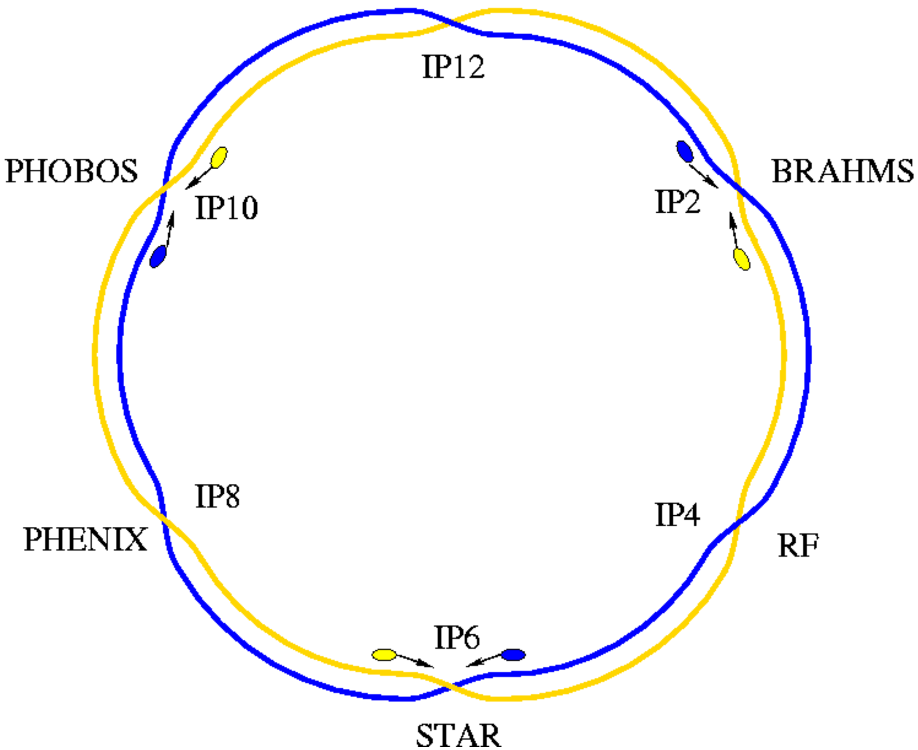
Observation of Strong-Strong and other Beam-Beam Effects in RHIC

Wolfram Fischer

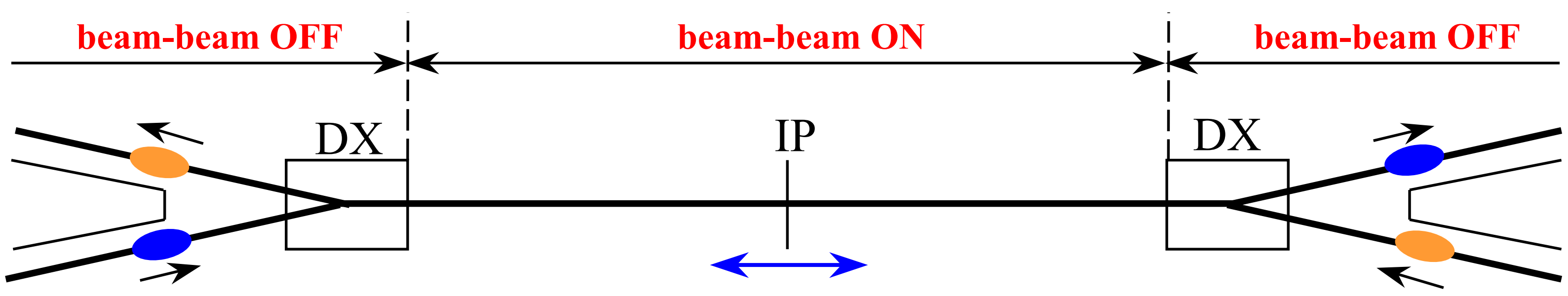
M. Blaskiewicz, J.M. Brennan, P. Cameron, R. Connolly,
C. Montag, S. Peggs, F. Pilat, V. Ptitsyn, S. Tepikian,
D. Trbojevic, J. van Zeijts

BROOKHAVEN NATIONAL LABORATORY

Particle Accelerator Conference 2003
Portland, Oregon
13 May 2003



- 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



[T. Roser, BNL, “RHIC status and plans”, MOPA002]
[T. Satogata et al., BNL, “Commissioning of RHIC deuteron-gold collisions”, TPPB043]

	ISR	SPS	Tevatron Run I	HERAp	RHIC* p 2003	LHC
Bunches per beam	coasting	3	6	174	55	2808
Experiments	6	2	2	2	4	4
Parasitic interactions		4	10	—	—	120
beam-beam ξ / IP	0.001	0.009	0.008	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 $N_b=0.7\ 10^{11}$

