Transition Jumps in RHIC & MI

M. Bai & S. Peggs

First order jump design – Peggs

Performance in RHIC – Bai

Conclusions

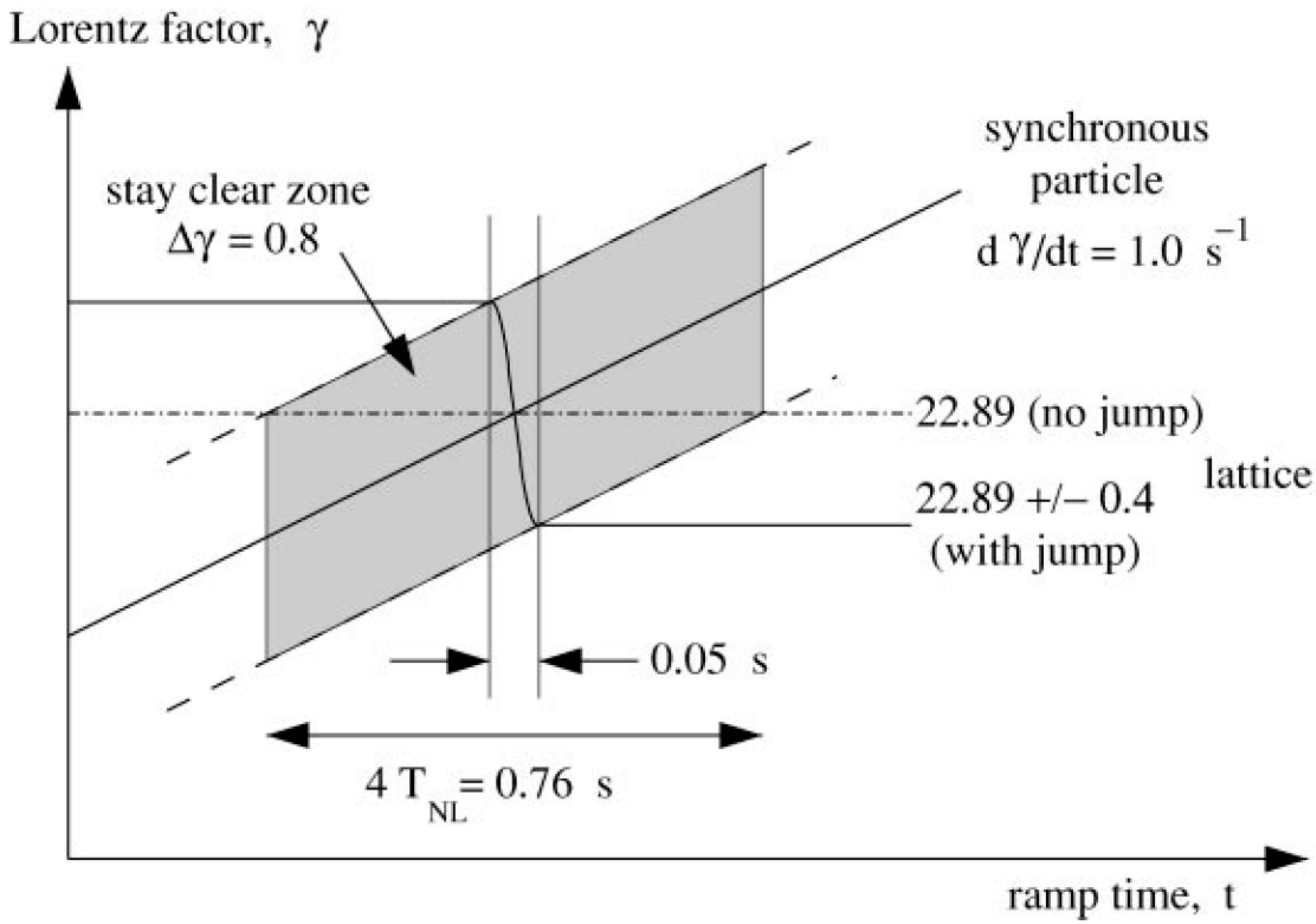
Special thanks to: W.Chou, W.Fischer, J.Johnstone, J.Kewisch, N.Malitsky, C.Montag, V.Ptitsyn, S.Tepikian, D.Trbojevic

Jump design

How big, how fast?

Original RHIC design specs

SLOW acceleration (SC magnets)



First order [Risselada 1990]

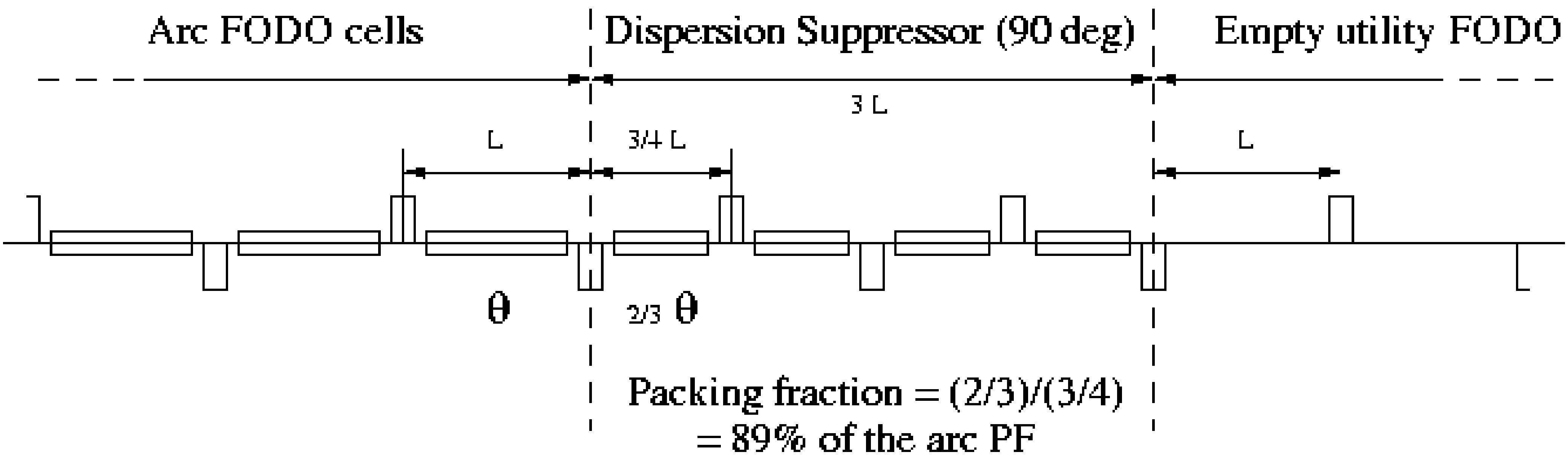
$$\Delta\gamma_T = \frac{\gamma_T^3}{2C} \sum_i q_i \eta_i^2$$

