Coherent Beam-Beam Effects

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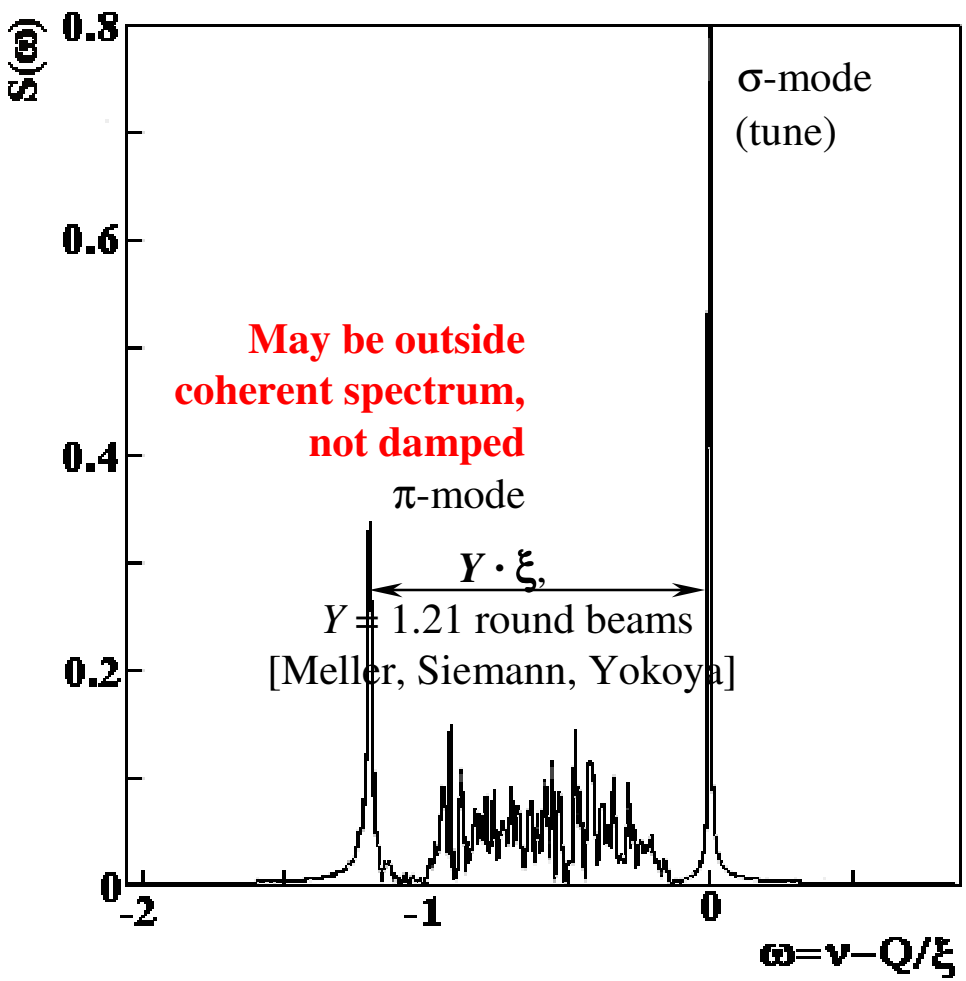
1. Introduction
2. RHIC as a test bench
3. RHIC strong-strong observations
4. Simulations (J. Qiang, LBNL)
5. Summary

Coherent mode simulation,
Hybrid Fast Multipole Method
R. Paparalla, W. Herr, CERN