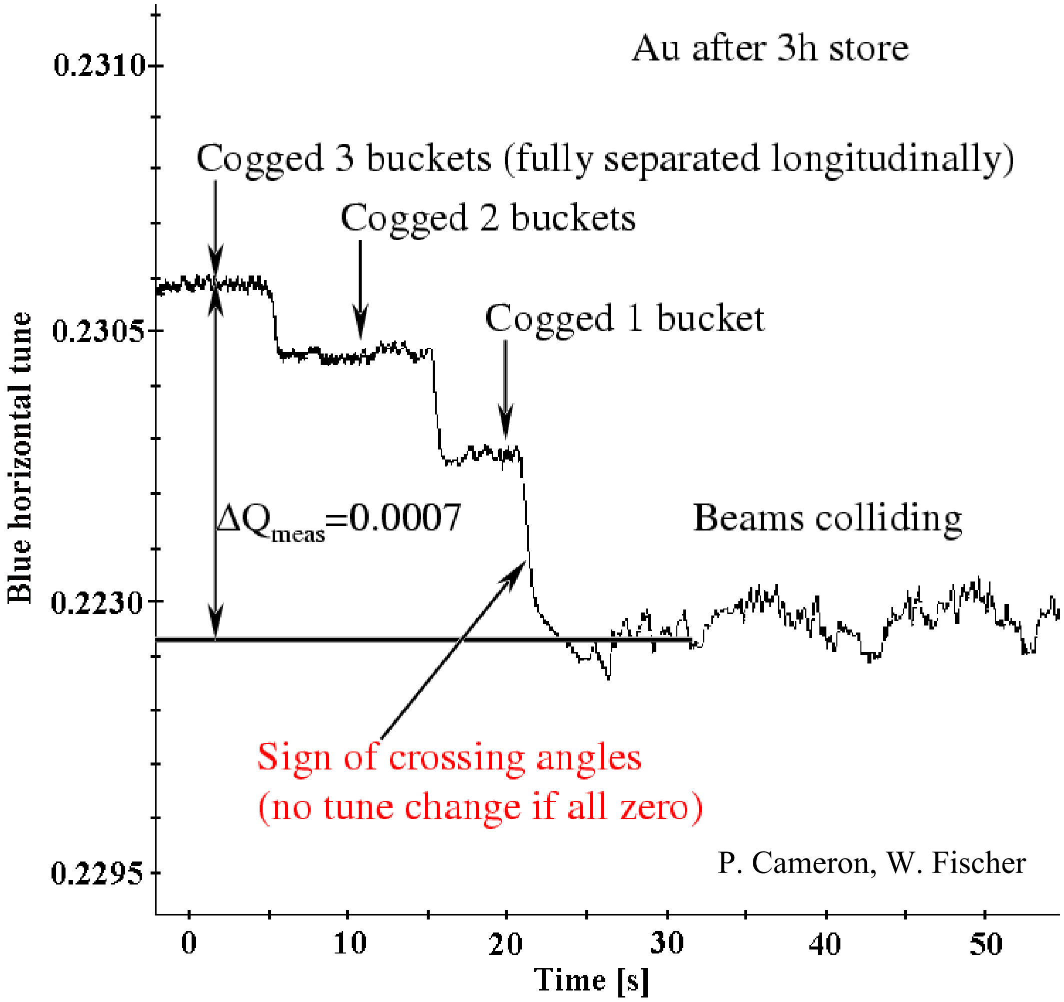
Sources: W. Schnell PAC75, W. Herr, V. Shiltsev, C. Montag

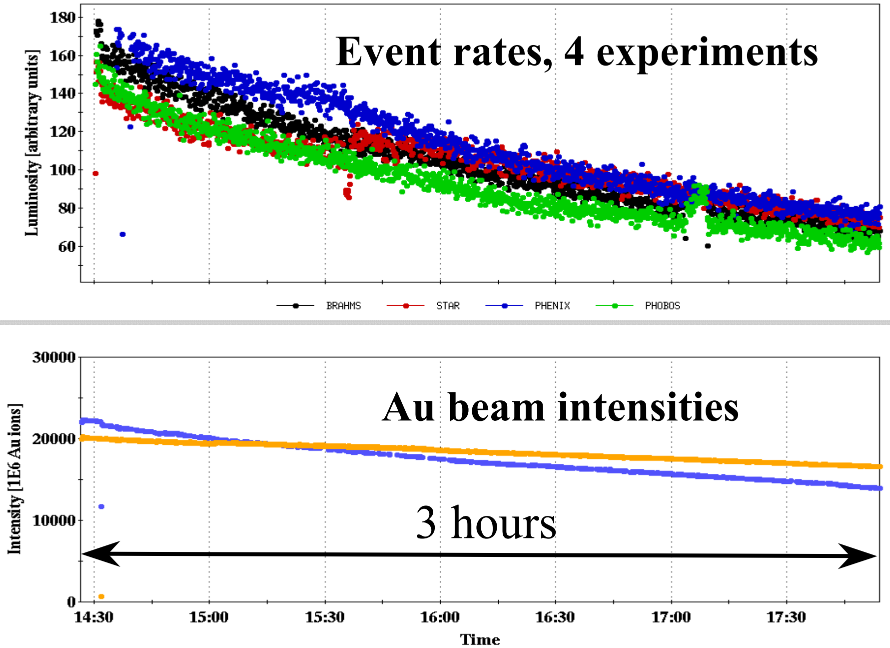
- Total tune spread from beam-beam in proton operation with ε_N=10μm (95%) and $N_b=10^{11}$ will be as large as the maximum achieved in any past hadron collider
- Unlike past hadron colliders (weak-strong except ISR), RHIC operates in a strong-strong regime

[T. Sen, FNAL, "New aspects of beam-beam interaction in hadron colliders", MOPA004]

- Beam-beam parameter measured with PLL (high precision)
  $\xi \approx 2 \cdot \Delta Q_{meas}/N_{IP}$

  [P. Cameron et al., BNL, "RHIC third generation PLL tune system", ROAB009]
- Also shows effect of crossing angles
- Is also an emittance measurement:
  $\varepsilon_N = 1.5 N_b/\xi$,
  N_b well known





