Weak-strong beam-beam simulations for SuperKEKB Phase-2

Demin Zhou

Acknowledgements:

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SuperKEKB beam-beam performance meeting

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Outline

- ➤ Introduction
- ➤ Tune scan using BBWS
  - Weak-strong simulations: Principle investigations, not good for predicting final lum. performance of a collider
- ➤ Tune scan with beam
- ➤ Summary

1. Introduction

➤ Observations in Phase-2

- Peak luminosity lower than predictions via simulations
- Easy blow-up in e- beam (HER)
- Small good lum. area in tune space via tune scan
- Unexpected Belle II detector background
- No (or small) gain via squeezing $\beta_{x,y}^*$

1. Introduction

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- No (or small) gain via squeezing $\beta_{x,y}^*$

➤ General remarks

- Large crossing angle: long-time investigations and experiences with realistic machines
- "Nano-beam scheme": Extremely large Piwinski angle (>= 10) with optional crab waist: popular idea (Super Tau/Charm, Super B, FCCs …) but lack of experiences with realistic machines. SuperKEKB is showing … Where we are? Where we go?

1. Introduction

Parameters can be different from operational ones because of wrong RF voltage

➤ Phase-2 machine parameters

- **Full crossing angle: θ=0.083 rad**

	200/6		200/4		100/4		100/2	
	HER	LER	HER	LER	HER	LER	HER	LER
E (GeV)	7.007	4	7.007	4	7.007	4	7.007	4
I_b (mA)	285	340	285	340	285	340	285	340
# bunch	789		789		789		789	
ε_x (nm)	4.7	2.0	4.7	2.0	4.5	1.9	4.5	1.9
ε_y (pm)	47	20	47	20	4.5	19	45	19
ε_z (μm)	3.7	4.5	3.7	4.5	3.4	3.5	3.4	3.6
β_x (mm)	200	200	200	200	100	100	100	100
β_y (mm)	6	6	4	4	4	4	2	2
σ_z (mm)	5.8	5.9	5.8	5.9	5.3	4.6	5.3	4.7
νx	45.57	44.57	45.57	44.57	45.57	44.57	45.57	44.57
νy	43.60	46.60	43.60	46.60	43.60	46.60	43.60	46.60
νs	0.0234	0.0176	0.0234	0.0176	0.0258	0.0223	0.0258	0.0225

1. Introduction

➤ Geometric lum. formula

- **Large Piwinski angle** $\phi \gg 1$
- **Negligible hourglass effect in overlap region**
- **Flat beam**

$$L_0 = \frac{N_+ N_- f_0 N_b}{2\pi\sqrt{\sigma_{x+}^2 + \sigma_{x-}^2}\sqrt{\sigma_{y+}^2 + \sigma_{y-}^2}}$$

$$L = L_0 R_{H\theta}$$

$$R_{H\theta} \approx \frac{1}{\sqrt{1 + \frac{\sigma_{z+}^2 + \sigma_{z-}^2}{\sigma_{x+}^2 + \sigma_{x-}^2}\tan^2\frac{\theta}{2}}} \approx \frac{1}{\phi}$$

$$\phi = \sqrt{\frac{\sigma_{z+}^2 + \sigma_{z-}^2}{\sigma_{x+}^2 + \sigma_{x-}^2}}\tan\frac{\theta}{2}$$

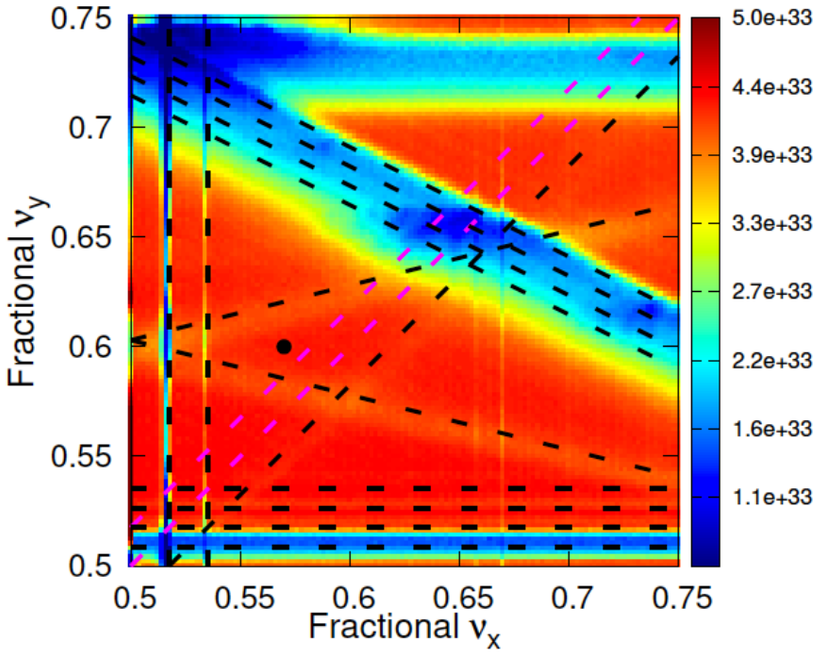
Generalized Piwinski angle

2. BBWS simulation

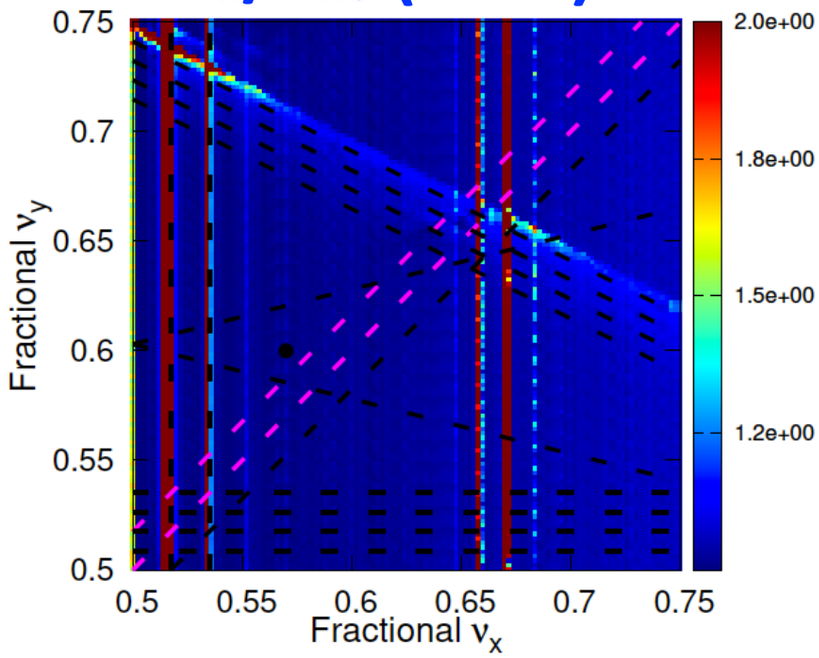
➤ Optics: HER 200/4 mm and LER 200/4 mm

- **Weak beam: LER:**

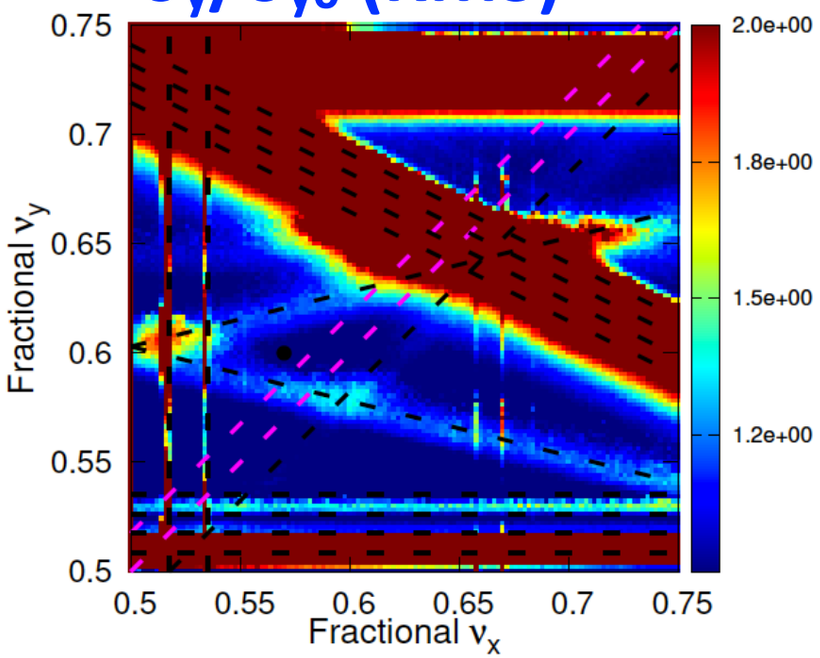
Luminosity



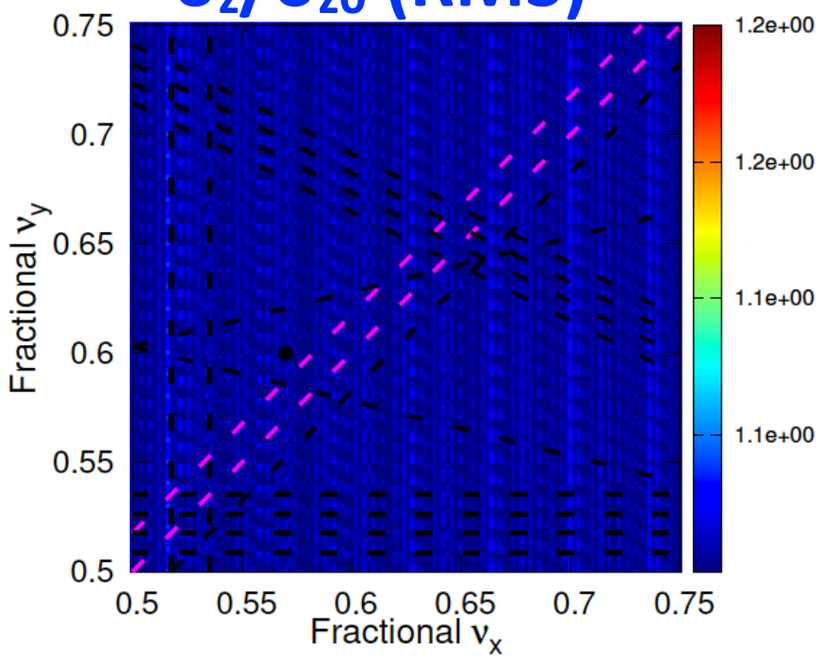
σ_x/σ_{x0} (RMS)



σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)



2. BBWS simulation

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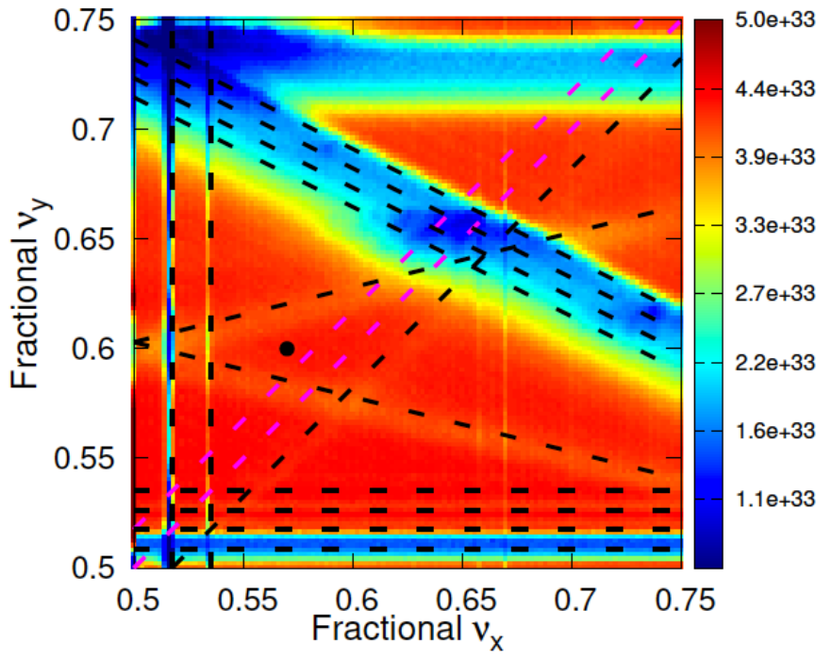
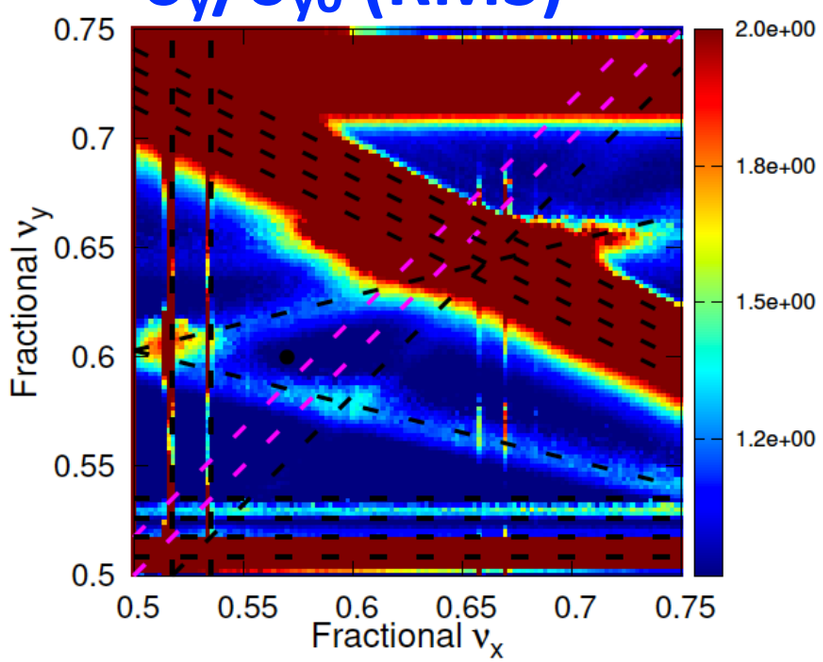
Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=4.2\times10^{33}cm^{-2}s^{-1}$

Beam-beam resonances:

$$\nu_x - k\nu_s = N, \quad k = 1, 2$$

$$2\nu_y - j\nu_s = N, \quad j = 1, 2, 3, 4$$

$$\nu_x + 2\nu_y + k\nu_s = N, \quad k = 1, 2, 3, 4$$

$$\pm\nu_x + 4\nu_y + k\nu_s = N$$

Lattice resonances:

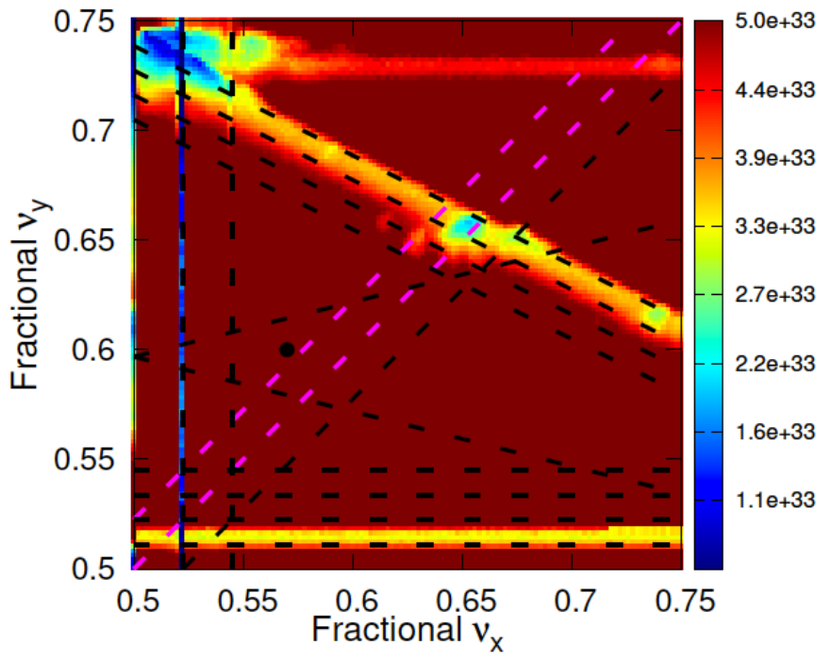
$$\nu_x - \nu_y + k\nu_s = N, \quad k = -1, 0, 1$$

2. BBWS simulation

➤ **Optics: HER 100/2 mm and LER 100/2 mm**

- **Weak beam: LER:**

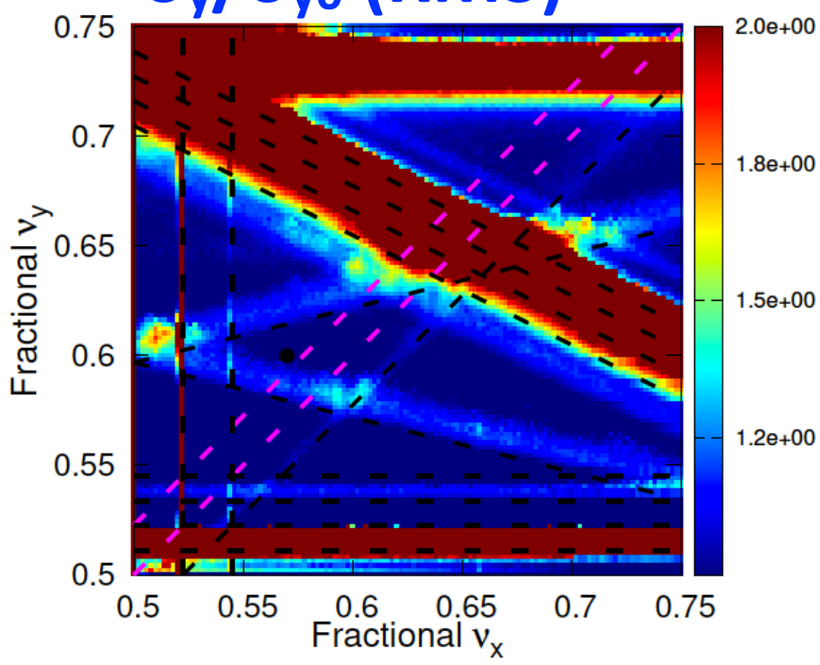
Luminosity



Geometric luminosity:

$L=7.1\times10^{33}cm^{-2}s^{-1}$

σ_y/σ_{y0} (RMS)



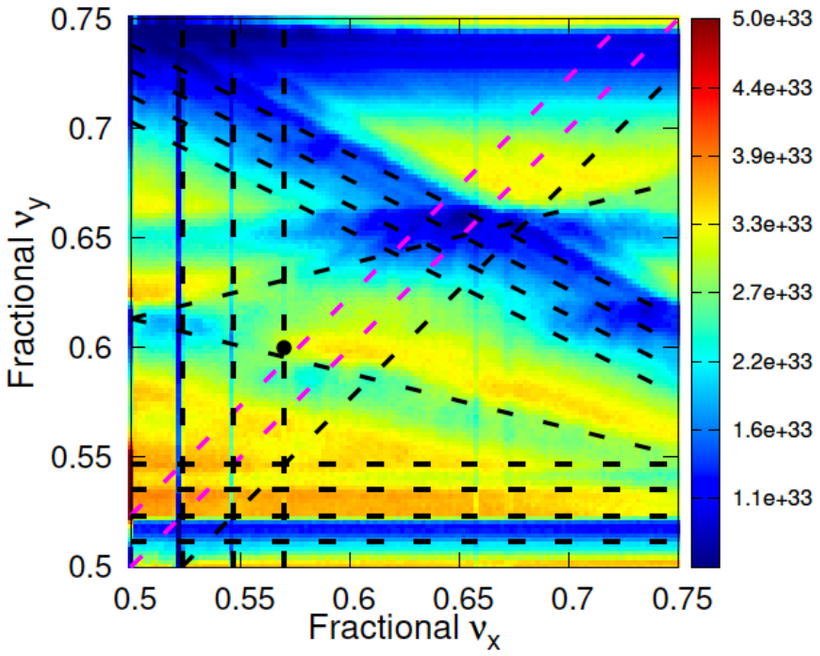
Good lum. region fairly large around (.57, .60)

2. BBWS simulation

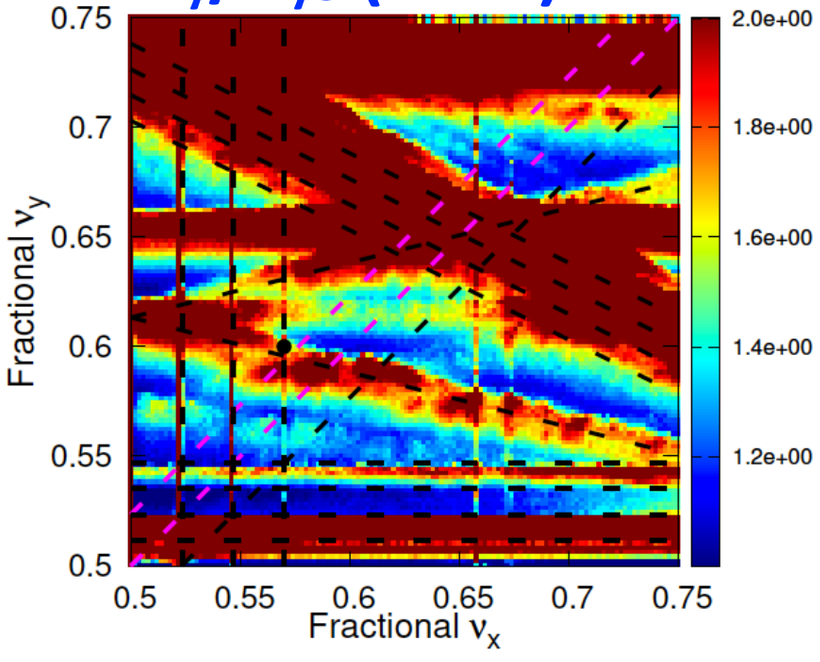
➤ Optics: HER 200/6 mm and LER 200/6 mm

- **Weak beam: HER:**

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=3.5\times10^{33}cm^{-2}s^{-1}$

Strong high-order beam-beam resonances:

$$\pm\nu_x + 4\nu_y + k\nu_s = N$$

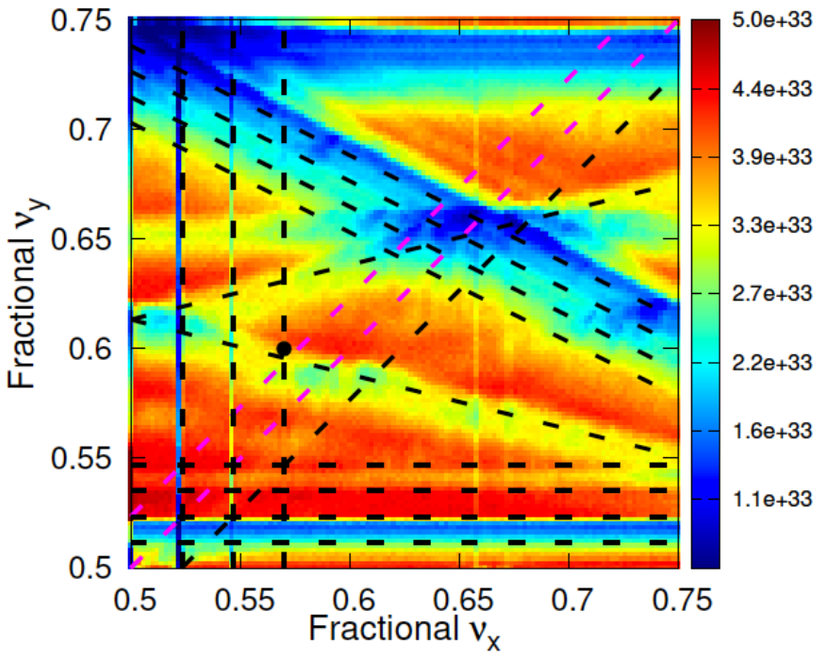
=> Small good lum. region around working point (.57,.60)

2. BBWS simulation

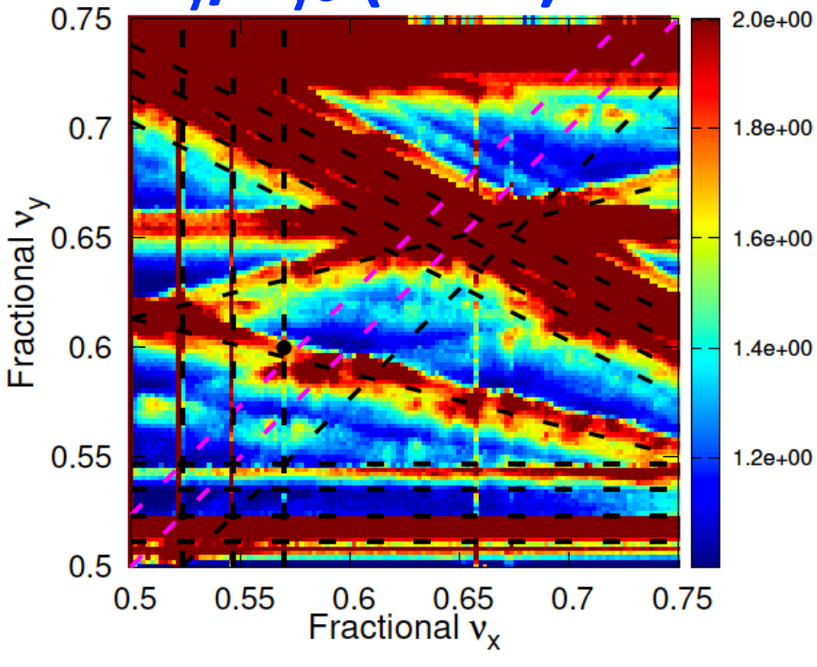
➤ Optics: HER 200/4 mm and LER 200/4 mm

- **Weak beam: HER: plots with normalization**

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=4.2\times10^{33}cm^{-2}s^{-1}$

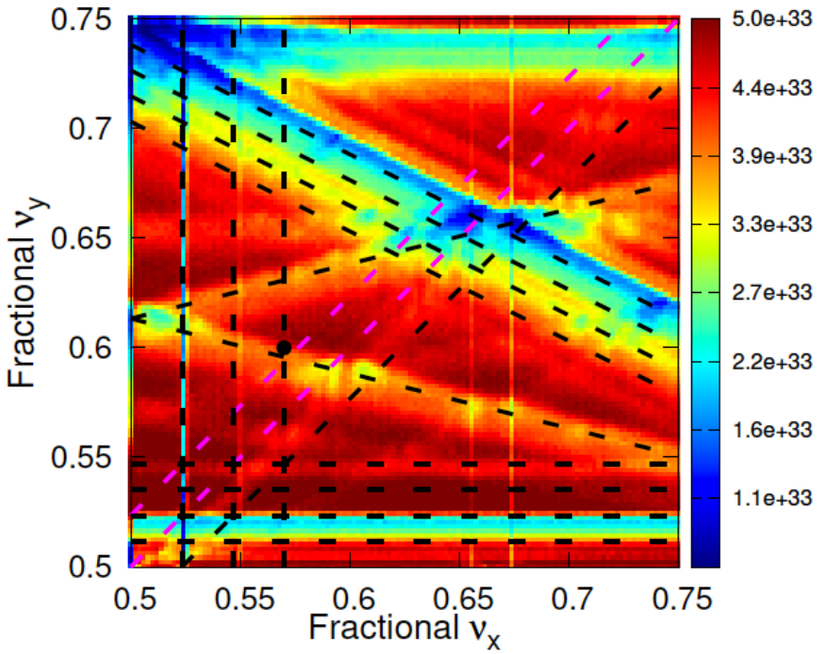
Beam-beam resonances relaxed?

2. BBWS simulation

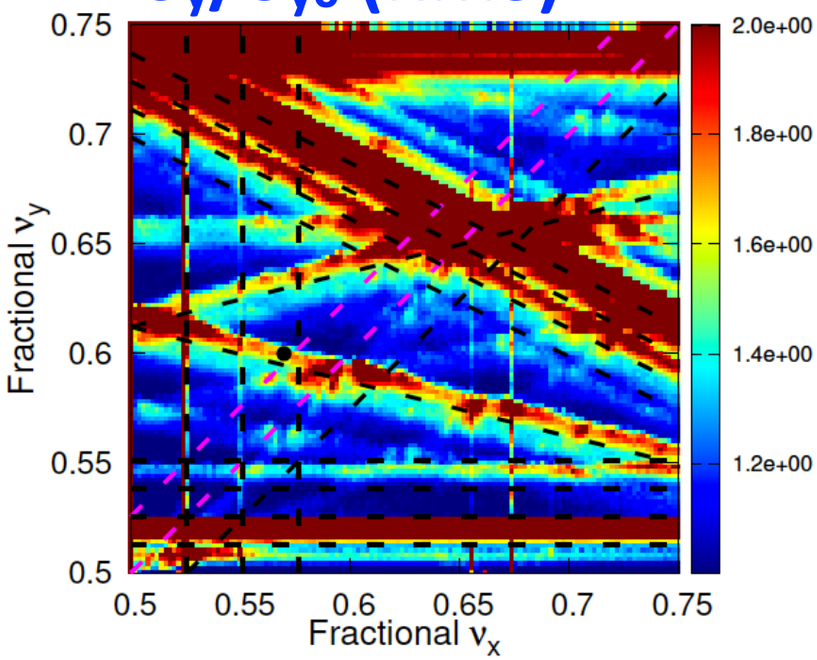
➤ Optics: HER 200/3 mm and LER 200/4 mm

- **Weak beam: HER: plots with normalization**

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=4.8\times10^{33}cm^{-2}s^{-1}$

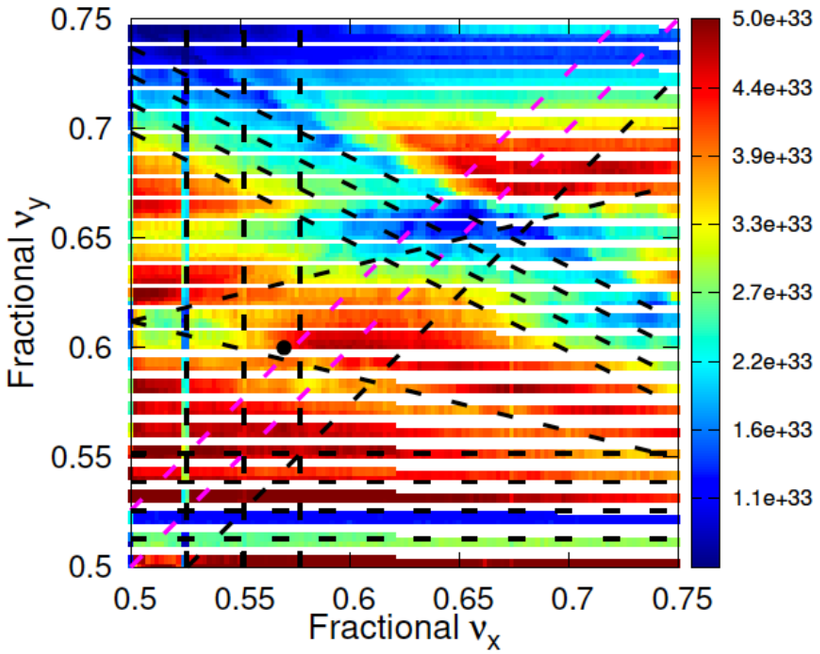
Beam-beam resonances relaxed?