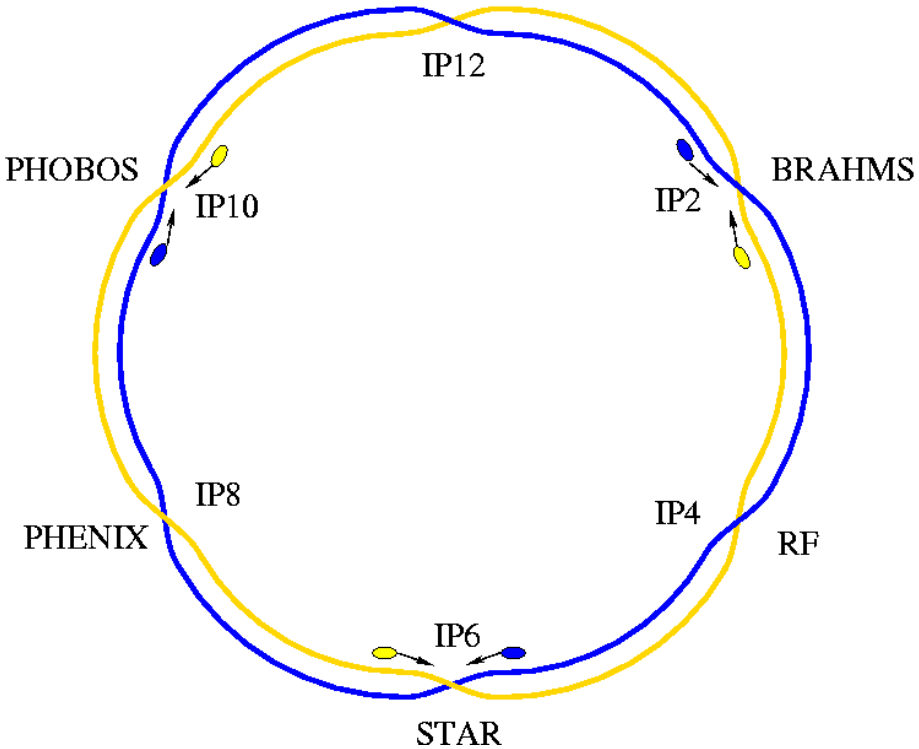


Coherent π-mode can appears for sufficiently symmetric conditions:
- tunes in both rings close
- intensities not too different

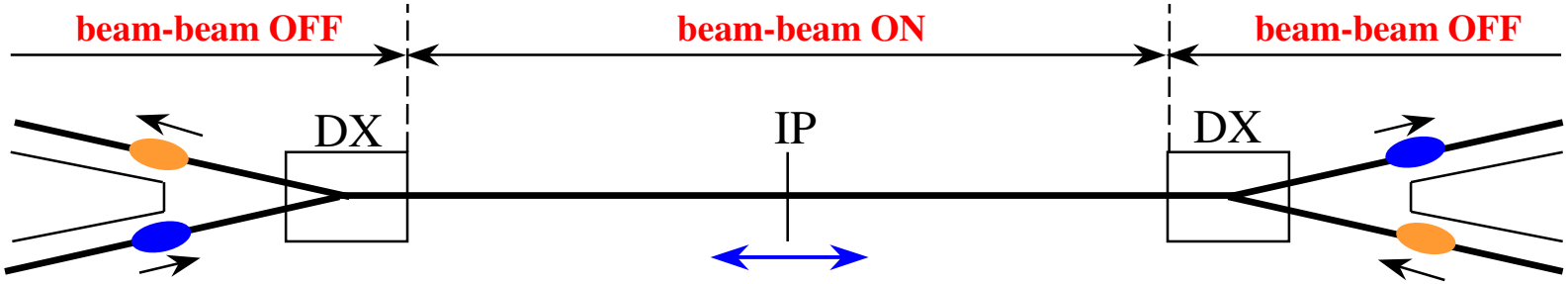
π-mode is not damped if incoherent tune spectrum is from beam-beam only

π-mode suppression requires symmetry breaking or feedback, may impose restrictions in operation

[Y.I. Alexahin, Part. Accel. Vol. 54 (1997)
Beam-Beam'03 contribution]



- Beams of comparable charges
- Two independent rings
- No parasitic collisions in stores
- Nominally no crossing angle
- Beam-beam couples 6 bunches (3 Blue and 3 Yellow)
- More complicated on ramps if rf not locked