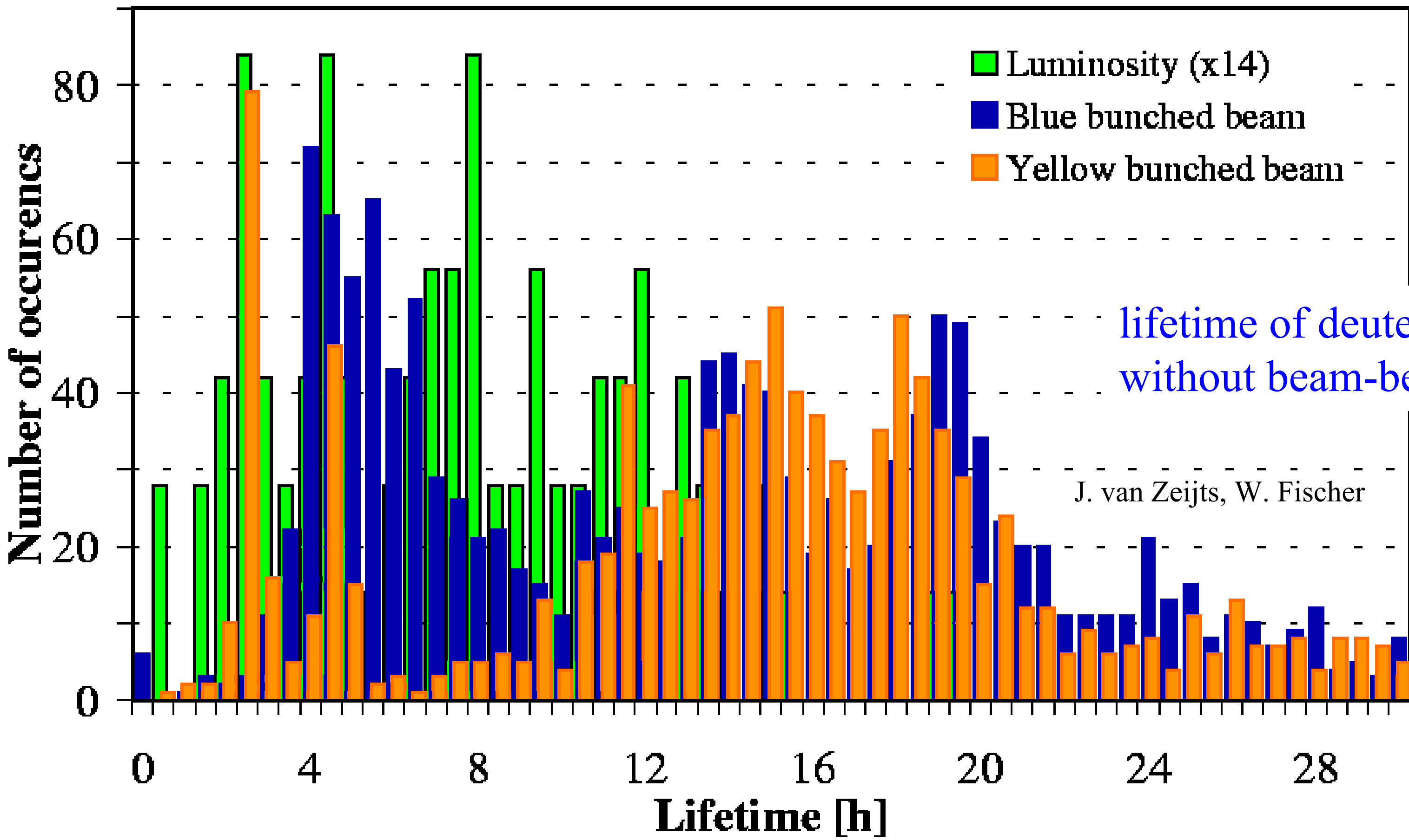
- Time dependent beam intensity easily measurable
- Emittance growth can be determined from intensity and luminosity decay via

$$\varepsilon(t) = f \frac{N_B(t) N_Y(t)}{L(t)}$$

or with profile monitors

- Beam lifetime is affected by
  - Beam-beam interaction (beam-beam ξ largest for protons)
  - Nonlinear field errors in uncorrected triplets (lattices with $\beta^* \leq 2$ m)
  - Intrabeam scattering (high charge state species – Au^{79+})
- For beam-beam effect compare
  - Proton-proton stores with $\beta^* = 3$ m and 4 collisions with
  - Deuteron store with $\beta^* = 2$–10 m without collisions

proton-proton collisions, ξ / IP ≈ 0.002, β^* = 3 m, 1 month of operation 2002

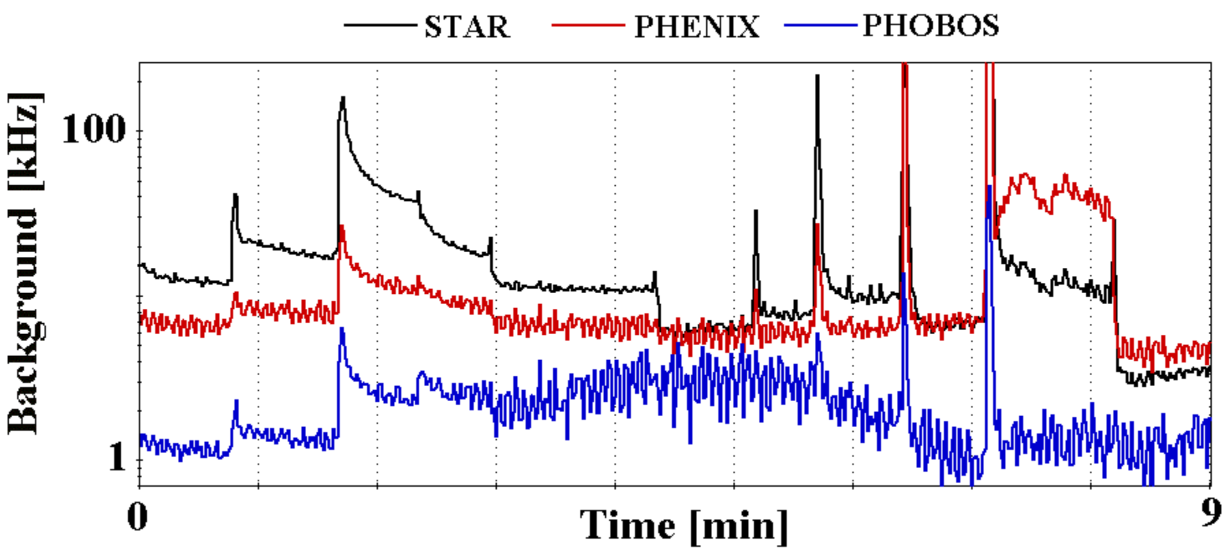


lifetime of deuteron beam without beam-beam: 830 hours

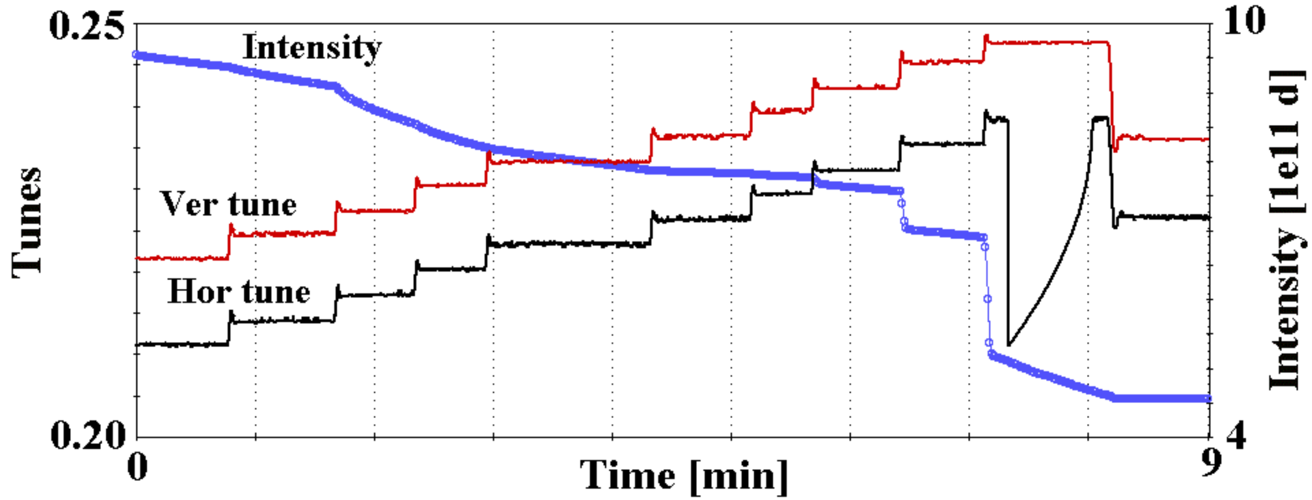
⇒ $\Delta\varepsilon/\varepsilon$ = **4%** (1st hour)
protons, 4 head-on collisions
(intensity and luminosity decay)