2. BBWS simulation

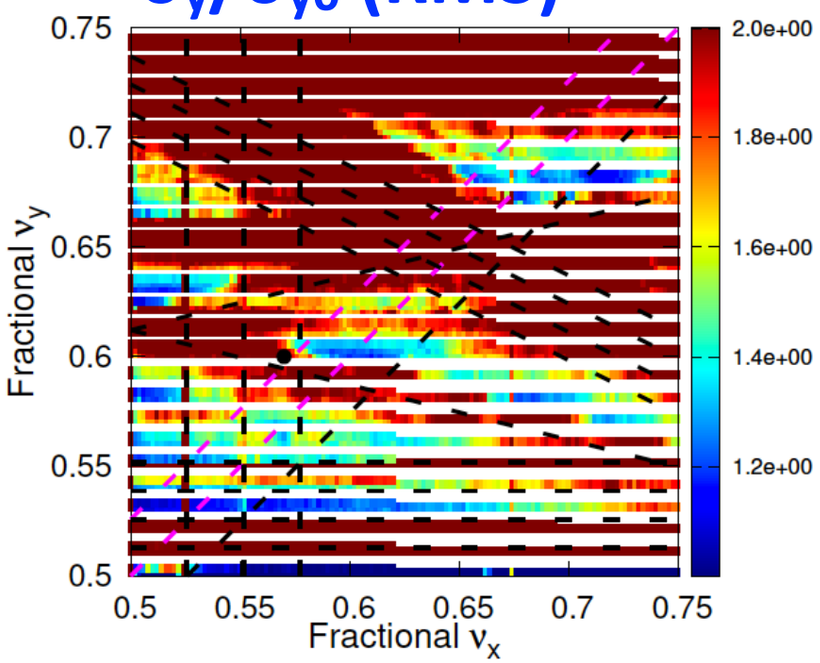
➤ Optics: HER 100/4 mm and LER 100/4 mm

- **Weak beam: HER: plots with normalization**

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=5.1\times10^{33}cm^{-2}s^{-1}$

Simulations not finishes…

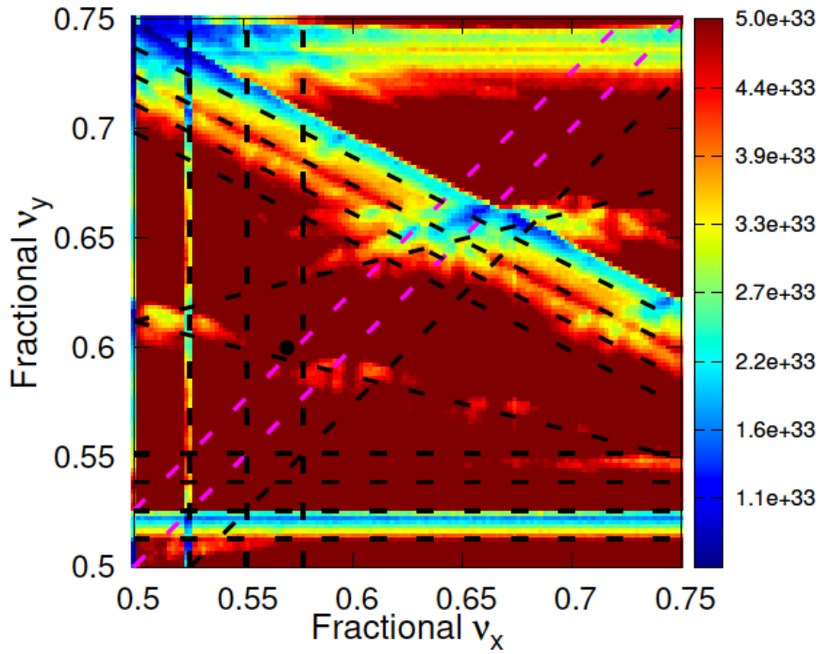
But beam-beam resonances NOT relaxed?

2. BBWS simulation

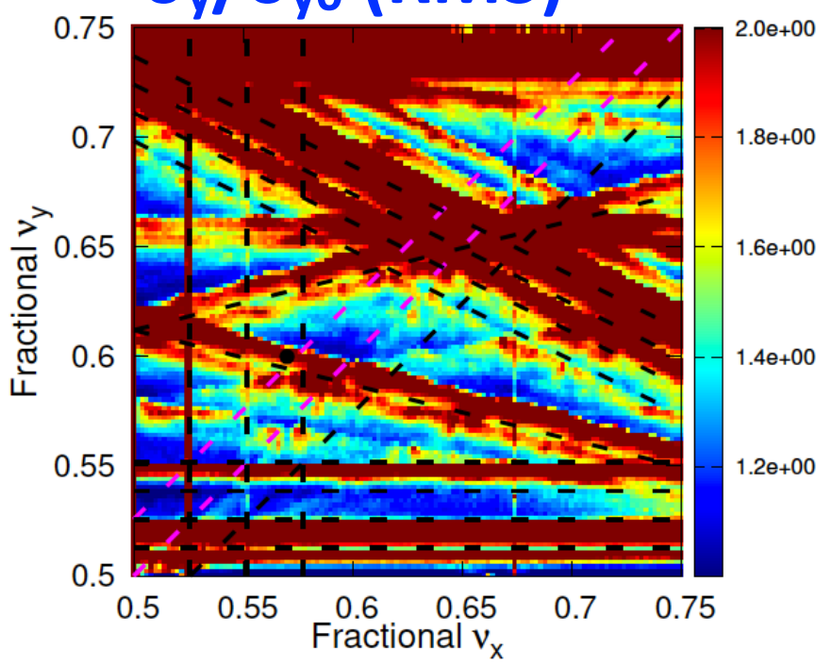
➤ Optics: HER 100/2 mm and LER 100/2 mm

- **Weak beam: HER: plots with normalization**

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:

$L=7.1\times10^{33}cm^{-2}s^{-1}$

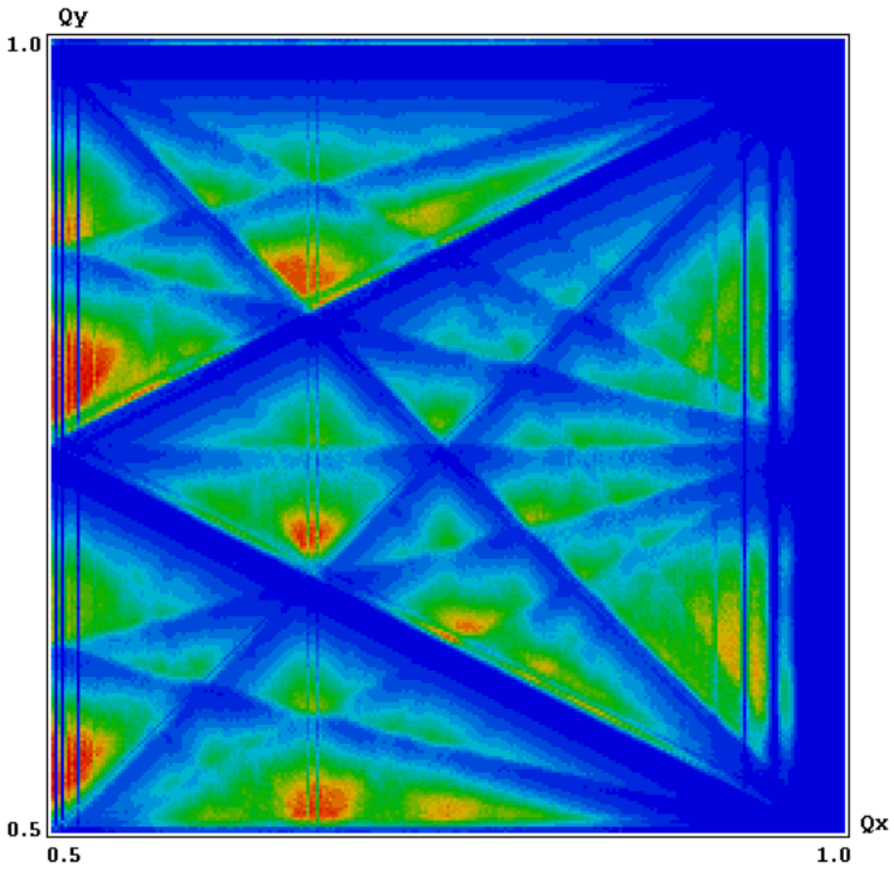
Surprisingly beam-beam resonances not further relaxed…

=> Need further studies.

2. BBWS simulation

➤ Compare with Lifetrac by D. Shatilov (Talk at IHEP, Apr. 11, 2014)

- **w/o crab waist**



$\beta_y = \sigma_z / \phi$

This plot approximately corresponds to the scheme currently adopted for SuperKEKB

Beam-beam resonance also predicted by Lifetrac, similar to BBWS!

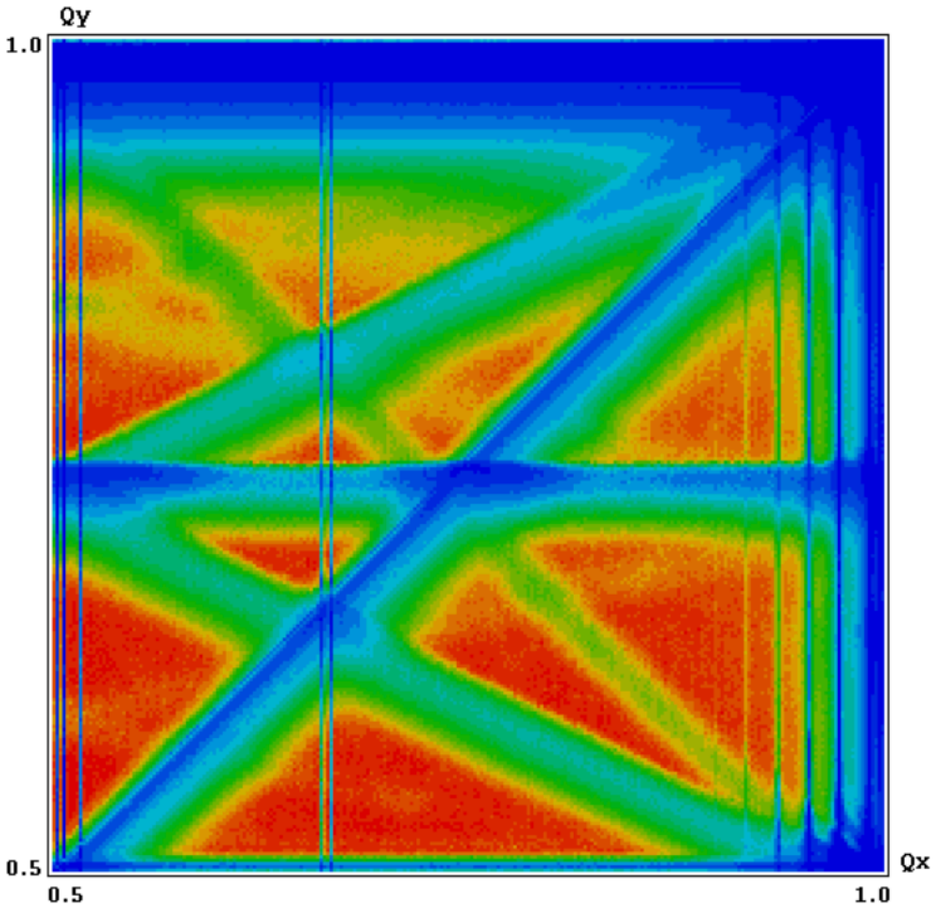
Thanks to Y. Zhang for sending the slides

2. BBWS simulation

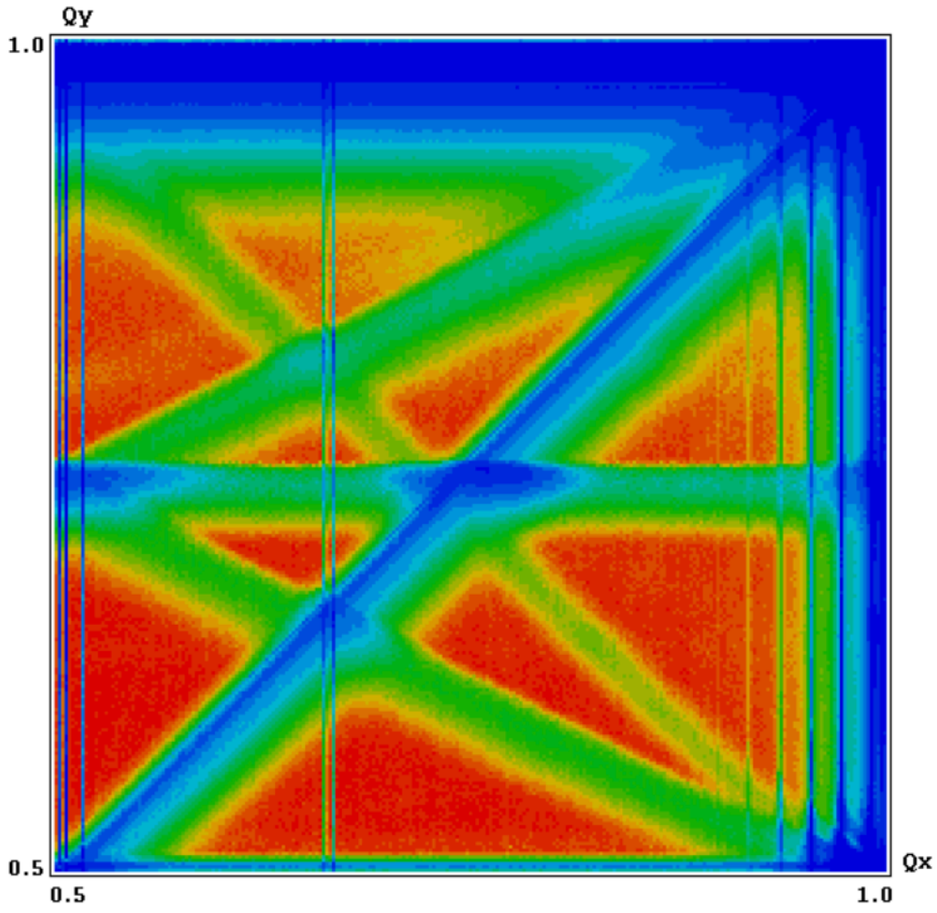
➤ **Compare with Lifetrac by D. Shatilov (Talk at IHEP, Apr. 11, 2014)**

- **w/o crab waist**

Crab waist is powerful…
Mission impossible?