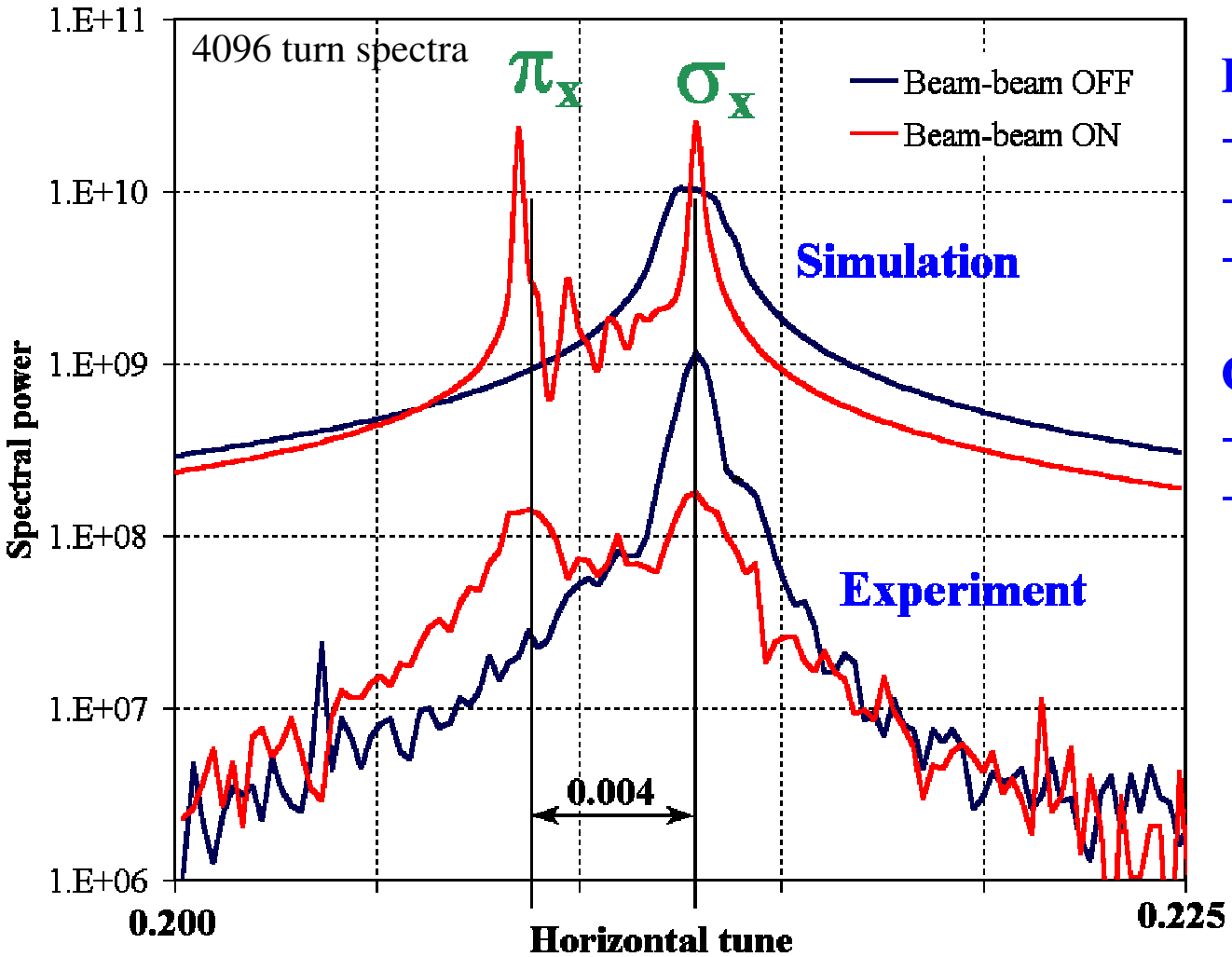


	ISR	SPS	Tevatron	HERAp	RHIC*	LHC
			Run II		p 2003	
	(achieved	(achieved	(design)	(achieved	(achieved	(design)
Bunches per beam	coasting	3	6	174	55	2808
Experiments	6	2	2	2	4	4
Long-range interactions		4	70	—	—	120
beam-beam ξ / IP	0.001	0.009	0.010	0.0007	0.004	0.003
Total bb tune spread, max	0.008	0.028	0.024	0.0014	0.015	0.010

* Numbers assuming ε_N=15μm and N_b=0.7 10^{11}

Sources: W. Schnell PAC75, W. Herr, T. Sen, C. Montag

- Total tune spread from beam-beam in proton operation with ε_N=10μm (95%) and $N_b=2\cdot10^{11}$ will be as large as the maximum achieved in any past hadron collider (ΔQ_{min} = 0.030 with two collisions)
- Unlike past hadron colliders (weak-strong except ISR), RHIC operates in a strong-strong regime



Experiment:

- single p bunch/ring
- ξ **= 0.003**
- $|Q_{x,B}-Q_{x,Y}| < 0.001$

Observation:

- π_x-mode shift: 0.004
- expectation:

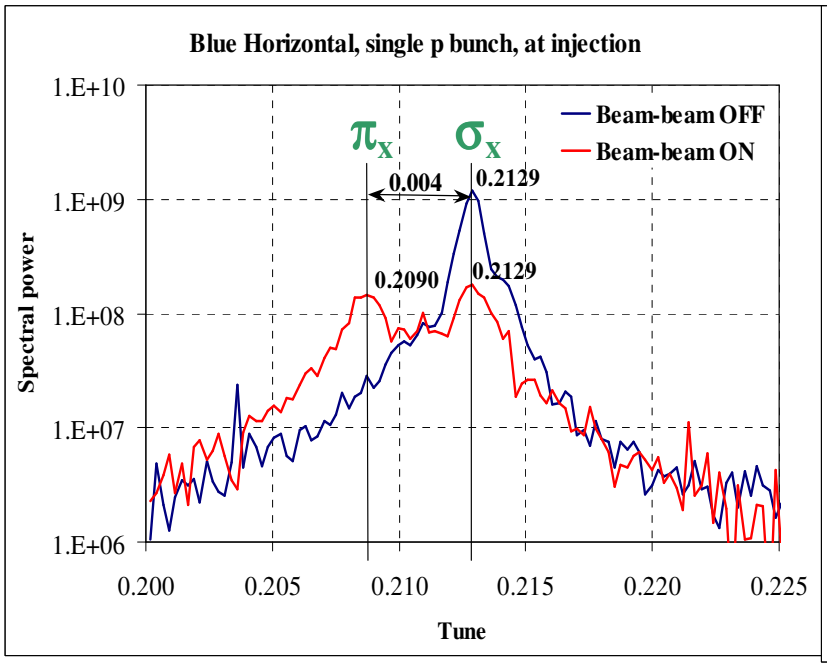
$$1.21 \cdot \xi = 0.0036$$

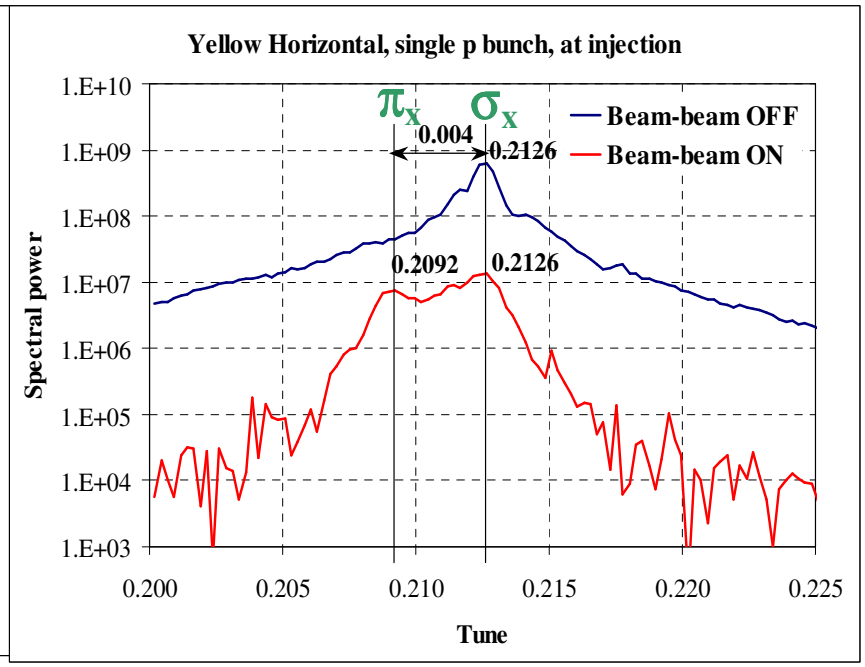
[Yokoya, Meller, Siemann]