⇒ $\Delta\varepsilon/\varepsilon \approx$ **0%** (1st hour)
deuterons, no collision
(profile monitor)

Deuteron–gold collisions, ξ / IP ≈ 0.001, 4 head-on collisions

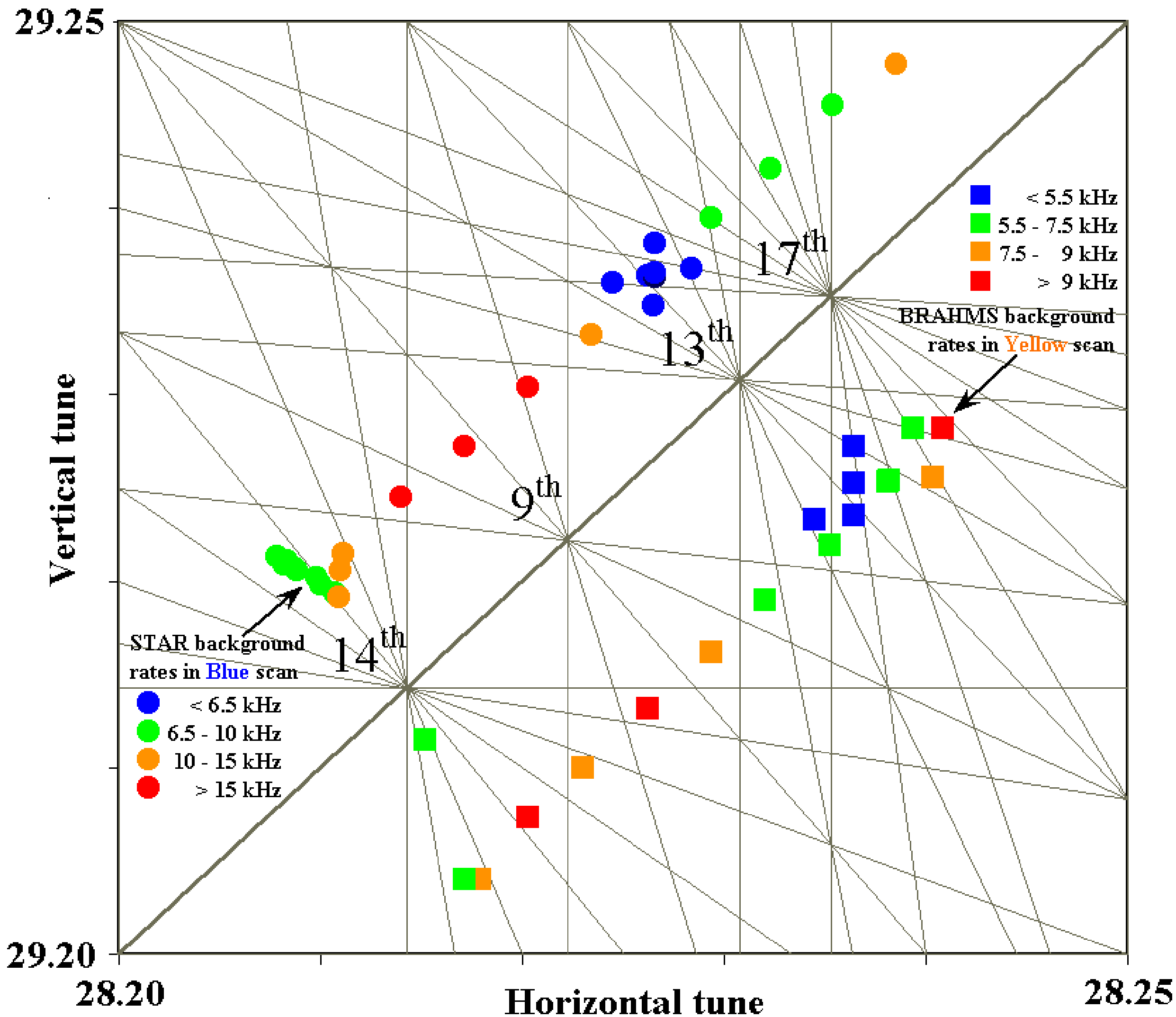


Experimental backgrounds



Tunes and beam intensity

Deuteron-gold collisions, ξ / IP ≈ 0.001, 4 head-on collisions

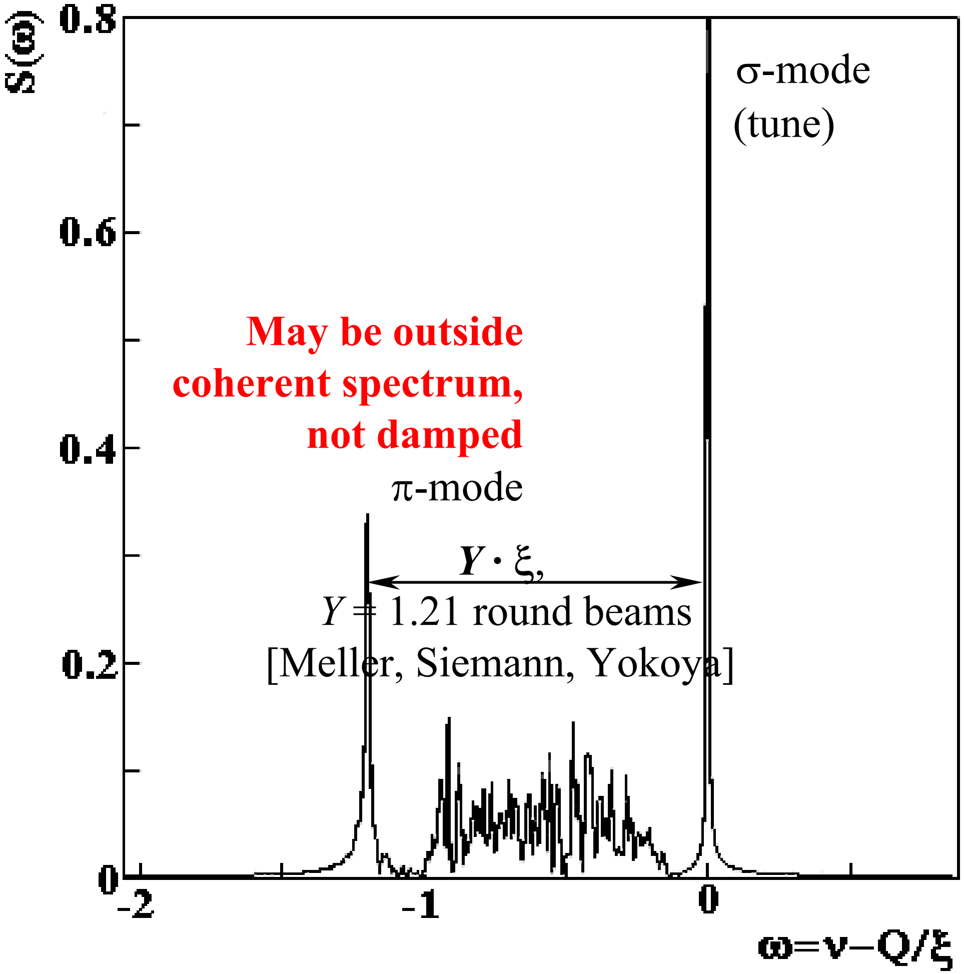


Lowest order resonances are of order 9 between 0.2 and 0.25

High background rates near 9th order resonances (residual crossing angles)

