Beam-Beam Experiments

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Beam-Beam in Past Hadron Colliders

	ISR	SPS	Tevatron	HERAp	RHIC	RHIC	RHIC*
			Run I		Au 2001	p 2001	p 2002
Bunches per beam	coasting	3	6	174	55	55	110
Experiments	6	2	2	2	4	4	4
Parasitic interactions		4	10	—	—	—	—
ξ / IP	0.0010	0.0093	0.0075	0.0007	0.0015	0.0022	0.0074
Total bb tune spread, max	0.008	0.028	0.024	0.001	0.006	0.009	0.030

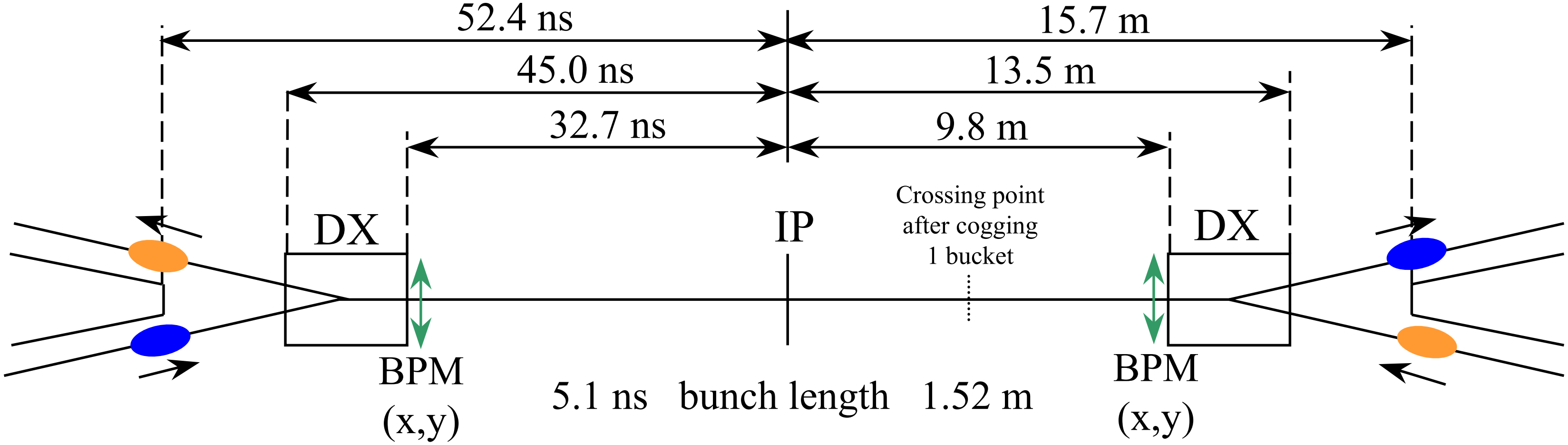
* Numbers for **next run** assuming ε_N=20μm and N_b=2 10^{11}

Sources: W. Schnell PAC75, W. Herr, V. Shiltsev, C. Montag

- Total tune spread from beam-beam in proton operation with ε_N=20μm and $N_b=2\cdot10^{11}$ will be as large as the maximum achieved in any past hadron collider
- Unlike past hadron colliders (weak-strong except ISR), RHIC will operate in a strong-strong regime

