Long-range beam-beam compensation tests at RHIC

Wolfram Fischer

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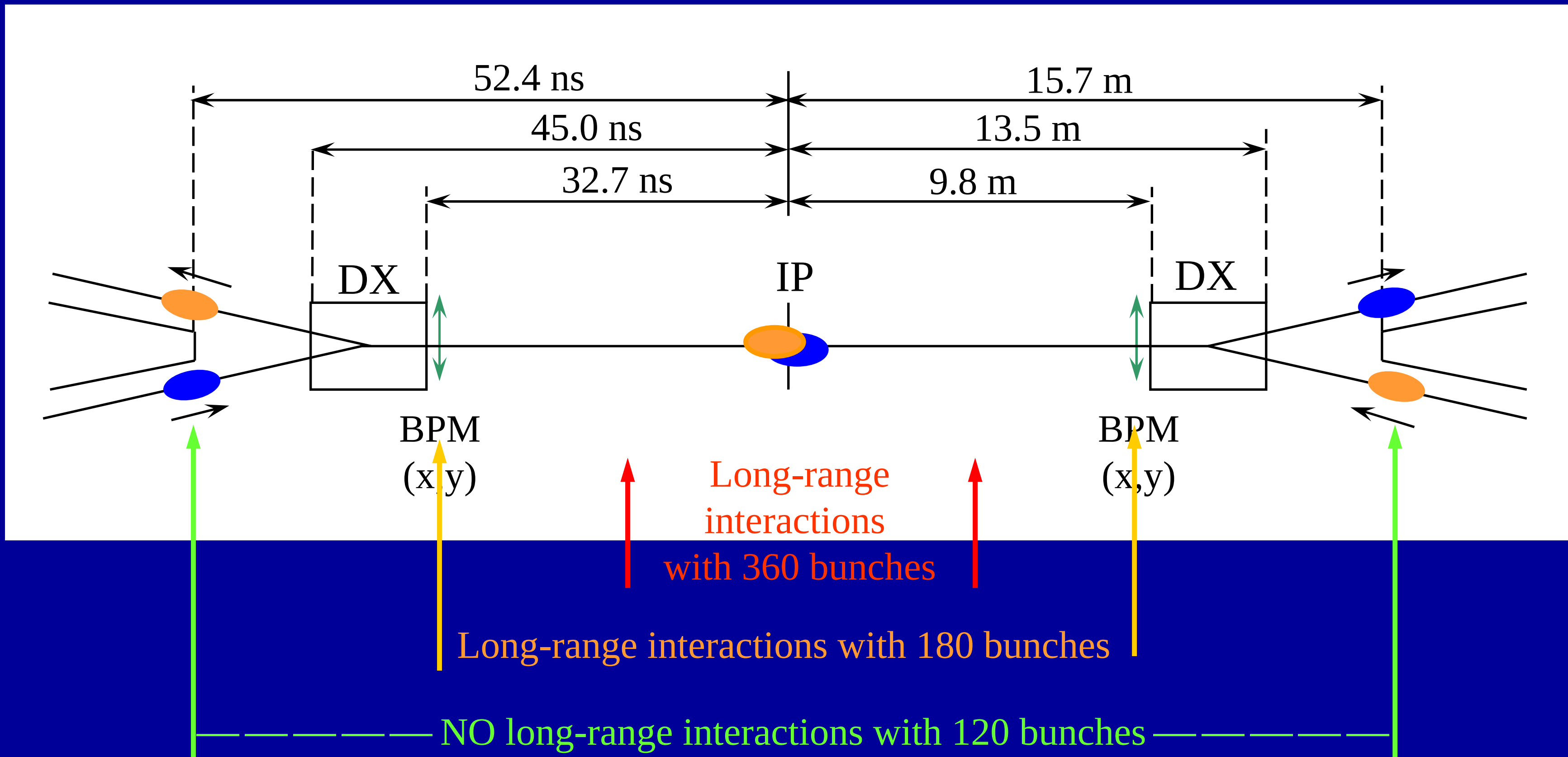
Content

- Long-range beam-beam effect in RHIC
- Beam tests so far (2005/2006)
- RHIC BBLR wires
- Planned beam tests with BBLR wires

RHIC interaction region

- Currently (120 bunches) no long-range interactions in store
- Can create 1 or 2 long-range interactions per IR
- With >120 bunches cannot avoid long-range beam-beam interactions
  (possible upgrades like eRHIC)