Where

q_i is jump quad strength

η_i is dispersion

Modular optics

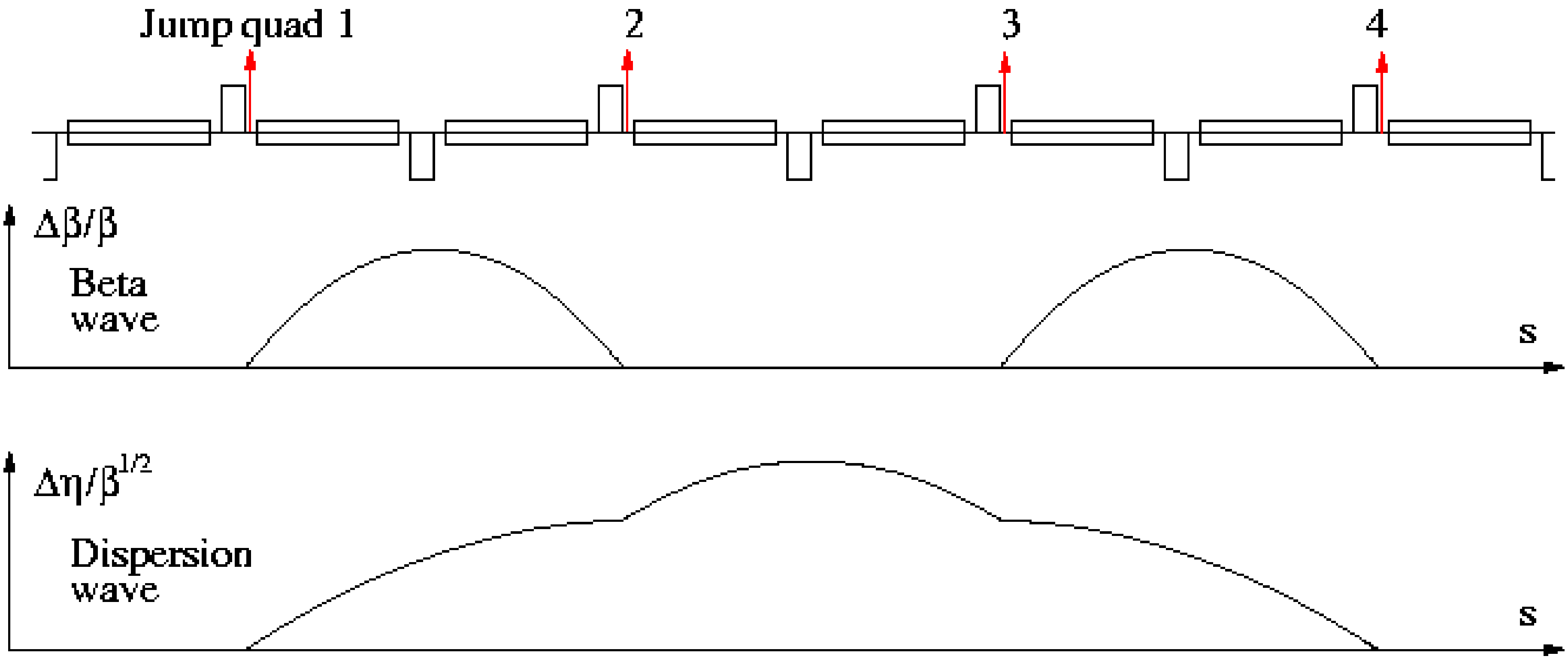


Modular optics have the fewest magnet types & power supplies, ultimately smooth optics, small circumference, design flexibility.

First order jumps integrate cleanly with FODO modules near 60, 72, 90 degrees

Main Injector optics are more rigorously modular than RHIC. The MI jump will work better than RHICs.