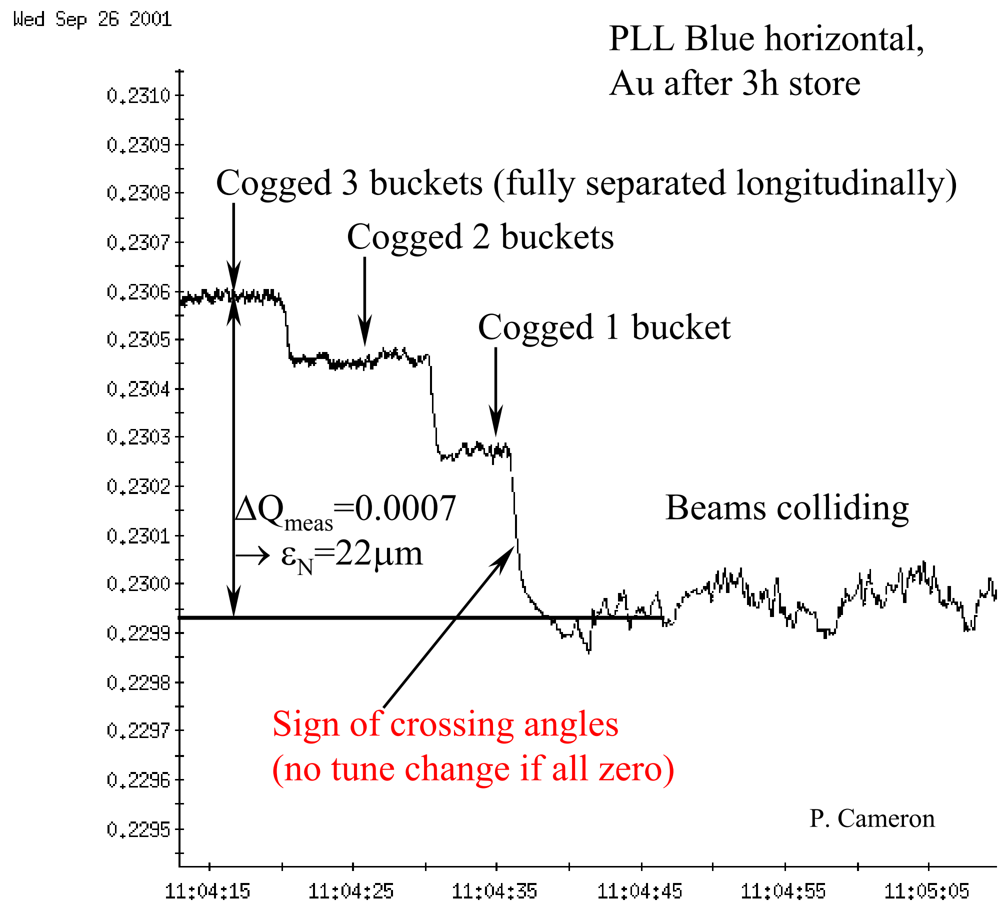
RHIC Interaction Region

Bunch length and spacing for rf storage system (2520 buckets), 120 bunch pattern



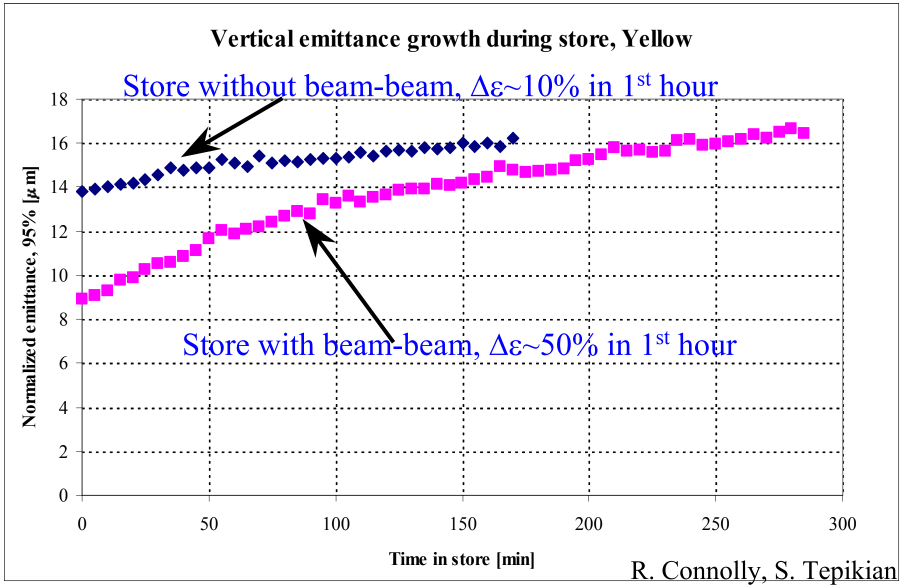
Beam-Beam Tune Shift

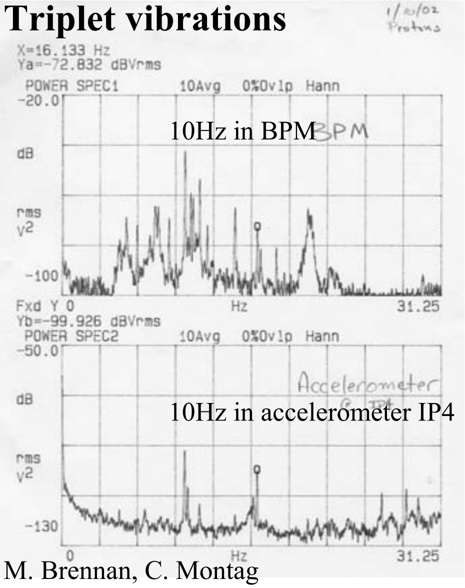
- Beam-beam parameter measured with PLL (high precision needed)
  $\xi = 2 \cdot \Delta Q_{meas}/N_{IP}$
- Also shows effect of crossing angles
- Is also an emittance measurement:
  $\varepsilon_N = 1.5 N_b/\xi$,
  N_b well known
- Need to measure all four planes, also with different intensities in Blue and Yellow



Emittance Growth

- Beam-beam enhances transverse emittance growth, need more comparison data without beam-beam interaction
- Effect of transverse collision offsets not yet measured
- Modulated offsets (from triplet vibration) may further increase emittance growth
- Effect of tune modulation ($\xi_{x,y} \neq 0$, PS ripple) not studied