Strong beam is not crabbed



Both beams are crabbed

Thanks to Y. Zhang for sending the slides

2. BBWS simulation

➤ Prediction of luminosity by BBWS

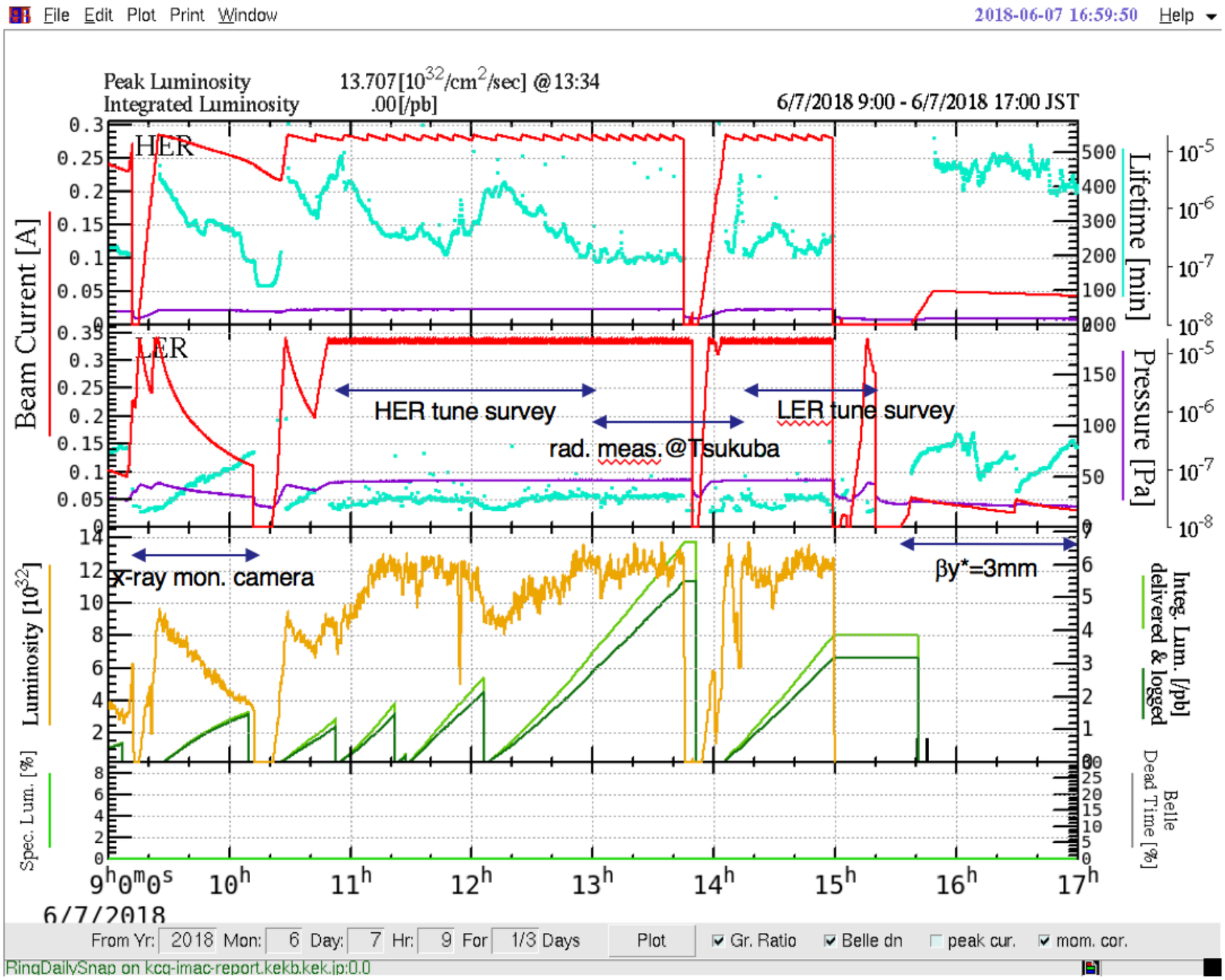
- Working point: (.57, .60)
- Strong-strong simulation undergoing (K. Hirosawa)

HER		LER		Geometric Lum.	Lum. by BBWS
β_x^*	β_y^*	β_x^*	β_y^*		
200	6	200	6	3.48	2.93
200	4	200	4	4.23	3.56
200	3	200	4	4.84	4.26
100	4	100	4	5.08	4.09
100	2	100	2	7.15	5.58

3. Tune scan with beam

➤ 200/4 mm optics (both HER and LER)

- **2018.06.07 Day shift (2018_06_07_09_oki_fukuma.pptx)**

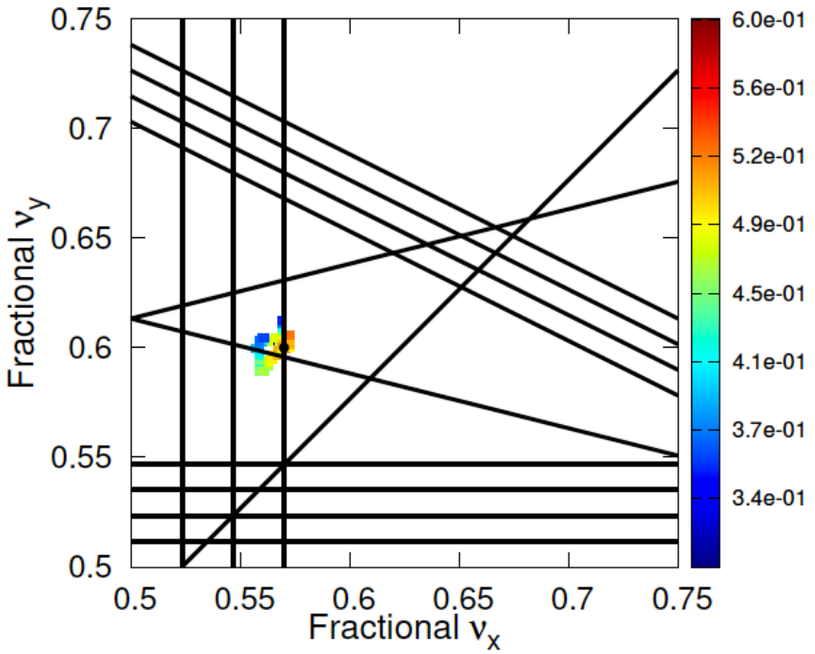


3. Tune scan with beam

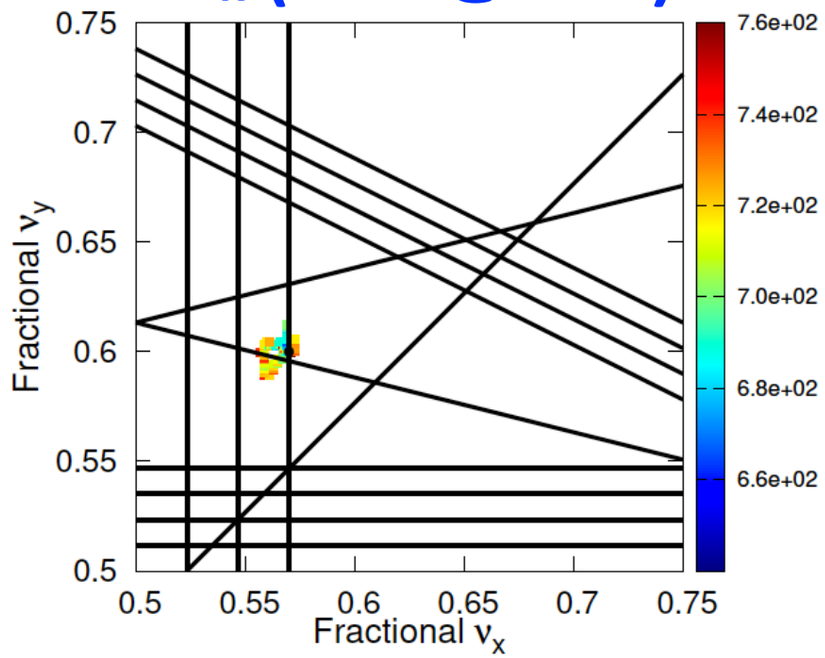
➤ 200/4 mm optics (both HER and LER)

- **2018.06.07: HER tune survey**

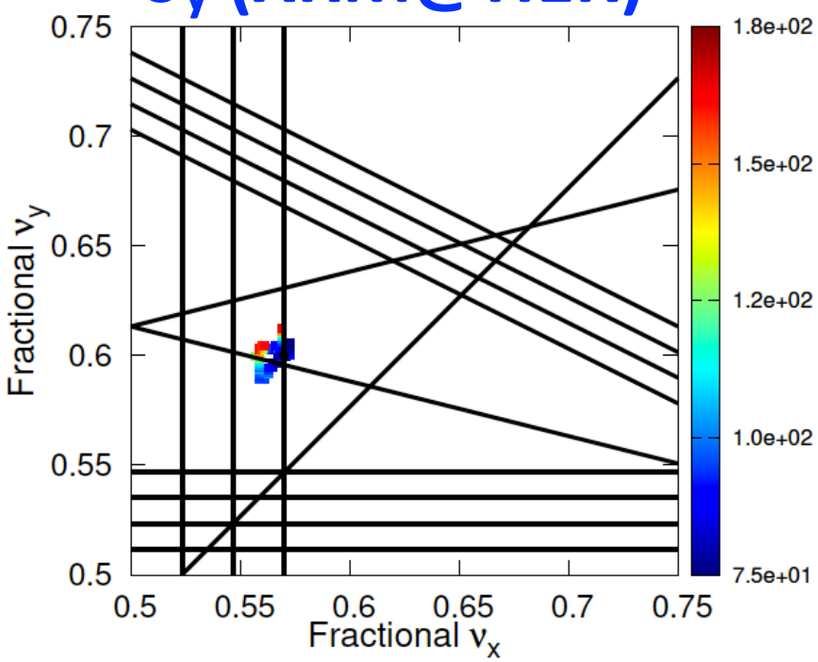
Luminosity (PV value)



σ_x (SRM@HER)



σ_y (XRM@HER)



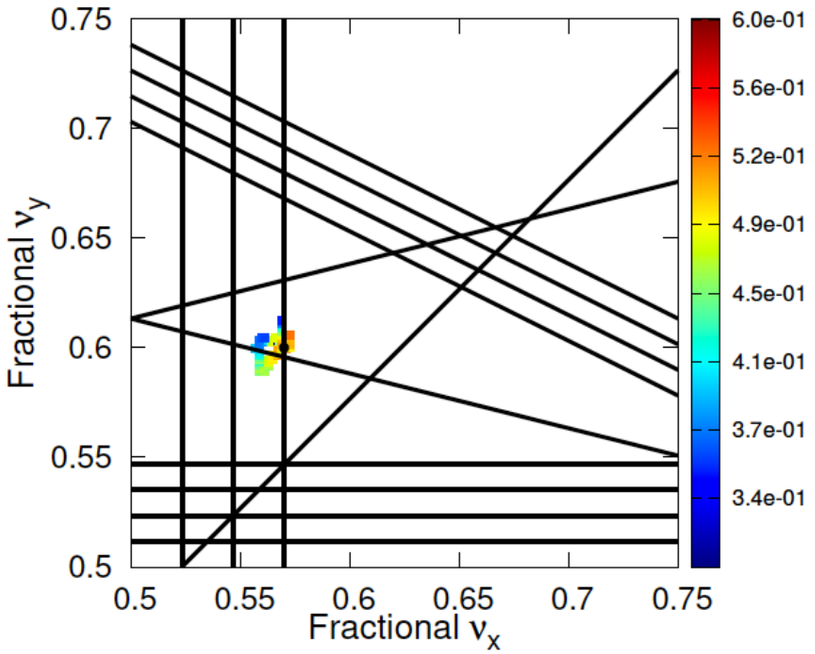
Luminosity is sensitive to vertical beam sizes

3. Tune scan with beam

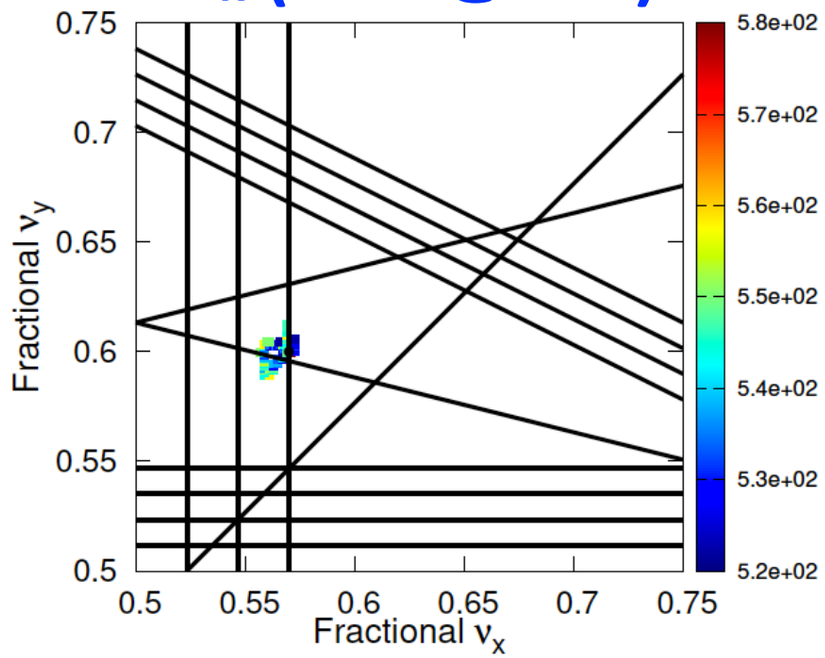
➤ 200/4 mm optics (both HER and LER)

- **2018.06.07: HER tune survey**

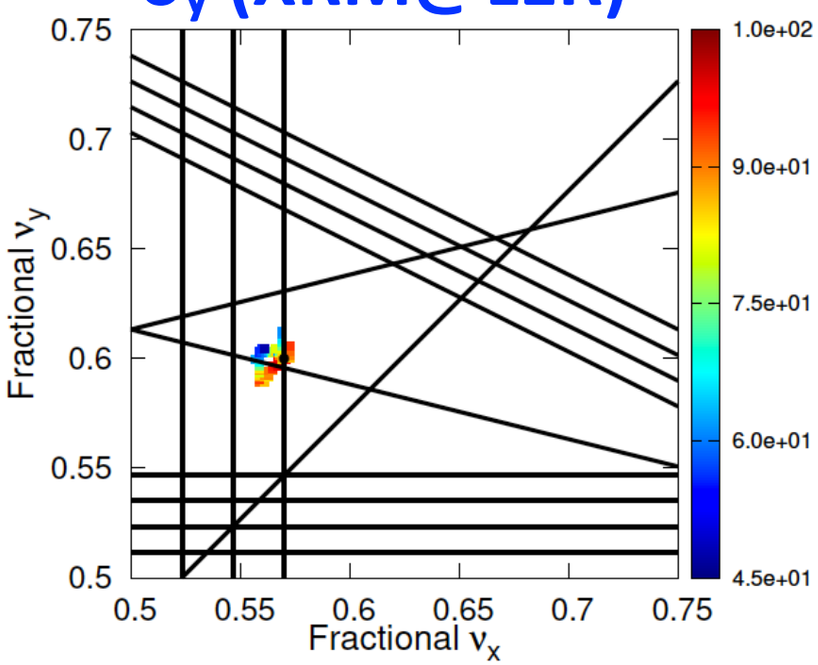
Luminosity (PV value)



σ_x (SRM@LER)



σ_y (XRM@LER)



When σ_y@HER shrinks, σ_y@LER blow up (by factor of ~2)!

