Beam-beam simulations for FCC-ee (tt)

D. Zhou

Acknowledgements: K. Ohmi and K. Oide

8th FCC-ee Optics Design meeting, Aug. 21, 2015

Outline

- Introduction
  - Lattice designed by K. Oide
  - Lattice version: FCCee_t_42_{3,4a}_cw.sad
- Motivations
  - Beam-beam issues
  - Interplay of beam-beam and lattice nonlinearity
- Beam-beam simulations
  - BBWS: Weak-strong with linear map
  - SAD: Weak-strong with realistic lattice
- Summary

1. Parameters for half ring

C (km)	49019.4	49009.9
E (GeV)	175	175
Number of IPs	1	1
N_b	51	51
$N_p(10^{11})$	2.6	2.6
Full crossing angle(rad)	0.03	0.03
ε_x (nm)	2	2
ε_y (pm)	2	2
β_x^* (m)	1	1
β_y^* (mm)	1	2
σ_z (mm)^{SR} [BS[1]]	2.39 [3.13]	2.39 [3.13]
$\sigma_\delta(10^{-3})^{SR}$ [BS[1]]	1.33 [1.74]	1.33 [1.74]
Betatron tune ν_x/ν_y	162.52/163.57	162.52/163.57
Synch. tune ν_s	0.0472	0.0472
Damping rate/turn (10^{-2}) [x/y/z]	0.942/0.942/1.857	0.942/0.942/1.857
Geometric Lum./IP($10^{34}cm^{-2}s^{-1}$)	2.4 [2.0]	2.0 [1.7]

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

2. BBWS simulations

➤ **BBWS developed by K. Ohmi**

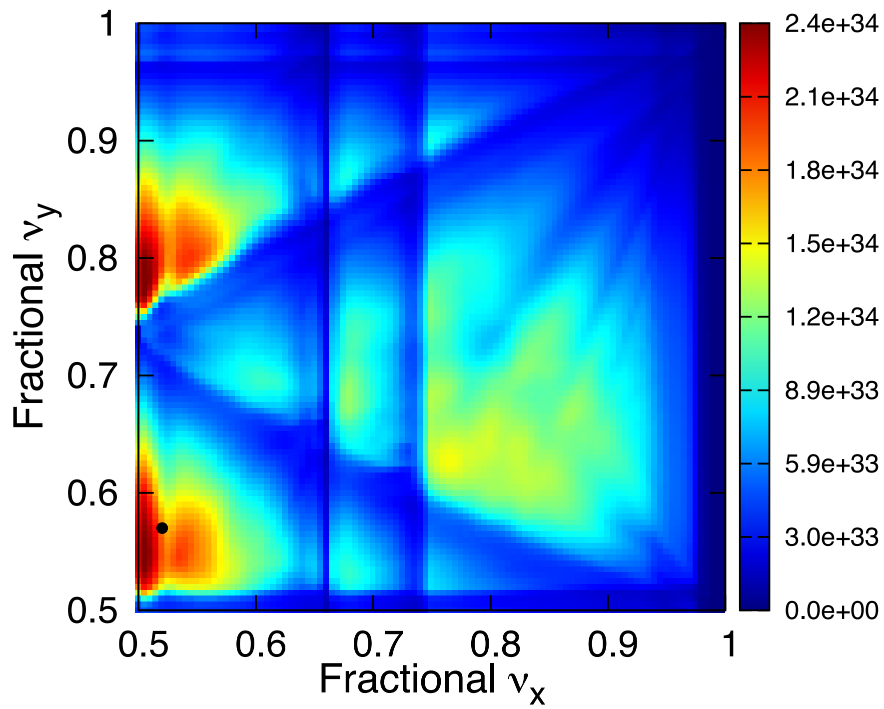
- **Crab waist (CW) transform for weak beam**
- **No CW for strong beam**
- **Beamstrahlung included. For symmetric beams, the bunch length is also updated for the strong beam, but transverse beam sizes not updated.**

2. BBWS simulations: Lum. tune scan

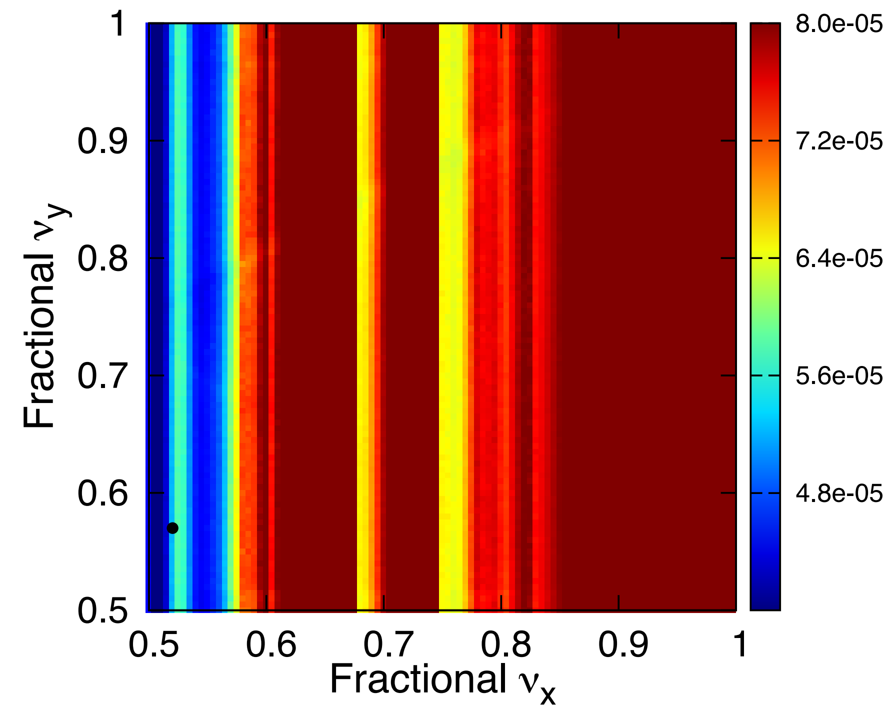
➤ **w/o CW w/o BS (Black dot indicates [.52,.57])**

- **β_y^*=1mm**

Lum.



σ_x



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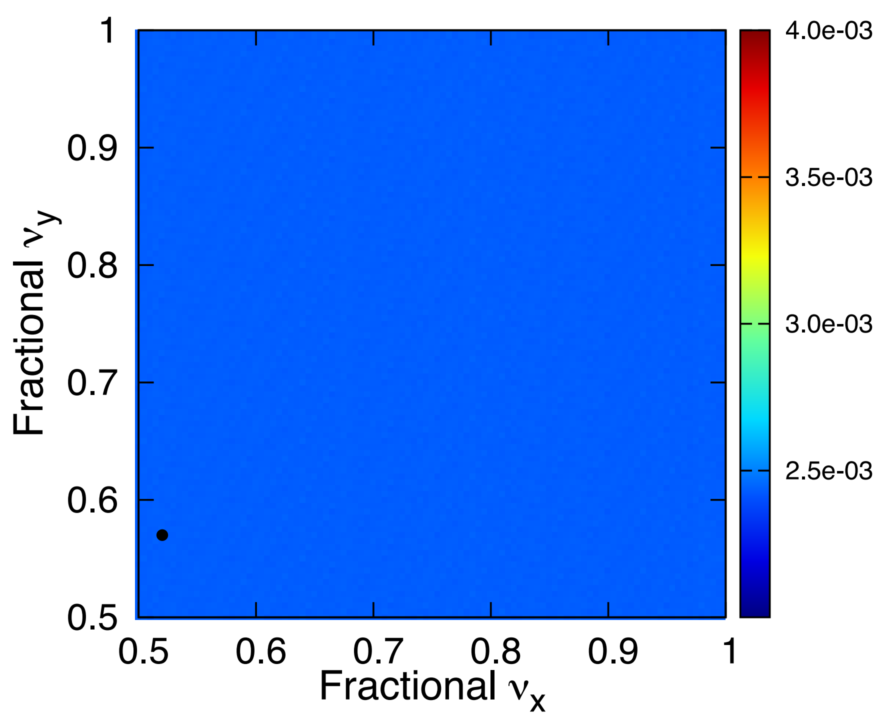
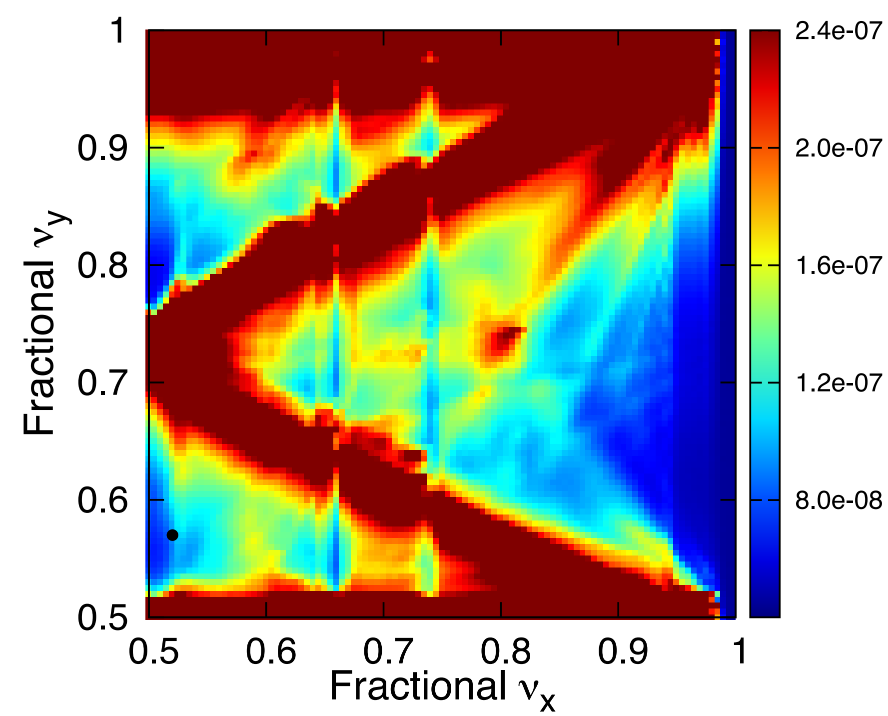


σ_y

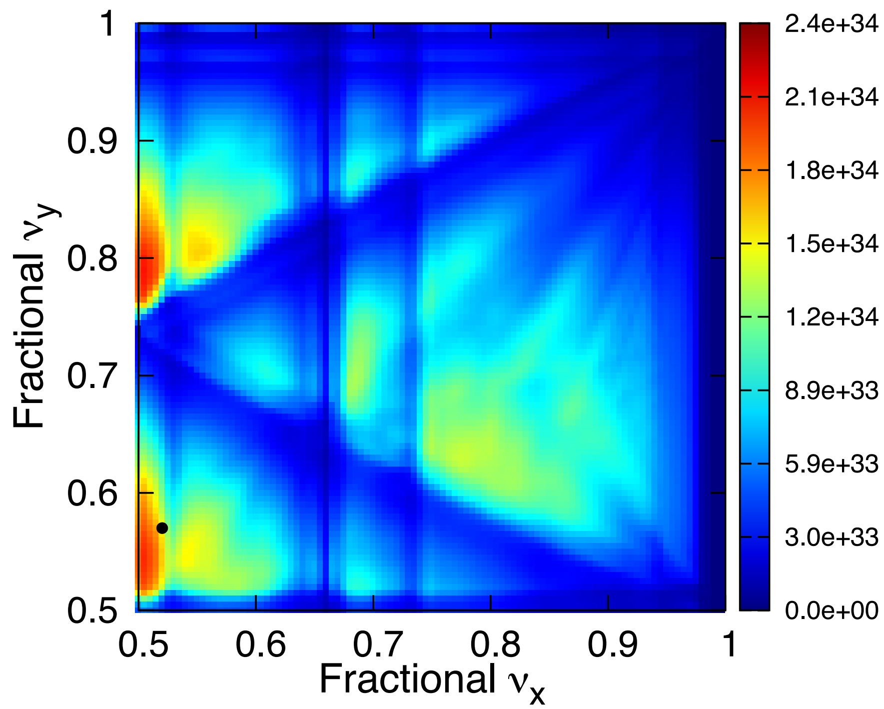


2. BBWS simulations: Lum. tune scan (cont.)

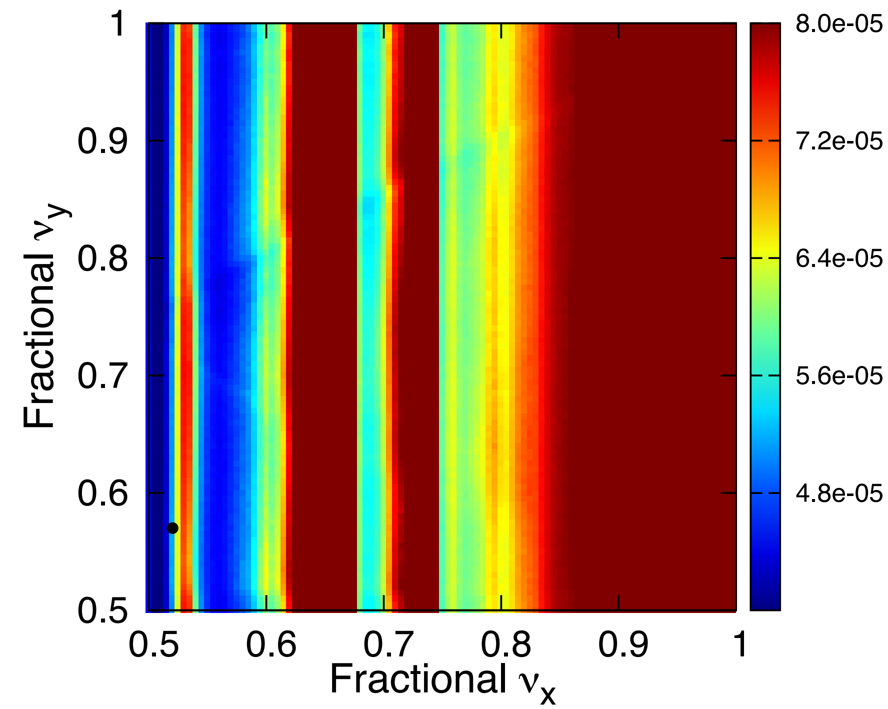
➤ w/o CW w/ BS (Black dot indicates [.52,.57])

- β_y^*=1mm

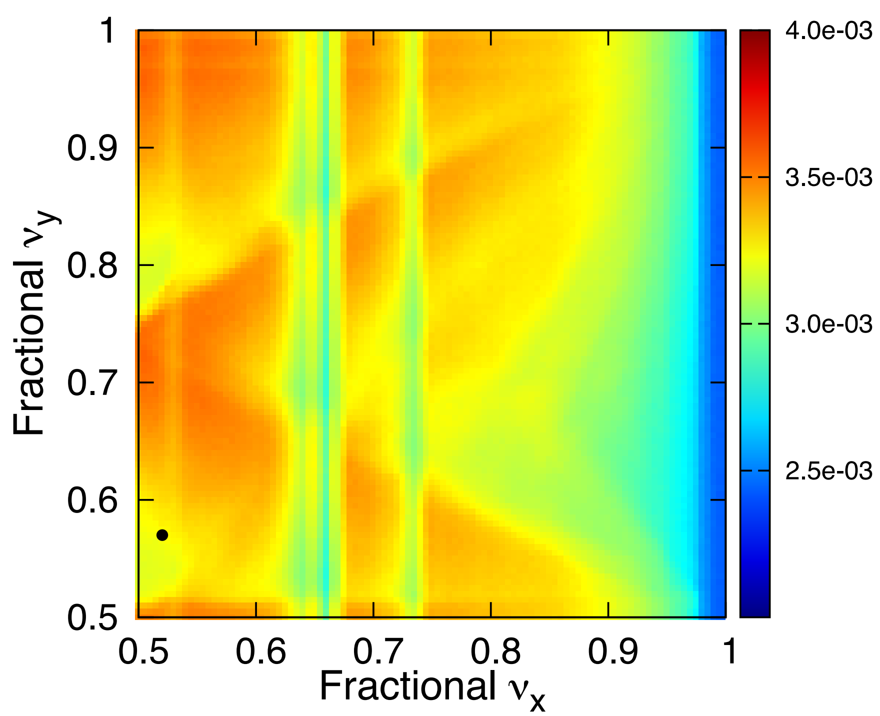
Lum.



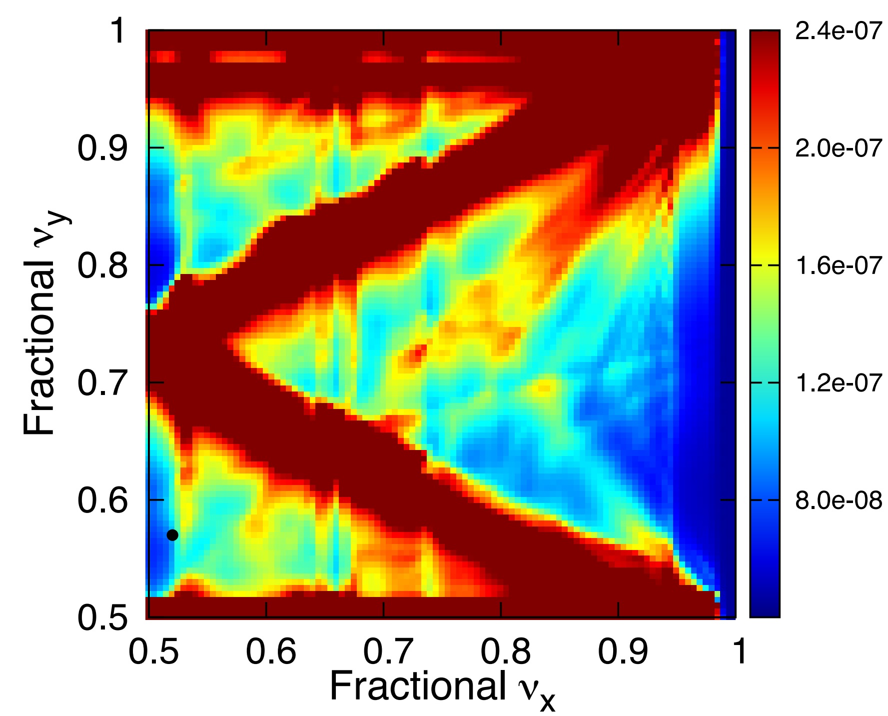
σ_x



σ_z



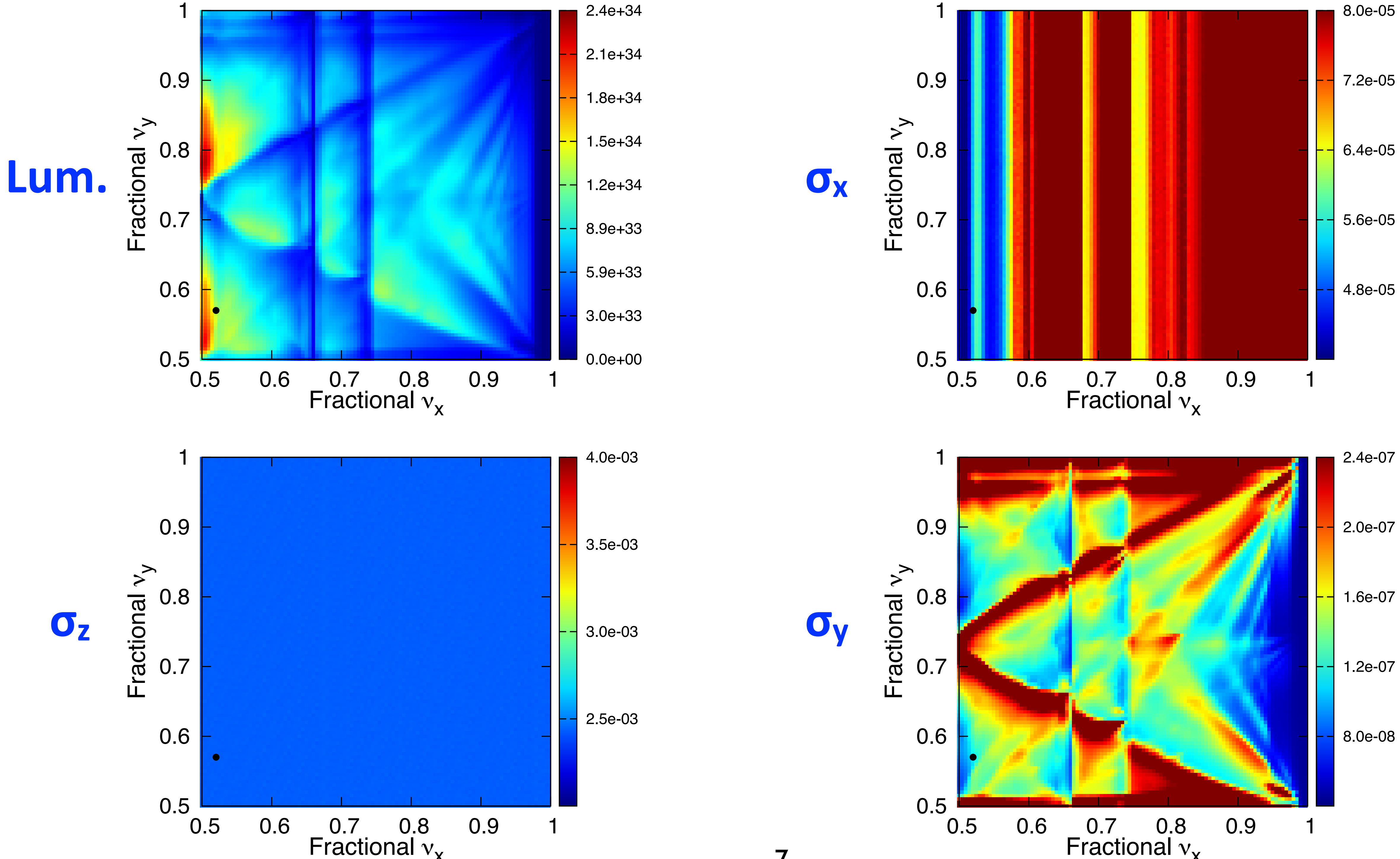
σ_y



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

➤ **w/ CW w/o BS (Black dot indicates [.52,.57])**

- **β_y^*=1mm**



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➤ w/ CW w/ BS (Black dot indicates [.52,.57])