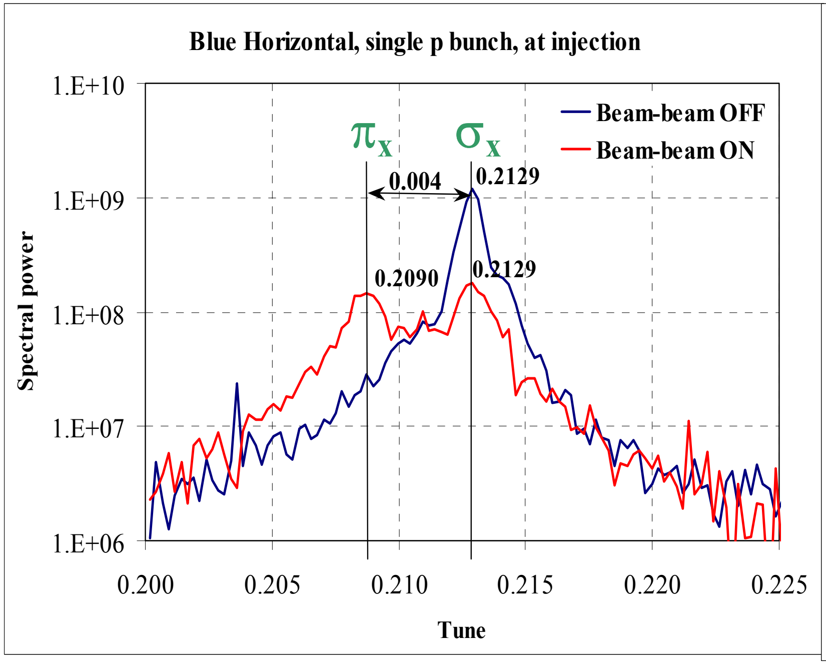


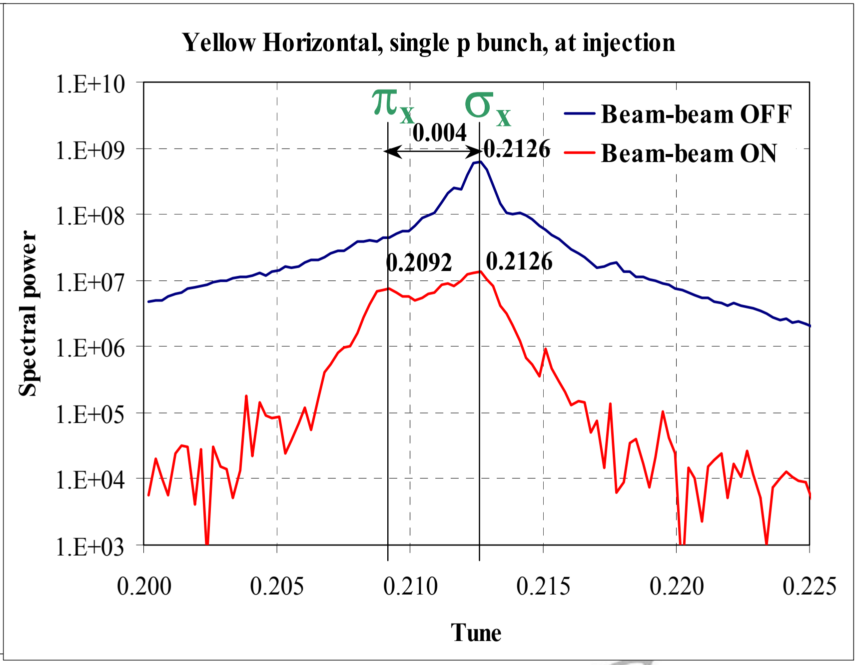


Coherent Modes in Experiment

- Coherent modes observed (possibly 1st time in a hadron collider)
- π-mode appears below σ-mode (= tune), shifted by G·ξ (G~1.33 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