4. Summary

➤ **In the present parameter regime for SuperKEKB**

- **Beam-beam effects are unexpectedly strong**
- **Various beam-beam resonances observed in tune scan via BBWS**
- **Near the (.57,.60) working point (current Phase-2 commissioning), the beam-beam resonance $\nu_x+4\nu_y+k*\nu_s=N$**

➤ **Tune scan with beam**

- **The two beams (e+ and e-) need to be balanced (bunch current, beam sizes, beta*, etc.)**
- **How to balance: B-B simulations in parallel to beam tuning**

➤ **Future tuning strategy**

- **Strong-strong simulation (Ohmi-san and Hirosawa-san)**
- **Optimizations of key parameters: (I_{bunch}, $\beta_{x,y}^*$, ν_x, ν_y) for HER and LER => More beam-beam simulations**
- **Optimizations of linear and nonlinear optics via optics measurements/corrections => Suppress lattice nonlinearity**
- **Crab waist (?)**

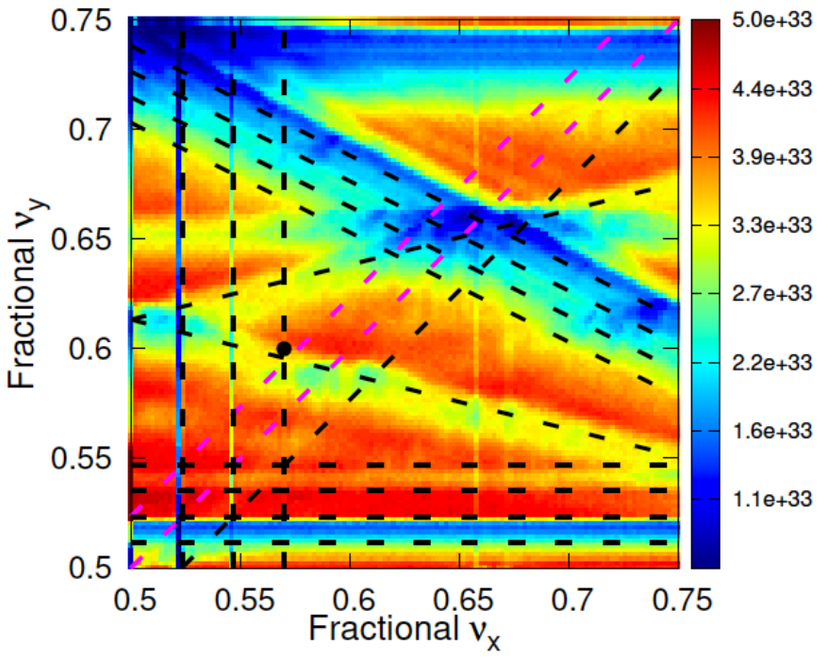
Backup

1. BBWS simulation

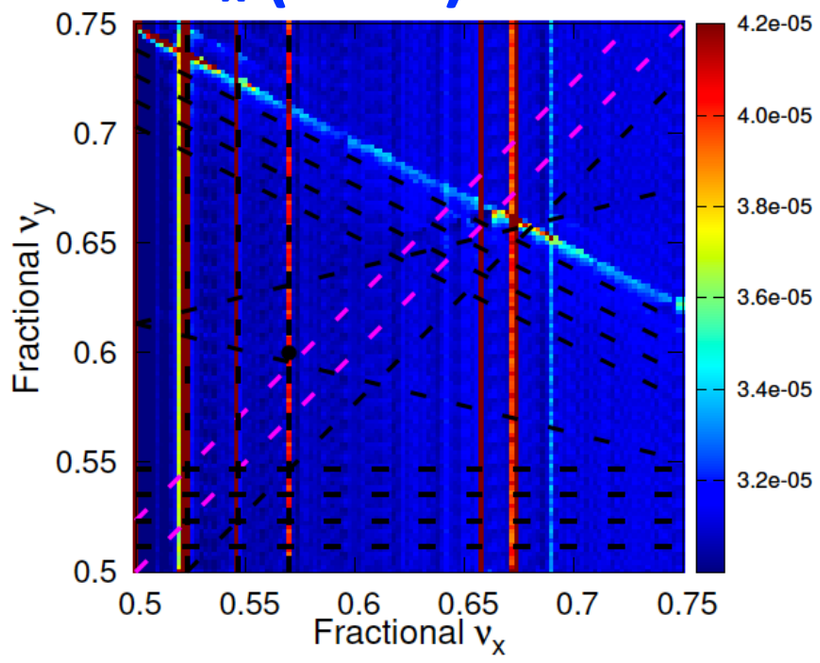
➤ Optics: HER 200/4 mm and LER 200/4 mm

- **Weak beam: HER:**

Luminosity

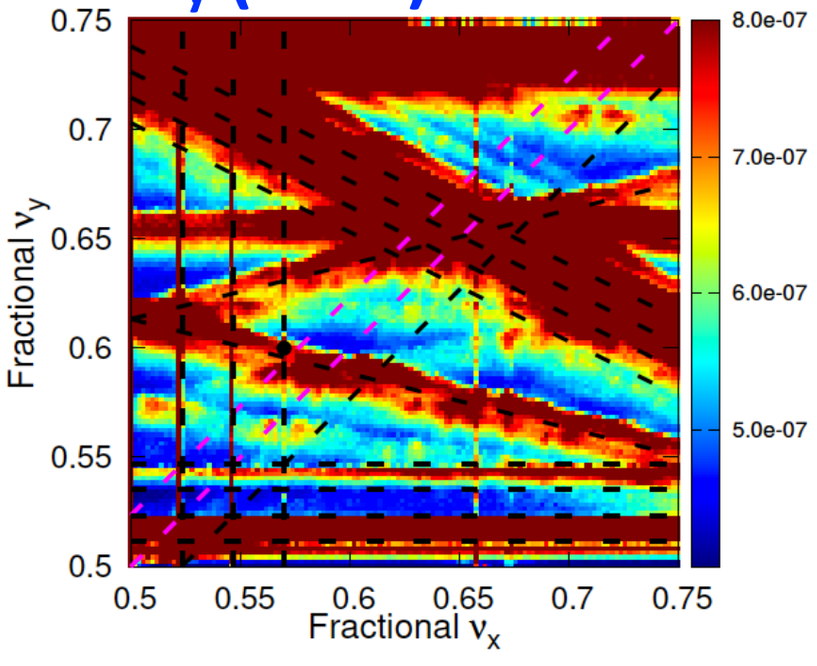


σ_x (RMS)

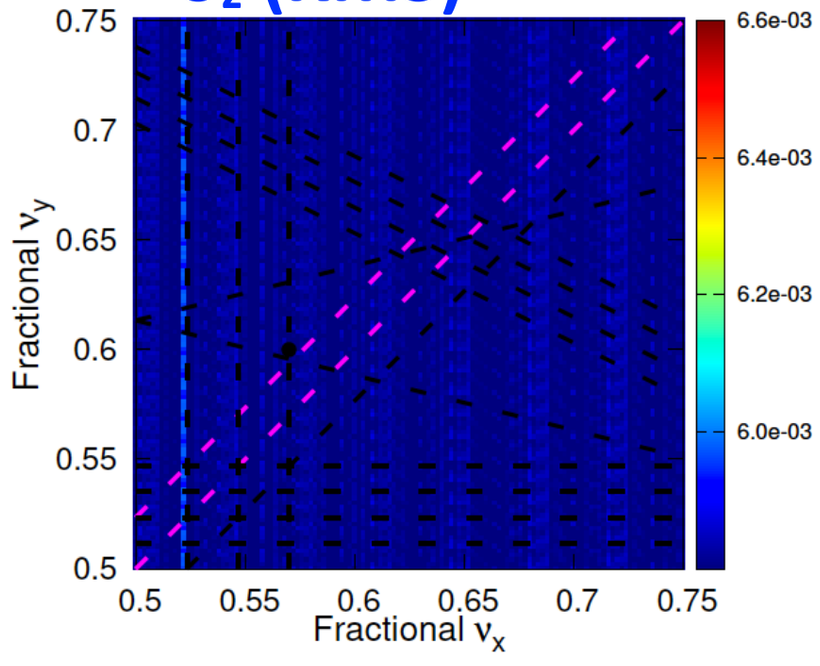


Beam-beam resonances also plotted

σ_y (RMS)



σ_z (RMS)

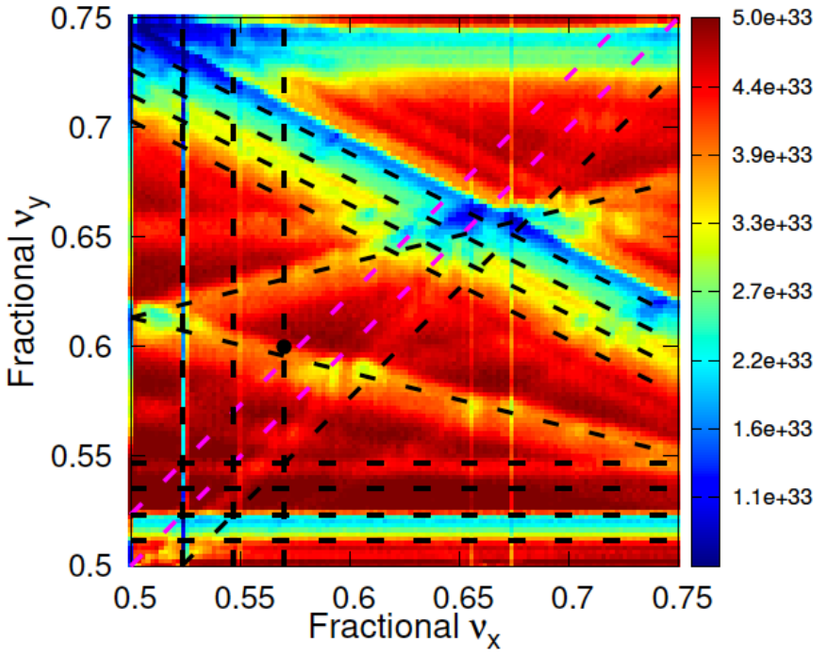


1. BBWS simulation

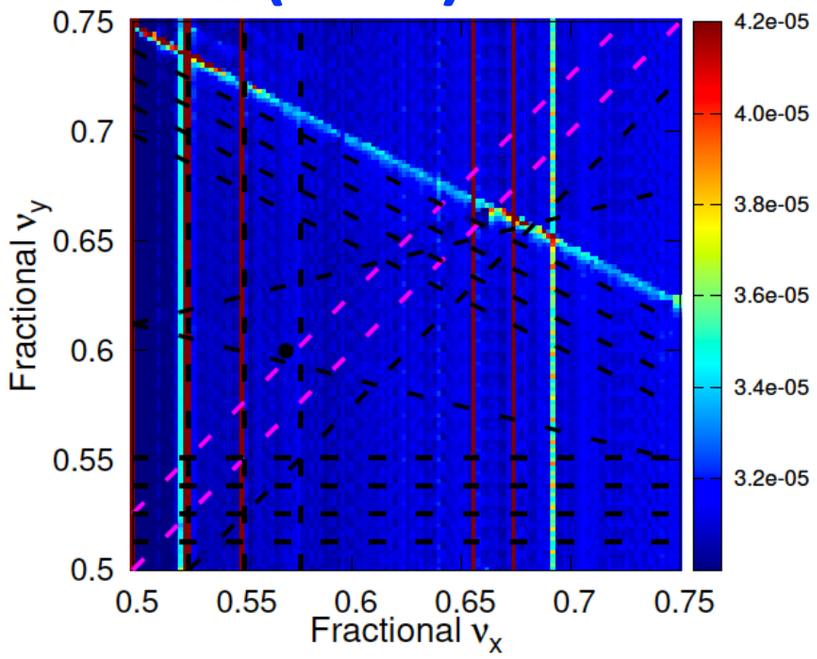
➤ **Optics: HER 200/3 mm and LER 200/4 mm**

- **Weak beam: HER:**

Luminosity

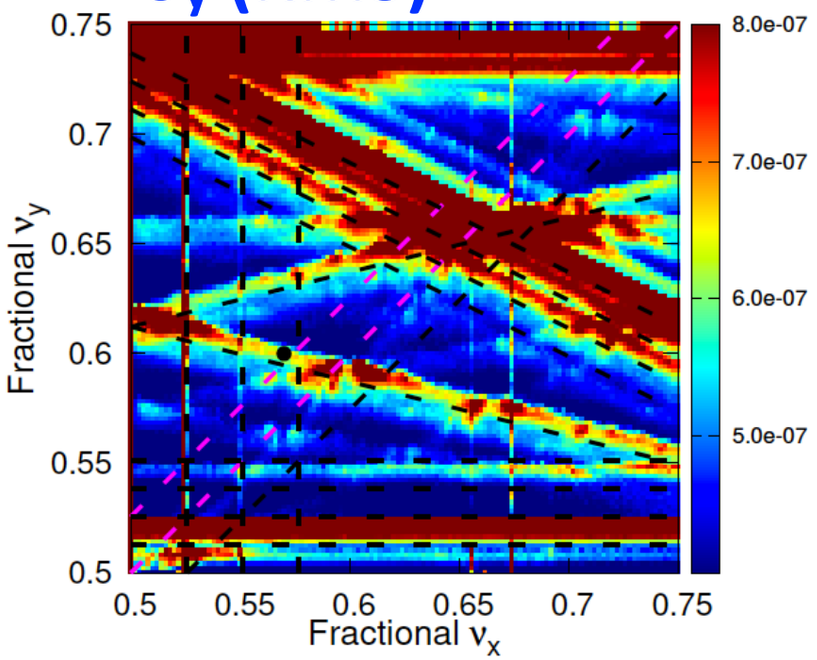


σ_x (RMS)