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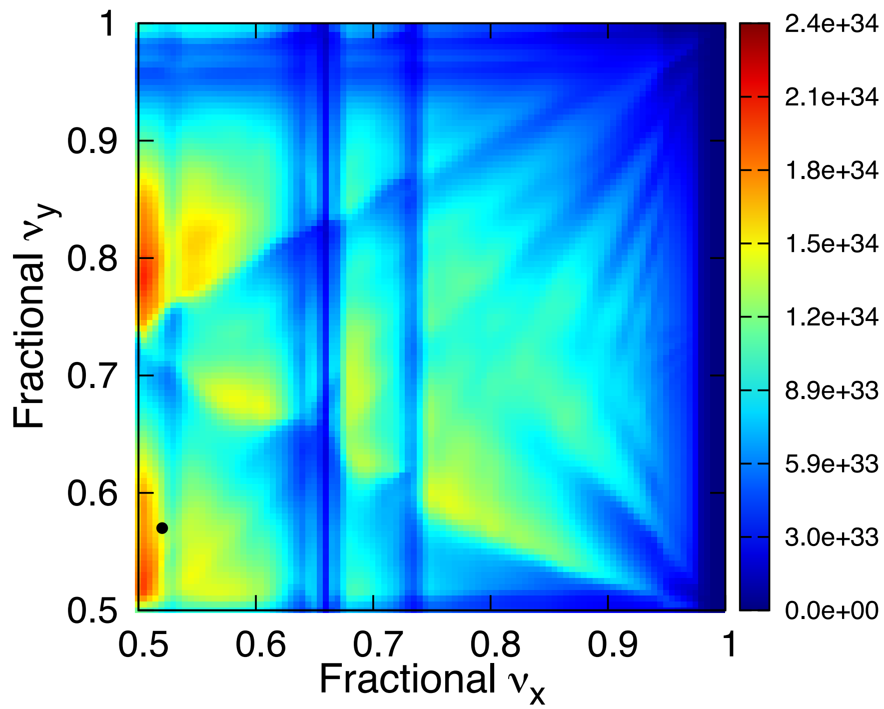
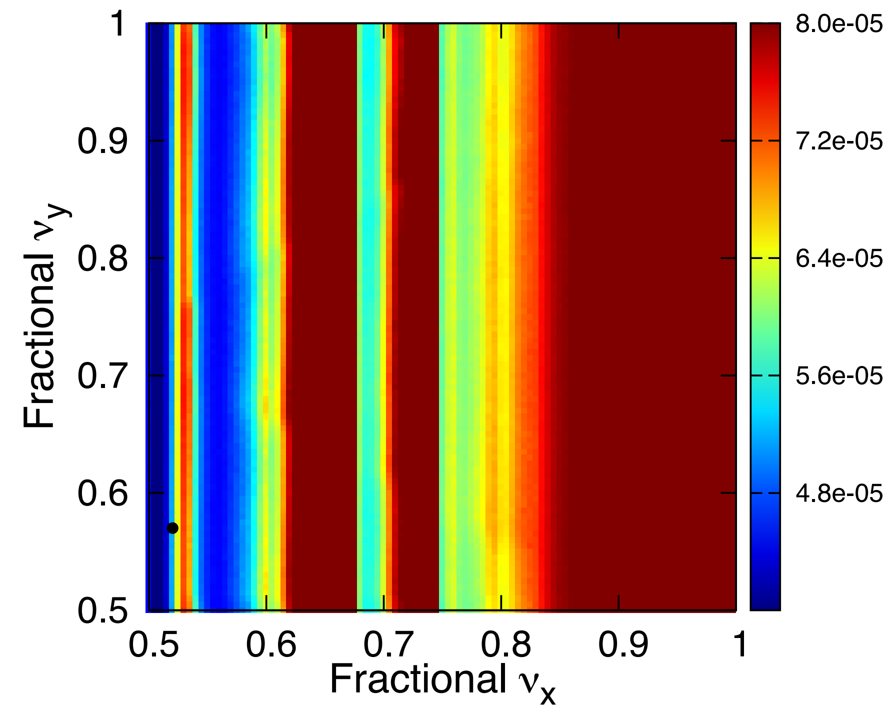
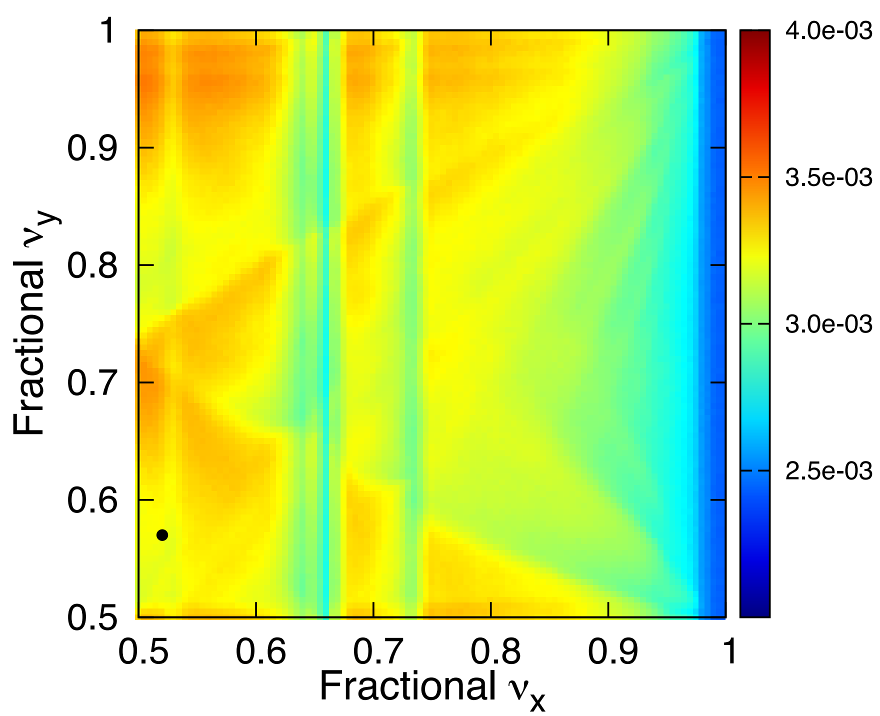
Lum.



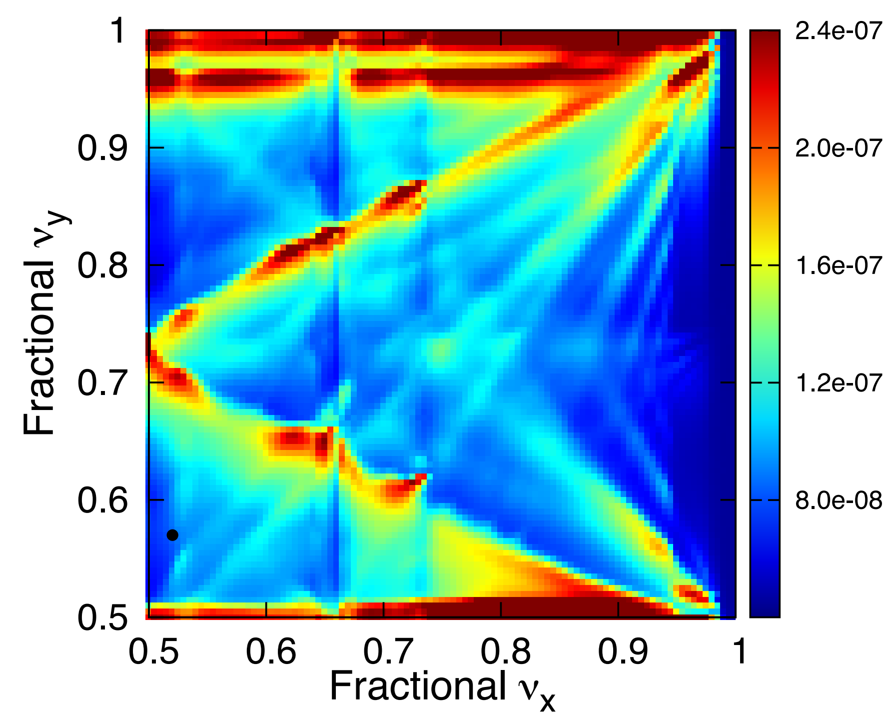
σ_x



σ_z



σ_y

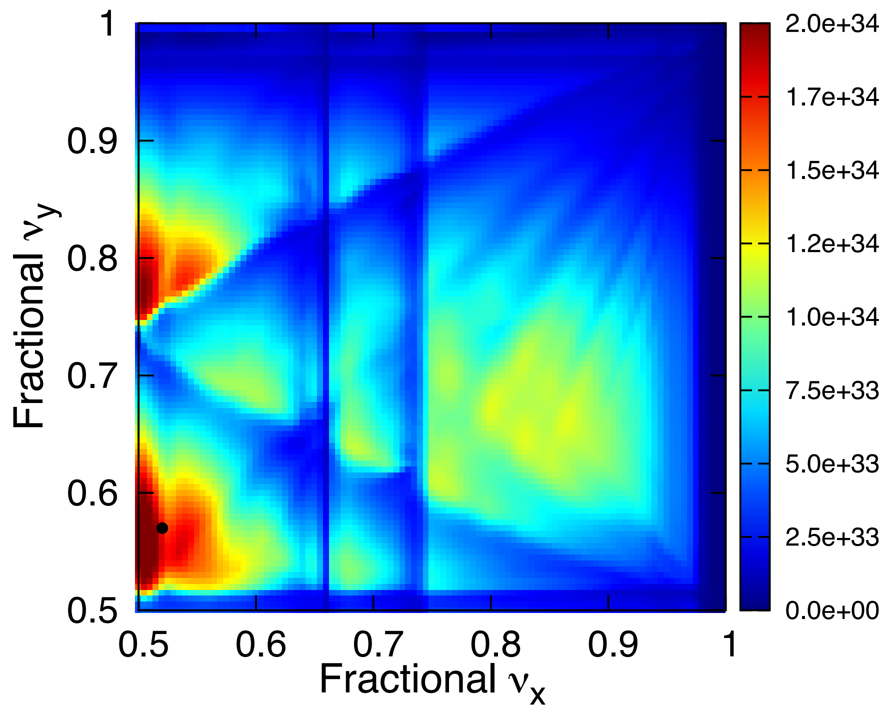


2. BBWS simulations: Lum. tune scan

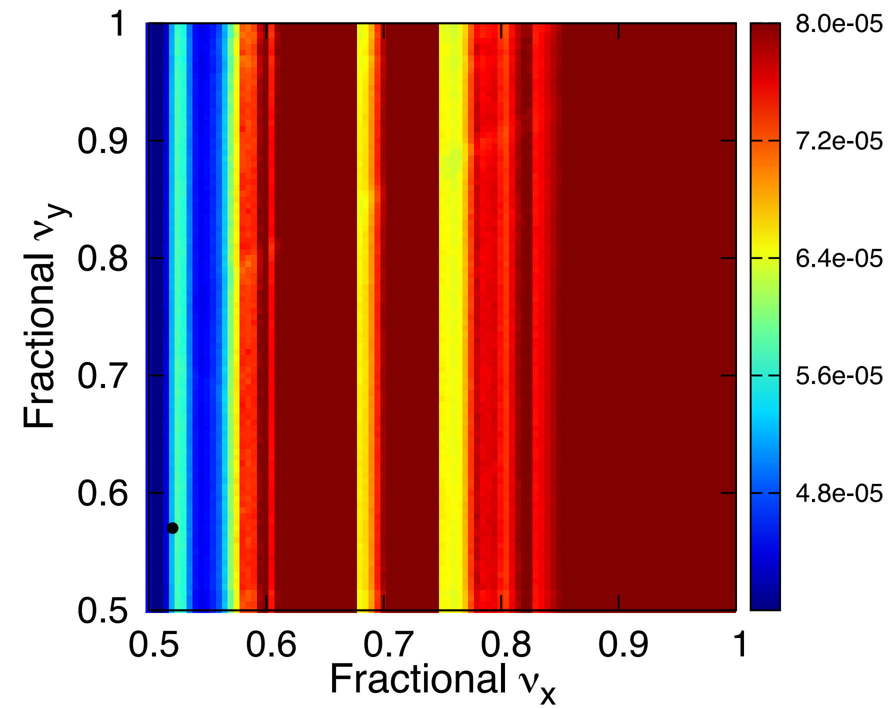
➤ **w/o CW w/o BS (Black dot indicates [.52,.57])**

- β_y^*=2mm

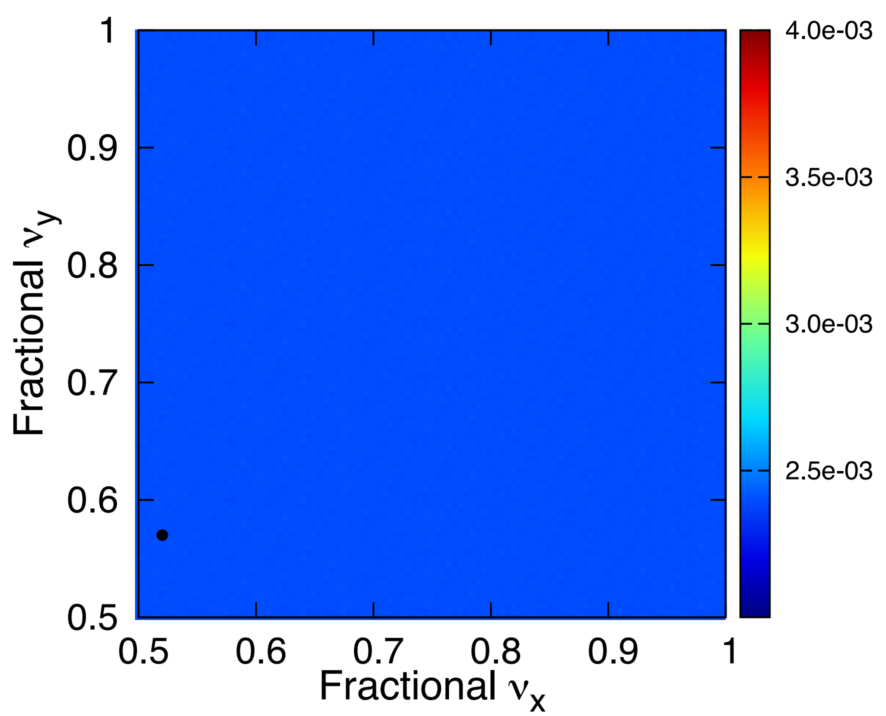
Lum.