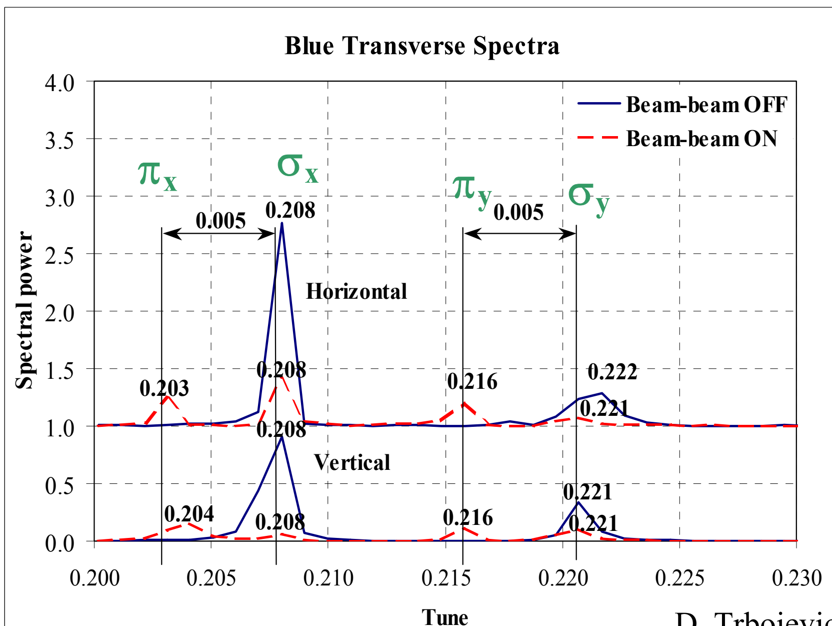


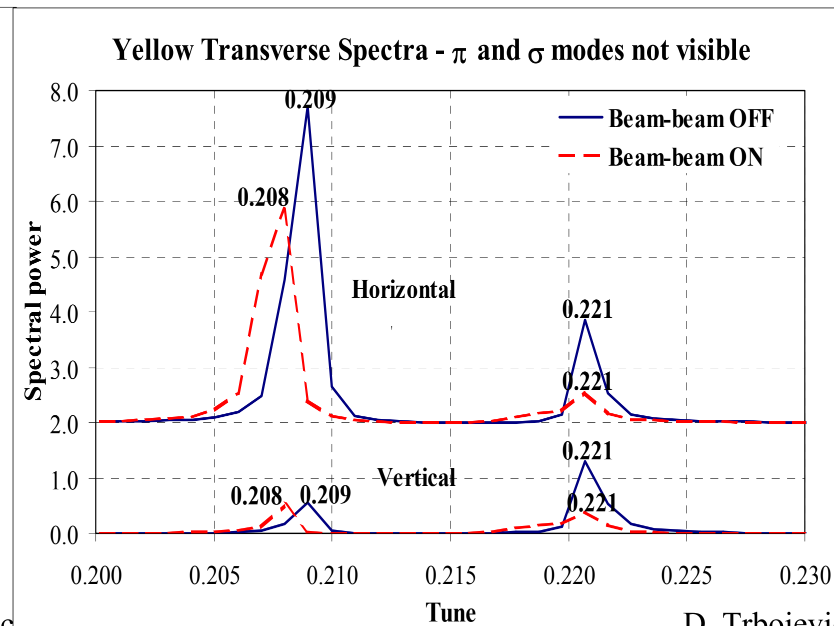


Coherent Modes in Operation

- 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)
- New resonance conditions: $k \cdot Q_{\pi 1} + l \cdot Q_{\sigma 1} + m \cdot Q_{\pi 2} + n \cdot Q_{\sigma 2} = p$