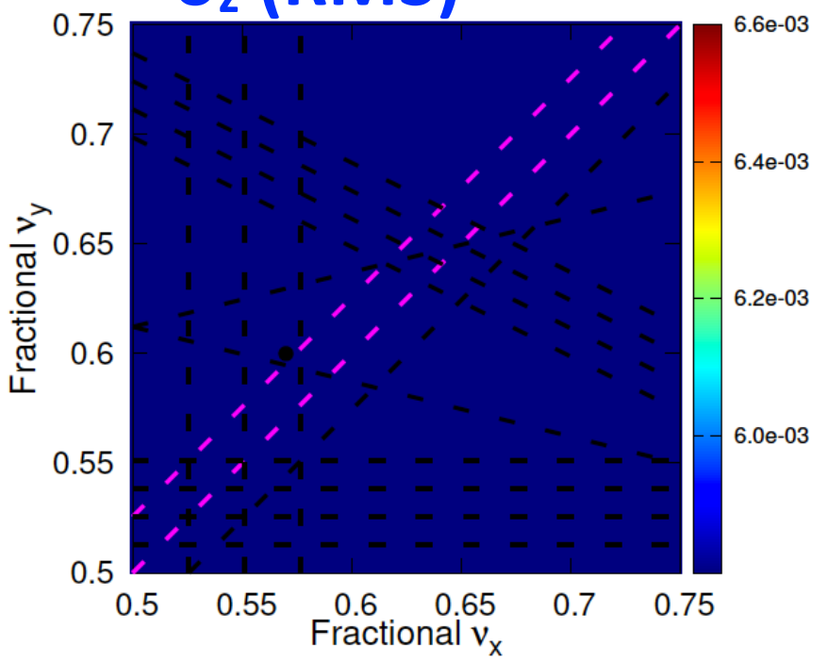


Beam-beam resonances also plotted

σ_y (RMS)



σ_z (RMS)

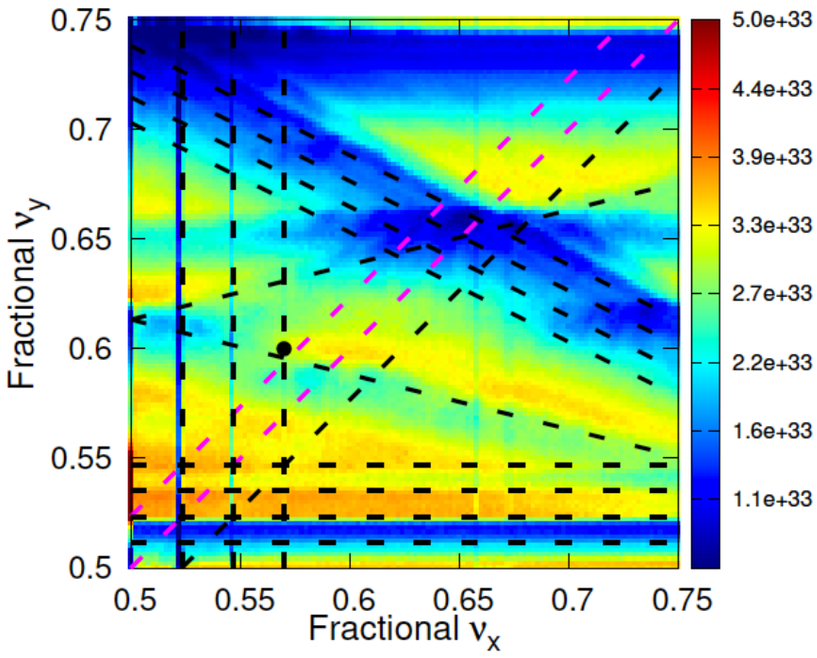


1. BBWS simulation

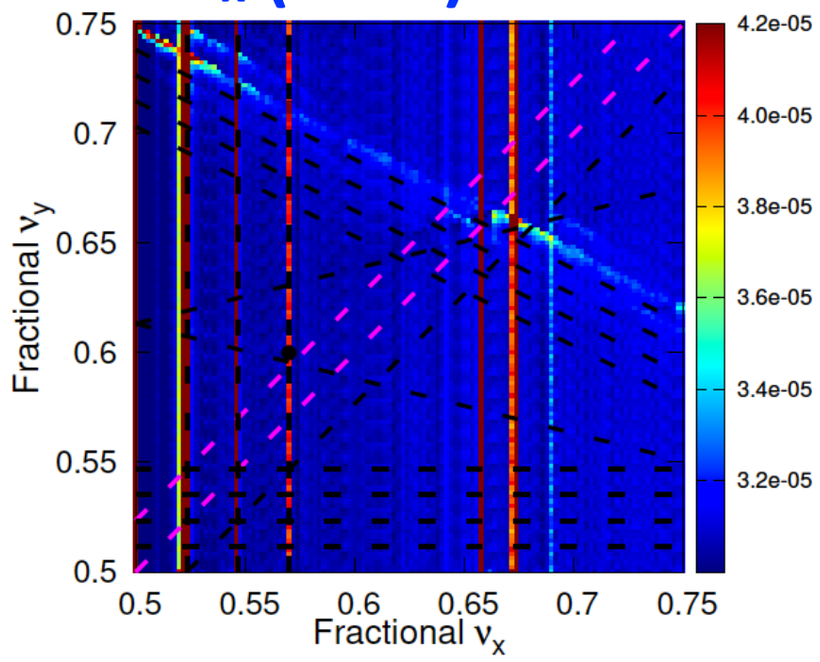
➤ **Optics: HER 200/6 mm and LER 200/6 mm**

- **Weak beam: HER:**

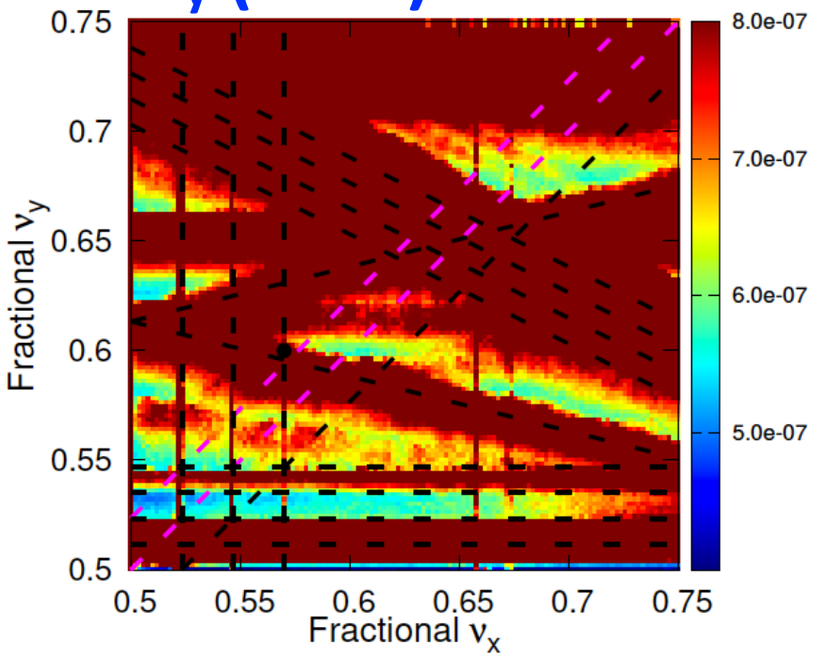
Luminosity



σ_x (RMS)

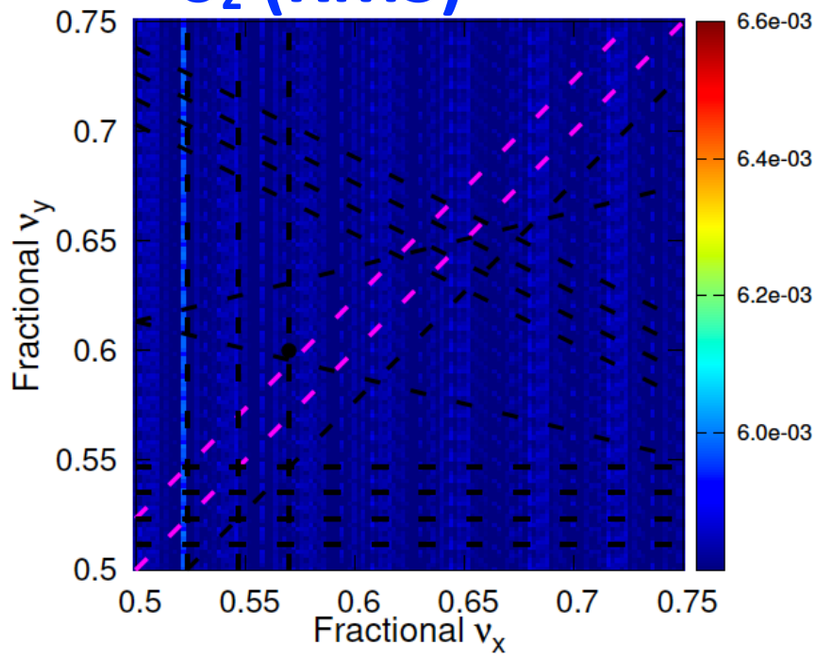


σ_y (RMS)



Beam-beam resonances also plotted

σ_z (RMS)

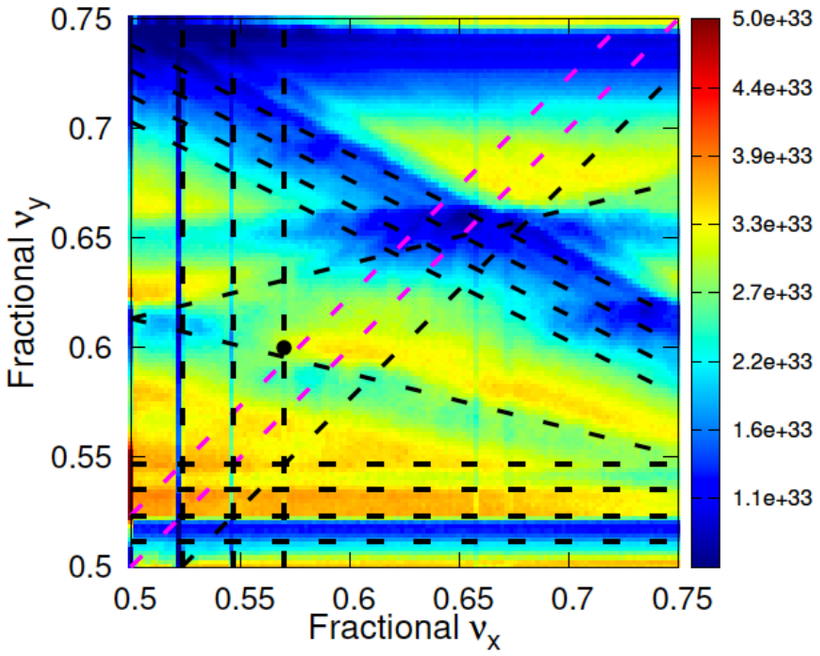


2. BBWS simulation

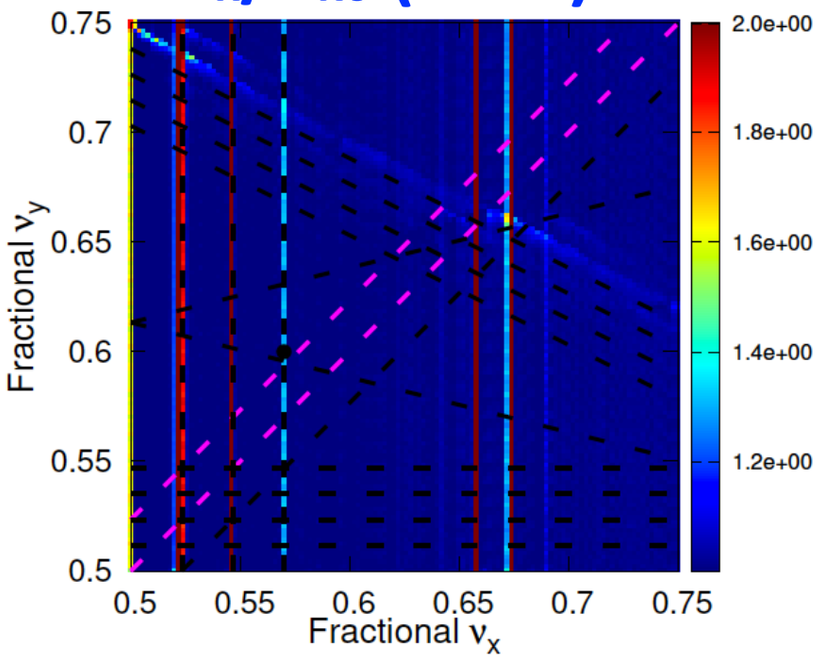
➤ Optics: HER 200/6 mm and LER 200/6 mm

- **Weak beam: HER: plots with normalization**

Luminosity

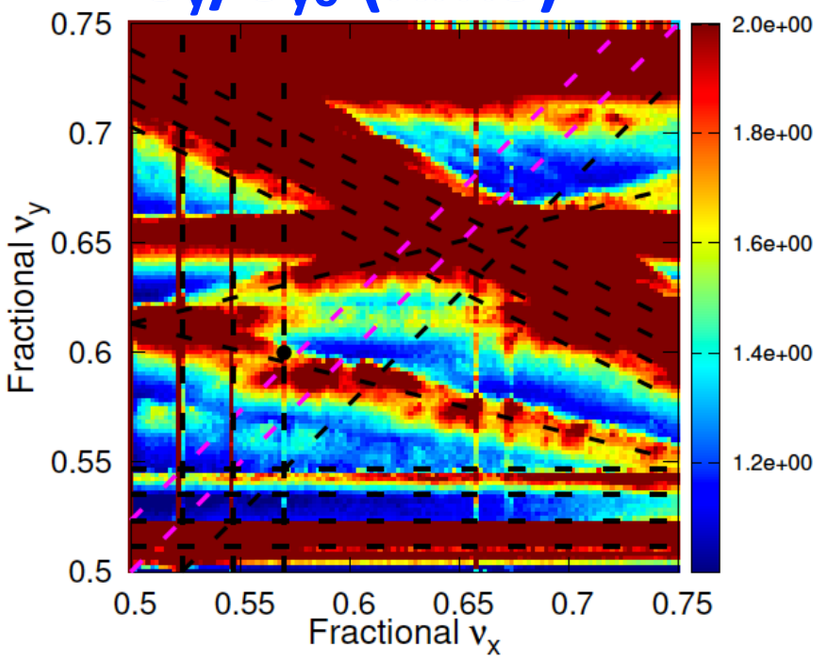


σ_x/σ_{x0} (RMS)