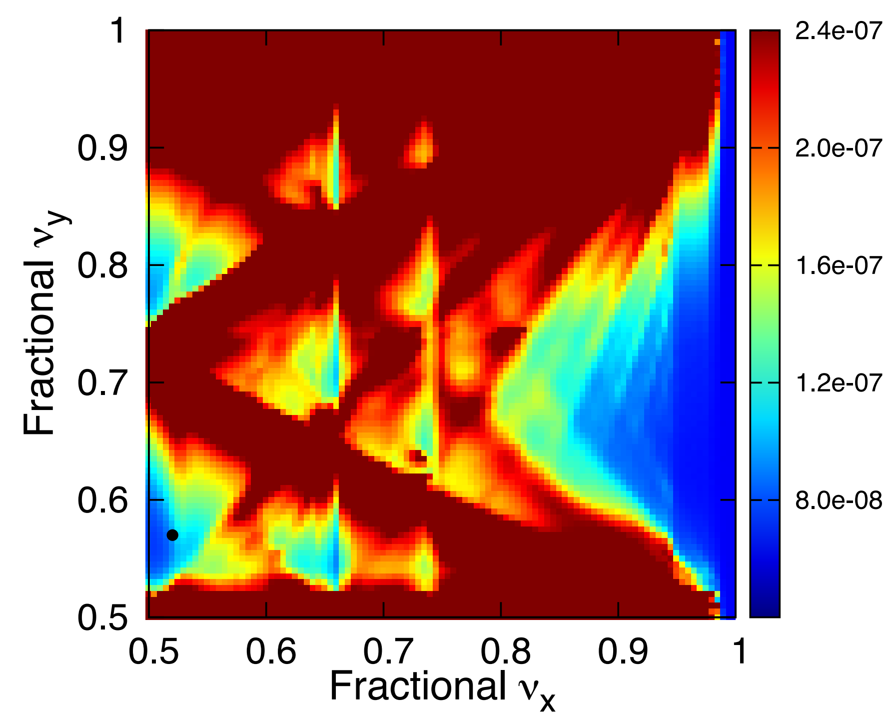
σ_x



σ_z



σ_y

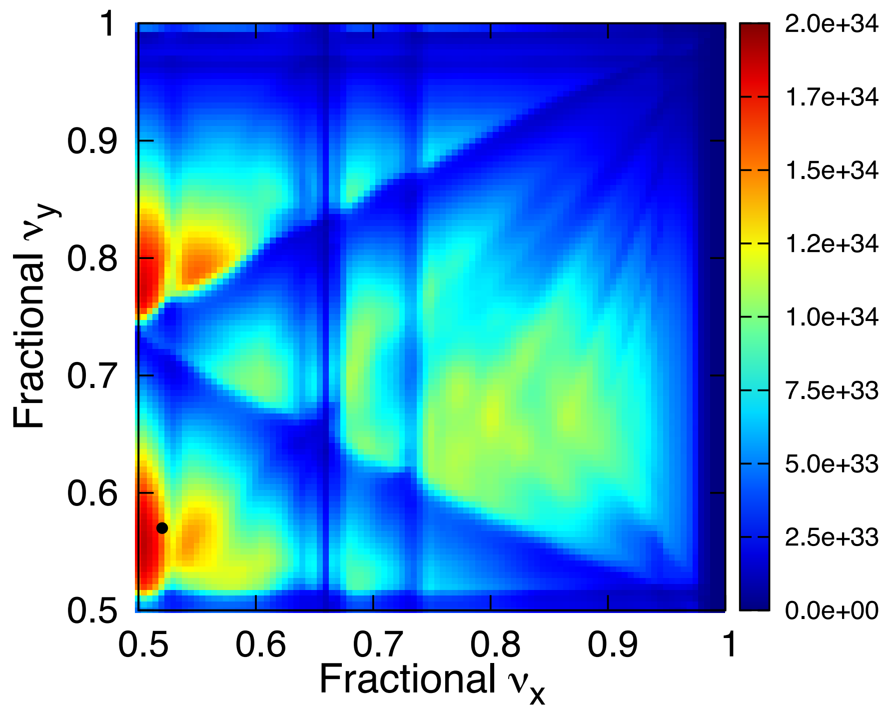


2. BBWS simulations: Lum. tune scan (cont.)

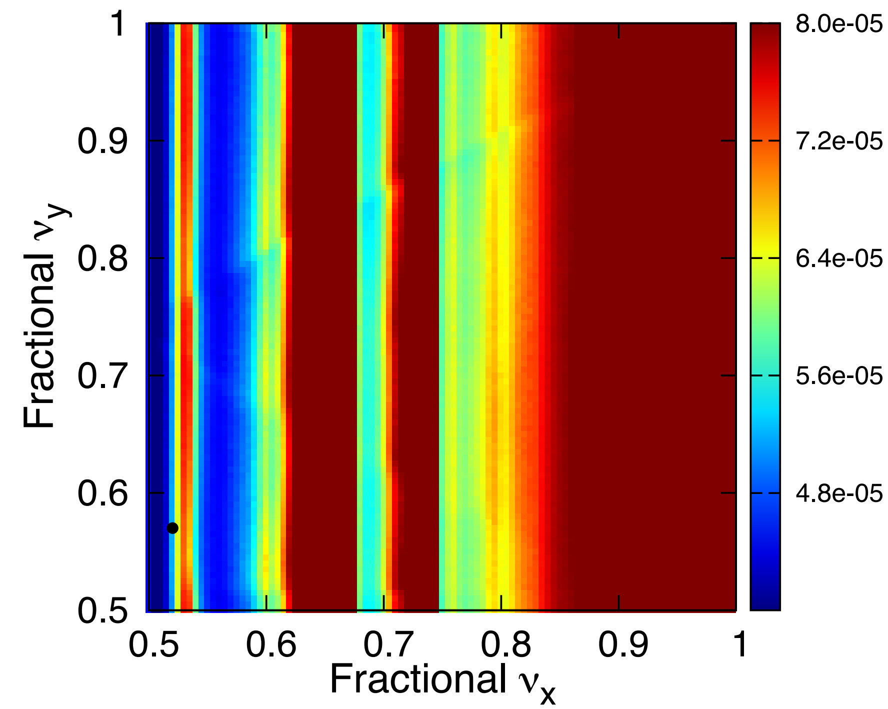
➤ w/o CW w/ BS (Black dot indicates [.52,.57])

- β_y^*=2mm

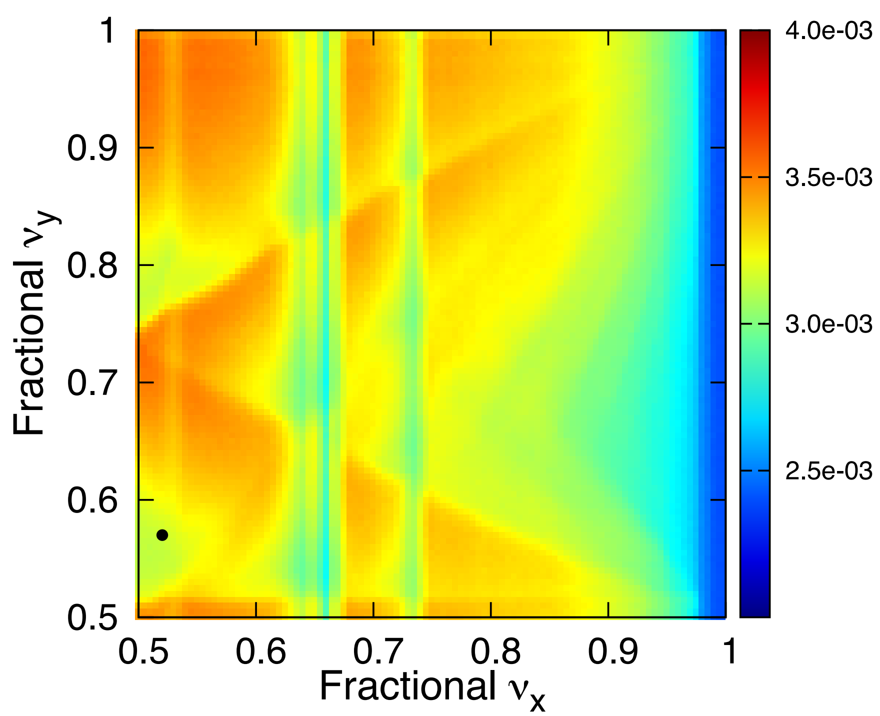
Lum.



σ_x



σ_z



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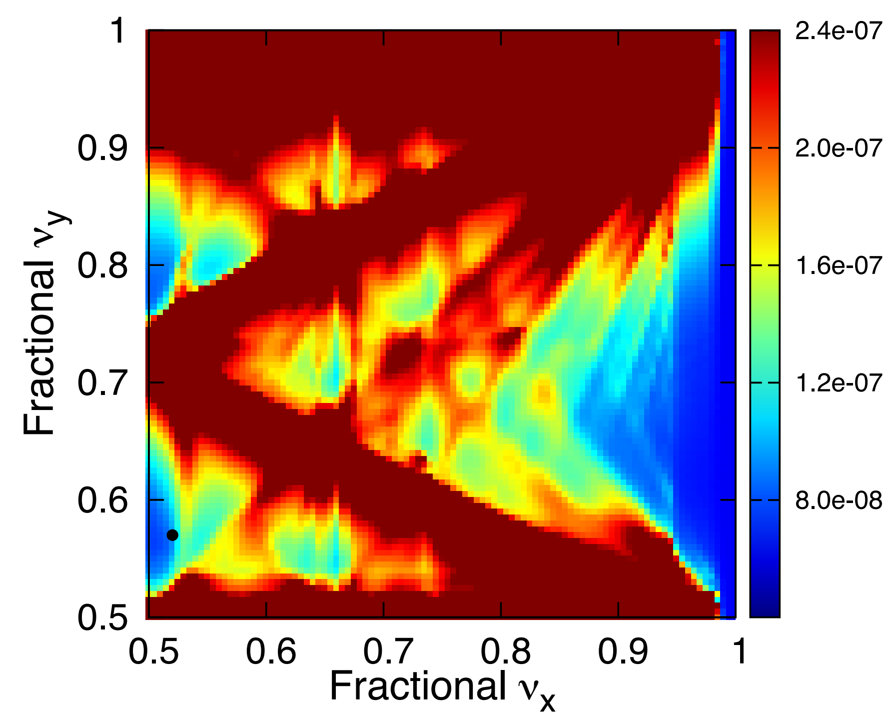
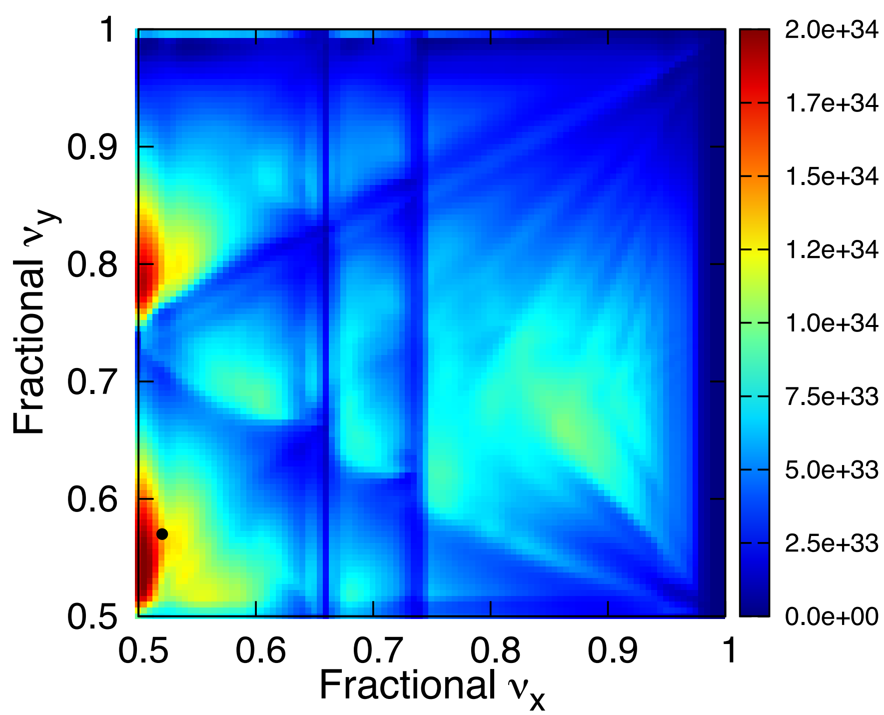


2. BBWS simulations: Lum. tune scan (cont.)

➤ w/ CW w/o BS (Black dot indicates [.52,.57])

- β_y^*=2mm

Lum.



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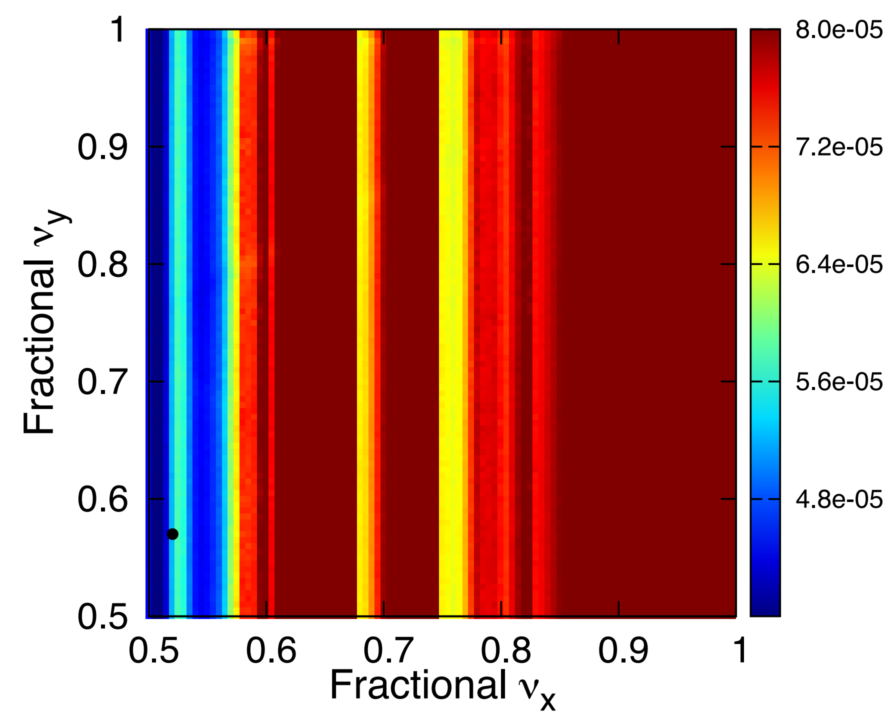

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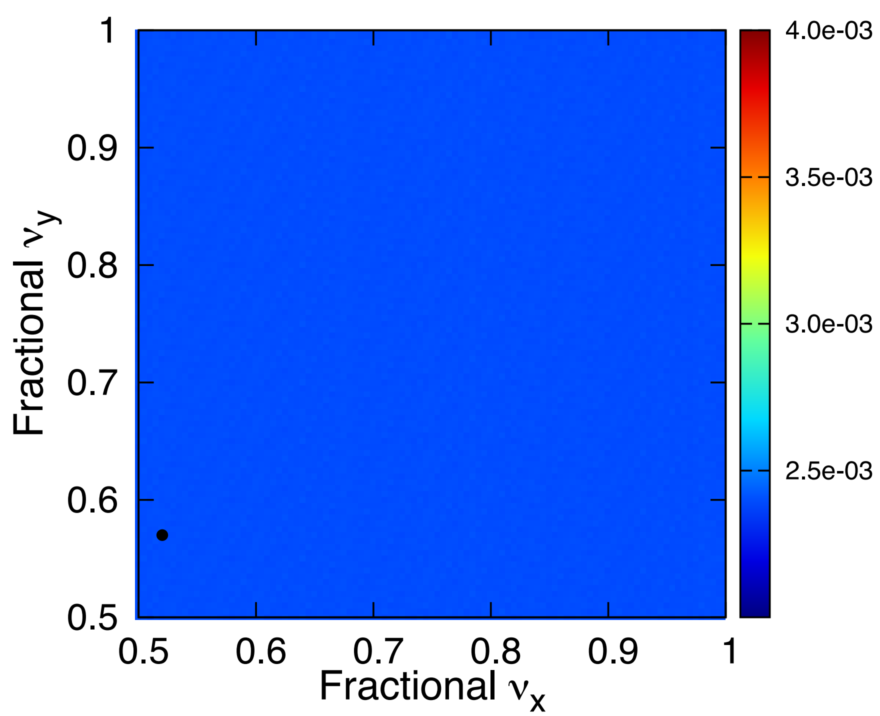
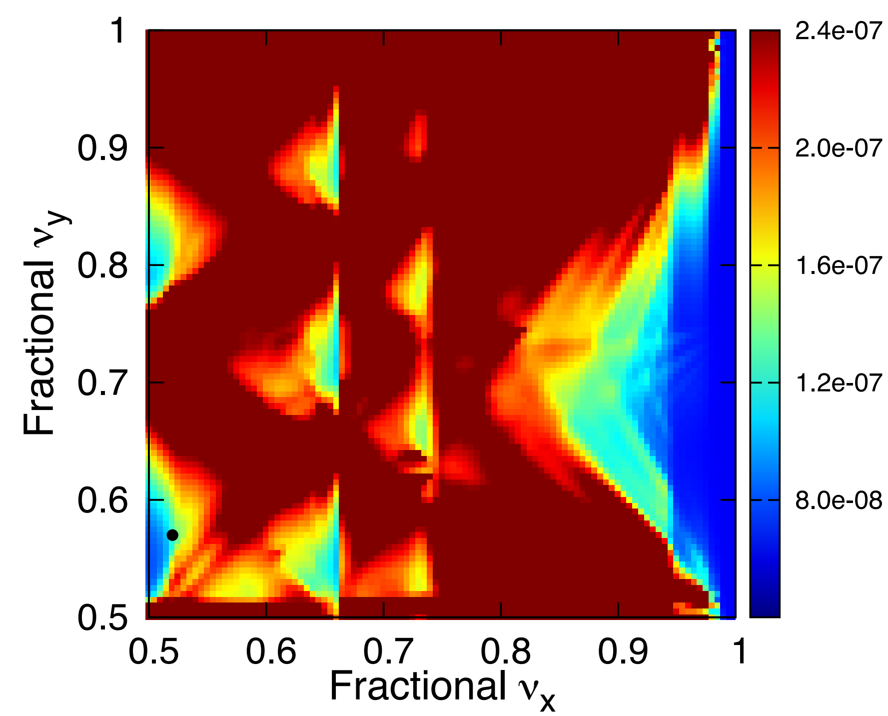


σ_y

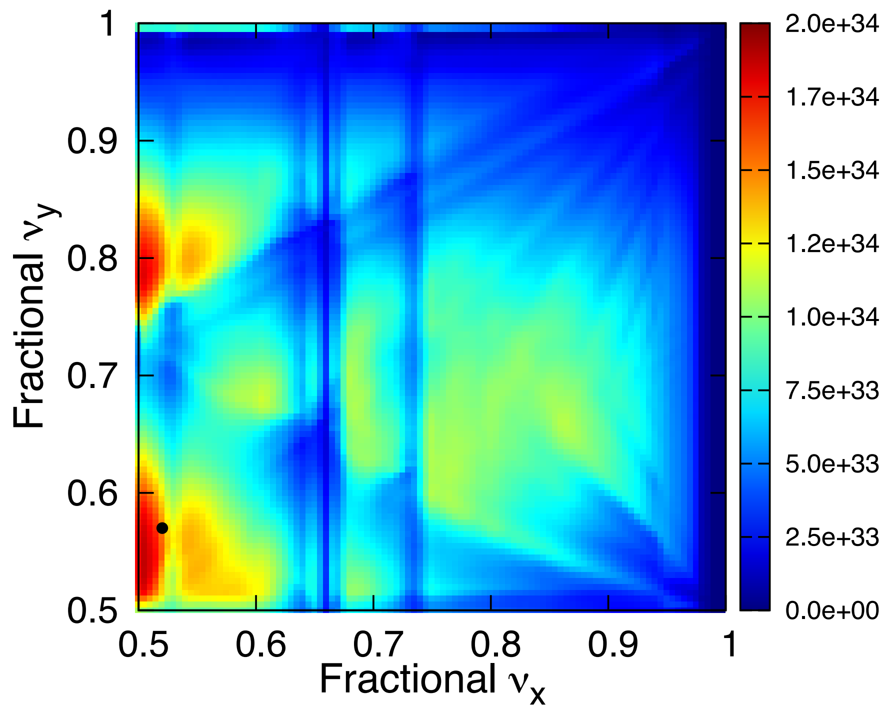


2. BBWS simulations: Lum. tune scan (cont.)

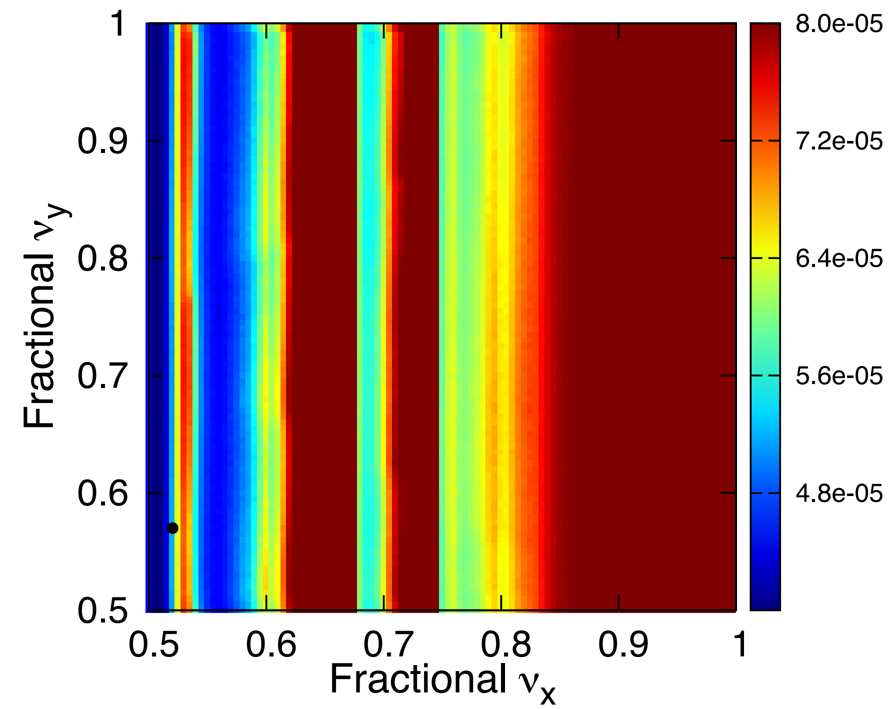
➤ **w/ CW w/ BS (Black dot indicates [.52,.57])**

- **β_y^*=2mm**

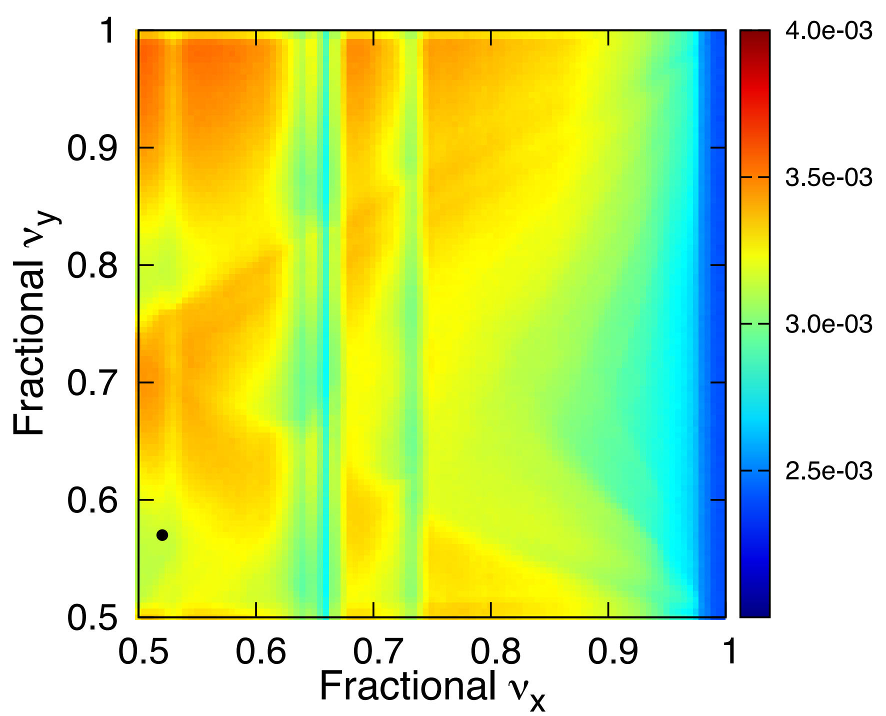
Lum.