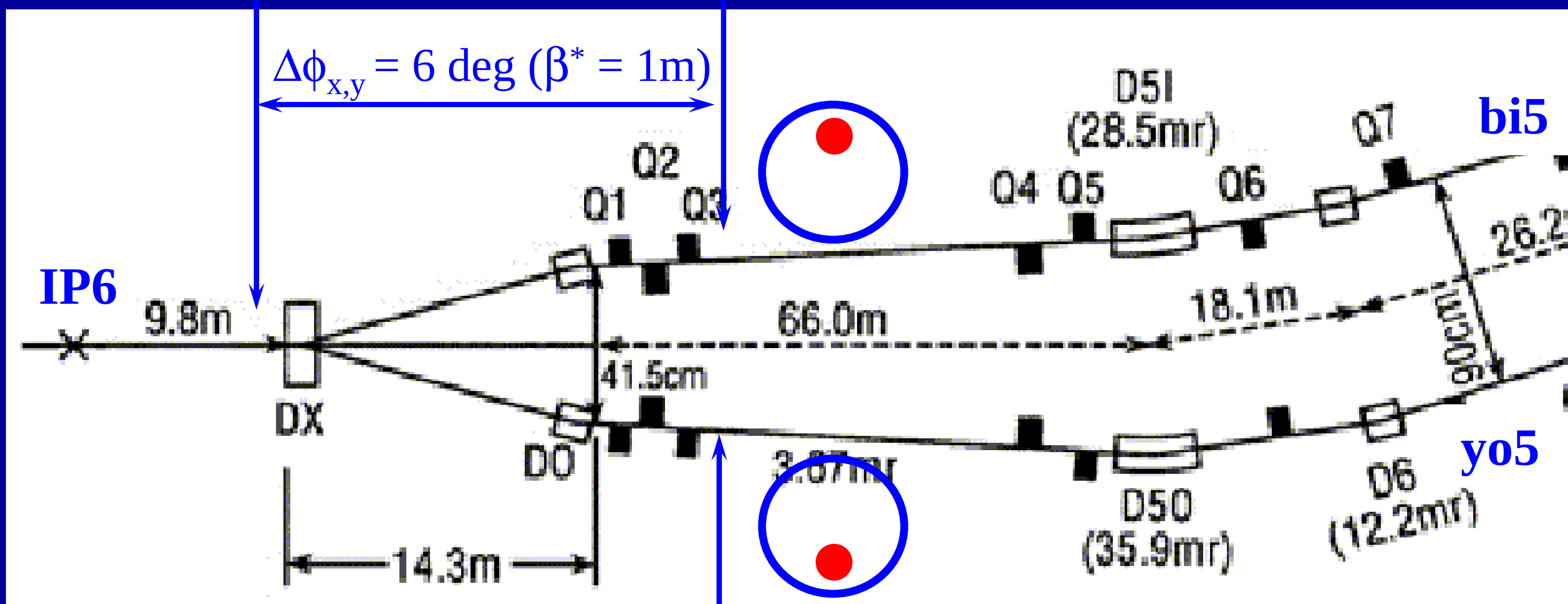


RHIC – possible location for compensation

long-range
interaction
(vertical)

long-range
compensation
(up)

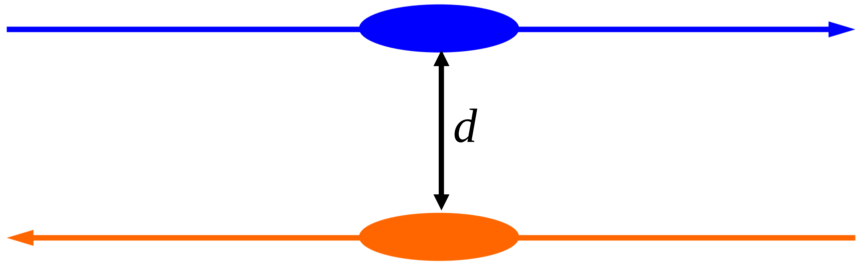
RHIC Sector 5



long-range
compensation
(down)

Small phase advance between long-range beam-beam interaction and possible compensator can only be realized at store.

Long-range beam tests in RHIC



Basic experiment:

1. Have large vertical separation in all IRs
2. Adjust rf to have LR interactions at desired location
3. Change vertical separation by moving one beam
4. Observe beam lifetime of other beam

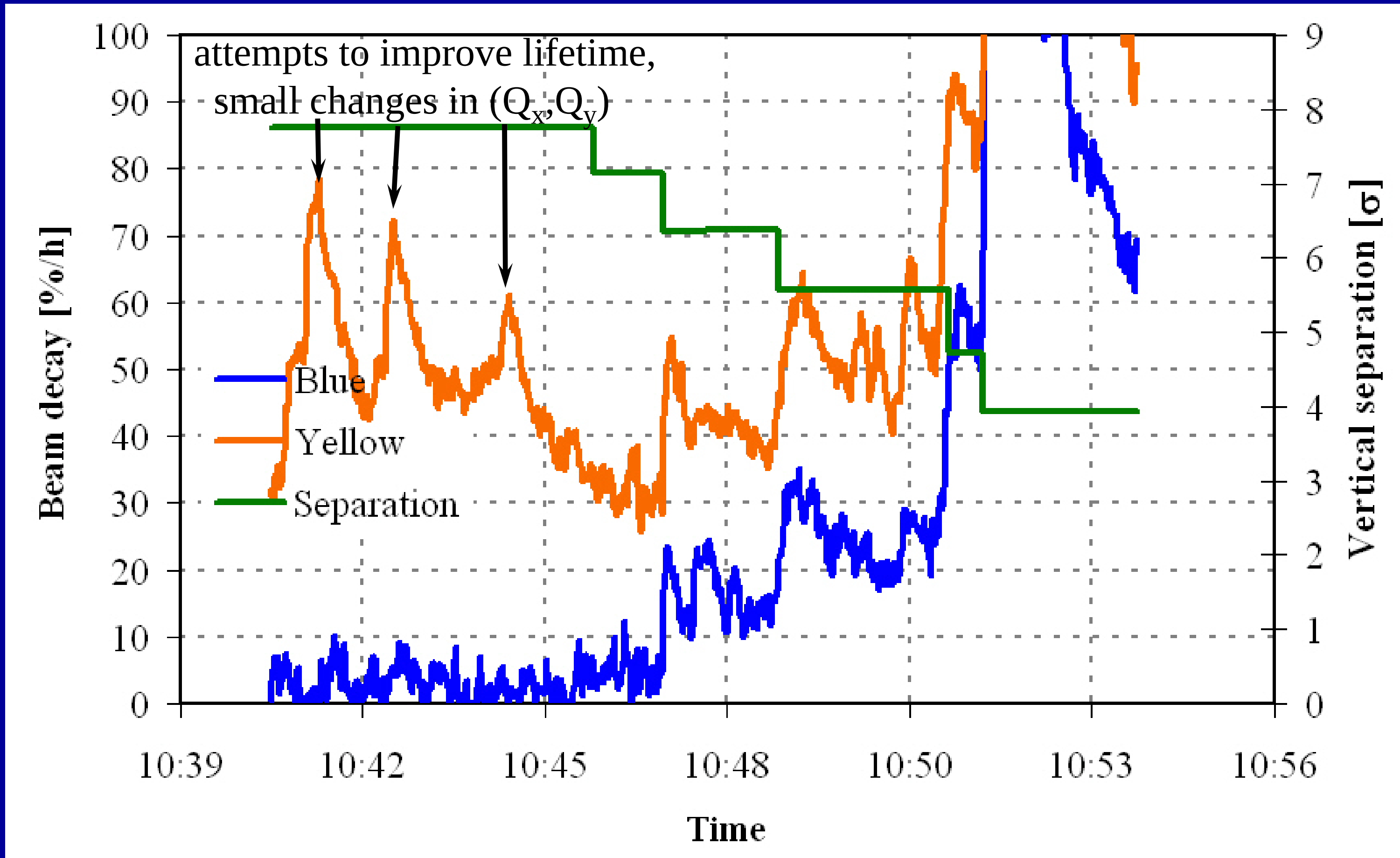
Comments:

- Beam lifetime most sensitive observable (almost no other)
- Need DCCT and multiple bunches for good measurement
  [single bunch intensity measurement from WCM too noisy]

Single LR effect at injection (24 GeV p)

Collision at s = 10.6 m, Blue beam moved vertically

Tunes B (0.739,0.727) Y (0.727,0.738)



Effect well observable at injection. (Compensation not possible at injection due to large phase advance across triplet.)

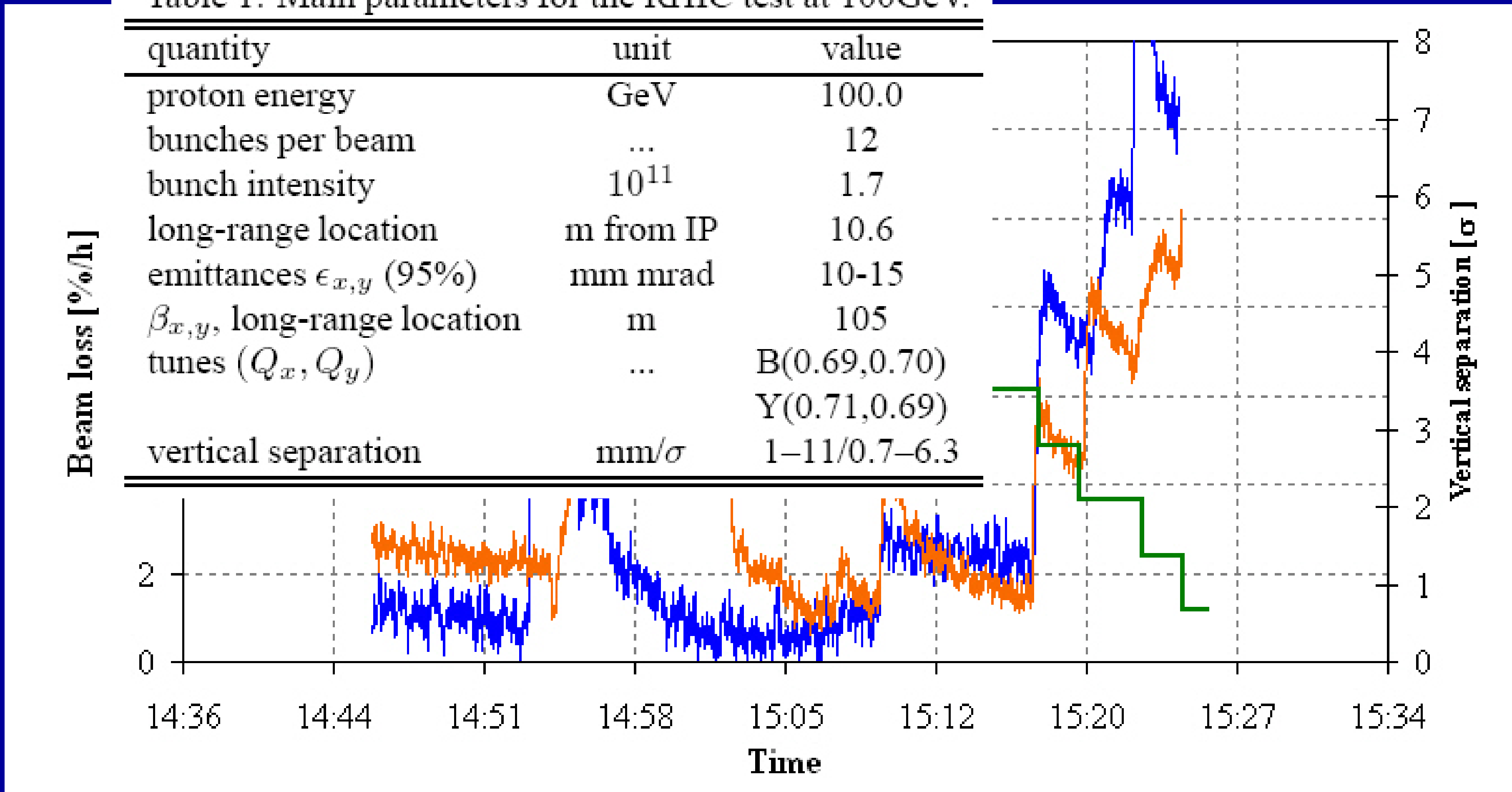
Single LR effect at store (100 GeV p)

Collision at s = 10.6 m, Yellow beam moved vertically (after 15:00)

Tunes

Table 1: Main parameters for the RHIC test at 100GeV.