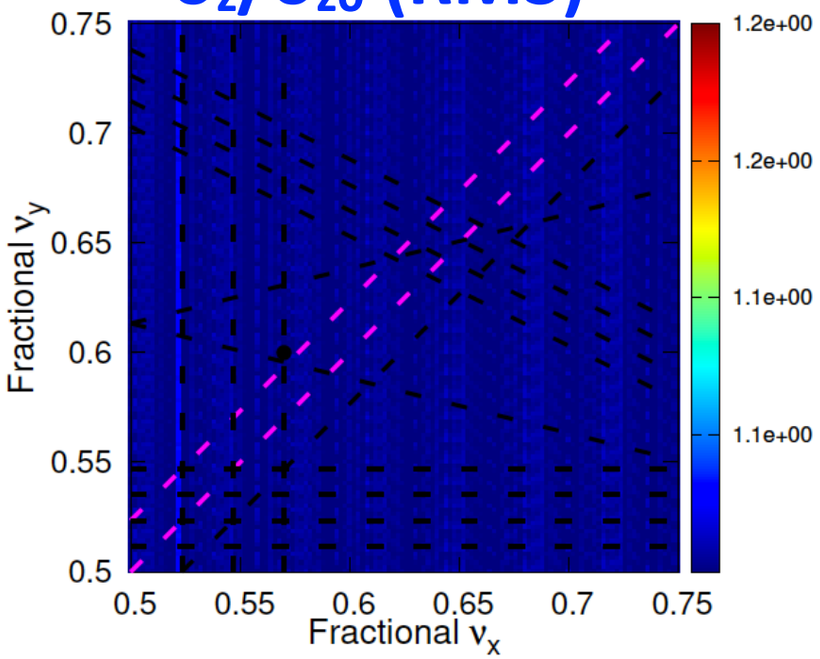


Beam-beam resonances also plotted

σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)

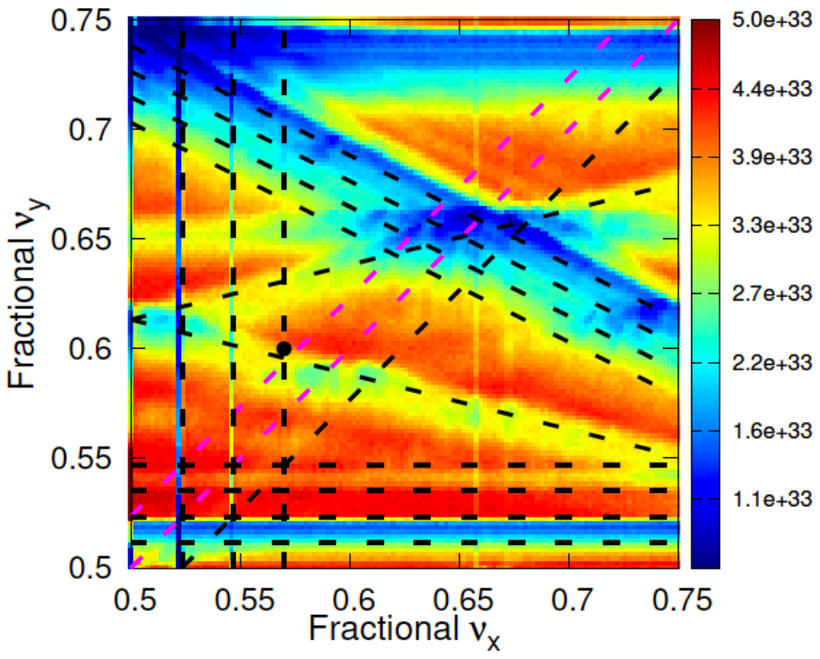


2. BBWS simulation

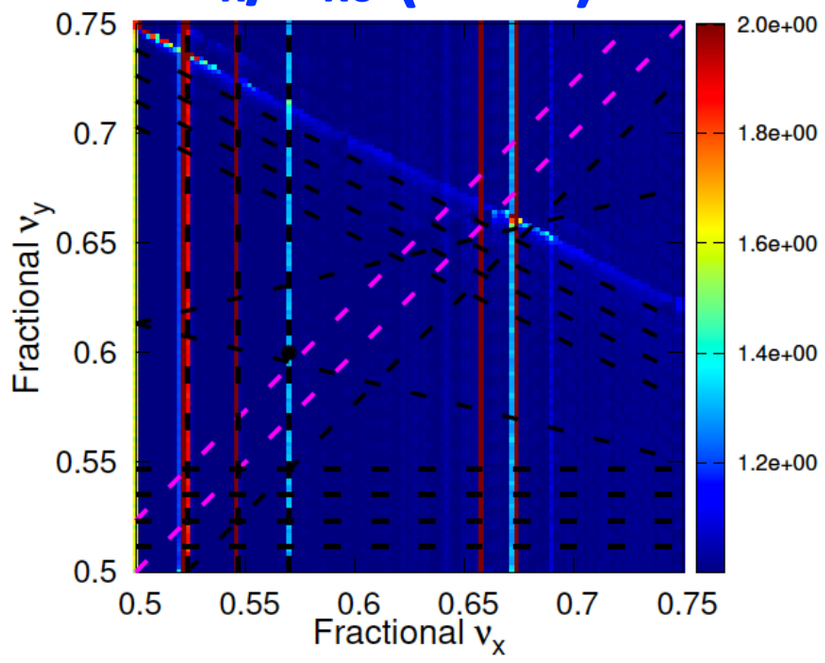
➤ Optics: HER 200/4 mm and LER 200/4 mm

- **Weak beam: HER: plots with normalization**

Luminosity

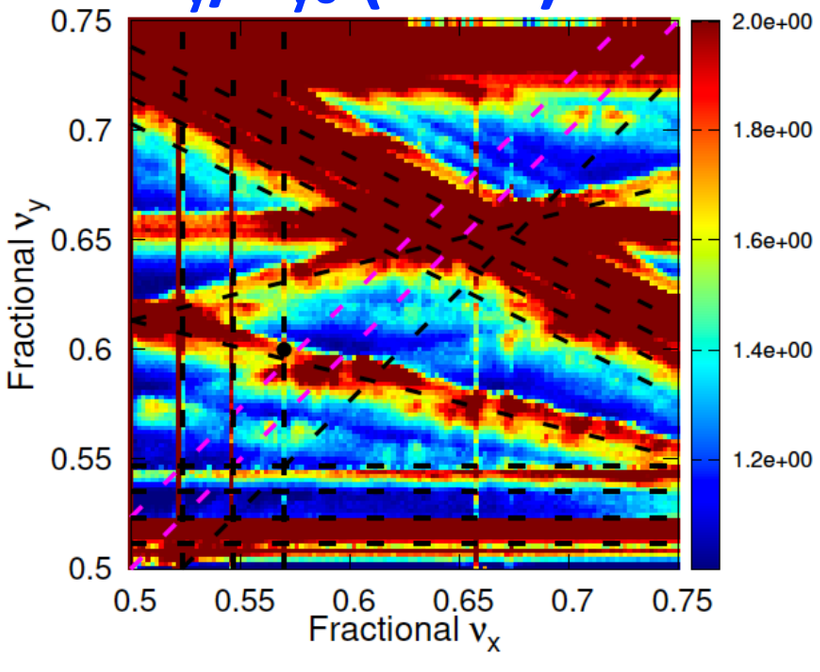


σ_x/σ_{x0} (RMS)

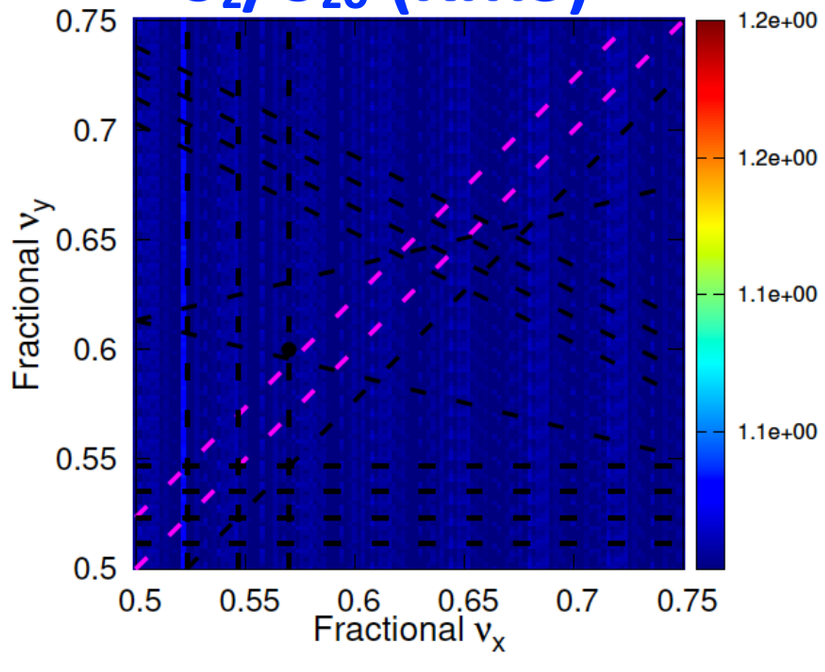


Beam-beam resonances also plotted

σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)

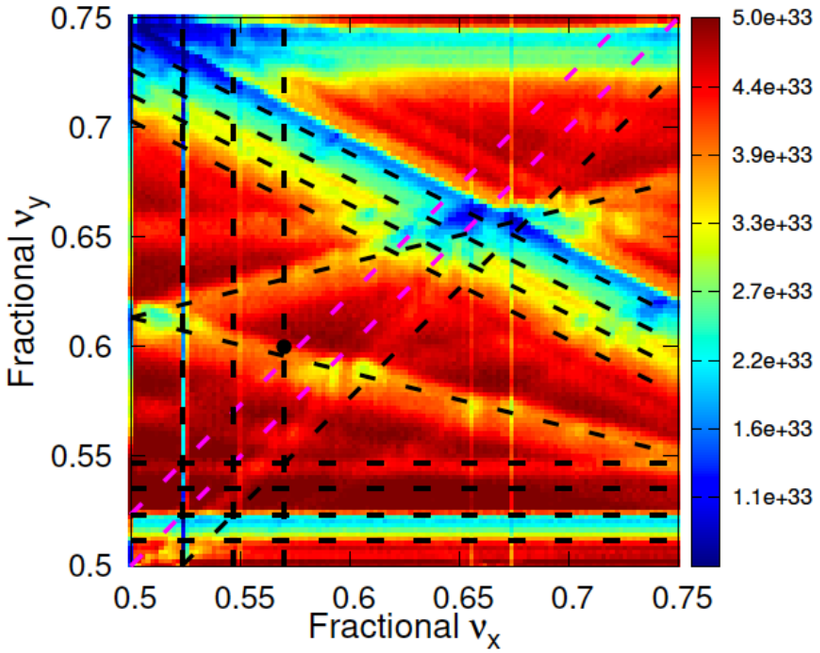


2. BBWS simulation

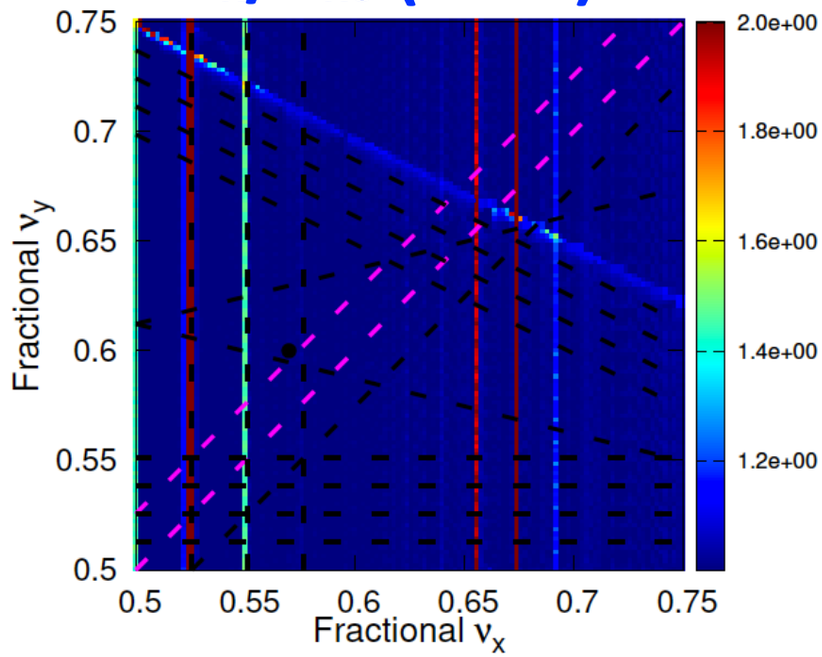
➤ **Optics: HER 200/3 mm and LER 200/4 mm**

- **Weak beam: HER: plots with normalization**

Luminosity

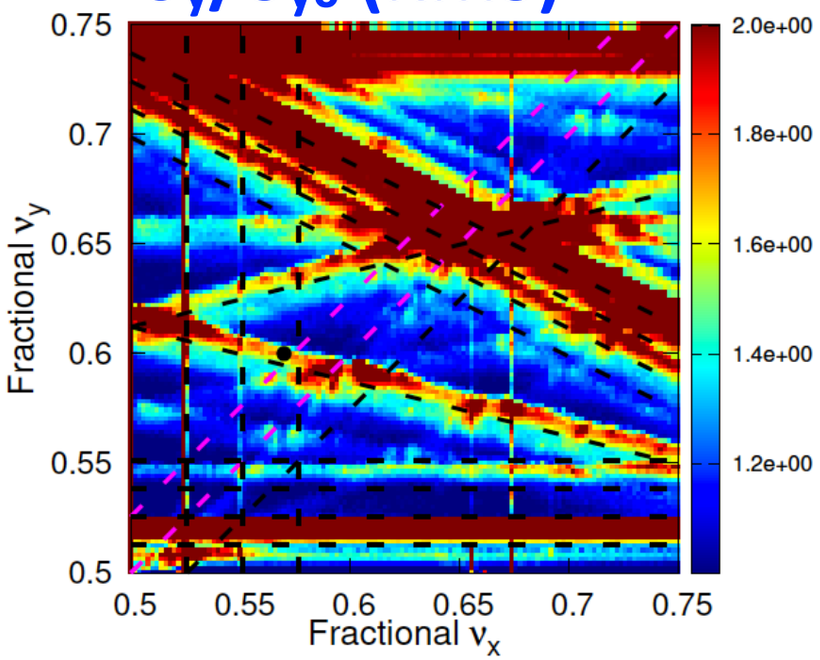


σ_x/σ_{x0} (RMS)