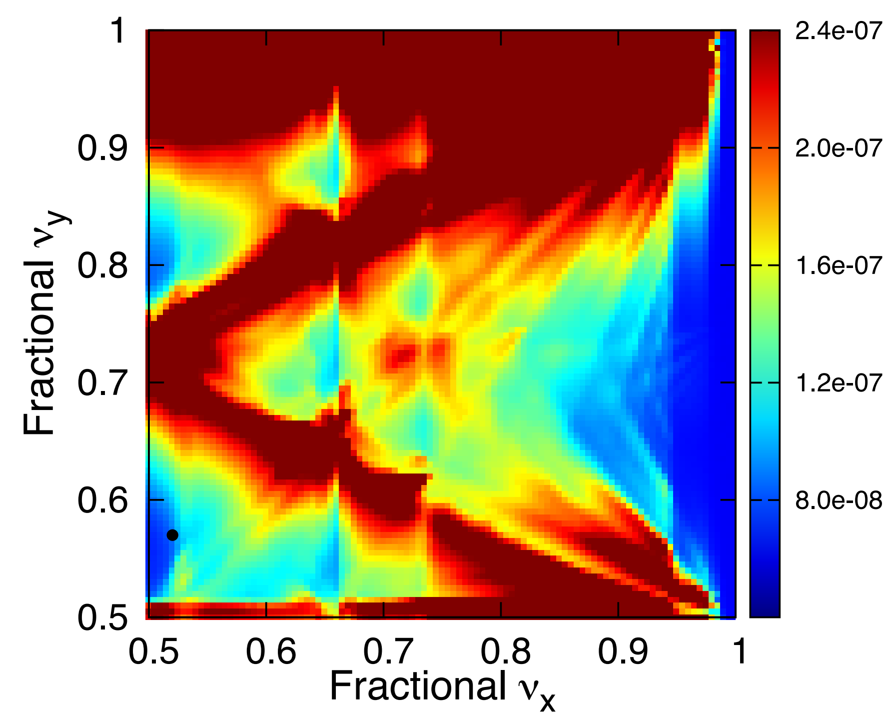
σ_x



σ_z



σ_y

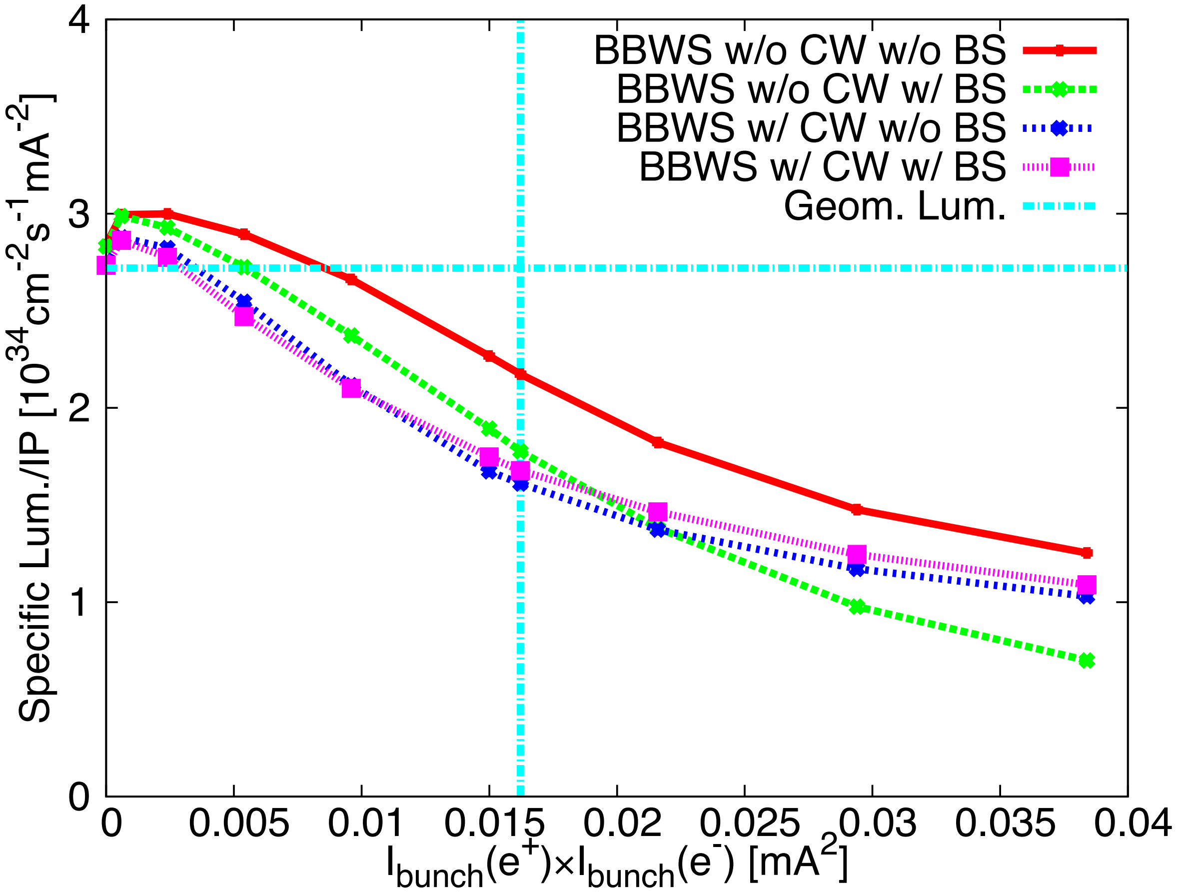


2. BBWS simulations: Specific luminosity

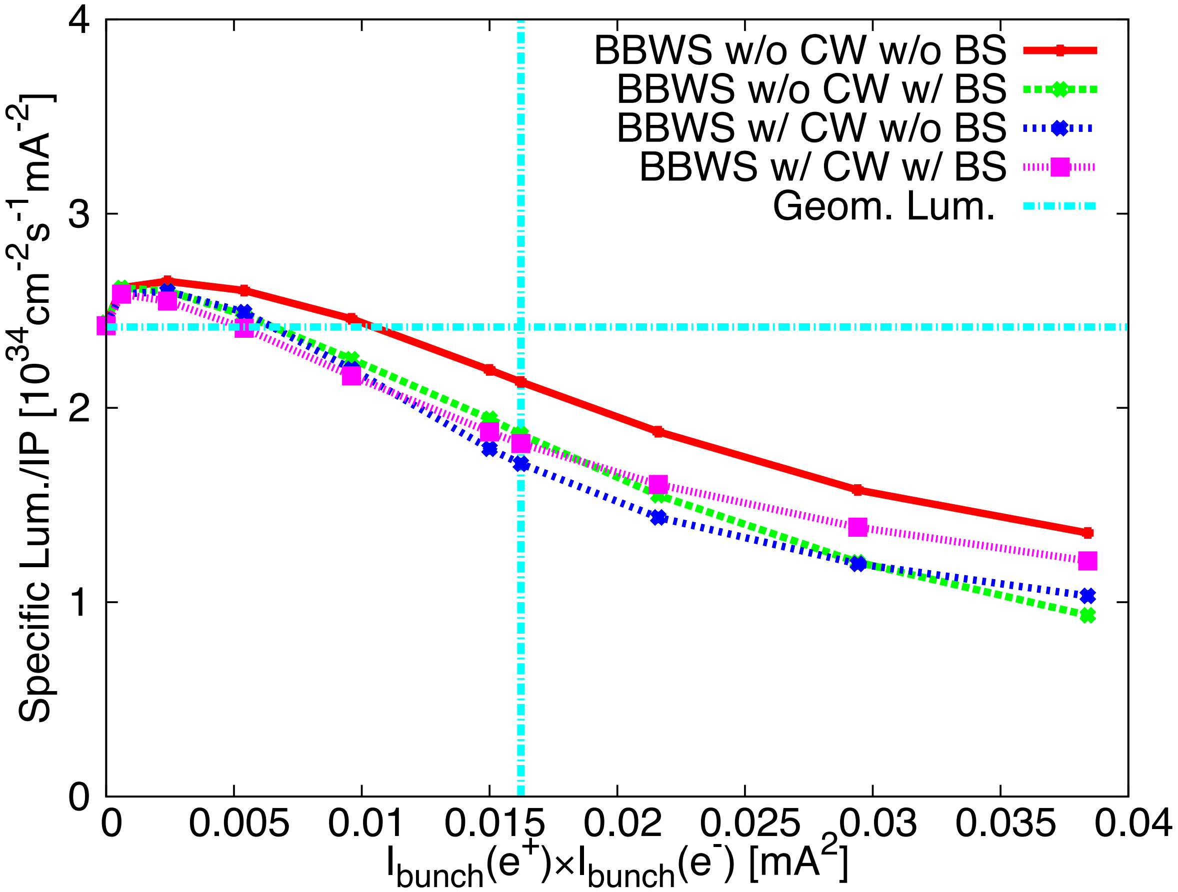
➤ **Conditions:**

- **w/ and w/o crab waist (CW)**
- **w/ and w/o beamstrahlung (BS)**
- **Working point: [.52, .57]**
- **Cyan line indicates geometric luminosity**

β_y^*=1mm



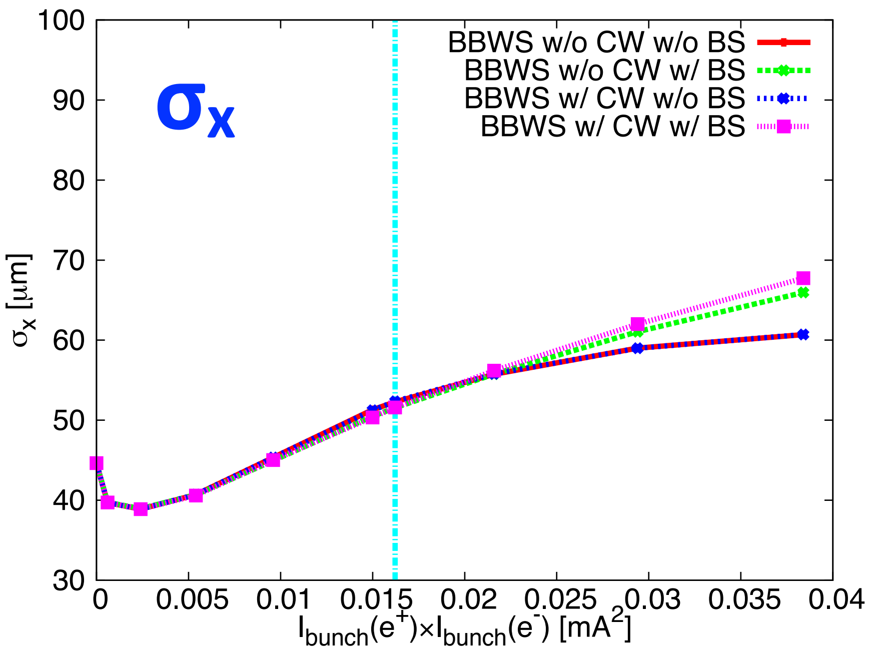
β_y^*=2mm

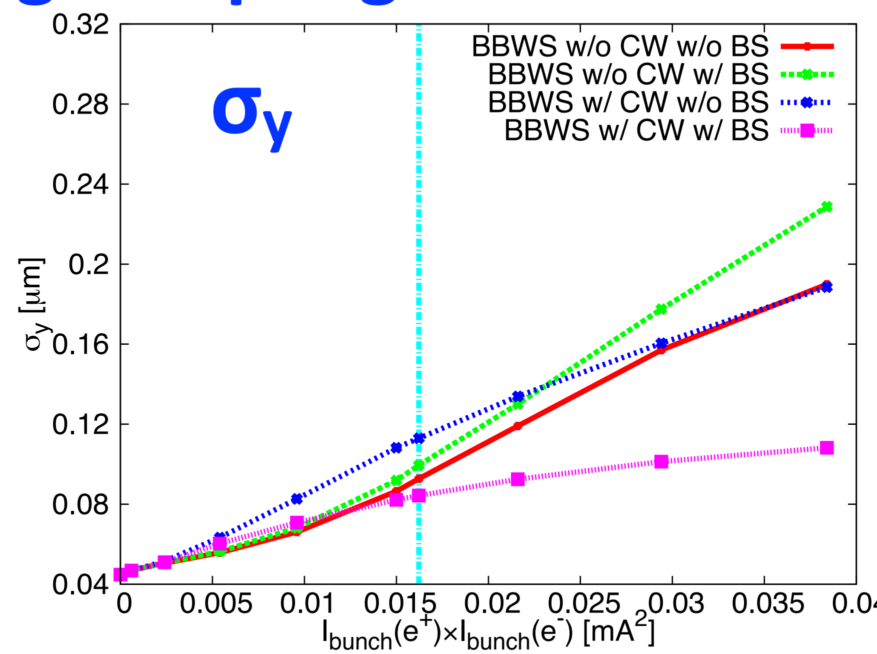


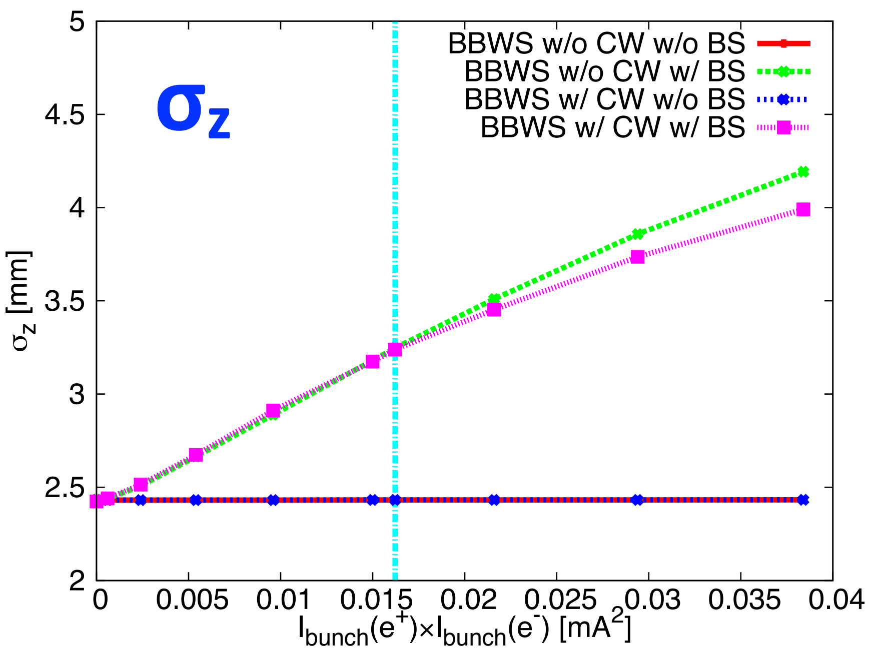
2. BBWS simulations: Specific luminosity (cont.)