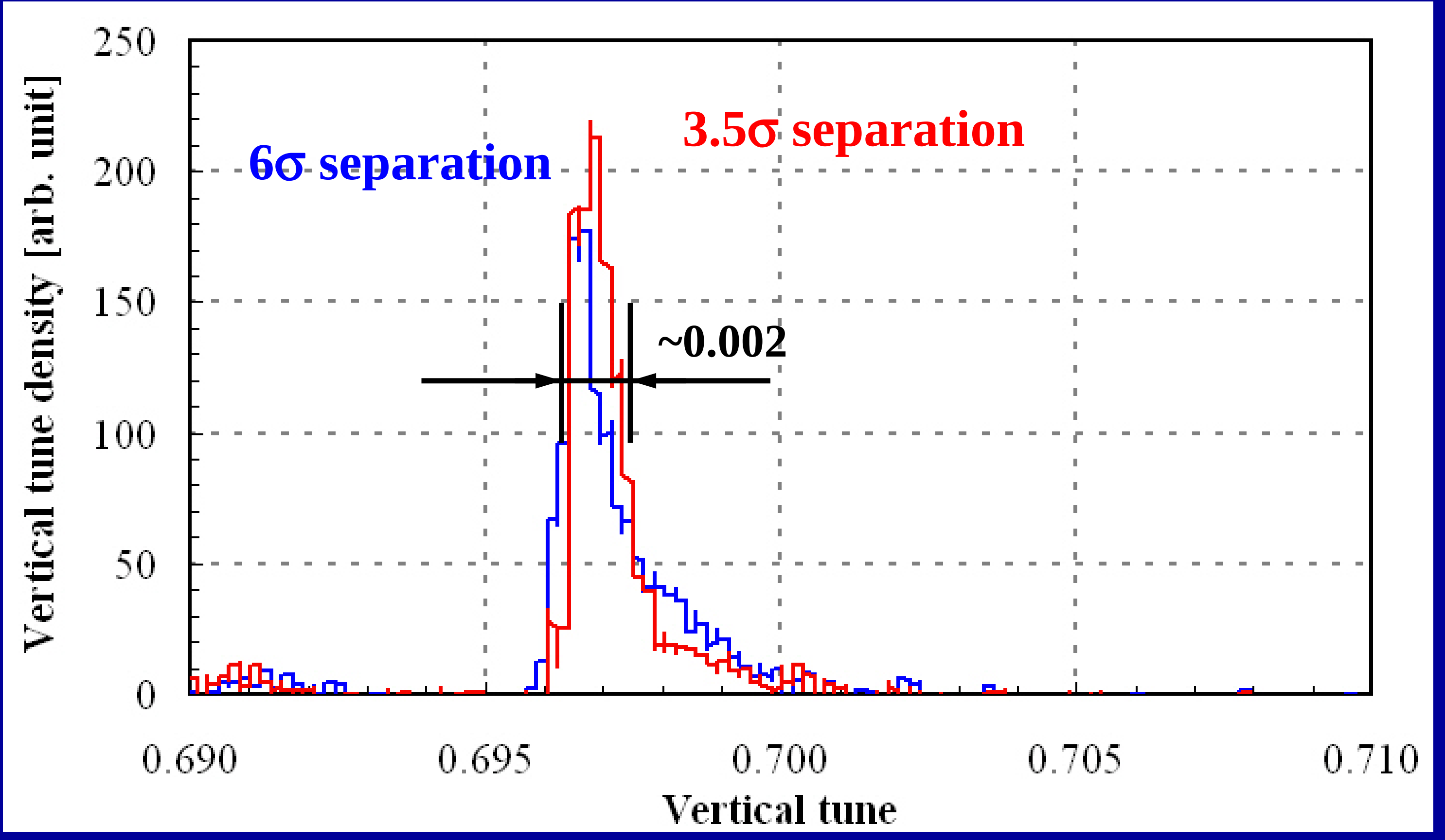
quantity	unit	value
proton energy	GeV	100.0
bunches per beam	...	12
bunch intensity	10^{11}	1.7
long-range location	m from IP	10.6
emittances $\epsilon_{x,y}$ (95%)	mm mrad	10-15
$\beta_{x,y}$, long-range location	m	105
tunes (Q_x, Q_y)	...	B(0.69,0.70)
		Y(0.71,0.69)
vertical separation	mm/σ	1–11/0.7–6.3



Conditions found after tune scan. Additional octupoles on in Yellow.

Single LR effect at store (100 GeV p)

Blue vertical tune distribution from BTF measurement.
(Yellow beam was moved – Blue is the probe.)