Low background rates near 13th order resonances (used in operation)

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

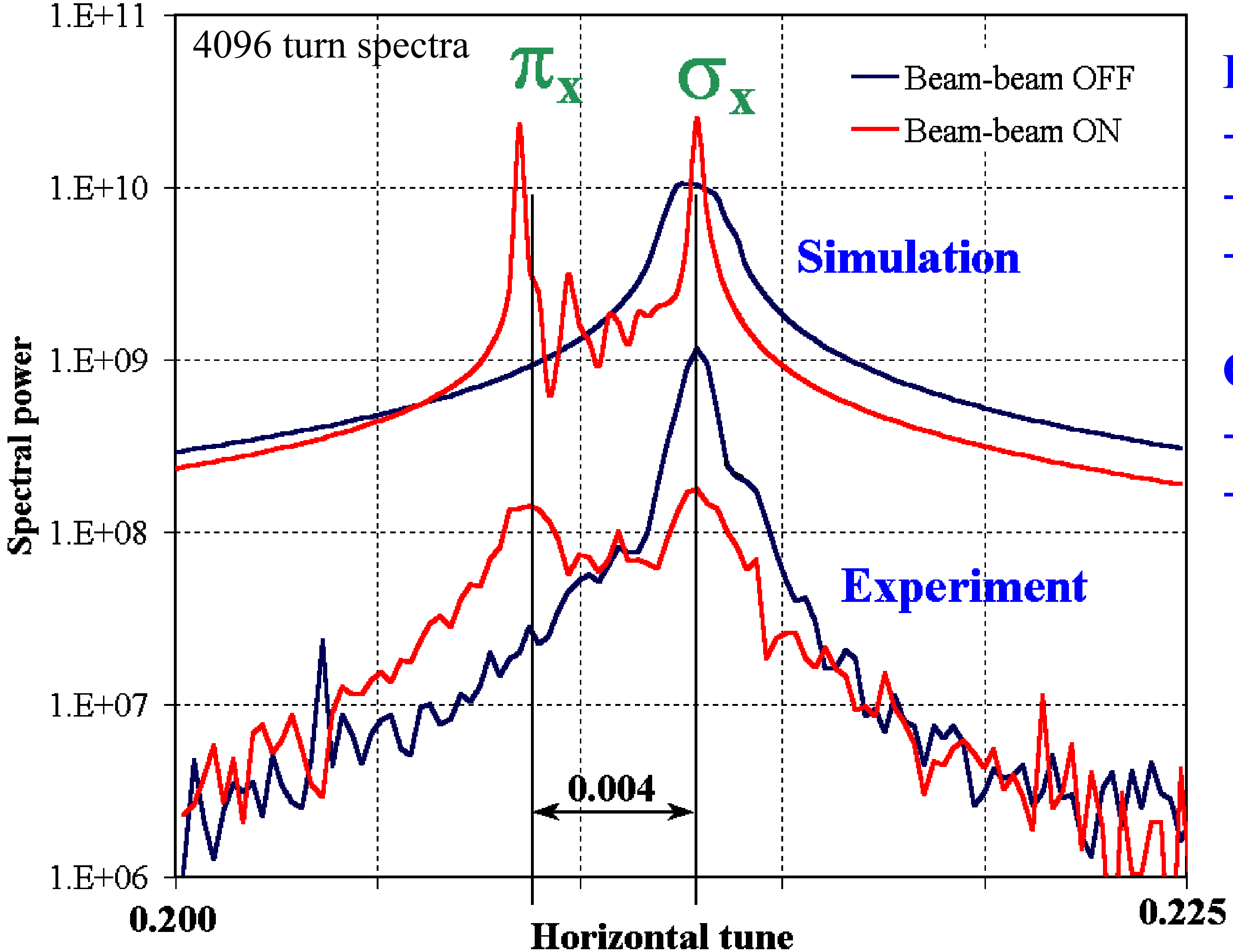


Coherent π-mode can appears for sufficiently symmetric conditions:
- tunes in both rings close
- intensities not too different

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)]



Experiment:

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

Observation:

- π_x-mode shift: 0.004
- expectation:

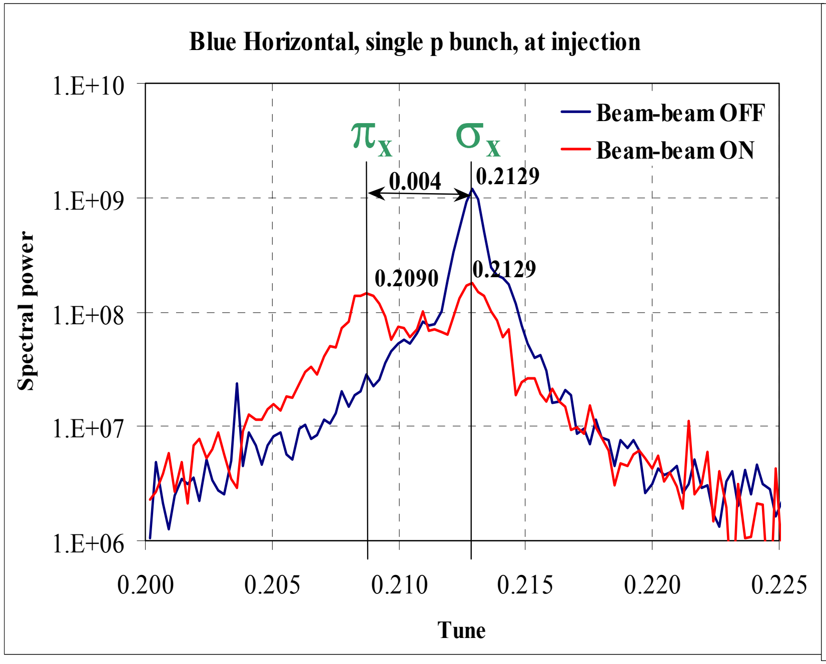
$1.21 \cdot \xi = 0.0036$

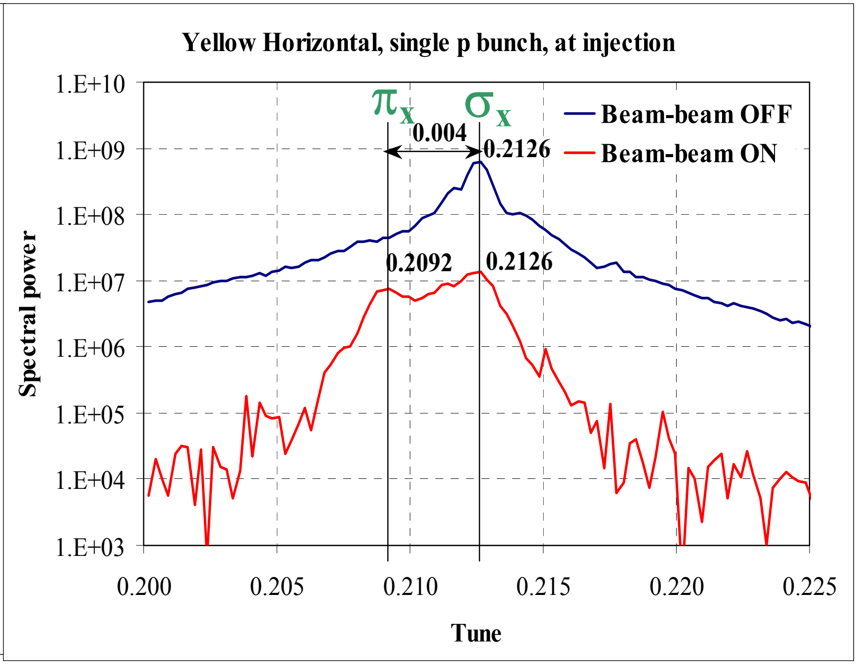
[Yokoya, Meller, Siemann]

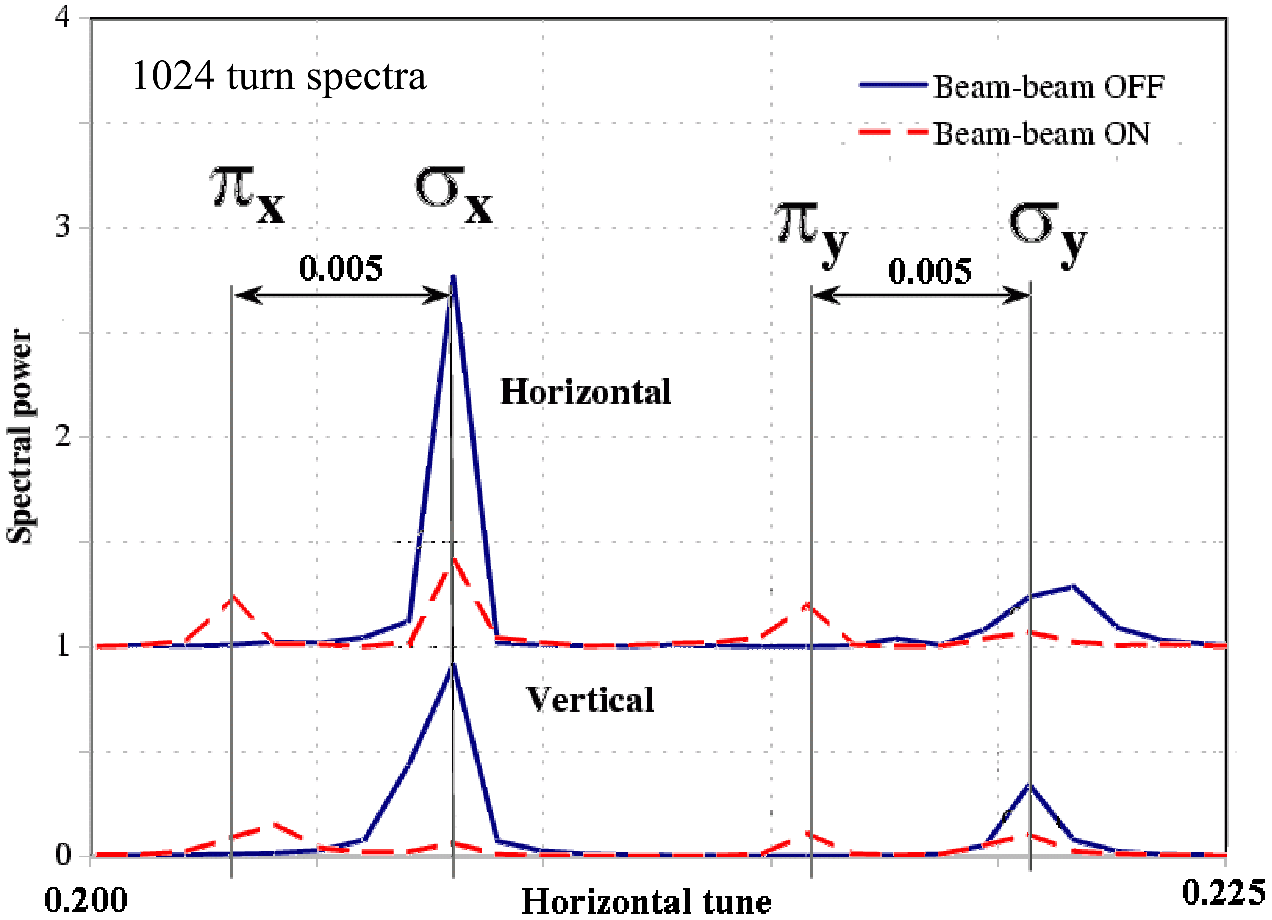
[Simulation: M. Vogt et al., DESY, "Simulations of coherent beam-beam modes at RHIC", EPAC02]