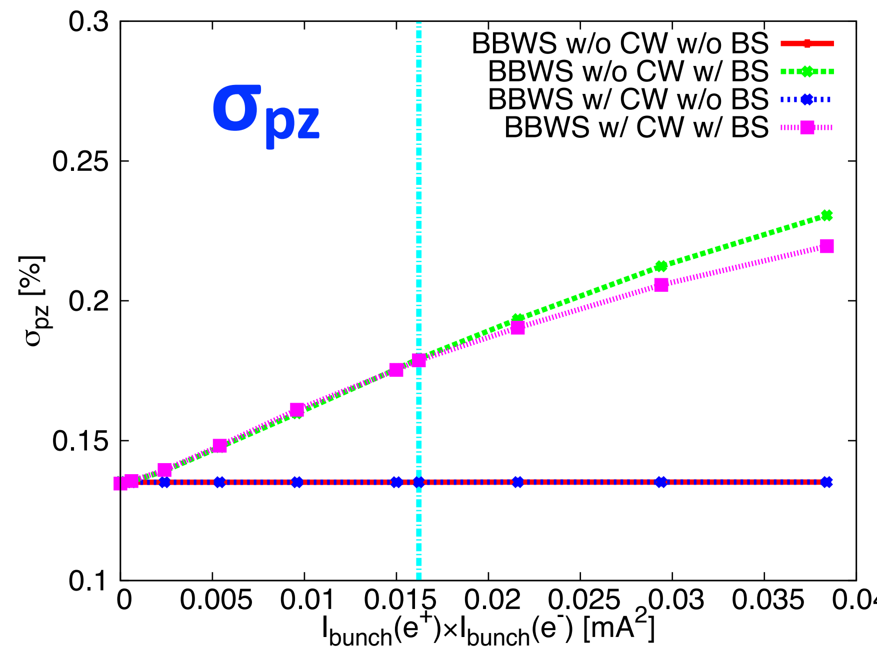
➤ Corresponding beam parameters [rms values]

- β_y^*=1mm
- BS correlates trans. and long. emittances
- BB resonances enhance trans.-long. coupling





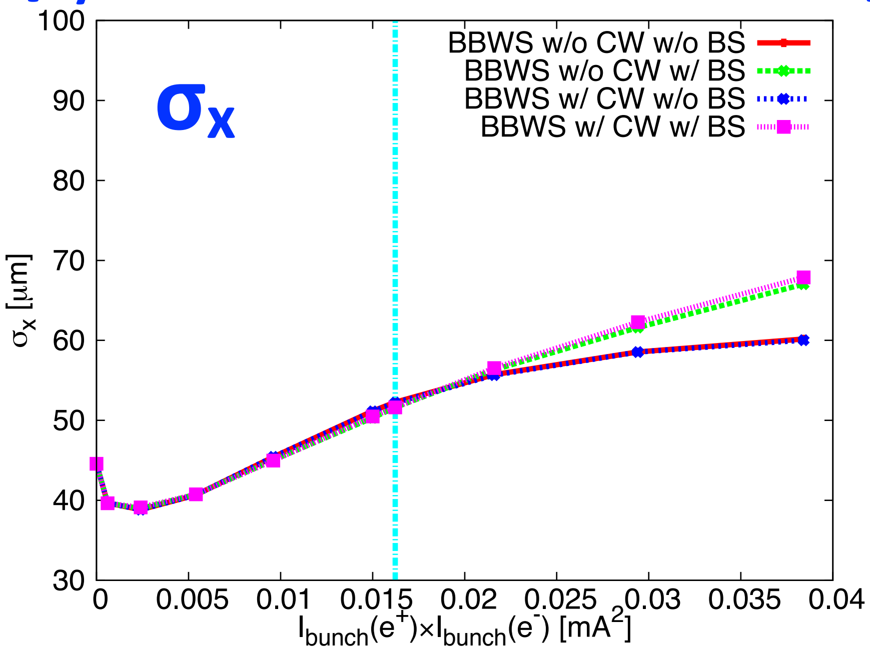


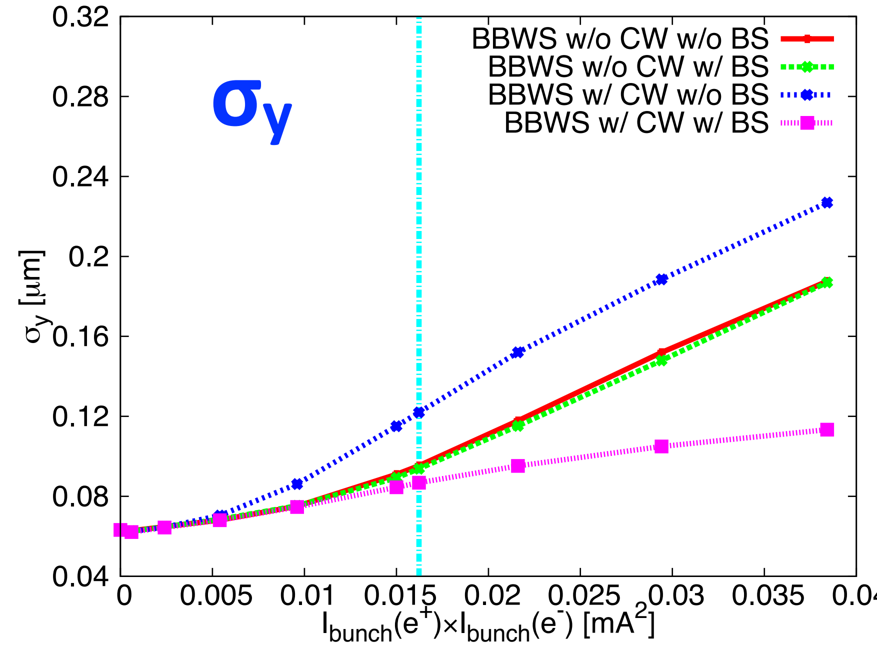


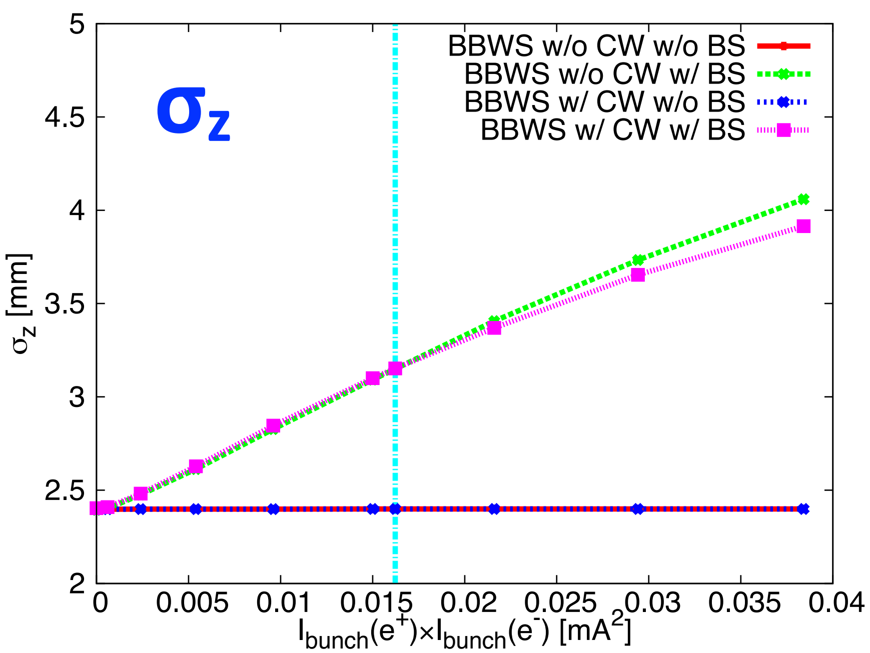
2. BBWS simulations: Specific luminosity (cont.)

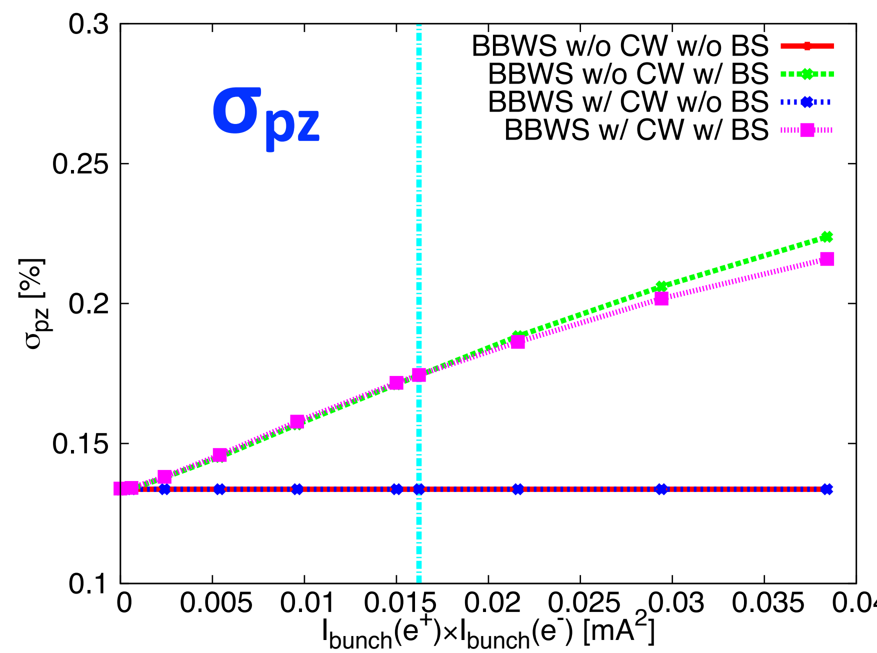
➤ Corresponding beam parameters [rms values]

- β_y^*=2mm
- Lum. ~8% higher than β_y^*=1mm at NP=2.6E11 w/ CW w/ BS
- β_y^*=2mm is better than β_y^*=1mm? Tune dependent?





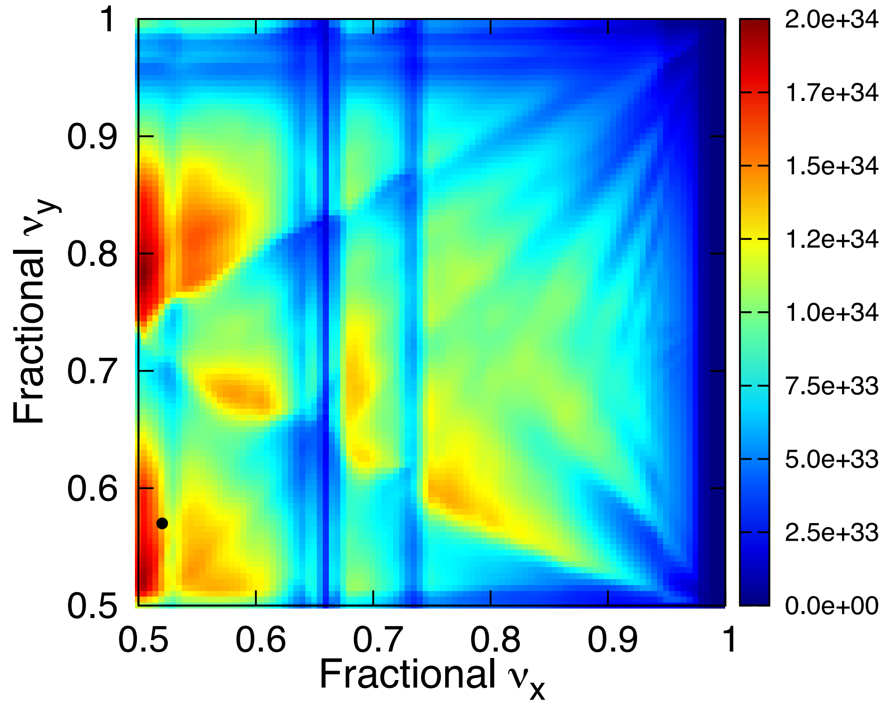




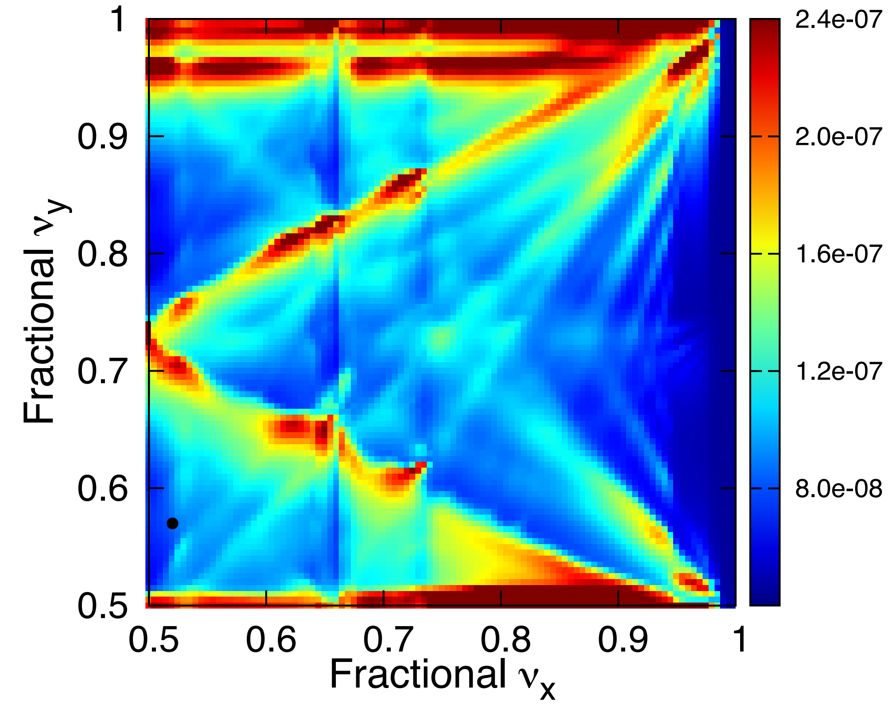
2. BBWS simulations: Lum. Scan

- **Compare β_y^*=1mm and β_y^*=2mm (NP=2.6E11)**
  - **β_y^*=1mm (w/ CW w/ BS):**

Lum.

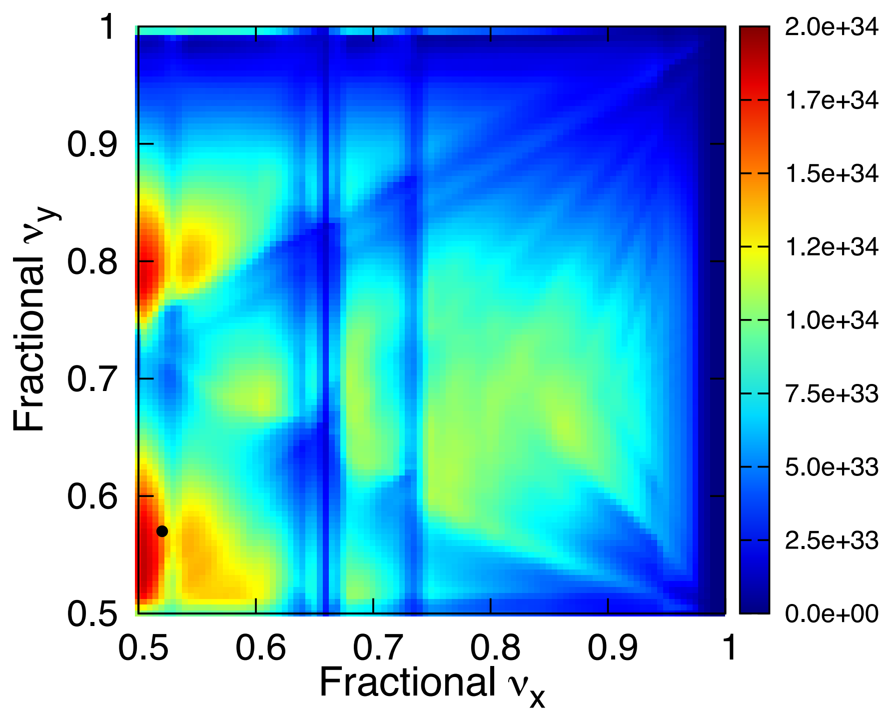


σ_y

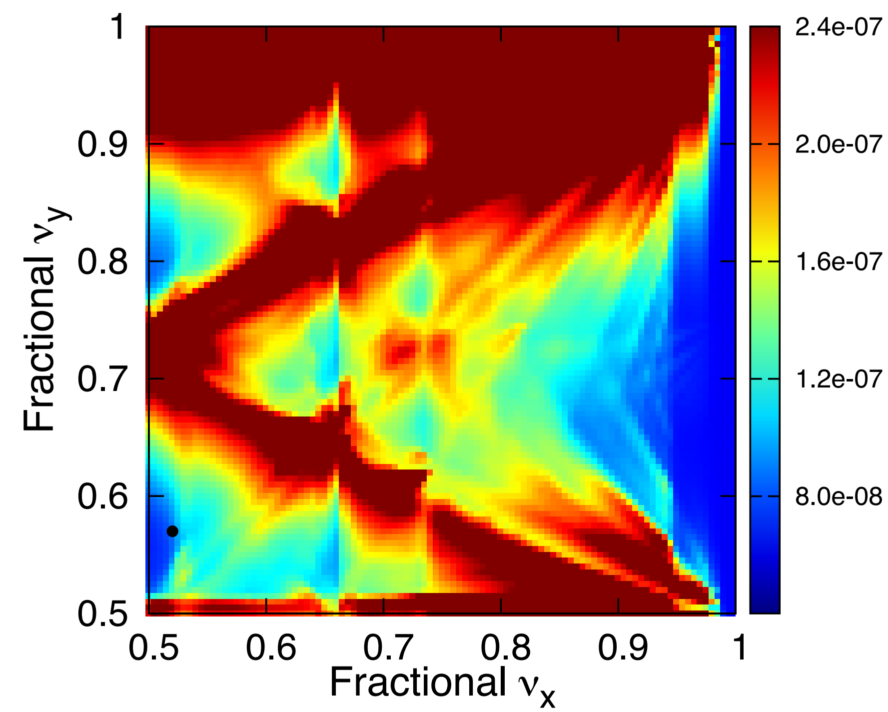


  - **β_y^*=2mm (w/ CW w/ BS):**

Lum.



