAC13**
  - **One-turn map:**

$$M = M_{\mathrm{RAD}} \circ M_{\mathrm{BB}} \circ M_0$$

  - M_0 **can be simple matrix or IP-to-IP realistic map**
- **Particle tracking => Beam unstable for FCC-ee (tt)**
  - **Beam unstable even w/o BB**
  - **Lumped damping/excitation at IP (see next 2 pages) => Questionable => But no problem for BBWS simulations**
  - **Need investigations**

4. Interplay of BB and latt. nonlin. (cont.)

➤ **Lumped damping/excitation: BBWS**

$$\vec{x} = (x, p_x, y, p_y, z, \delta)^T$$

$$\vec{X} = M_{\mathrm{p2n}}\vec{x}$$

$$\vec{\lambda} = (1 - D_x, 1 - D_x, 1 - D_y, 1 - D_y, 1 - D_z, 1 - D_z)$$

$$\vec{r} = \mathrm{GaussRandom}[6]^T$$

$$\vec{\beta}_D = \sqrt{2(\epsilon_x D_x, \epsilon_x D_x, \epsilon_y D_y, \epsilon_y D_y, \epsilon_z D_z, \epsilon_z D_z)}$$

$$\vec{X}_1 = \vec{\lambda} \cdot \vec{X}_0 + \vec{\beta}_D \cdot \vec{r}$$

$$\vec{x}_1 = M_{\mathrm{p2n}}^{-1}\vec{x}_0$$

FCC-ee (tt):

$$D_x = D_y = 9.54 \times 10^{-3}$$

$$D_z = 1.882 \times 10^{-2}$$

4. Interplay of BB and latt. nonlin. (cont.)

➤ **Lumped damping/excitation: Optional**

$$\vec{x} = (x, p_x, y, p_y, z, \delta)^T$$

$$\vec{X} = M_{\mathrm{p2n}}\vec{x}$$

$$\vec{\lambda} = (1 - D_x, 1 - D_x, 1 - D_y, 1 - D_y, 1, 1 - \sqrt{2}D_z)$$

$$\vec{r} = \mathrm{GaussRandom}[6]^T$$

$$\vec{\beta}_D = \sqrt{2(\epsilon_x D_x, \epsilon_x D_x, \epsilon_y D_y, \epsilon_y D_y, 0, 2\epsilon_z D_z)}$$

$$\vec{X}_1 = \vec{\lambda} \cdot \vec{X}_0 + \vec{\beta}_D \cdot \vec{r}$$

$$\vec{x}_1 = M_{\mathrm{p2n}}^{-1}\vec{x}_0$$

FCC-ee (tt):

$$D_x = D_y = 9.54 \times 10^{-3}$$

$$D_z = 1.882 \times 10^{-2}$$

5. Summary and future work

- **Beam-beam simulations using BBWS**
  - BB+BS simulated
  - Better to shift working point a little far from $2\nu_y-\nu_s=N$
- **Beam-beam simulations using SAD**
  - No significant loss of DA due to BB
  - Simulations for interplay of BB and latt. nonlin. not successful yet => Problem not related to BB=> To be understood
  - Model for beamstrahlung not available => Simply modify the strong beam
- **Future work**
  - FMA analysis to address lattice nonlinearity instead of DA
  - Strong-strong simulations (BBSS) to address BB instability
  - Suggestions are always welcome!