Closed perturbation waves

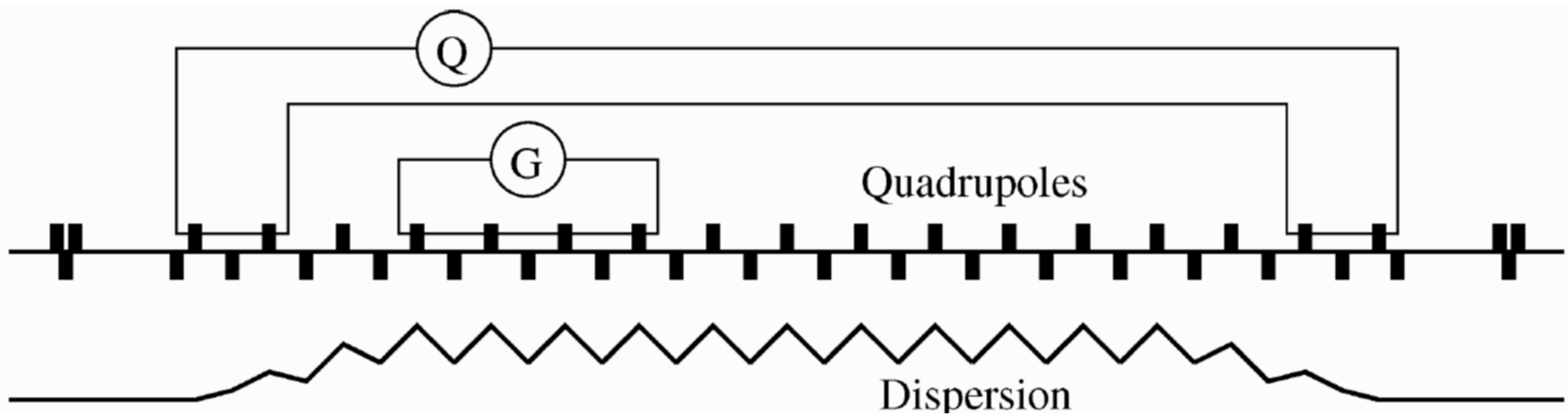


Beta waves advance twice as fast as dispersion waves

Pairs of jump quad doublets confine dispersion

Real phase advances are never exactly 90 degrees

RHIC implementation



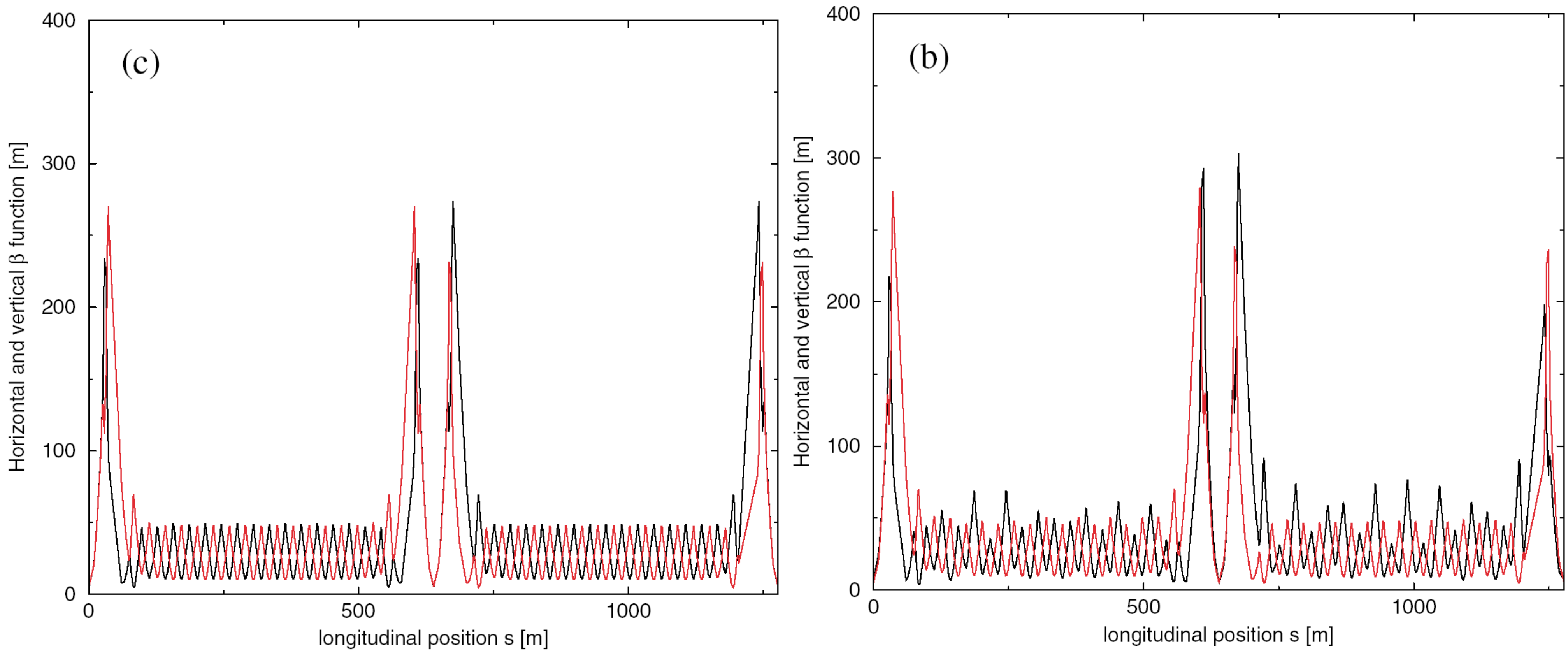
G families change γ_T, Q families compensate tunes

Unoptimized optics:

1) some dispersion leaks into the Q family
2) phase advances are not constant, or near 90 degrees