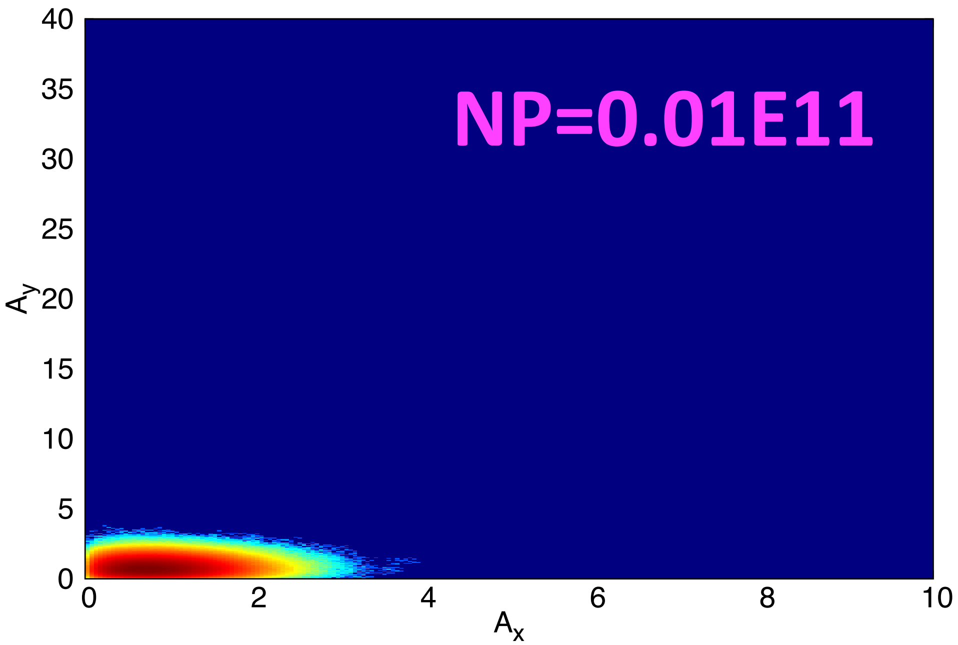
σ_y

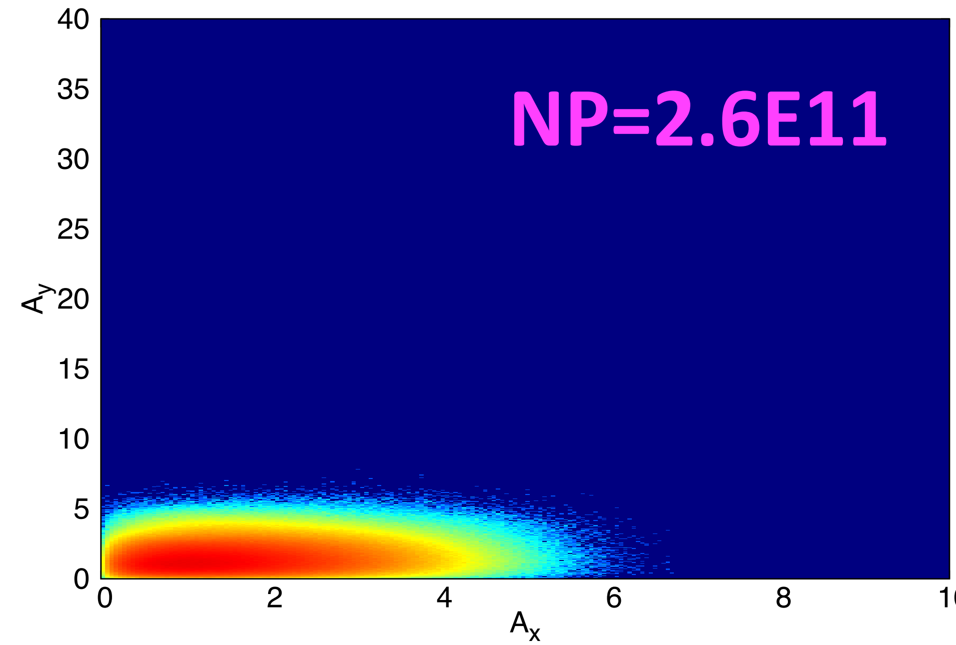


2. BBWS simulations: Beam tail

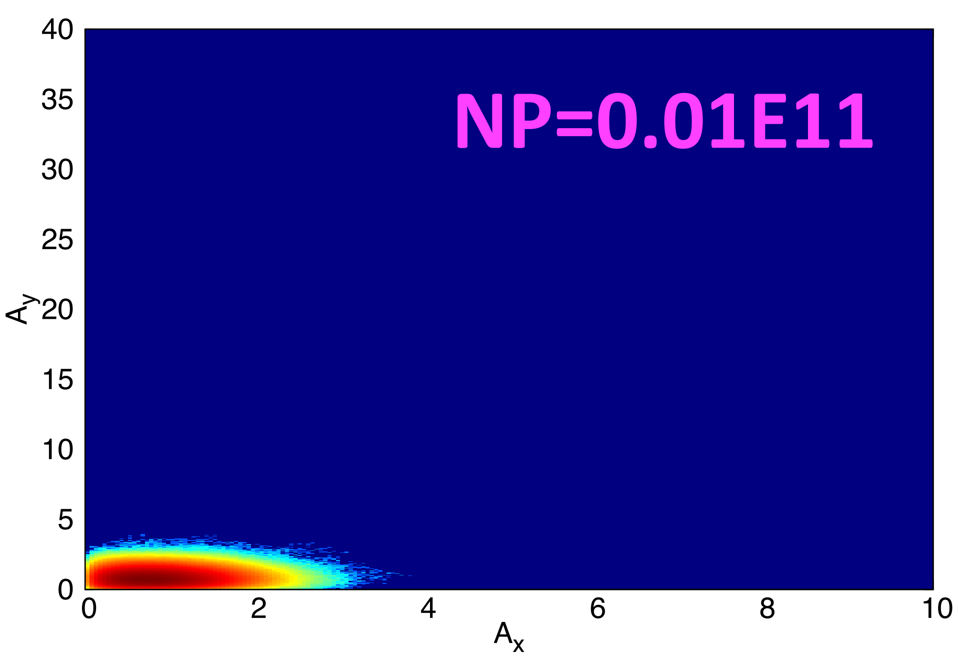
➤ **Compare β_y^*=1mm and β_y^*=2mm**

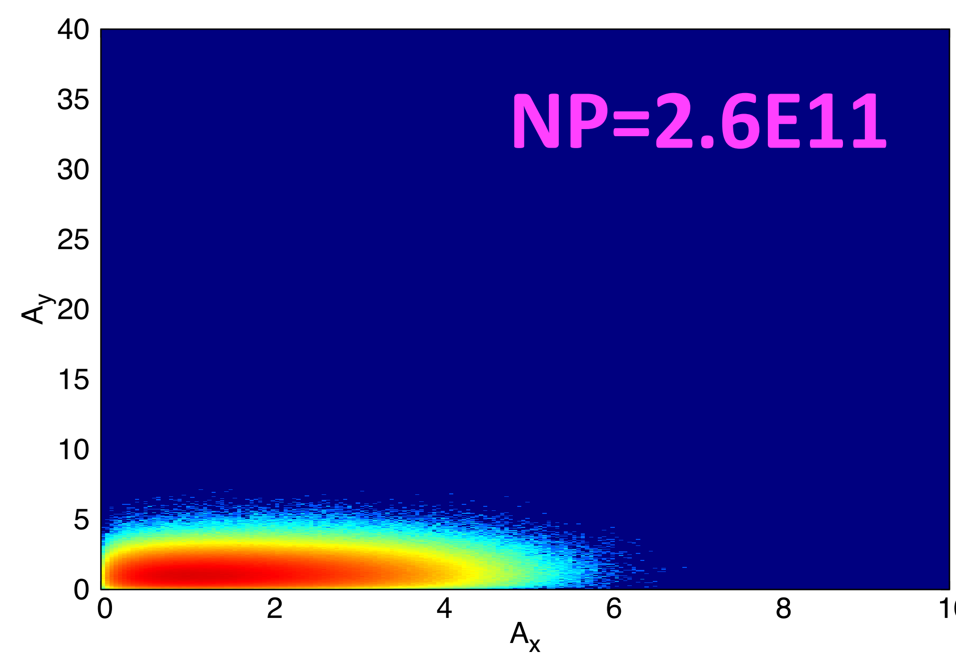
- **β_y^*=1mm (w/ CW w/ BS):**





- **β_y^*=2mm (w/ CW w/ BS):**

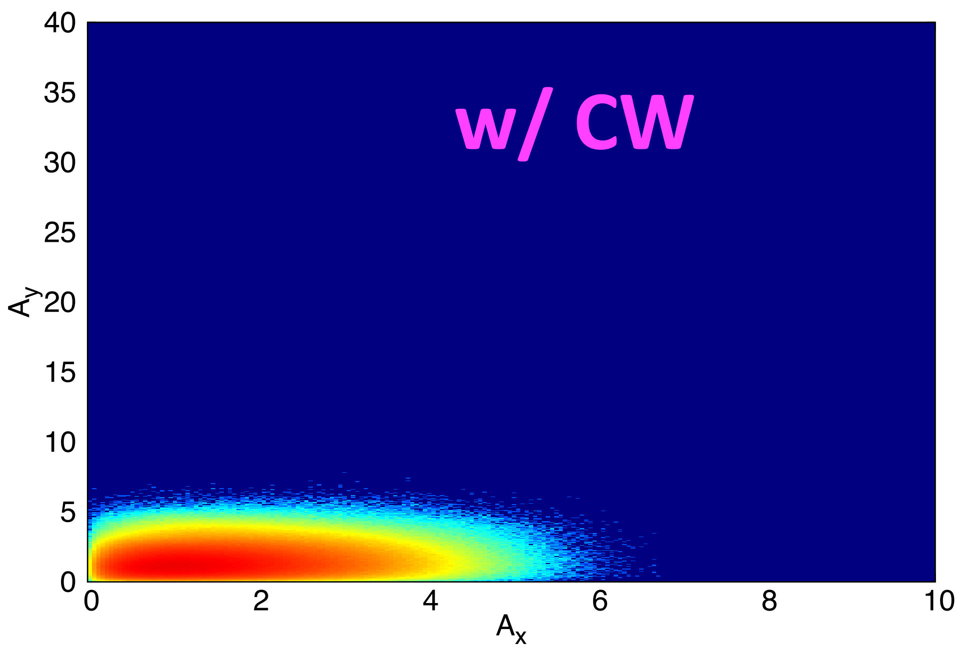


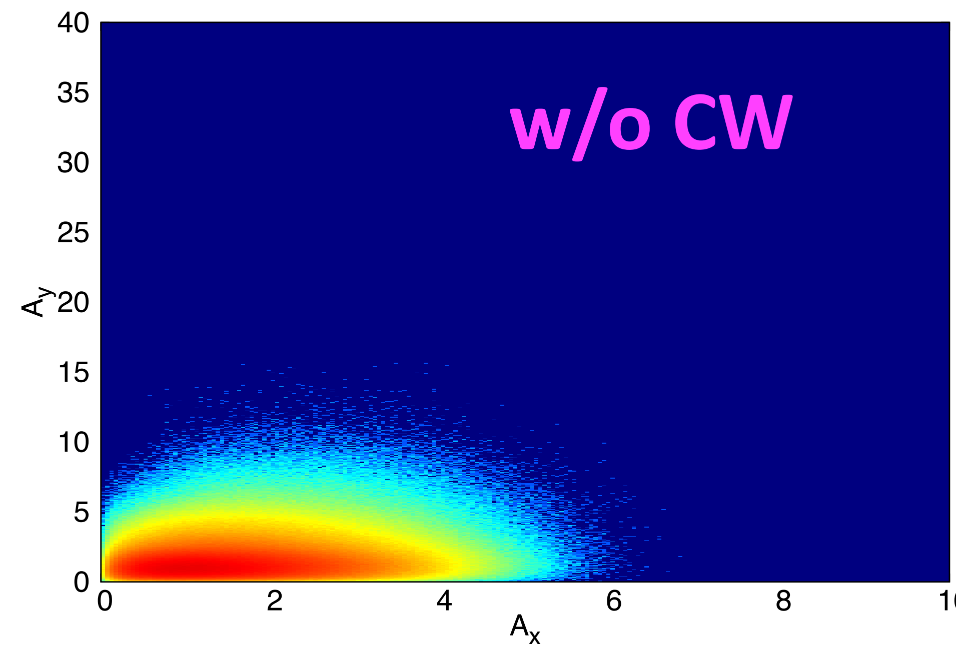


2. BBWS simulations: Beam tail

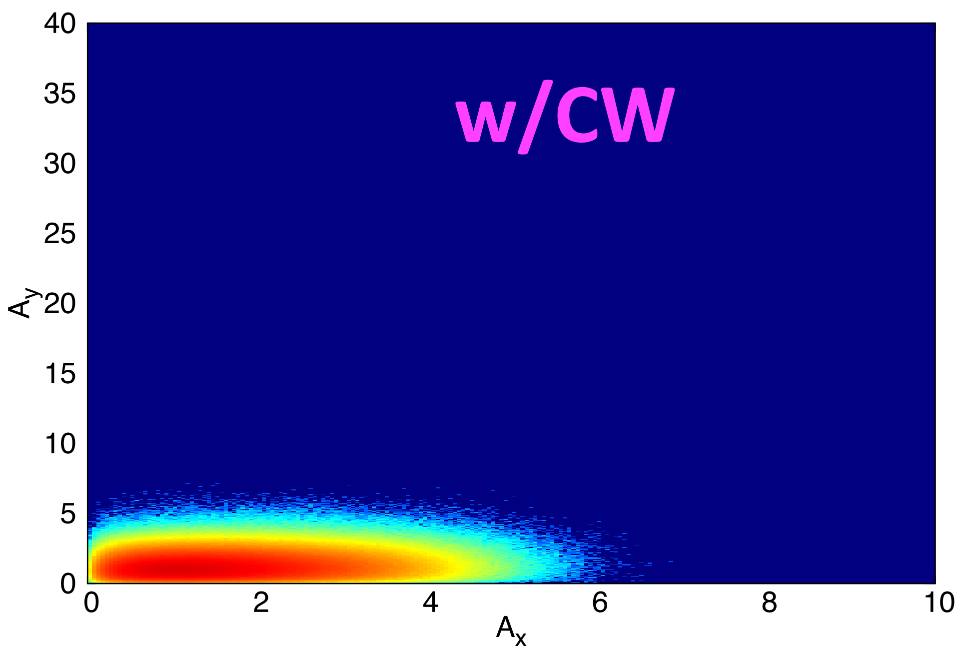
➤ **Compare w/ and w/ CW (NP=2.6E11)**

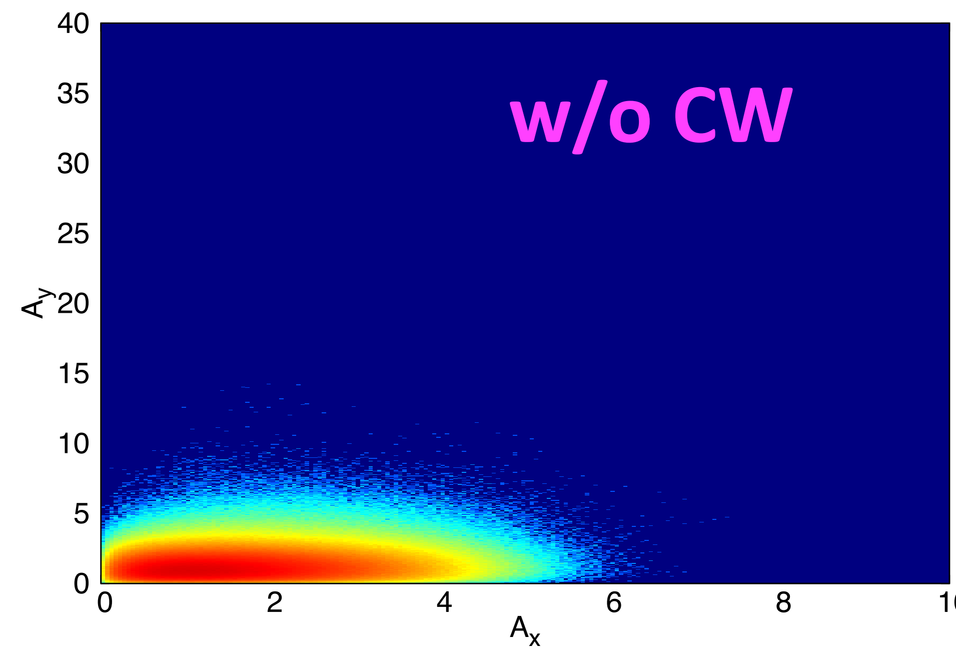
- **β_y^*=1mm (w/ BS):**





- **β_y^*=2mm (w/ BS):**





3. Interplay of BB and latt. nonlin.

➤ **SAD element-by-element tracking options:**

- **Case-1: Damping/excitation lumped at IP (similar to BBWS): beam always unstable**

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

- **Case-2: Damping/excitation lumped at FRF: beam reaches equilibrium, instability appear at high current**

$$M = M_{\mathrm{RAD}} \circ M_{\mathrm{IP}\to\mathrm{FRF}} \circ M_{\mathrm{BB}} \circ M_{\mathrm{FRF}\to\mathrm{IP}}$$

- **Case-3: Damping/excitation turned on at each element: beam unstable even w/o BB**
- **Case-4: Damping turned on at each element and excitation lumped at FRF: beam might be unstable w/ BB [depend on tune?]**

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

➤ **Lumped damping/excitation:**

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

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

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

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

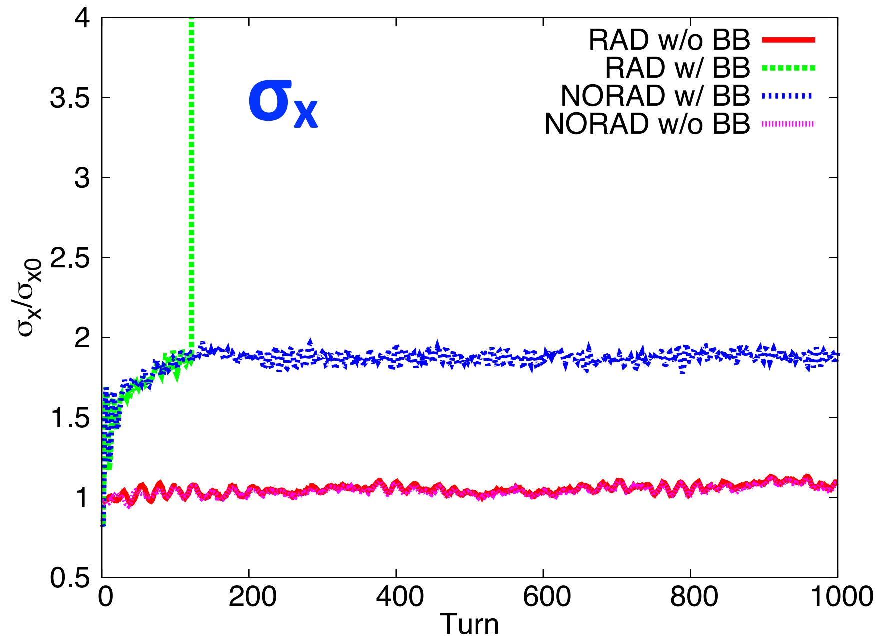
$$\vec{\beta}_D = \sqrt{2(\epsilon_x D_x, \epsilon_x D_x, \epsilon_y D_y, \epsilon_y D_y, \epsilon_z D_z, \epsilon_z D_z)}$$

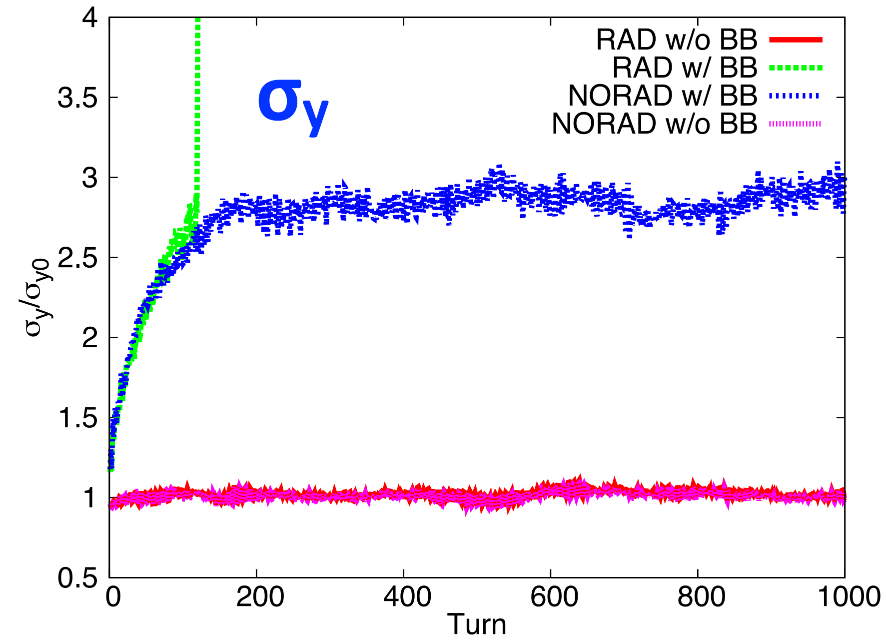
$$\vec{X}_1 = \vec{\lambda} \cdot \vec{X}_0 + \vec{\beta}_D \cdot \vec{r}$$

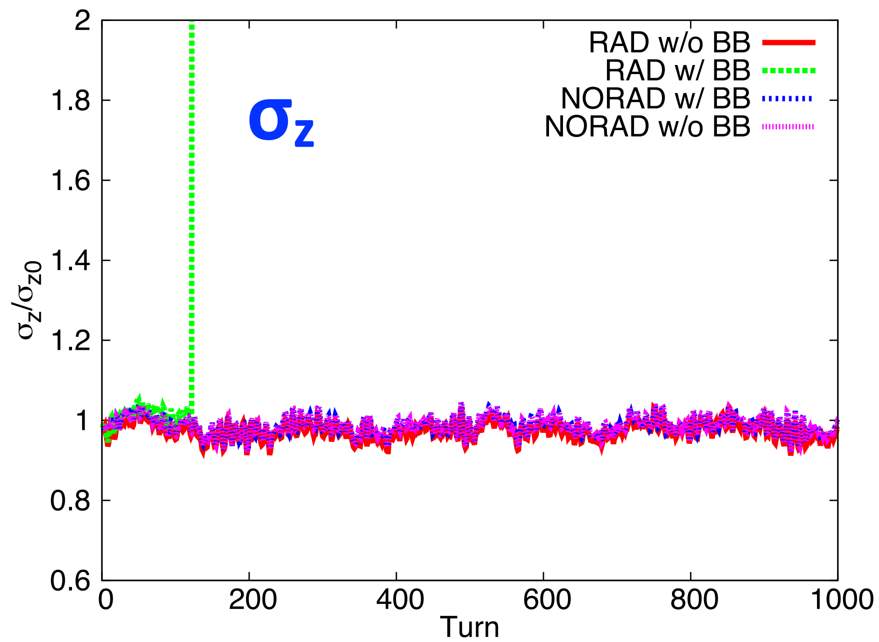
$$\vec{x}_1 = M_{\mathrm{p2n}}^{-1}\vec{x}_0$$