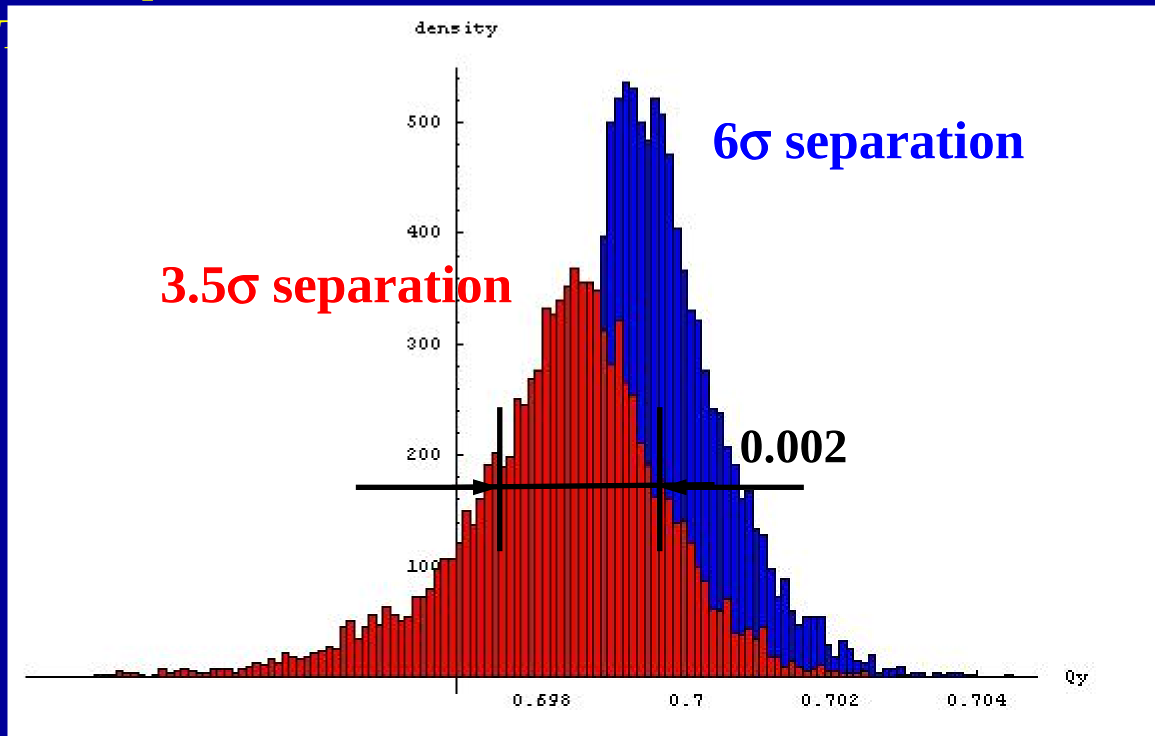
[Hardware for BTF measurement part of the Q&ΔQ_{min}-feedback system – P. Cameron et al.]

Single LR effect at store (100 GeV p)

Calculated Blue tune distributions including:

- long-range beam-beam
- amplitude dependent tune shift from nonlinear IR magnet errors
  (up to 2nd order in action – from tracking model, Y. Luo)
- nonlinear chromaticity and momentum spread
  (up to 3rd order in δp/p – Harmon, S. T

Random points in (x,y,δp) from Gaussian distributions, tune calculation and sorting into histogram (Mathematica)