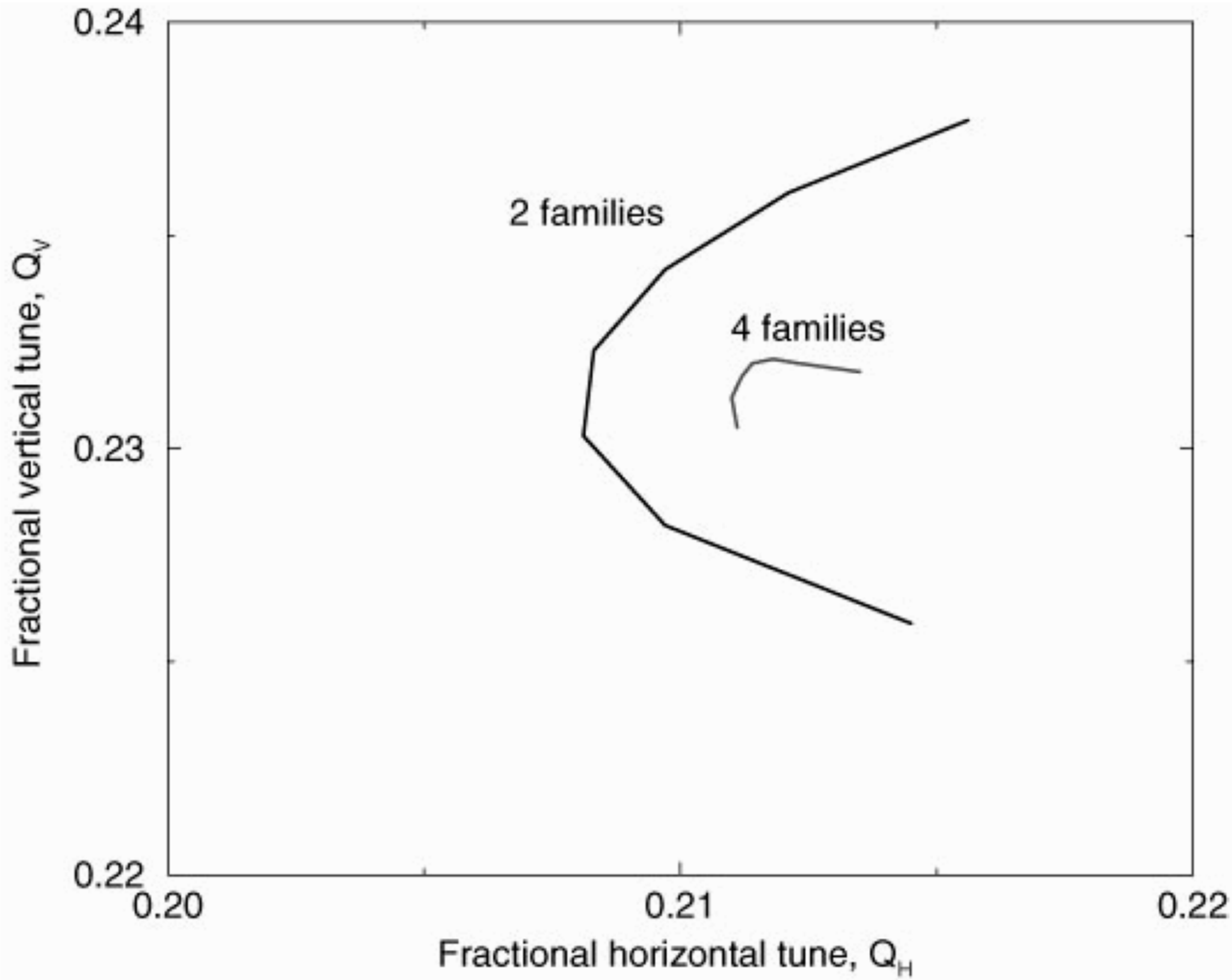
RHIC optics distortions

$\Delta\gamma_T = 0$ $\Delta\gamma_T = -0.5$



Beta waves leak, but not badly, in the original design
[Montag & Kewisch, PRST Vol 7 2004]

RHIC tune control (design)
in the range $-0.5 < \Delta\gamma_T < 0.5$



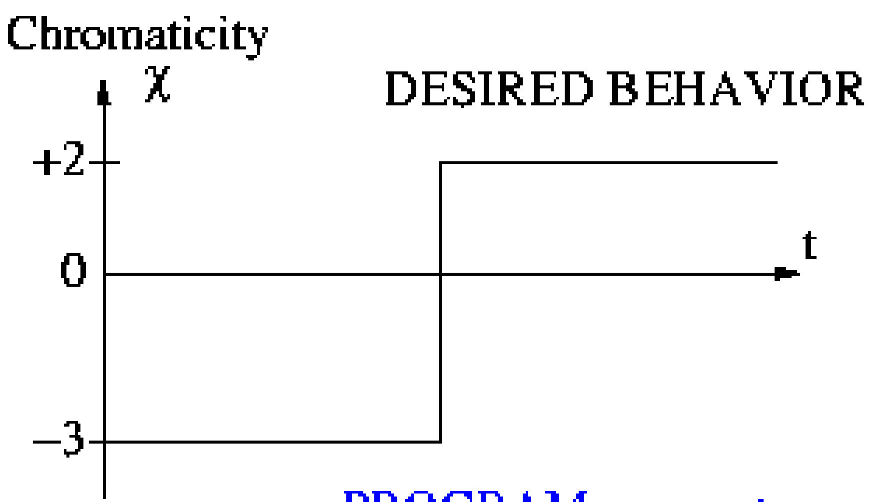
Second order effects are not negligible

4 families are better than 2 !

Scale ~ .01

Diagnosis with beam is non-trivial!

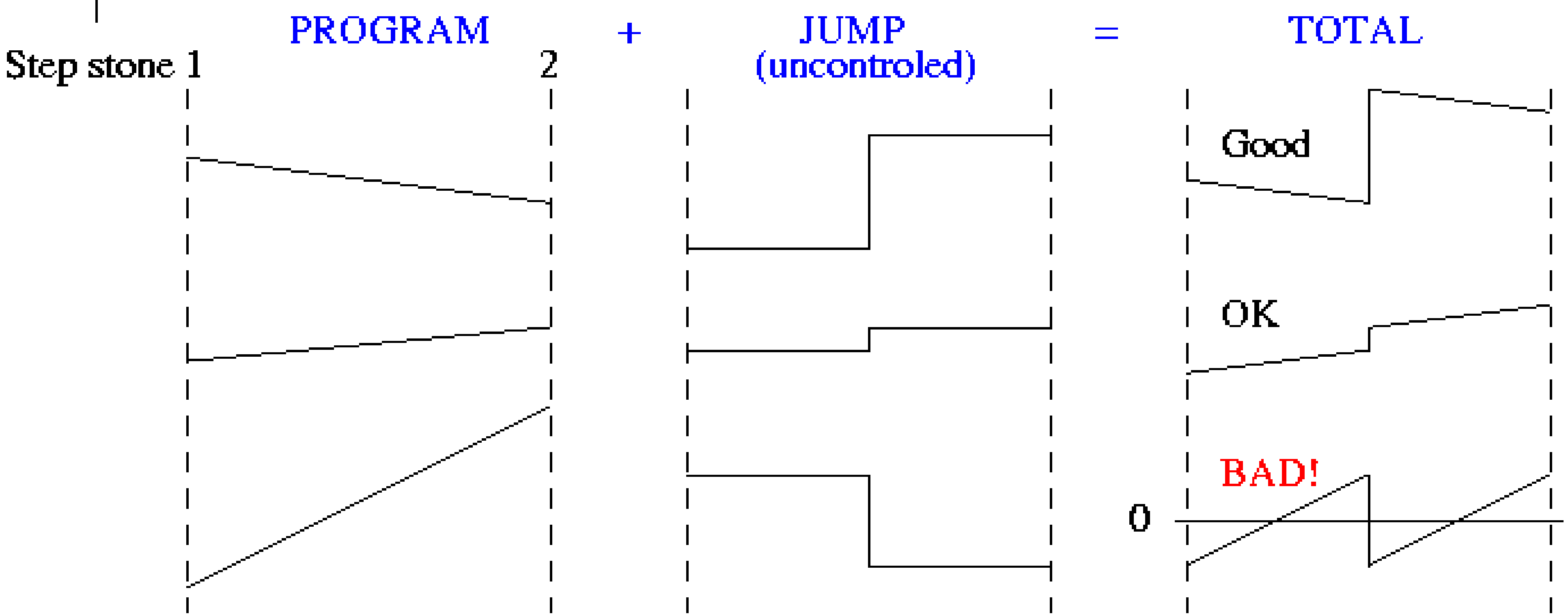
Chromaticity jump



RHIC may cross zero 3 times in current (evolved) optics!