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

➤ **Turn-by-turn rms beam sizes:**
β_y^*=1mm, NP=2.6E11, ν_x/ν_y=162.52/163.57





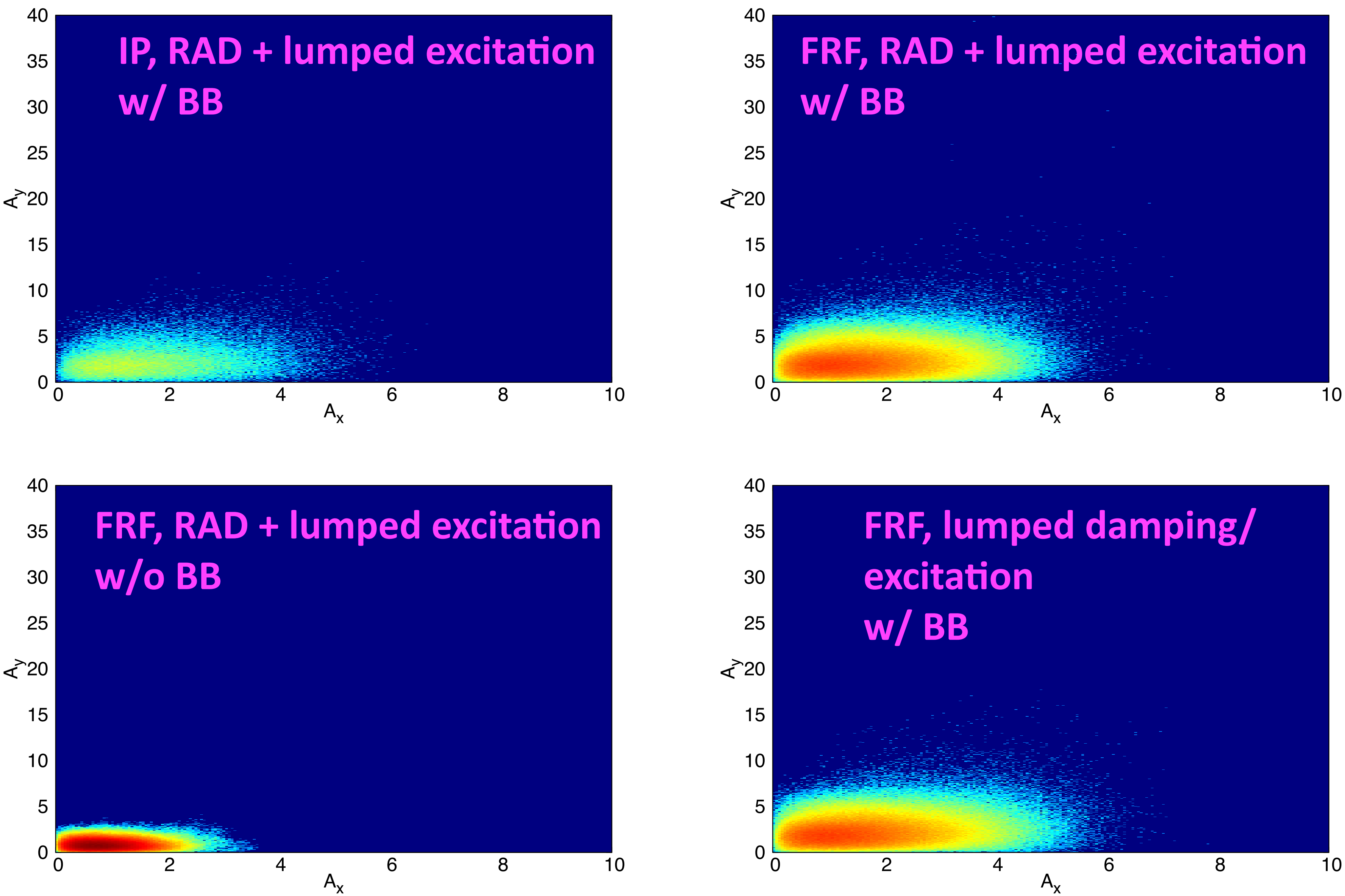


Red: Case-4 w/o BB
Green: Case-4 w/ BB
Blue: Case-2 w/ BB
Magenta: Case-2 w/o BB
Cyan: Nominal value

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

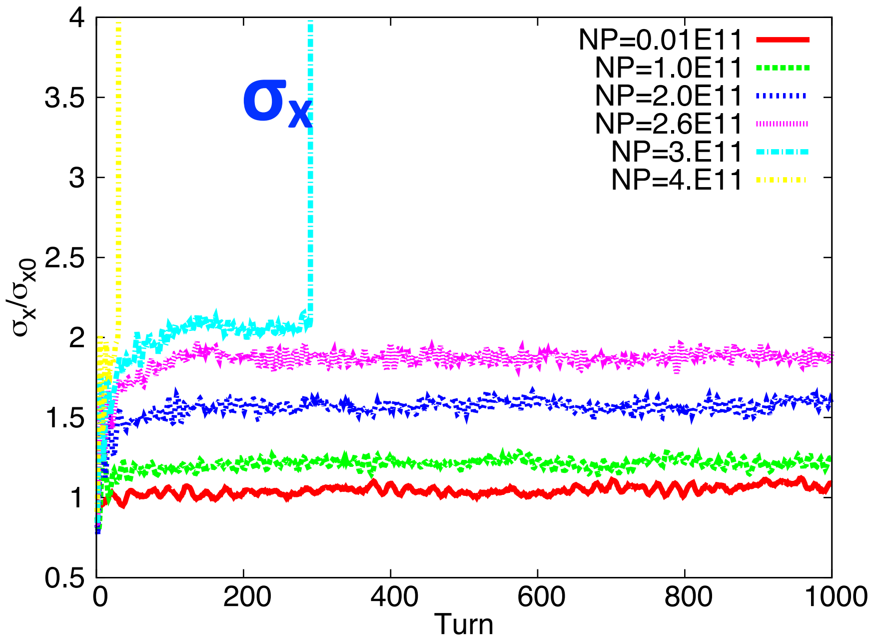
- **Beam tail:**

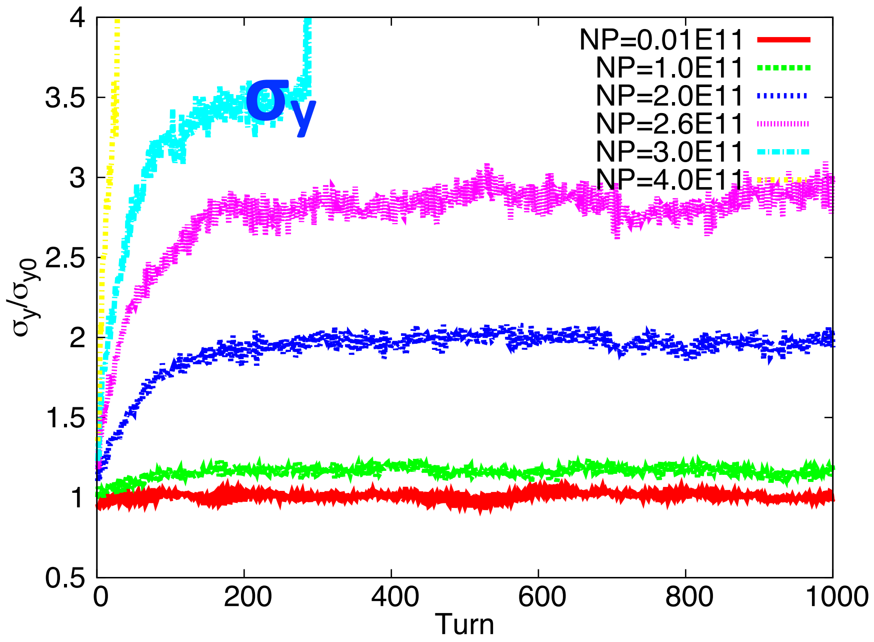
  β_y^*=1mm, NP=2.6E11, ν_x/ν_y=162.52/163.57

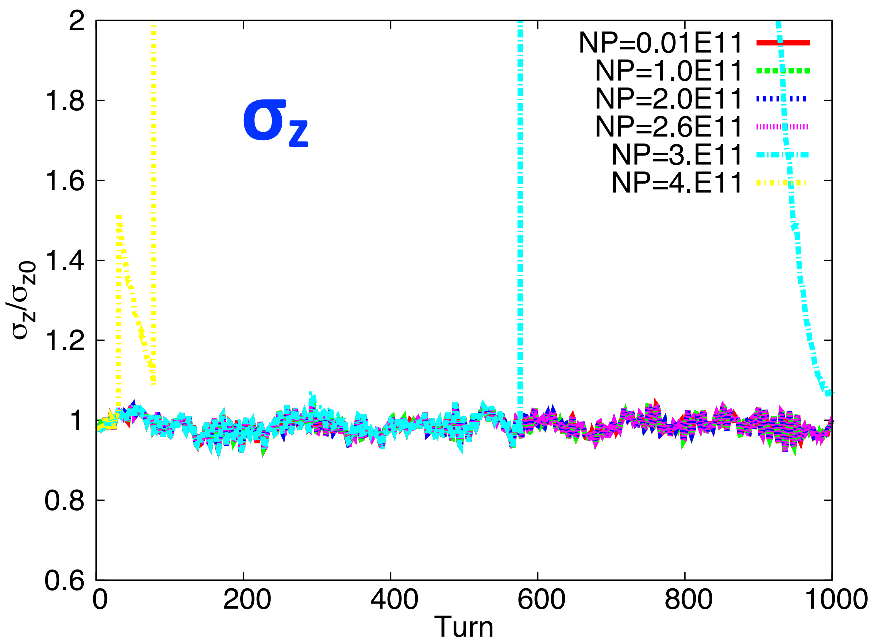


3. Interplay of BB and latt. nonlin. (cont.)

➤ **Turn-by-turn rms beam sizes (Case-2):**
β_y^*=1mm, NP=0.01-4E11, ν_x/ν_y=162.52/163.57

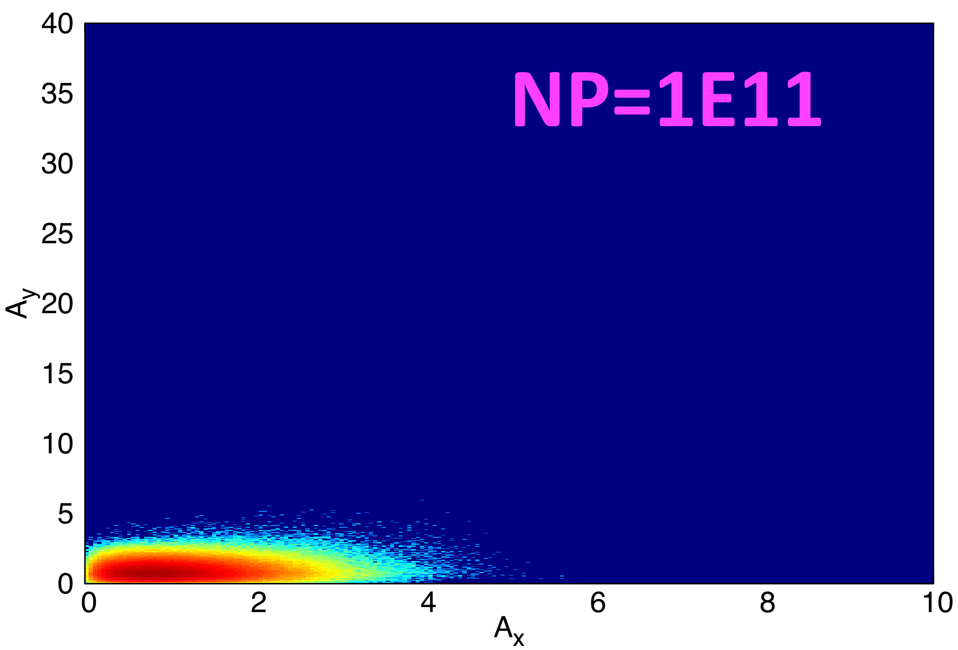


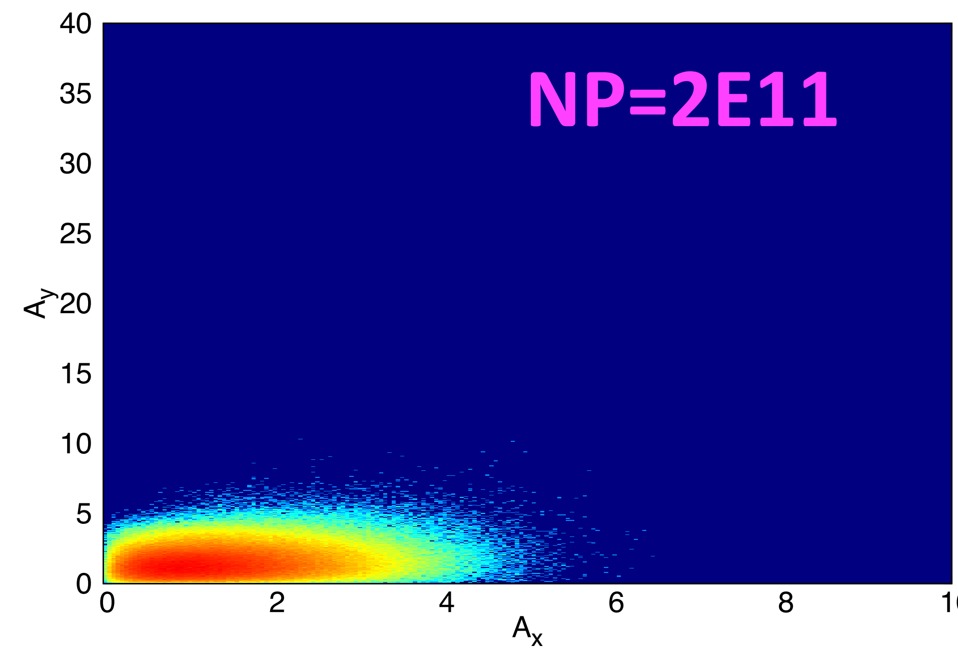


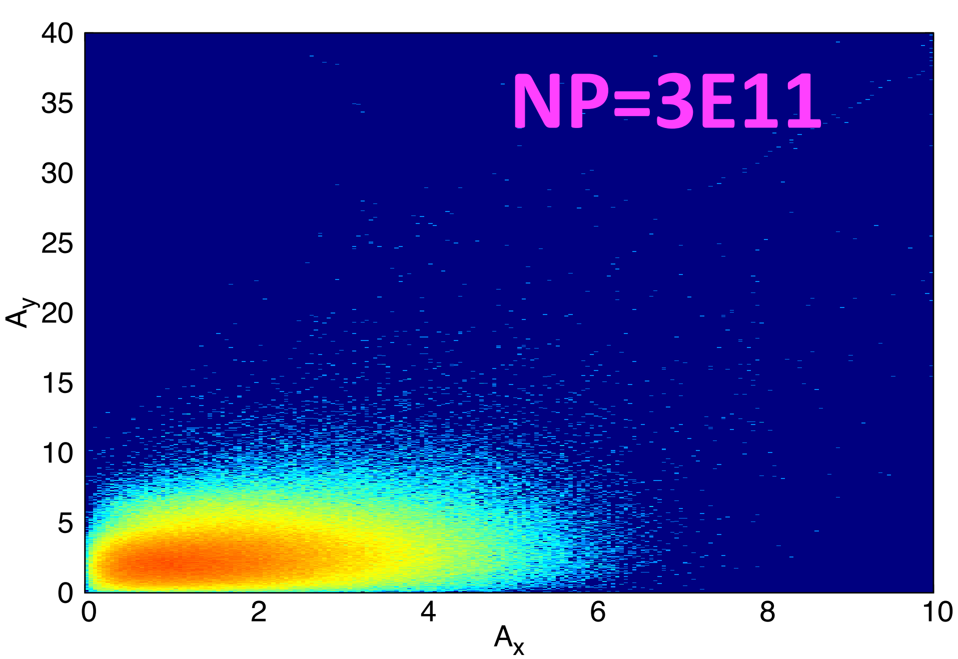


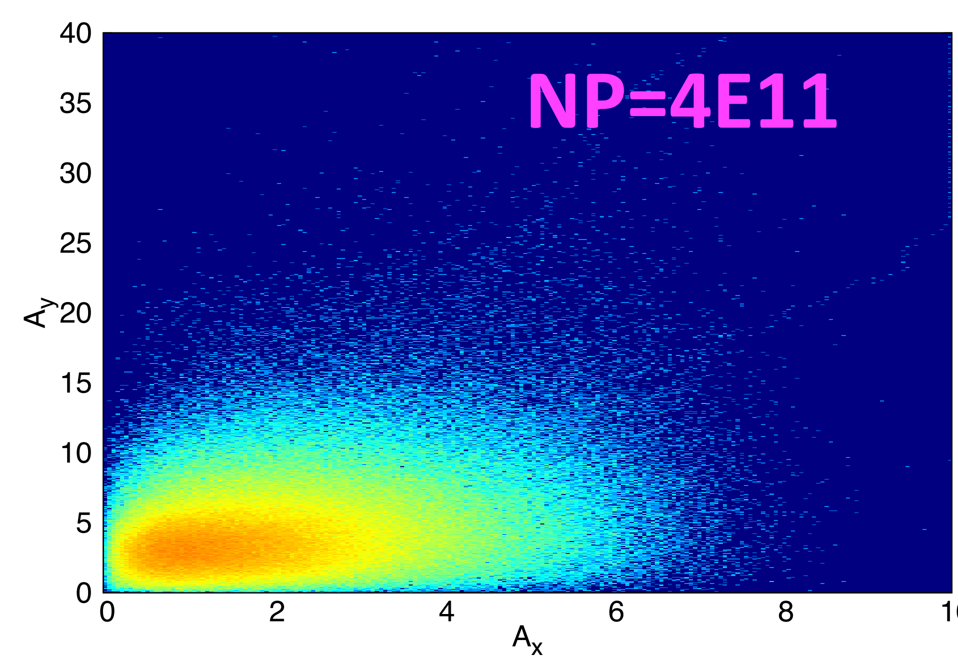
3. Interplay of BB and latt. nonlin. (cont.)