- 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**
- $\Delta Q_{min} = 0.01$

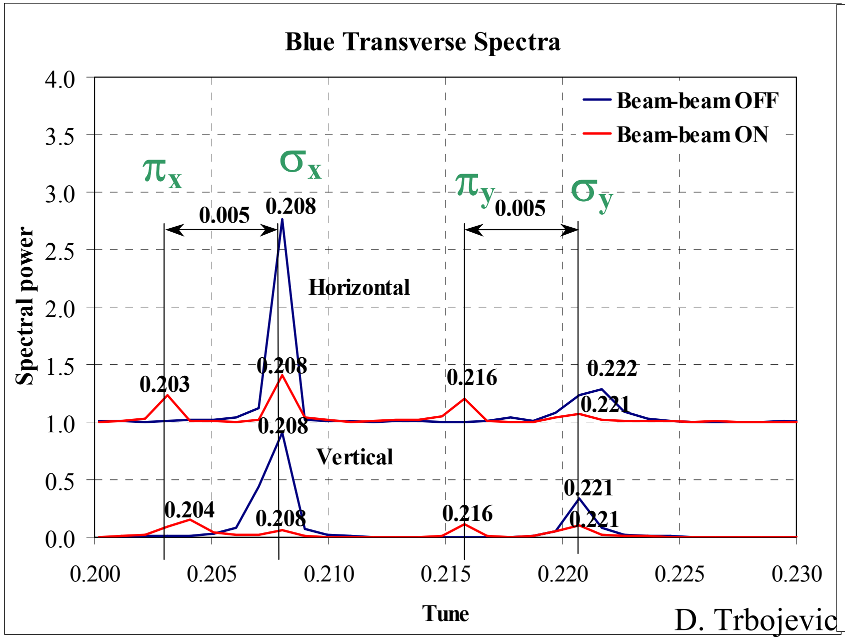
Observation:

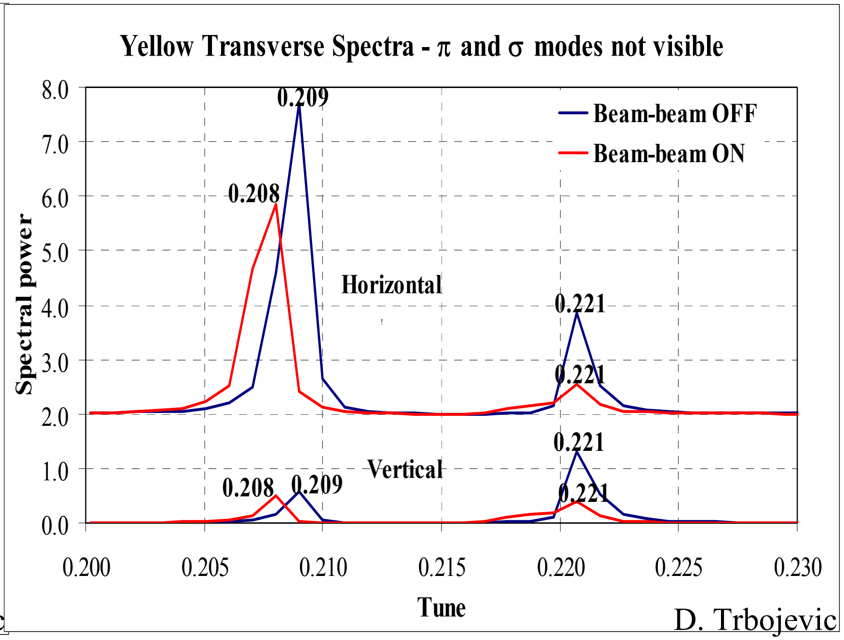
- π_x-mode shift: 0.005
- expectation: $\approx 1.21 \cdot \xi \times 4 = 0.007$