Original design did not do this

Fast measurements difficult!

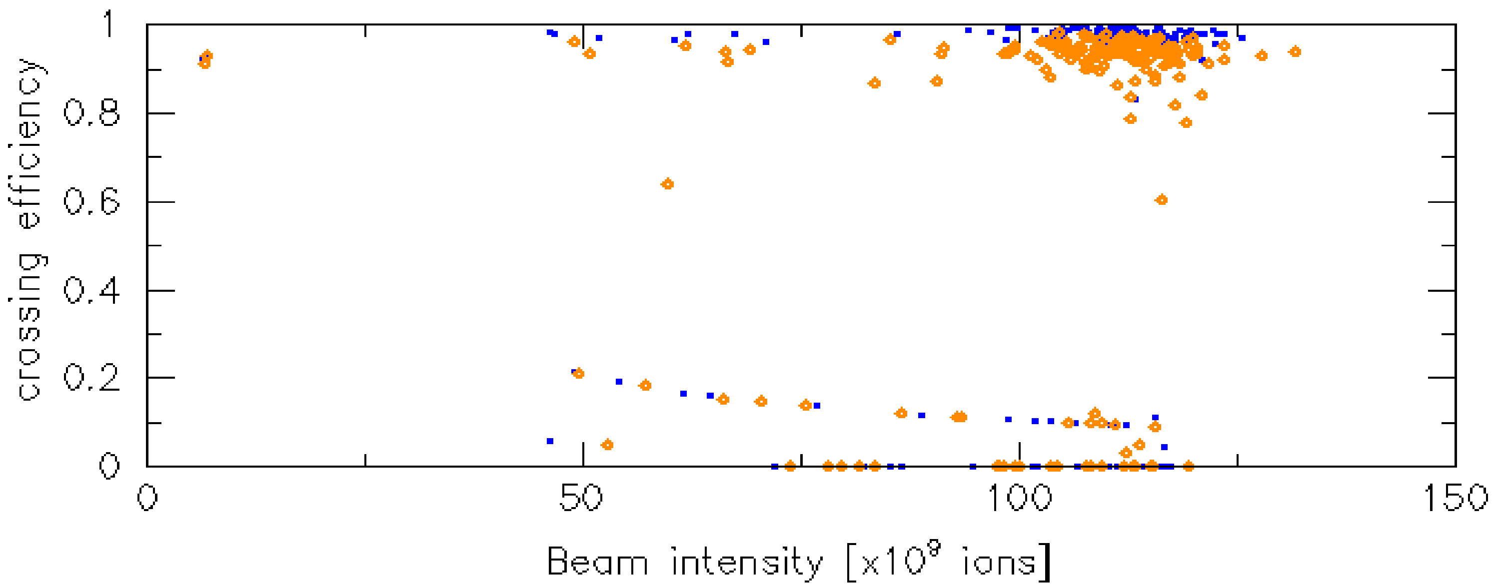


Performance in RHIC

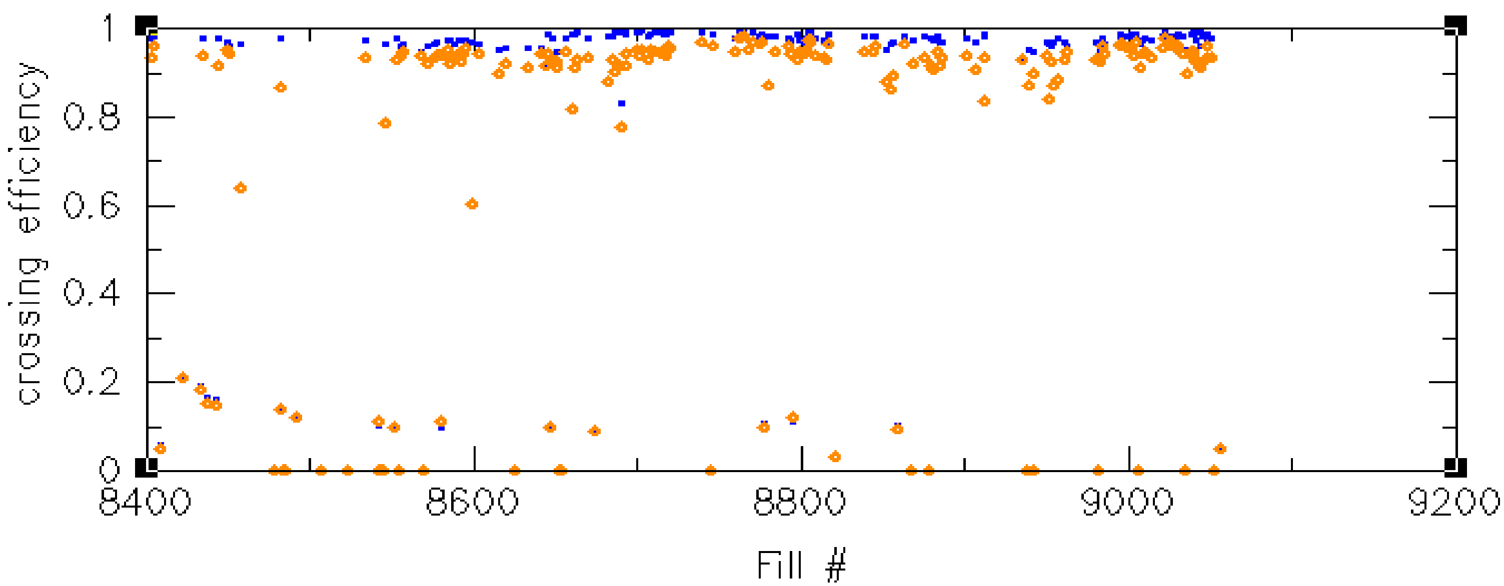
The gamma-T jump works!