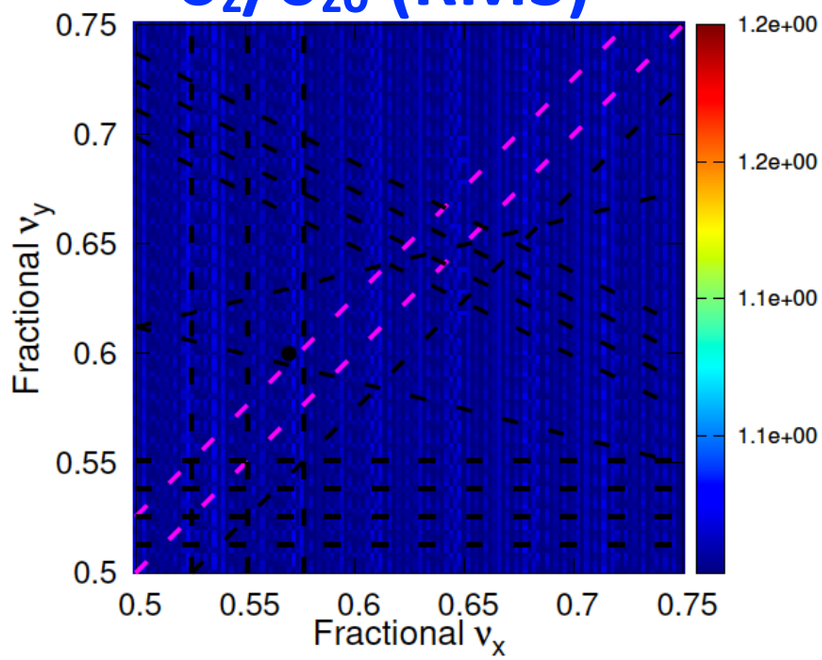


Beam-beam resonances also plotted

σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)

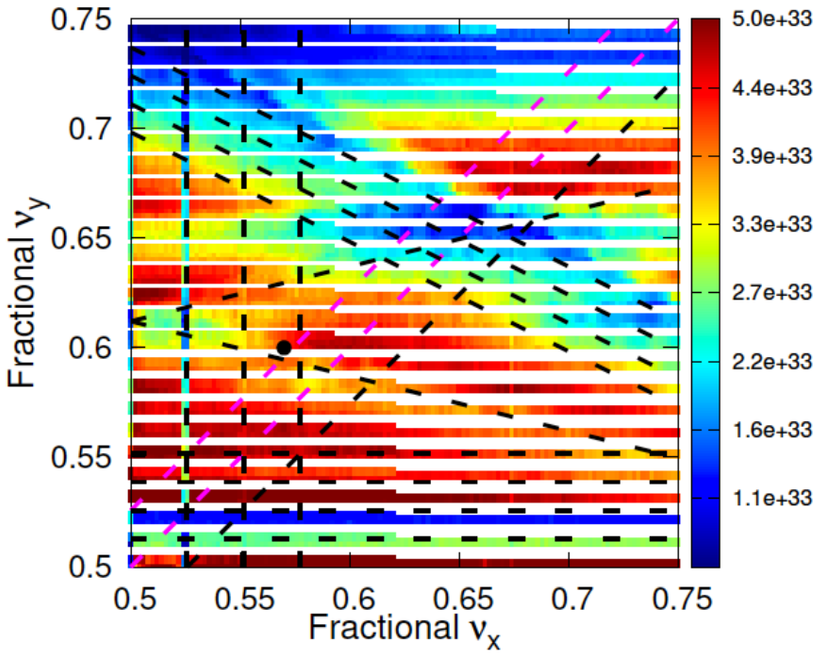


2. BBWS simulation

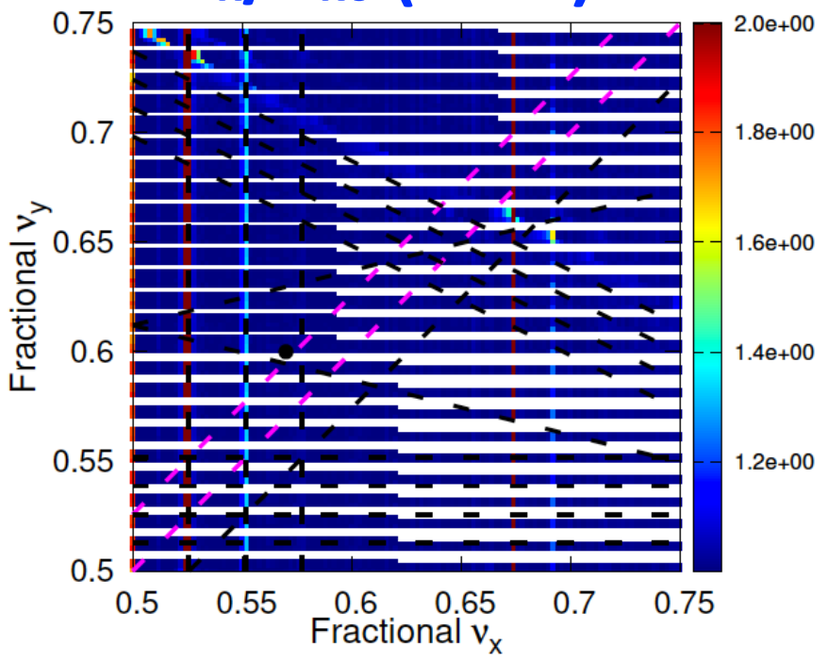
➤ Optics: HER 100/4 mm and LER 100/4 mm

- **Weak beam: HER: plots with normalization**

Luminosity

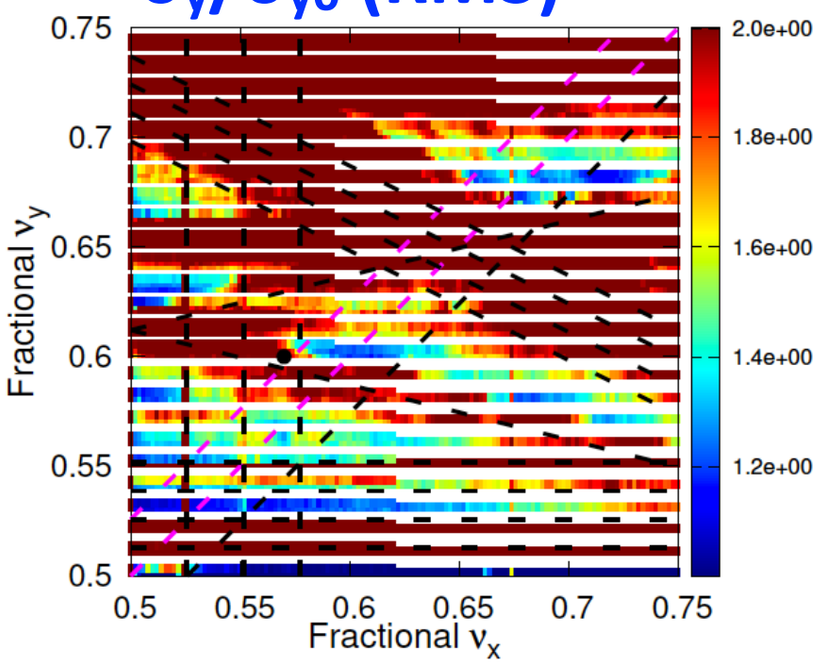


σ_x/σ_{x0} (RMS)

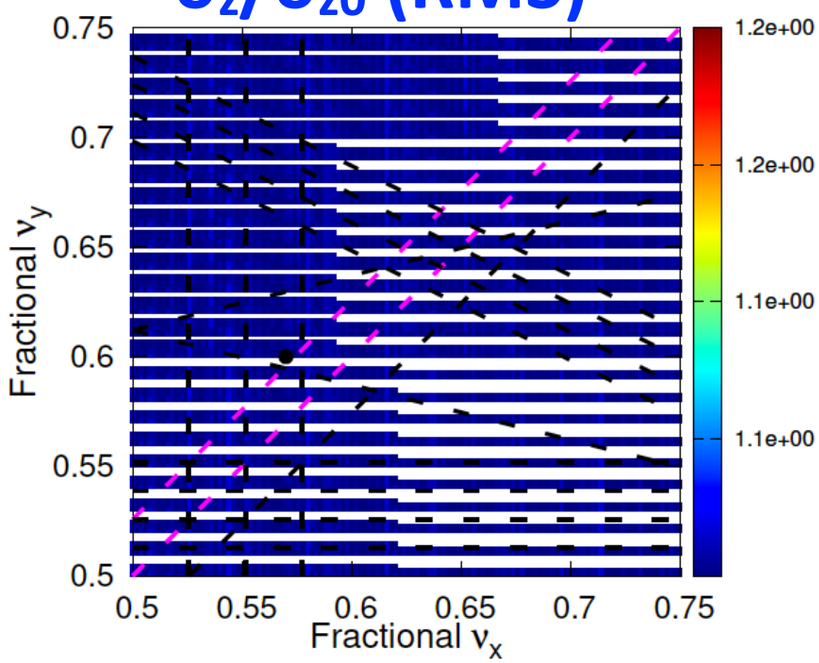


Beam-beam resonances also plotted

σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)

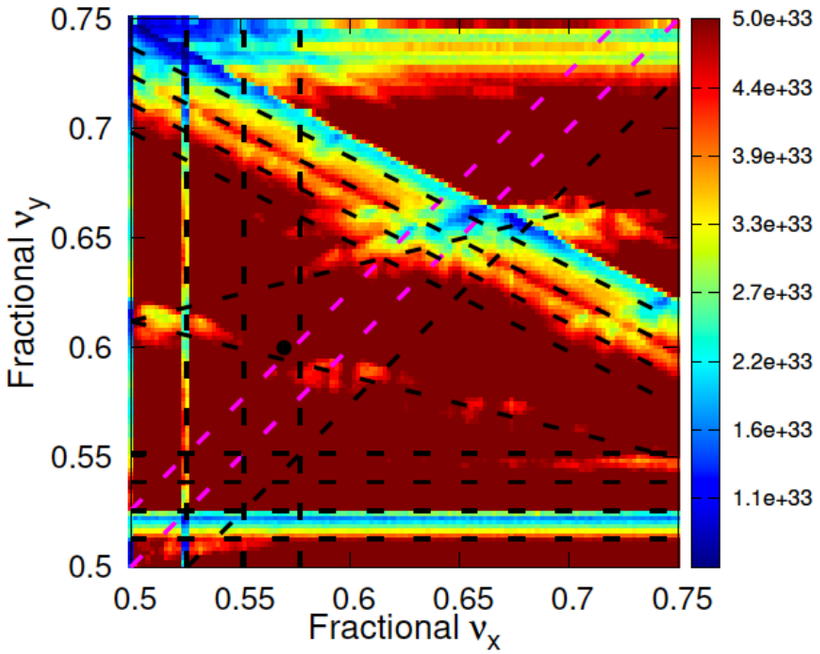


2. BBWS simulation

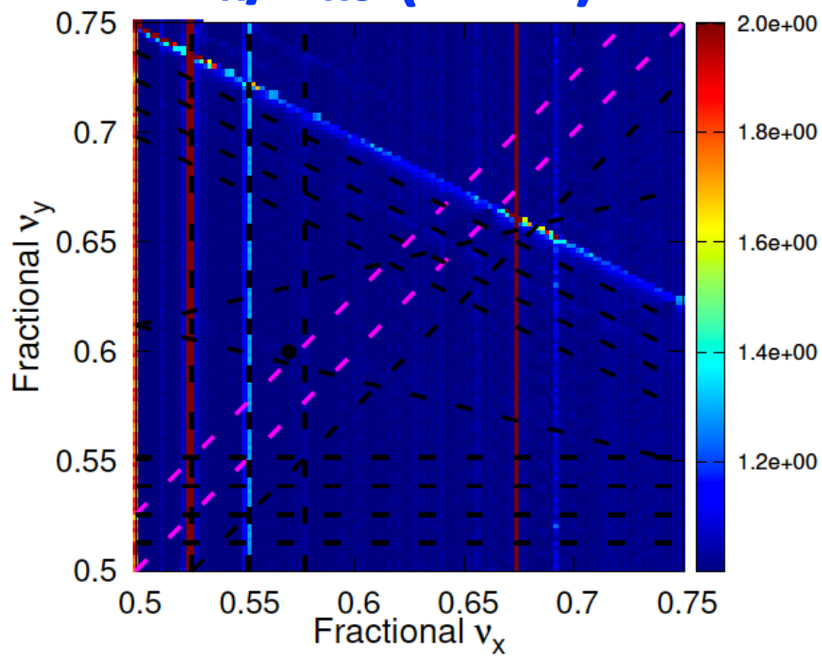
➤ Optics: HER 100/2 mm and LER 100/2 mm

- **Weak beam: HER: plots with normalization**

Luminosity

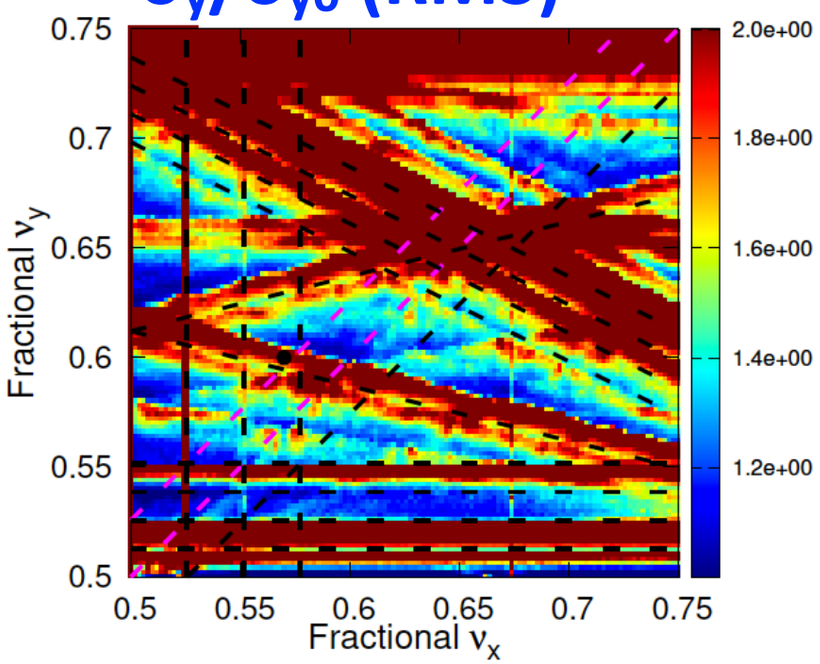


σ_x/σ_{x0} (RMS)



Beam-beam resonances also plotted

σ_y/σ_{y0} (RMS)



σ_z/σ_{z0} (RMS)