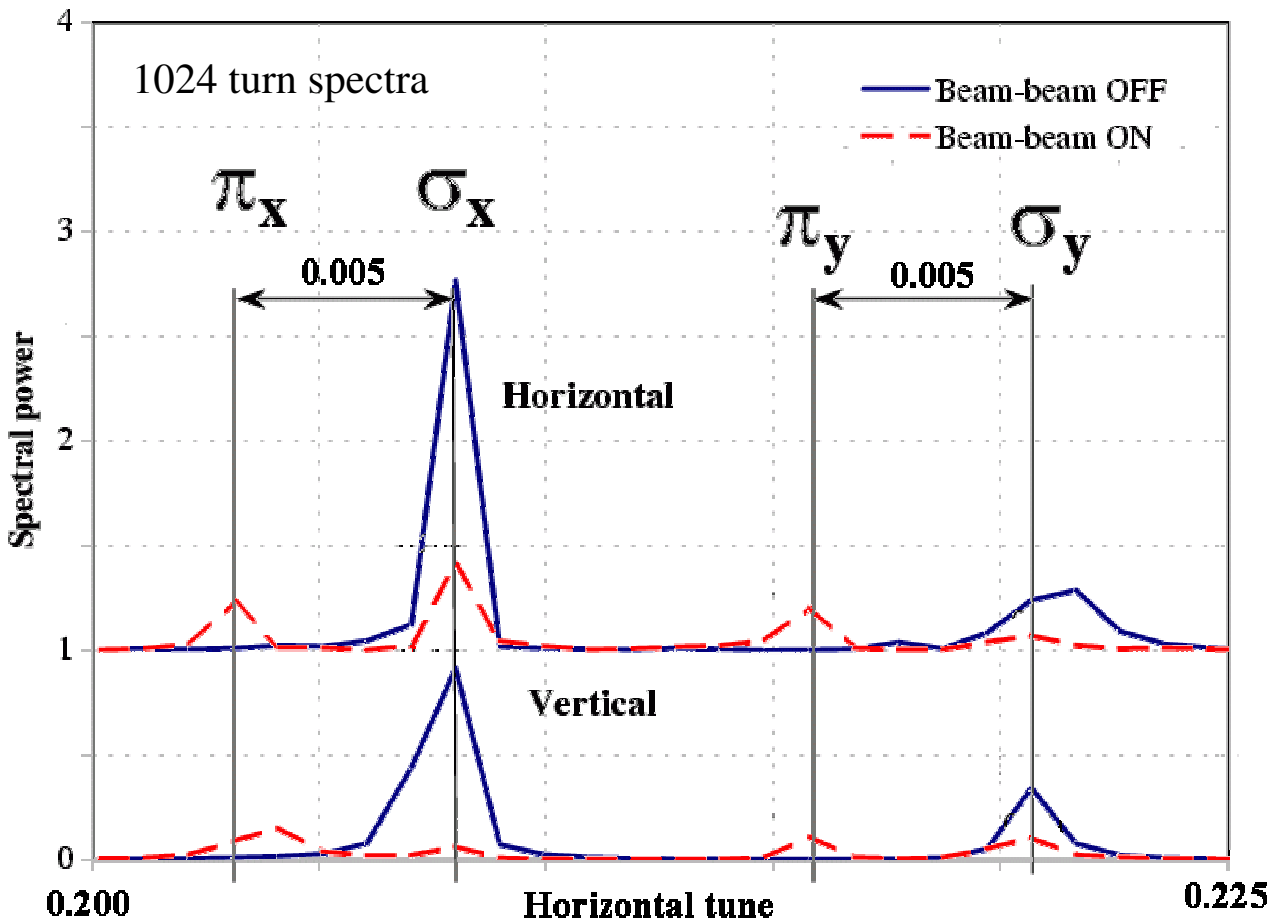
[Simulation: M. Vogt et al., DESY, "Simulations of coherent beam-beam modes at RHIC", EPAC02]

- Coherent modes observed (possibly 1st time in a hadron collider)
- π-mode appears below σ-mode (= tune), shifted by $G \cdot \xi$ (G~1.21 Yokoya factor)

		Blue	Yellow
Fractional tunes (Q_x,Q_y)		(0.2129,0.2412)	(0.2126,0.2392)
ΔQ_{min}		0.011	0.013
Chromaticities (ξ_x,ξ_y)		(~ 2, ~ 2)	(~ 3, ~ 3)
Norm. emittance ε_N (95%)	[μm]	~20	~20
Bunches / Head-on collisions		1 / 1	1 / 1
No of p/bunch	[10^{11}]	0.84	0.88
Beam-beam parameter ξ		0.003	0.003







Operation:

- 55 p bunches/ring
- **ξ = 0.0015, 4 IPs**
- $\Delta Q_{min} = 0.01$

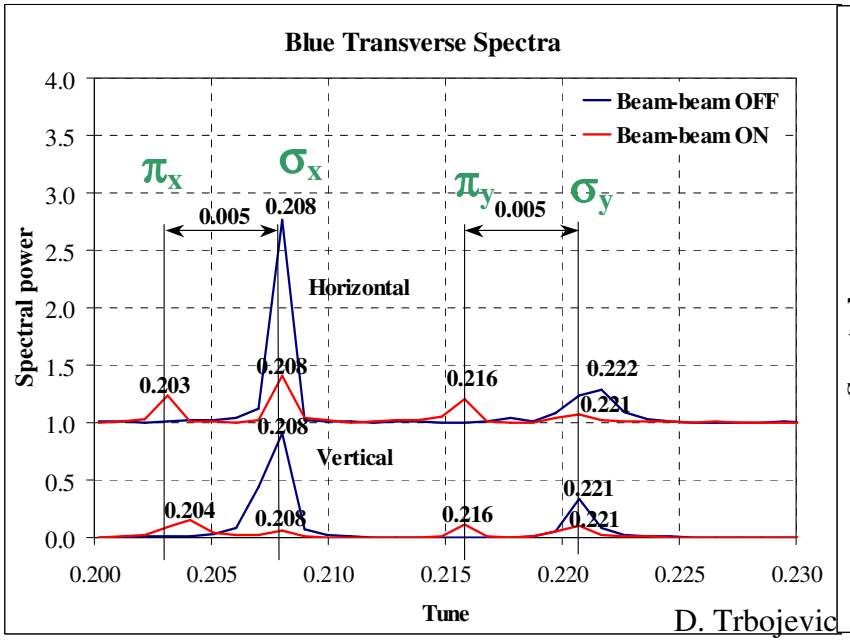
Observation:

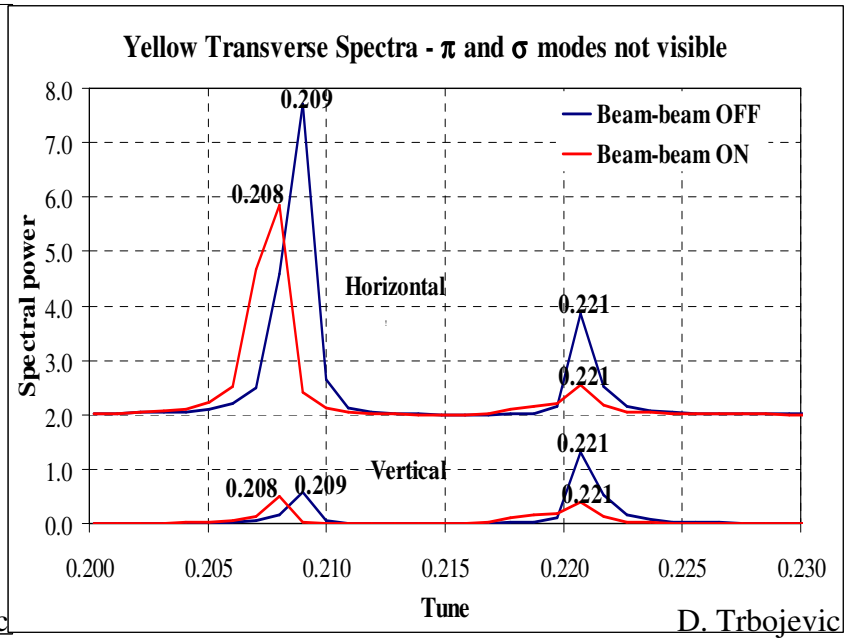
- π_x-mode shift: 0.005
- expectation:
  $\approx 1.21 \cdot \xi \times 4 = 0.007$

- tune change of $\Delta Q_x = 0.002$ did suppress π-modes
- no instabilities observed so far

- Created by tuning for lifetime
- Multiple collisions do not suppress coherent modes
- With x-y coupling 4 coherent modes exist in each beam (π and σ-mode for each transverse eigenmode)