Blue & Yellow crossing efficiencies reach 98% & 94%

NO strong correlation with the total beam intensity



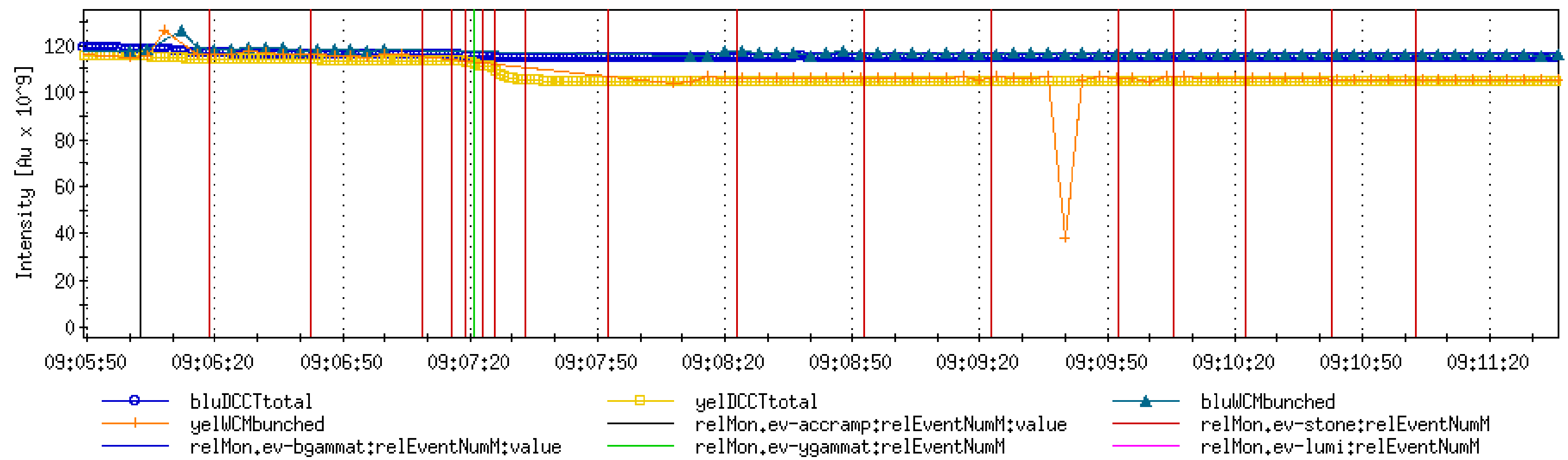
2007 Au run

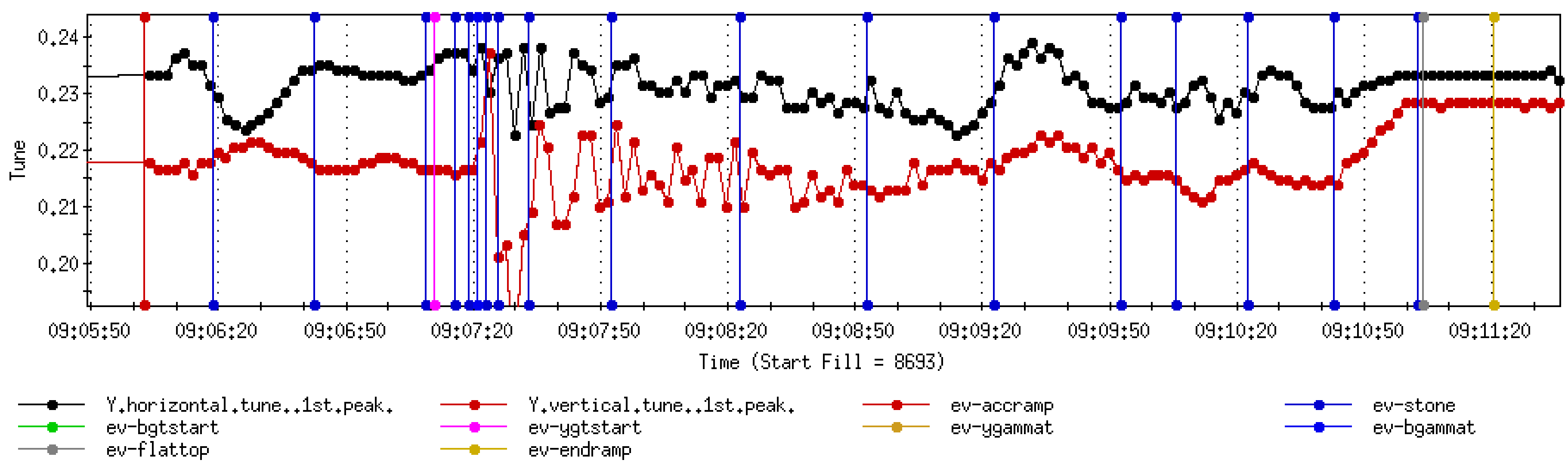


However, ...