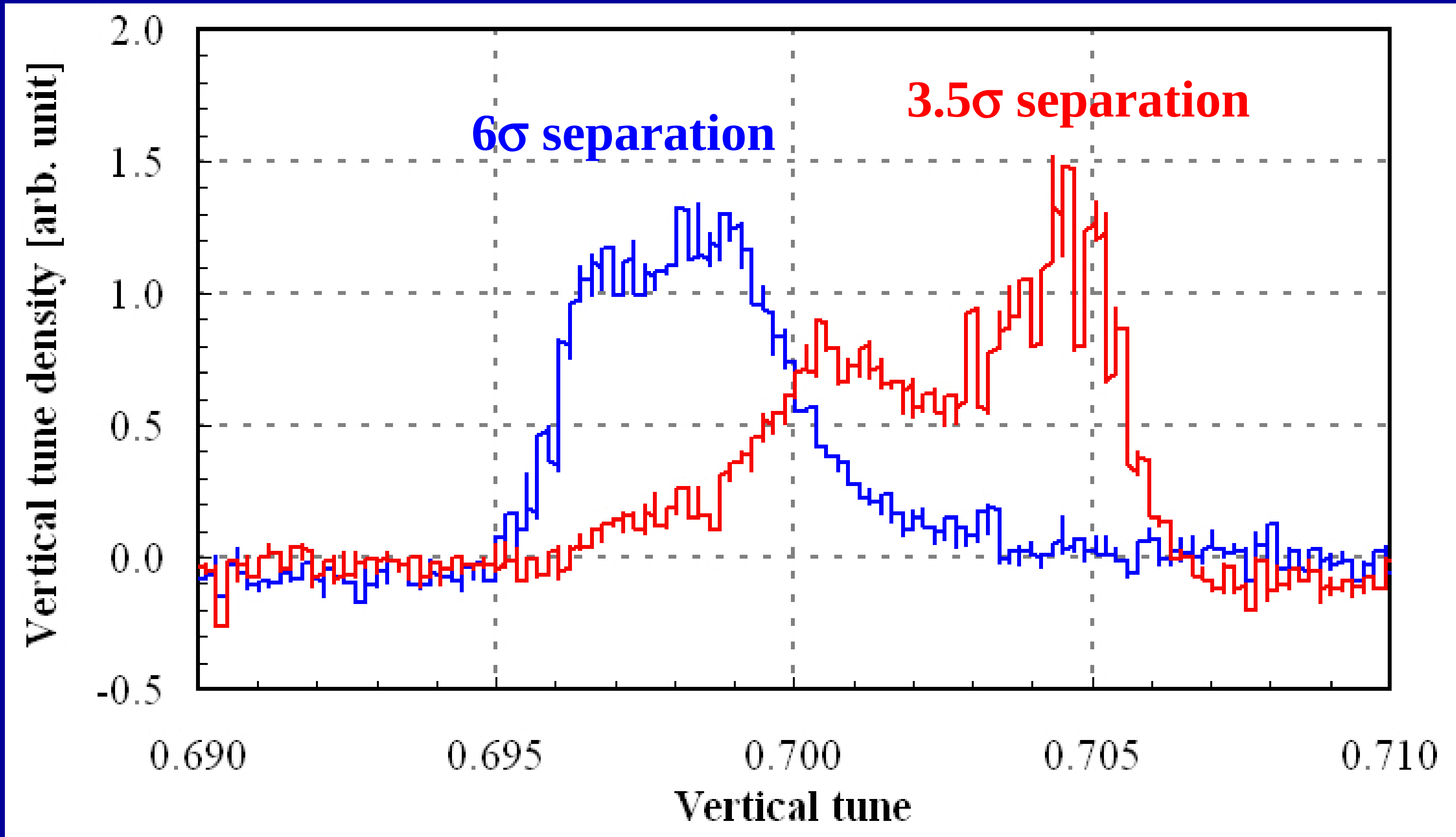


Width of tune distribution reproduced, but not details

[BTF tune step size, BTF noise, BTF phase offset, model not accurate enough, …]

Single LR effect at store (100 GeV p)

Yellow vertical tune distribution from BTF measurement.
(Yellow beam was moved, additional arc octupoles on.)



ε-growth simulations

Conditions:

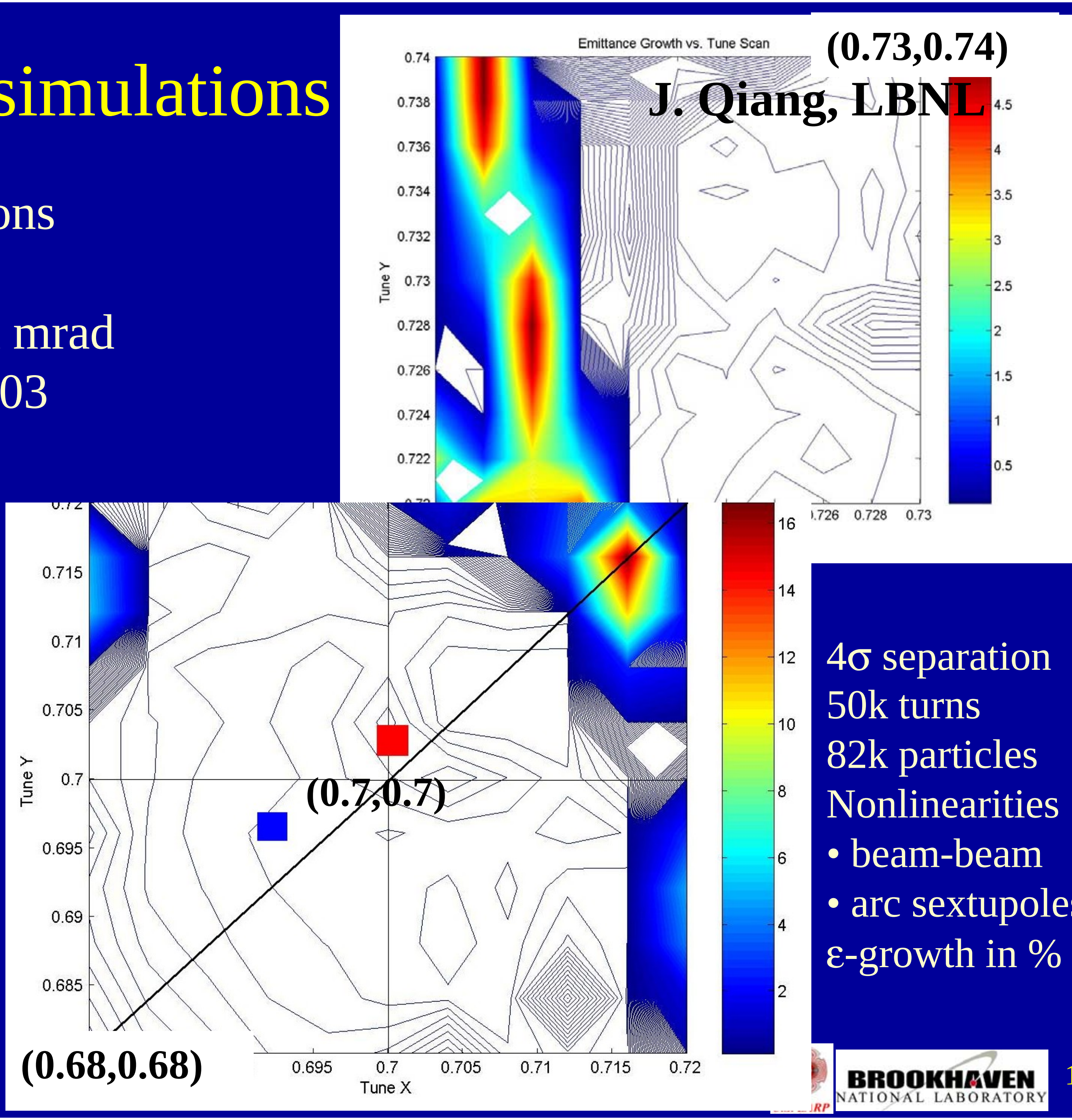
100 GeV protons

$N_b = 2\times10^{11}$

$\varepsilon_{n,rms}$ = 15 mm mrad

$(\delta p/p)_{rms} = 0.003$

$(\xi_x,\xi_y) = (2,2)$



4σ separation

50k turns

82k particles

Nonlinearities

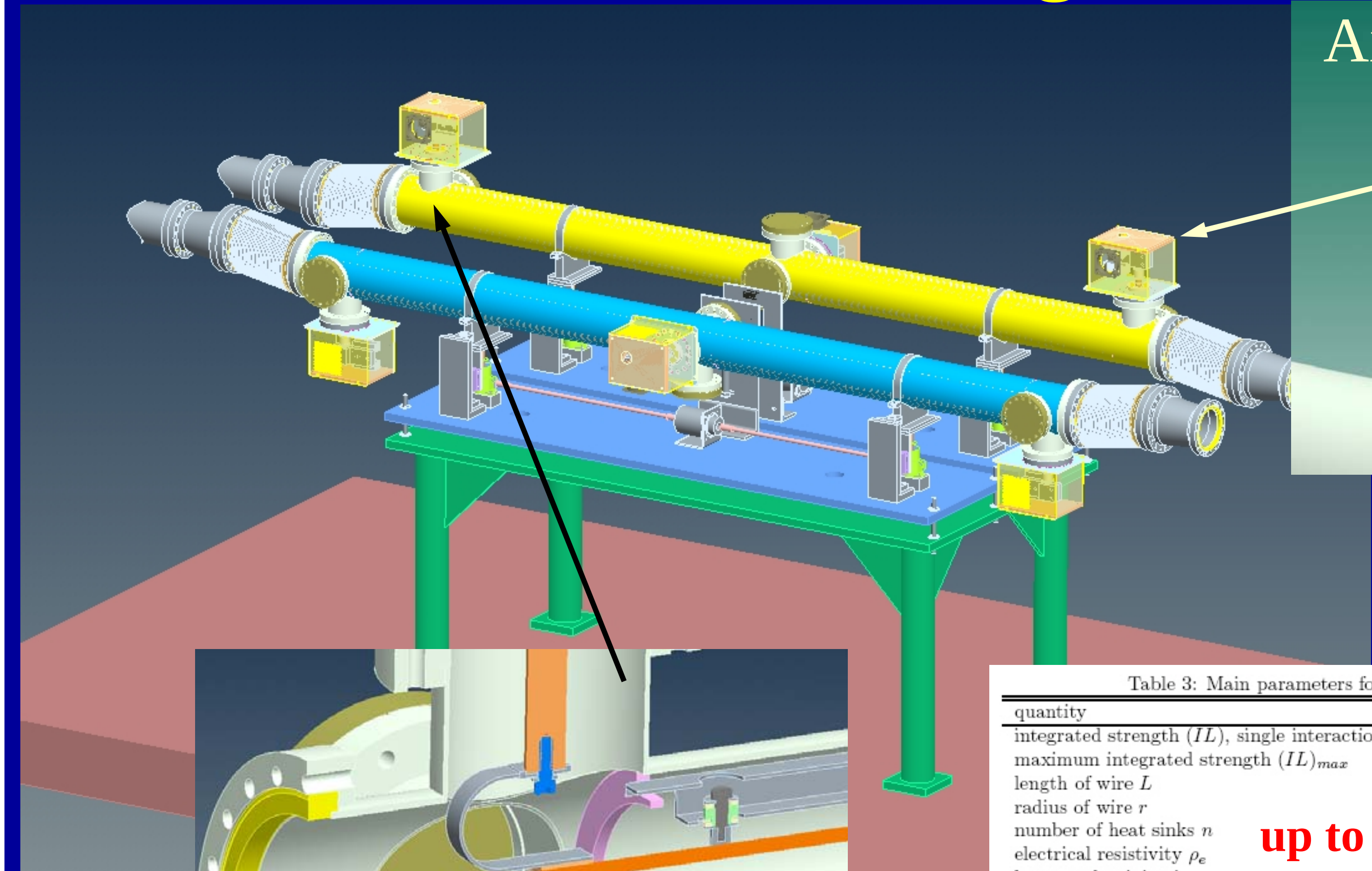
- beam-beam
- arc sextupoles

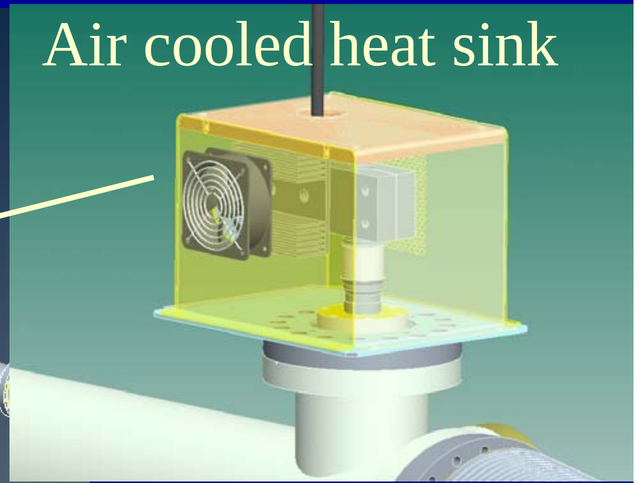
ε-growth in %

RHIC BBLR wires – design criteria

- Location in the ring
  → After Q3 in experimental IR (phase advance)
- Integrated strength
  → 10 Am for single LR, designed for 125Am (1× LHC strength)
- Wire temperature
  → < 100°C for vacuum (air cooled, 3 heat sinks, also NEG coated), allow for thermal expansion
- Positioning range and accuracy
  → wire in shadow of adjacent beam pipe if not in use, approach beam to $< 3\sigma$
  (65mm vertical range, accuracy of 0.2 mm $\approx 0.03\sigma$)
- Power supply requirements
  → $I_{rms}/I < 10^{-4}$ (simulations F. Zimmermann, ε-growth calculations)
- Controls and diagnostics
  → Local PIN diodes for loss observation

RHIC BBLR wires – design





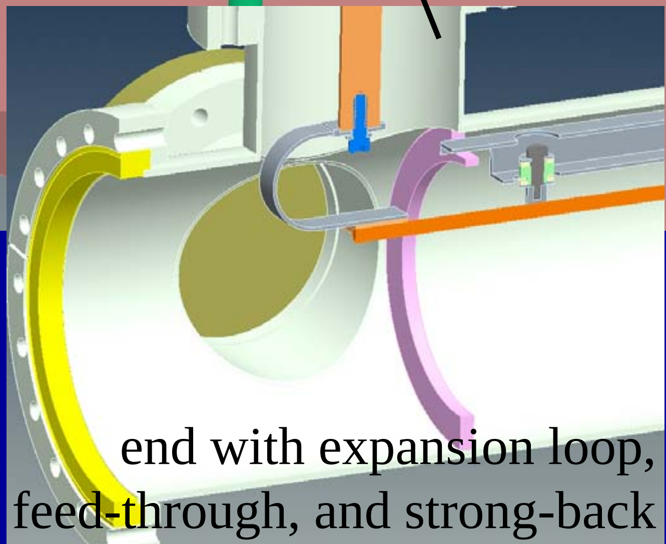


Table 3: Main parameters for RHIC long-range beam-beam compensators.

quantity	unit	value	comment
integrated strength (IL), single interaction	Am	9.6	
maximum integrated strength $(IL)_{max}$	Am	125	
length of wire L	m	2.5	
radius of wire r	mm	3.5	
number of heat sinks n	...	[illegible]	at both ends and in middle
electrical resistivity ρ_e	Ωm	1.72×10^{-8}	Cu (at 20°C)
heat conductivity λ	$\mathrm{Wm^{-1}K^{-1}}$	384	Cu (at 20°C)
density ρ_g	$\mathrm{kg/m^3}$	8.96×10^3	Cu (at 20°C)
thermal expansion coefficient	$\mathrm{K^{-1}}$	1.68×10^{-5}	Cu (0 to 100°C)
melting temperature	K	1083	Cu
radius of existing beam pipe r_p	mm	60	
current in wire I, single interaction	A	3.8	
maximum current in wire I_{max}	A	50	
electric resistance R	mΩ	1.12	
maximum voltage U_{max}	mV	55.9	
maximum dissipated power P_{max}	W	2.8	
maximum temperature change ΔT_{max}	K	15	