		Blue	Yellow
Fractional tunes (Q_x,Q_y)		(0.208,0.221)	(0.209,0.221)
ΔQ_{min}		0.005	0.011
Chromaticities (ξ_x,ξ_y)		(~ 1, ~ 2)	(~ 3, ~ 2)
Norm. emittance ε_N (95%)	[μm]	~30	~30
Bunches / Head-on collisions		55 / 4	5 / 4
No of p/bunch	[10^{11}]	0.72	0.69
Beam-beam parameter ξ		0.0015	0.0015





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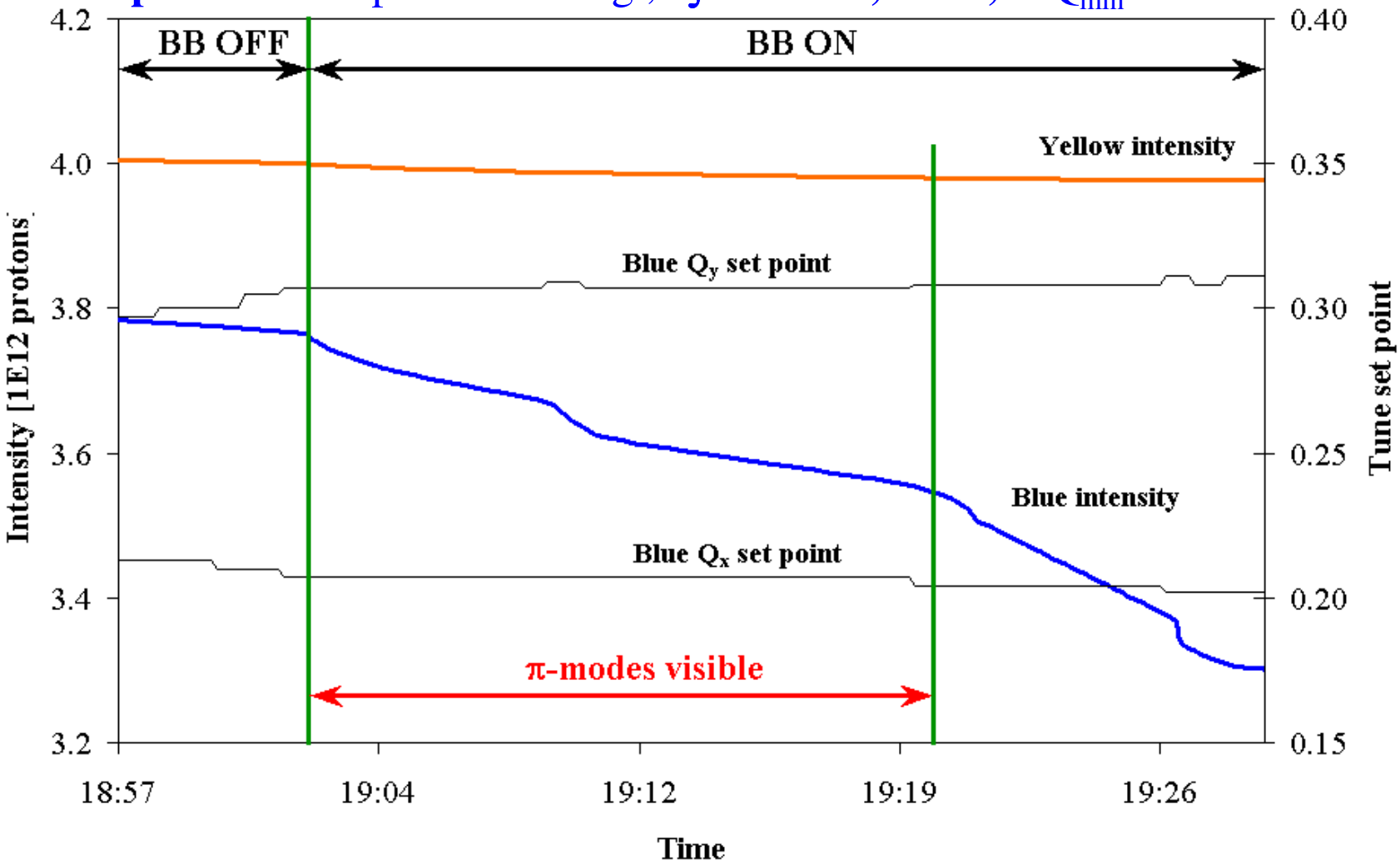
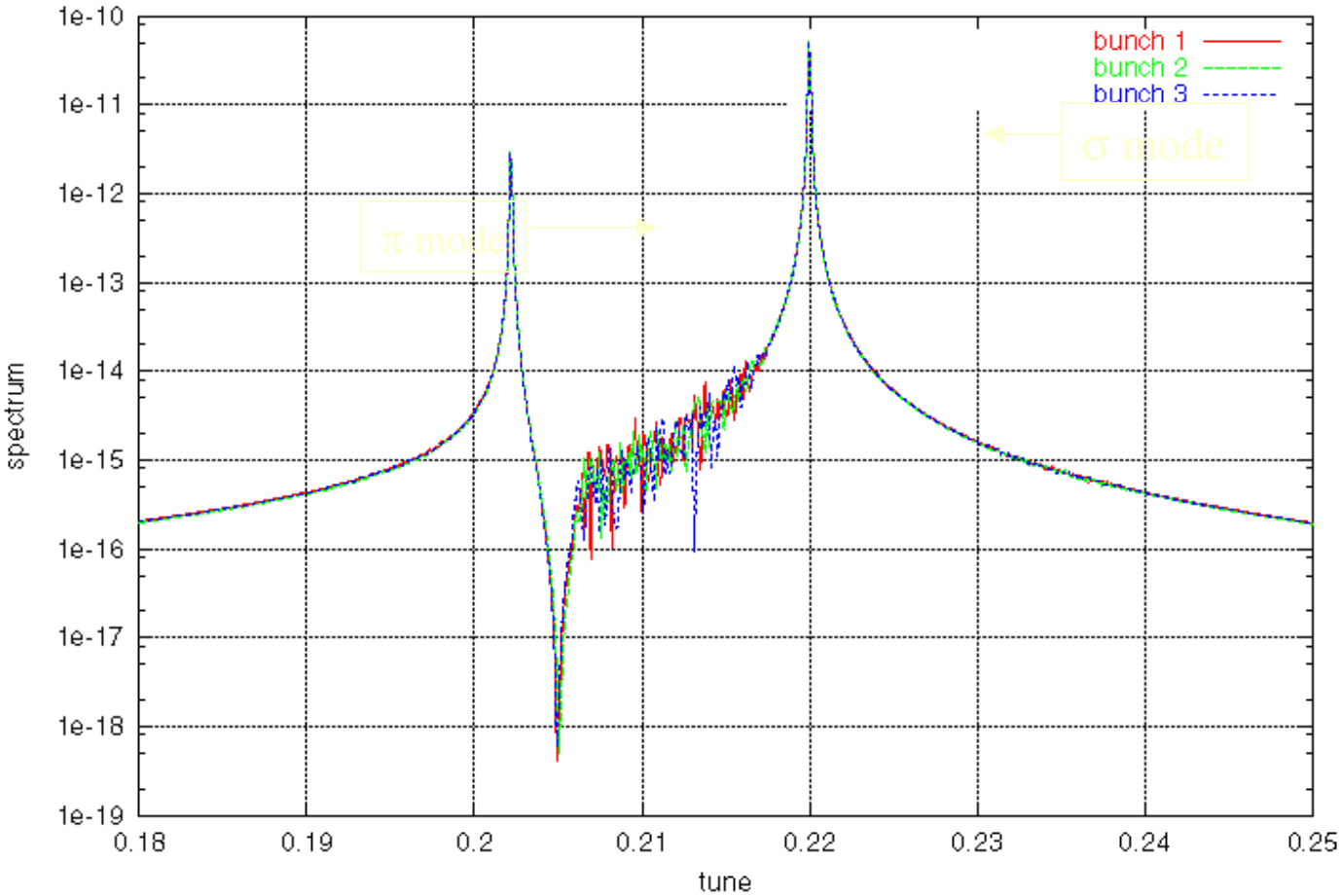


Power Spectrum of Horizontal Centroid Motion of Three Bunches with Four Collisions (Self Consistent Strong-Strong Simulation)



Normal RHIC operating condition

- Strong-strong effects may be important in LHC
  - Possibility of undamped π-modes
- RHIC is a good test bed for strong-strong effects
  - Only hadron collider in existence with same intensity in both beams
  - Beam-beam driven dipole modes already observed
  - Effect should become more pronounced in future