Tune swing at transition
causes beam loss

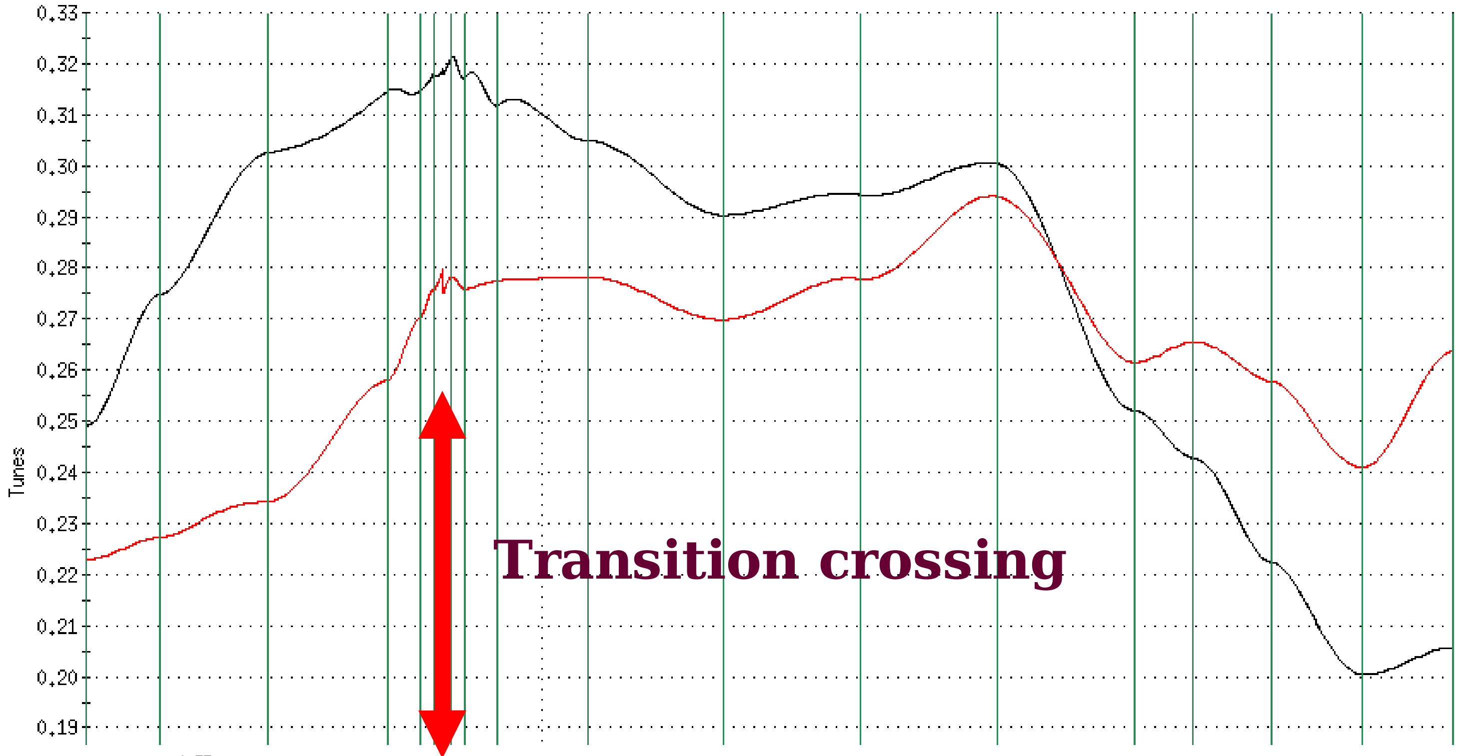
Current optics are not optimized for transition! Worse for Yellow.