➤ **Beam tail (Case-2):**
β_y^*=1mm, NP=0.01-4E11, ν_x/ν_y=162.52/163.57



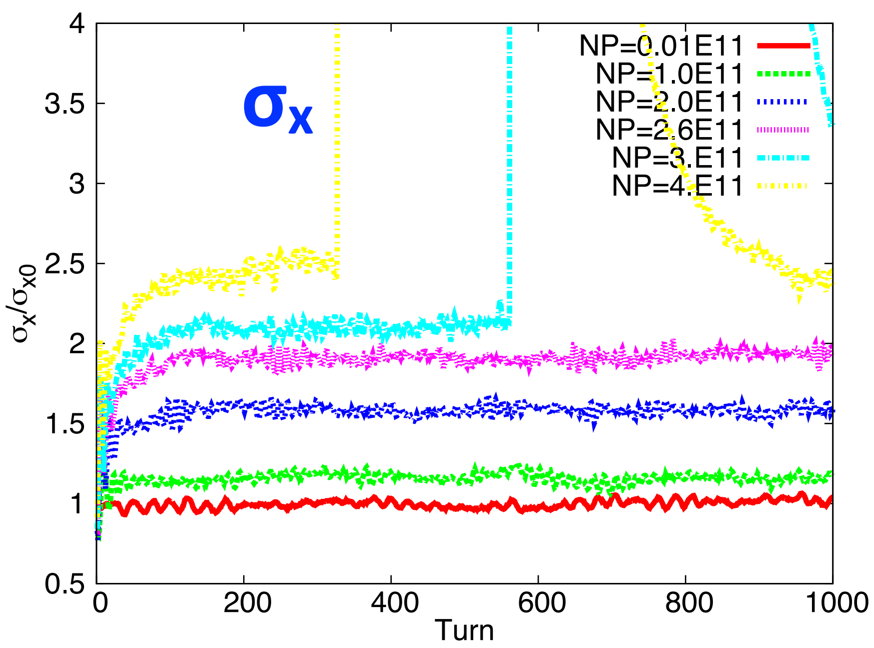


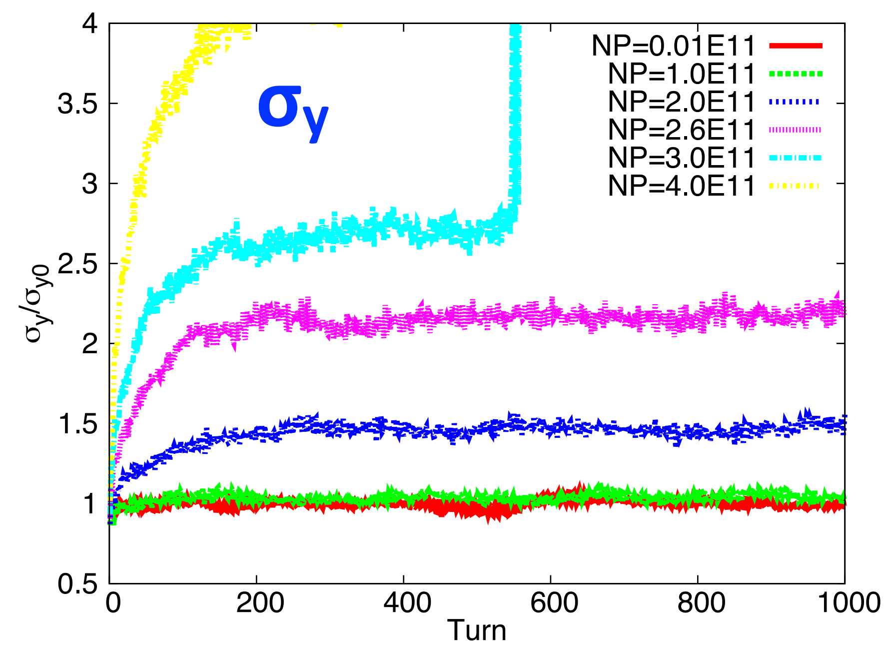


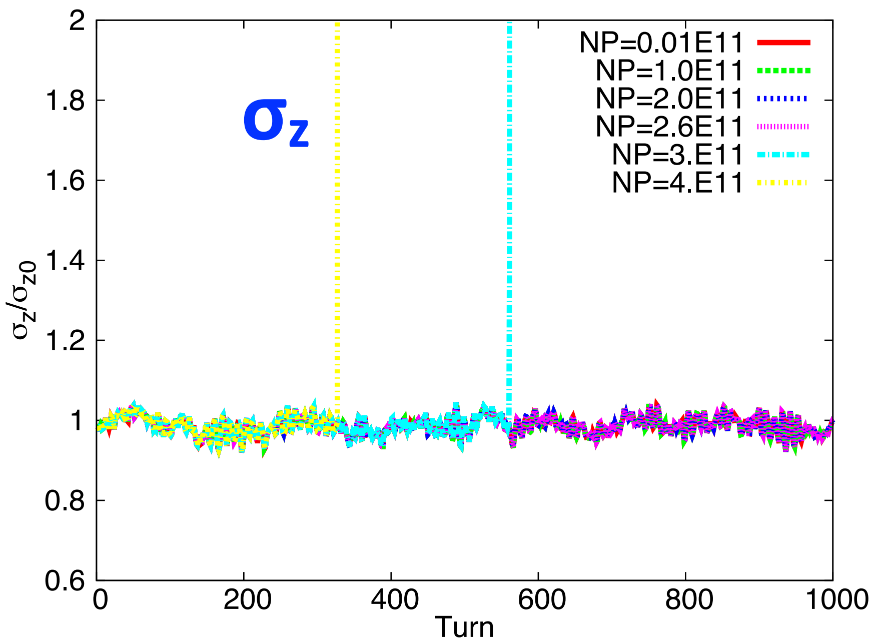


3. Interplay of BB and latt. nonlin. (cont.)

➤ **Turn-by-turn rms beam sizes (Case-2): β_y^*=2mm, NP=0.01-4E11, ν_x/ν_y=162.52/163.57**







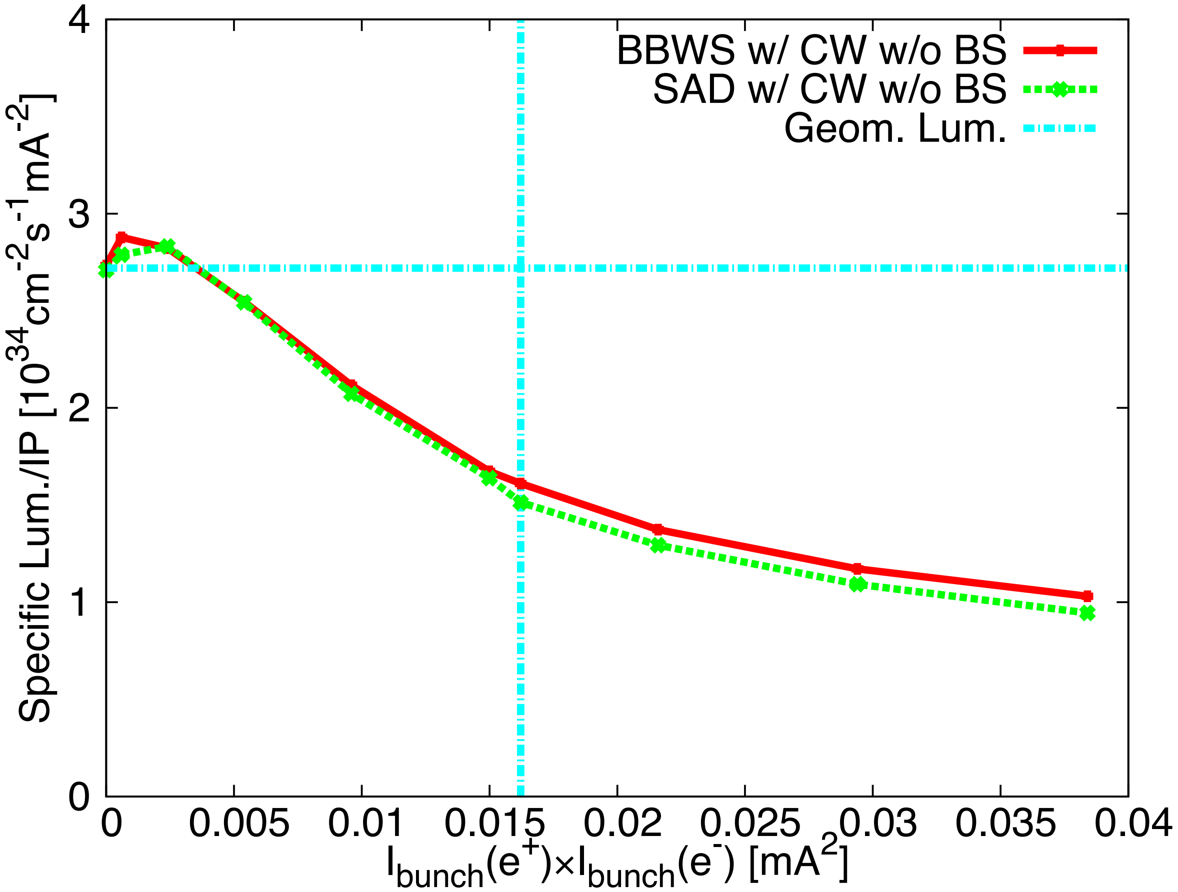
3. Interplay of BB and latt. nonlin. (cont.)

➤ **Specific luminosity (Case-2):**

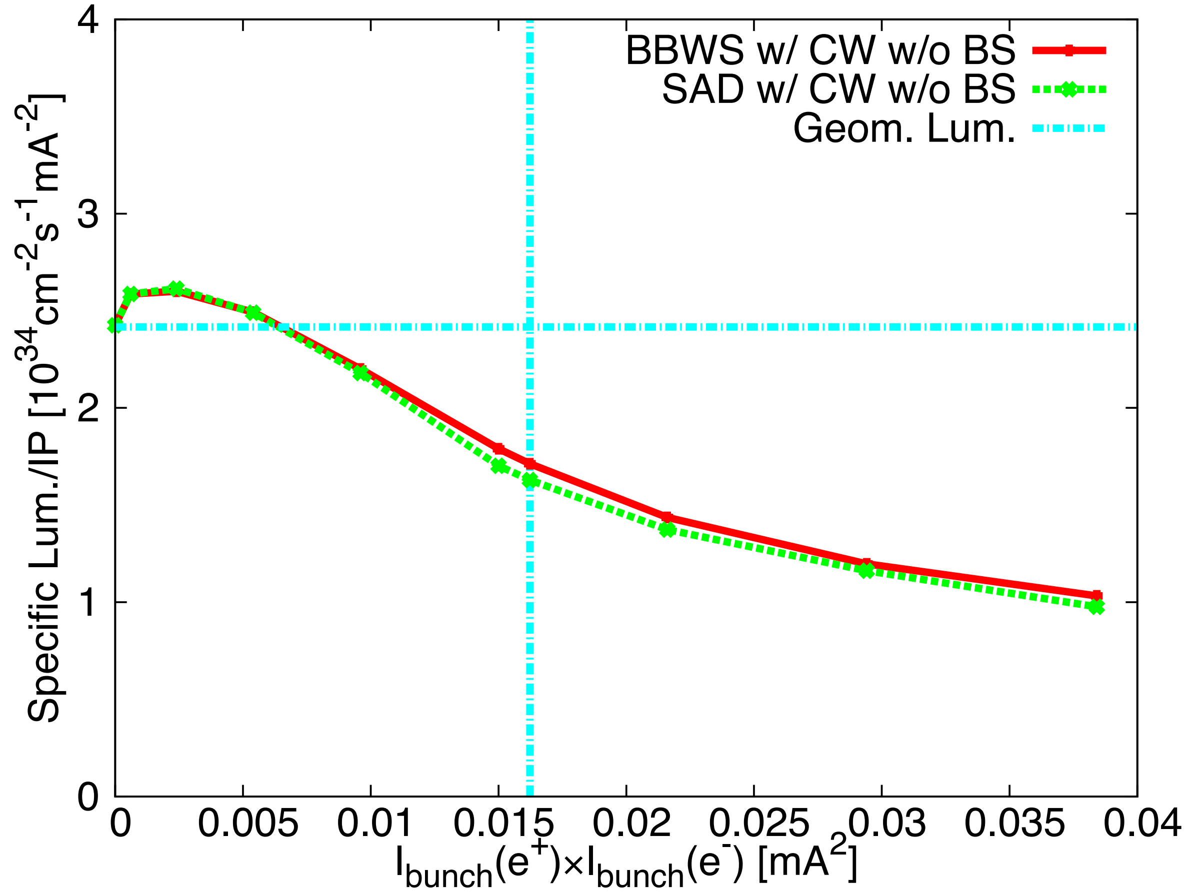
β_y^*=1/2mm, NP=2.6E11, ν_x/ν_y=162.52/163.57

- **Almost no (or tiny) interplay of BB and LN?**
- **A realistic machine has more LN (or imperfections) when going to the engineering stage**

β_y^*=1mm



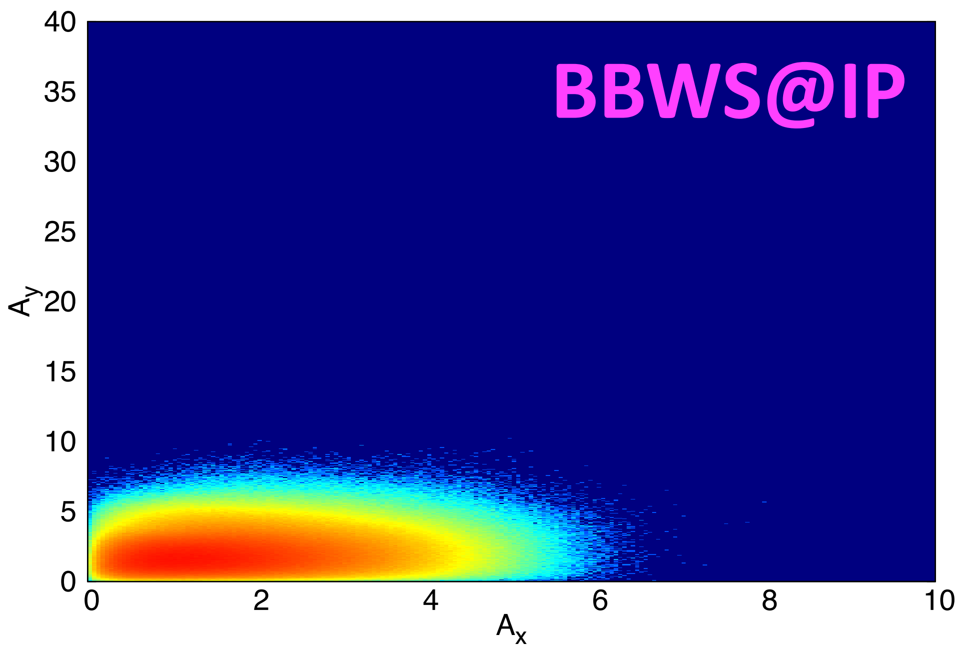
β_y^*=2mm

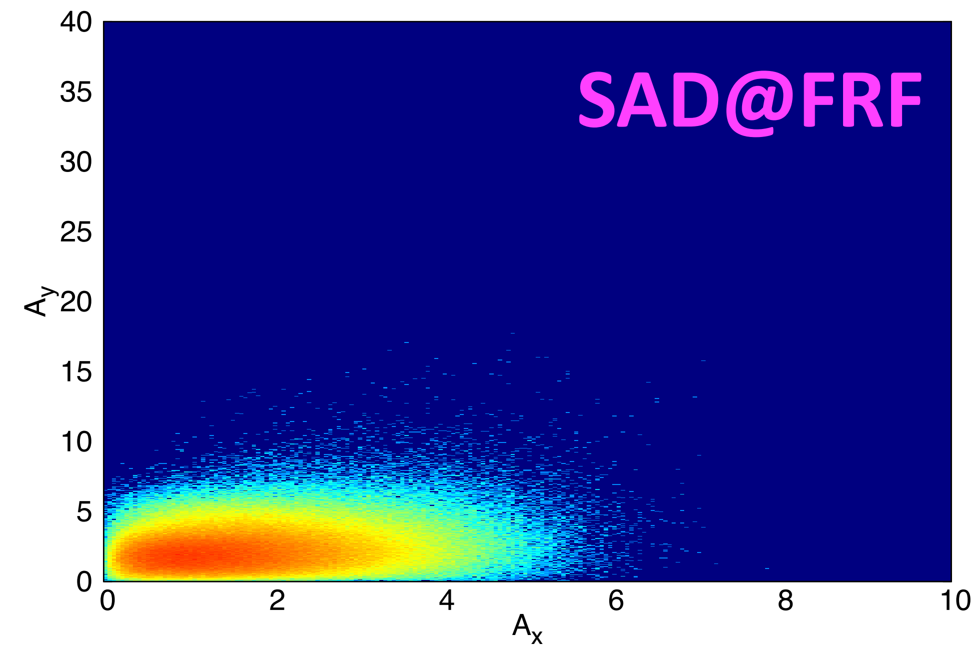


3. Interplay of BB and latt. nonlin. (cont.)

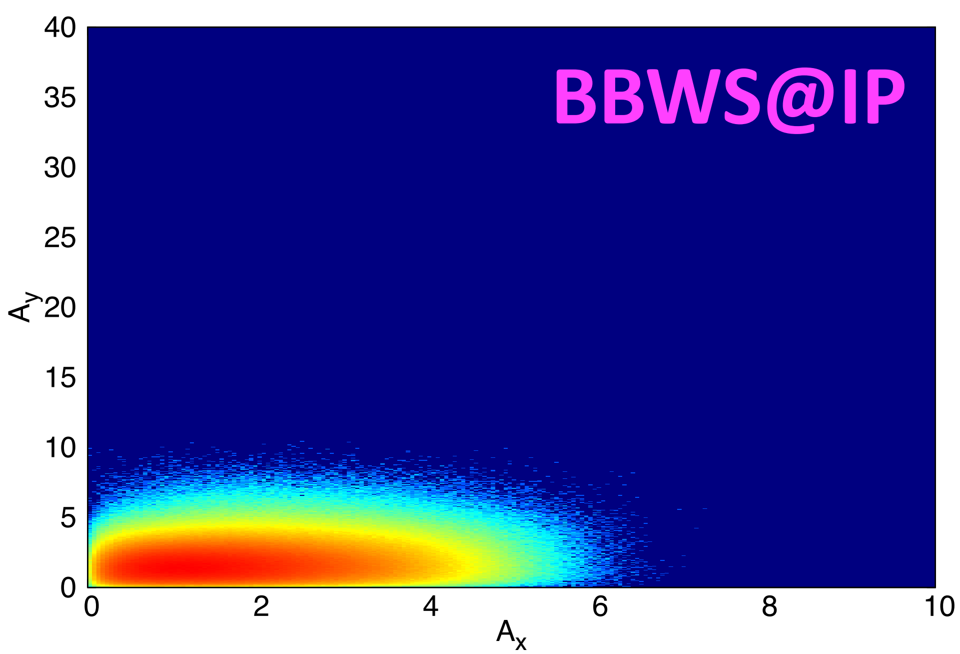
- **Beam tail (Case-2, w/ CW w/o BS):**

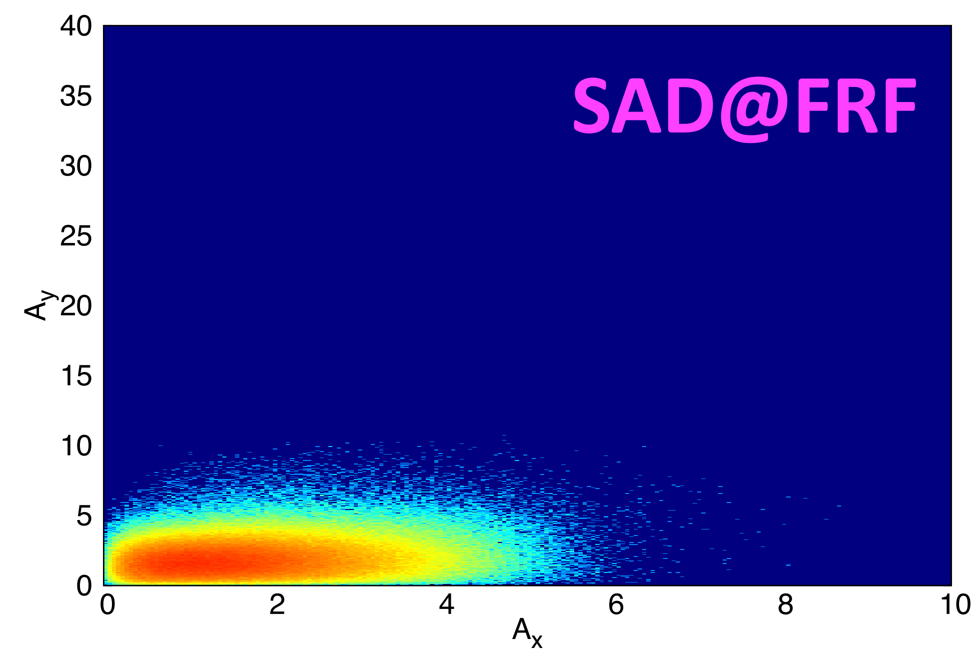
β_y^*=1mm, NP=2.6E11, ν_x/ν_y=162.52/163.57:





β_y^*=2mm, NP=2.6E11, ν_x/ν_y=162.52/163.57:





4. Summary

➤ BBWS simulations

- Optimal working point likely to be around [.51,.56]
- β_y^*=2mm gives better lum. than β_y^*=1mm
- β_y^*=1mm shows larger good lum. area in the tune space than β_y^*=2mm
- CW suppresses beam tail, and no lum. gain

➤ SAD simulations

- No significant loss of lum. or beam tail due to interplay of BB and LN
- Beam loss observed with element-by-element damping/excitation, or with high beam current (to be understood)