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

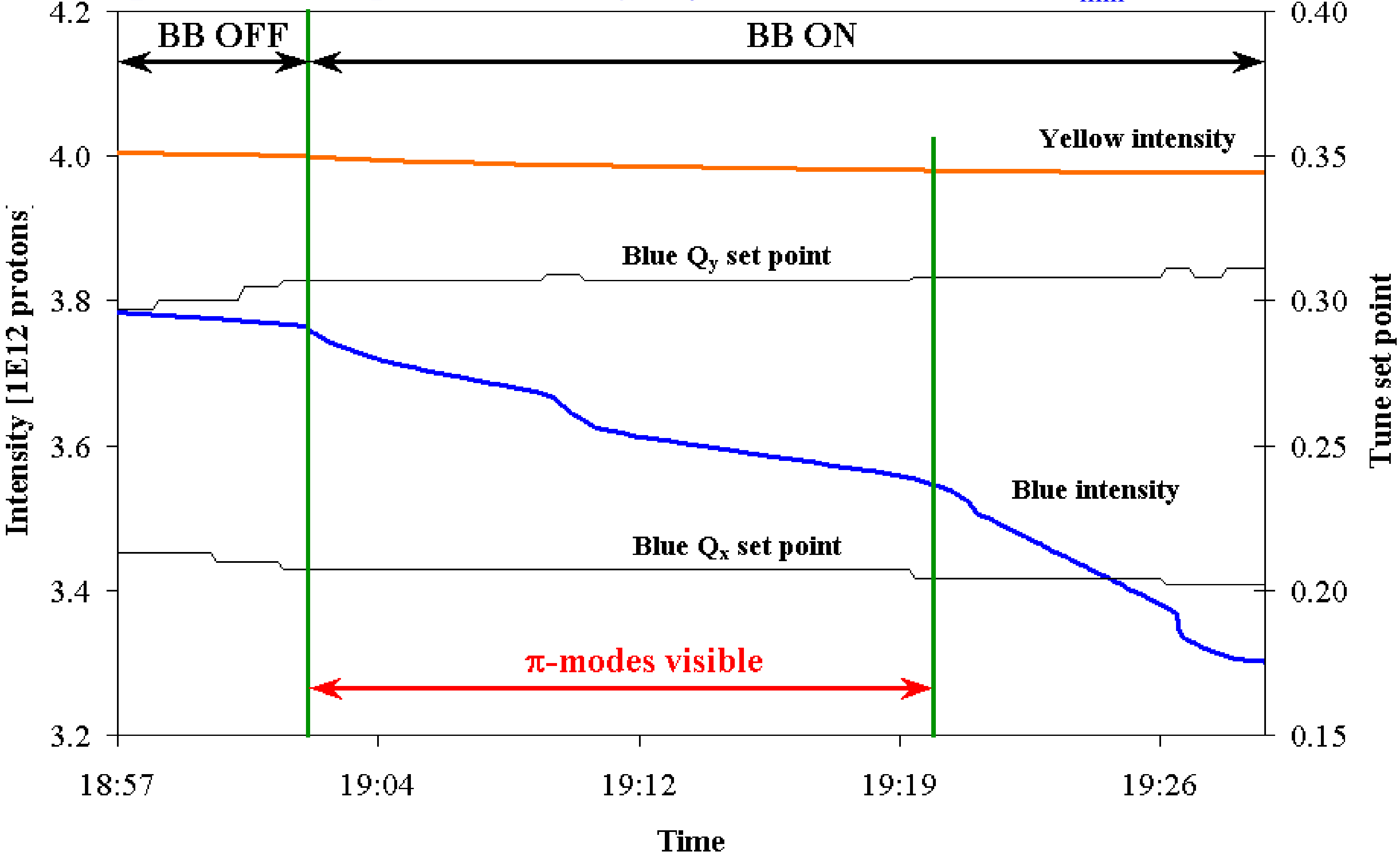
- Created by tuning for lifetime
- Multiple collisions do not suppress coherent modes
- With x-y coupling 4 coherent modes exist in each beam (π and σ-mode for each transverse eigenmode)

		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**



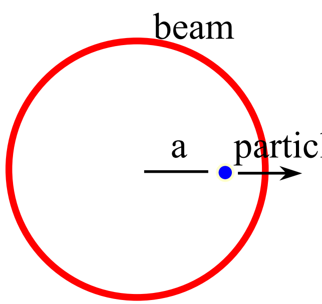


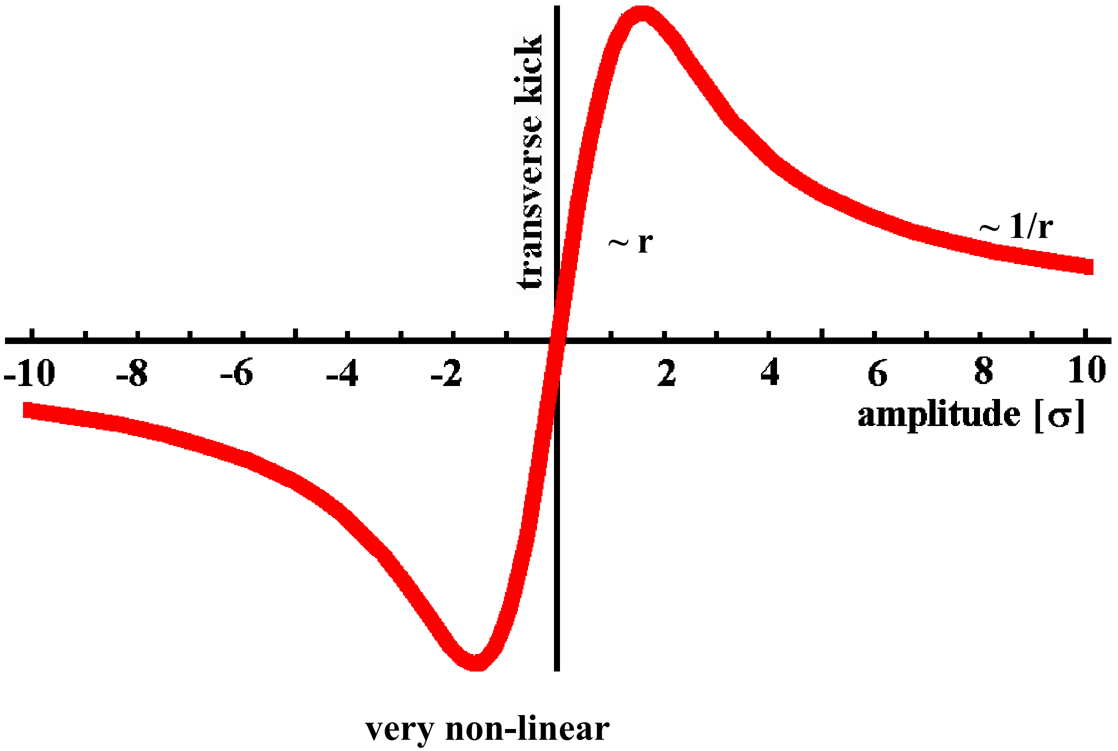
Operation: 55 p bunches/ring , ξ = **0.0015, 4 IPs,** $\Delta Q_{min} = 0.01$



New data taken 2 weeks ago, analysis to be done.

- Beam-beam interaction is an important consideration in the operation of RHIC
  - → Dominates beam lifetime with pp ($\tau \approx 15$ hrs), increases transverse emittance ($\Delta\varepsilon/\varepsilon \approx 4\%$ in 1st hr), leads to increased background (near 9th order resonances)
- For the first time coherent dipole modes were seen in a bunched beam hadron collider
  - → No instabilities observed so far
  - → Suppression by tune change effective (can be tested against simulation, not yet done)
  - → Coherent modes suppression may limit tune set points





$$\Delta r' = -\frac{N_b r_0}{\gamma r}\left(1 - e^{-r^2/2\sigma^2}\right)$$

Problems with:
– Different beam sizes
– Offsets, static and modulated
– Crossing angle and longitudinal offset