		Blue	Yellow
Fractional tunes (Q_x,Q_y)		**(0.208,0.221)**	**(0.209,0.221)**
ΔQ_{min}		**0.012**	**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**





Summary Beam-Beam Experiments

- In the next run beam-beam should be a dominant limit for the luminosity lifetime
  → Requires good control over basics (orbit, $Q_{x,y}$, ΔQ_{min}, $\xi_{x,y}$, IR errors,…)
- Beam-beam tune shift measurement with PLL yields several quantities (ξ, ε_N, total crossing angle)
  → Can be used in operation
- The contribution of beam-beam interactions to the transverse emittance growth (in conjunction with other effects) needs investigation
  → Should clarify luminosity lifetime limits
- Consequences and suppression of beam-beam driven coherent modes should be studied

  → Further operational limitations expected

pp-Beam-Beam Compensation with e-Beam

- Basic idea: compensate beam-beam induced tune spread from p-p collisions with e-p collisions
- For simplicity assume round hadron and electron beams of same size

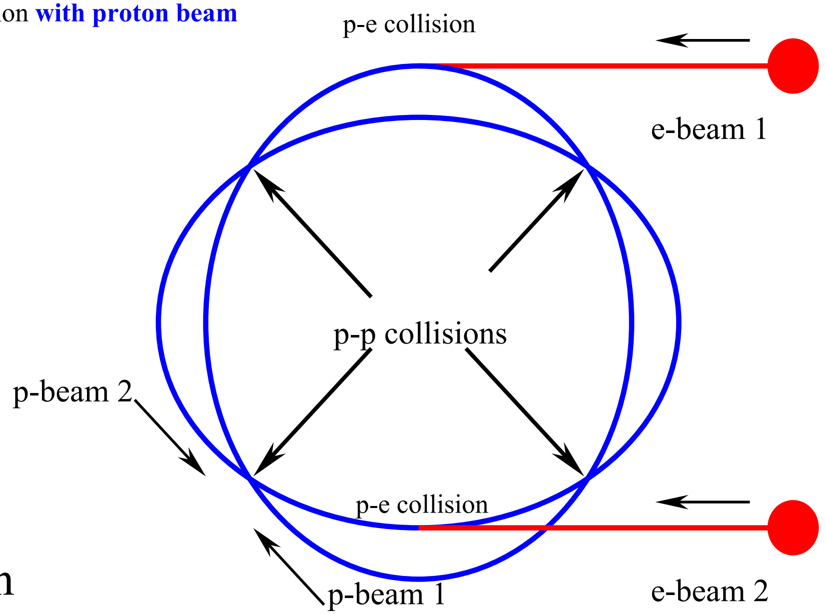
$$\xi^{pe} = \frac{3}{2\pi}\frac{N_e r_p}{\varepsilon_N^p} \quad and \quad \xi^{pp} = \frac{3}{2\pi}\frac{N_p r_p}{\varepsilon_N^p} \quad \Rightarrow \quad \xi^{pe} = \xi^{pp}\frac{N_e}{N_p}$$

Incoherent beam-beam **tune spread of proton beam** from collision **with electron beam**

Incoherent beam-beam **tune spread of proton beam** from collision **with proton beam**

- For M_p p-p collisions and M_e p-e collision one needs for complete compensation

$$\frac{M_p}{M_e} = \frac{N_e}{N_p}$$



- Example: 2 p-p and 1 p-e collision, N_p=1e11 $\Rightarrow$ N_e=2e11 needed [N_e= 3e10 in RHIC e-cooling]
- p-p and p-e collision not at same position $\Rightarrow$ residual beam-beam effect