maximum change in length ΔL_{max}	mm	0.4	
vertical position range	mm	65	
vertical position range	σ_y	10.6	for $\gamma = 107$, $\beta^* = 1$ m, and $\epsilon_n = 20$ mm·mrad
weight of wire G	kg	0.9	

up to 1× LHC BBLR strength

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RHIC BBLR wires – assembly

NEG coated chambers
during assembly

wires (2.5m long) with
strong-back (-profile)
7 support points

RHIC Accelerator Physics Experiments

- 12h/week when running for physics
  (for 2007: ~10 weeks Au-Au, ~8 weeks p↑-p↑ or d-Au,
  — no budget passed yet by US Congress)

- Proposal submission, reviewed by committee, scheduled by APEX coordinator

- Had ~3×3 hours in 2006 for LR BB studies

- Not yet clear if operation with p↑ in 2007
  (beam-beam parameters of ions ~2× smaller)

Planned test with RHIC BBLR wires

1. Better signal from LR interaction
   (include head-on BB as another nonlinearity)

2. RHIC BBLR wire commissioning
   (may be partially parasitic to operation)

3. Use wires to simulate LHC-like conditions
   (wires designed for LHC strength, beam lifetime better than in SPS tests)

4. Test compensation of single LR interaction
   (in presence of head-on collision)

5. Test pulsed power supply [not yet in 2007]
   (confirm that beam lifetime is not negatively affected)

Summary – long-range beam-beam in RHIC

- Long-range beam-beam conditions in RHIC:
  - Can create up to 2 long-range interaction per IR
  - Can potentially compensate single LR interaction at store
- Beam tests so far [2005/2006 with protons]:
  - Measurable effect of single LR at injection (24 GeV)
  - Smaller effect at store (100 GeV), still measurable
- RHIC BBLR wires to be installed this week
- LHC relevant tests with RHIC BBLR wires are:
  - Test close to nominal LHC BB conditions before LHC [not possible in any other machine]
  - Test compensation of single LR BB interaction
  - Test pulsed power supply