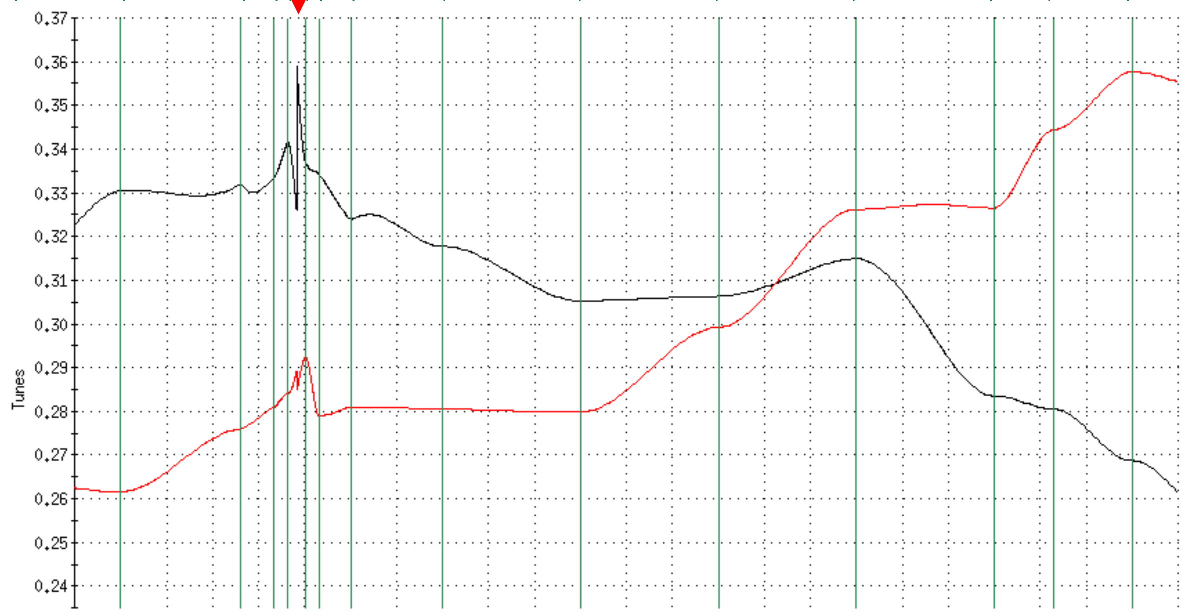


Ramp tune settings

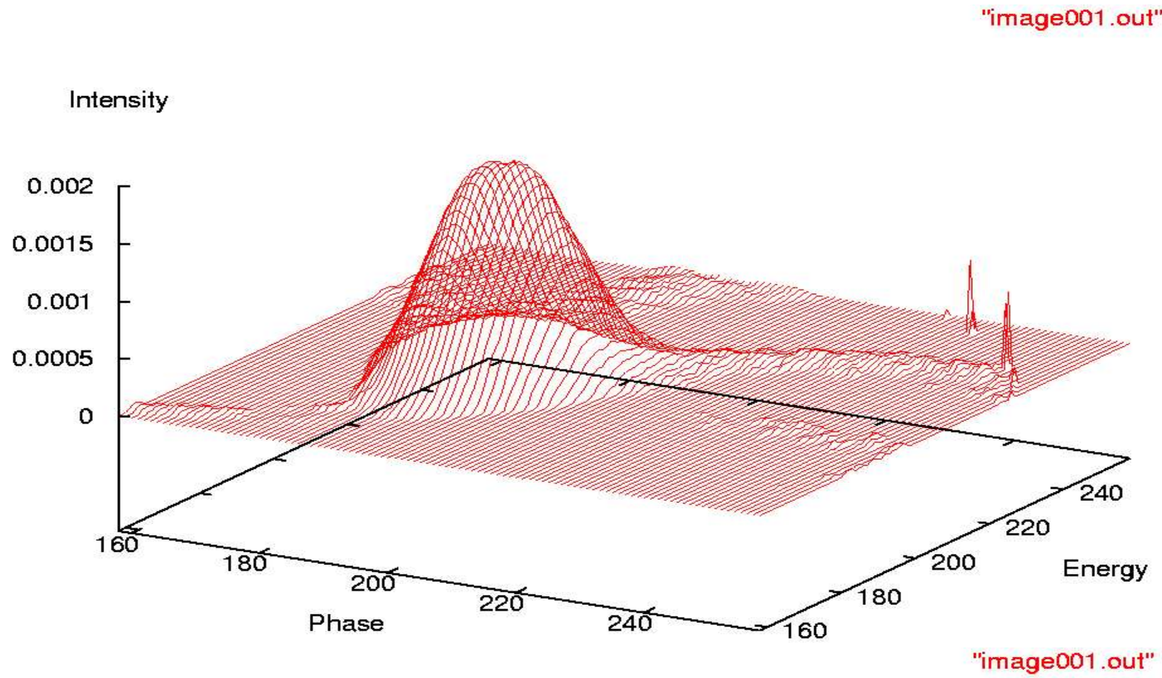
BLUE

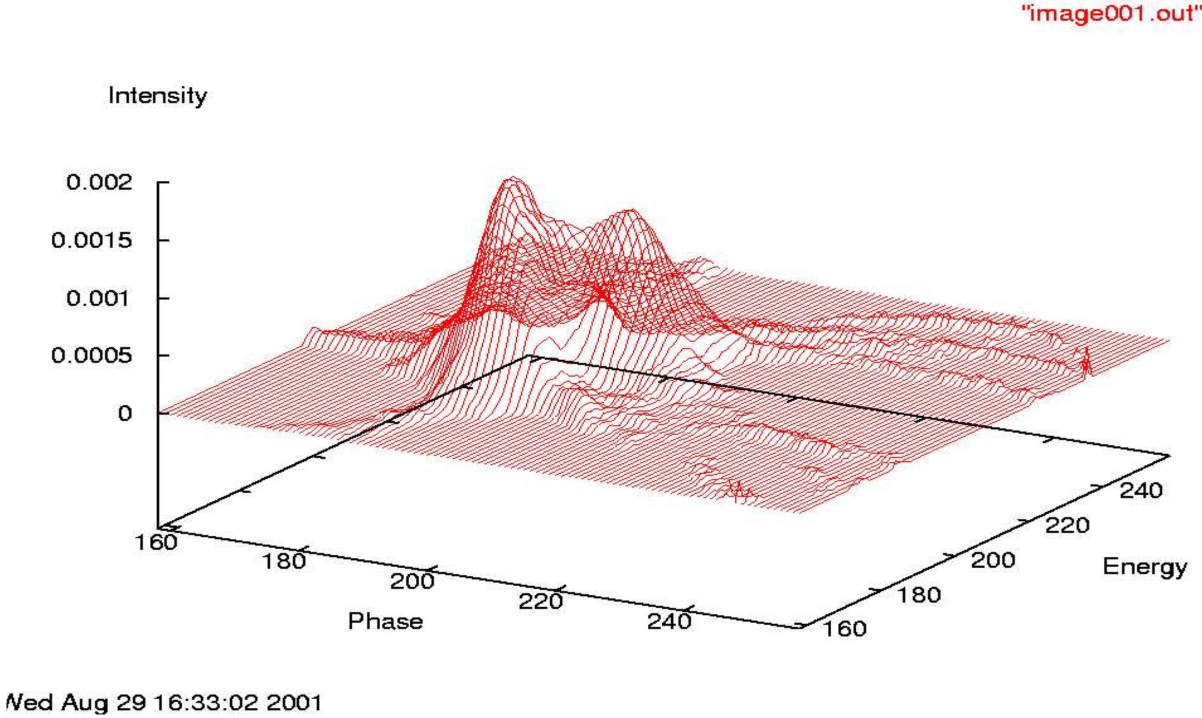


YELLOW



Transverse instability
causes transverse emittance growth





Tomographic reconstruction of 2D bunch density

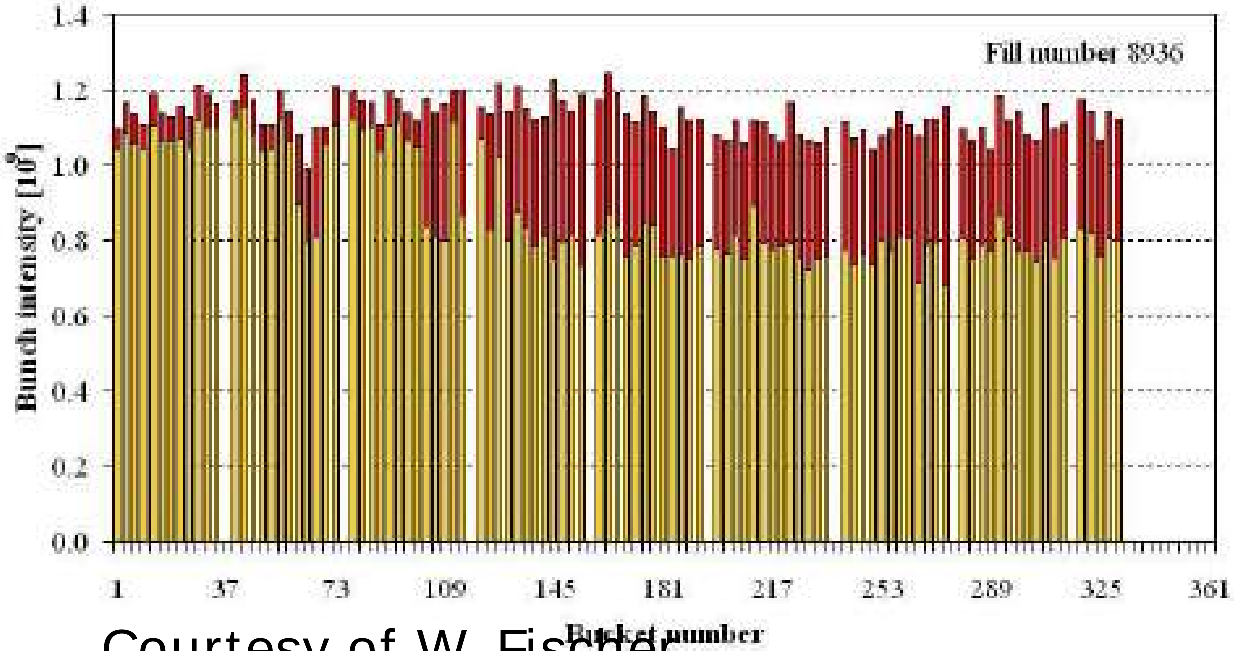
TOP: Before instability

BOTTOM: After instability with ~ 10 ms growth rate

Electron cloud hypothesis

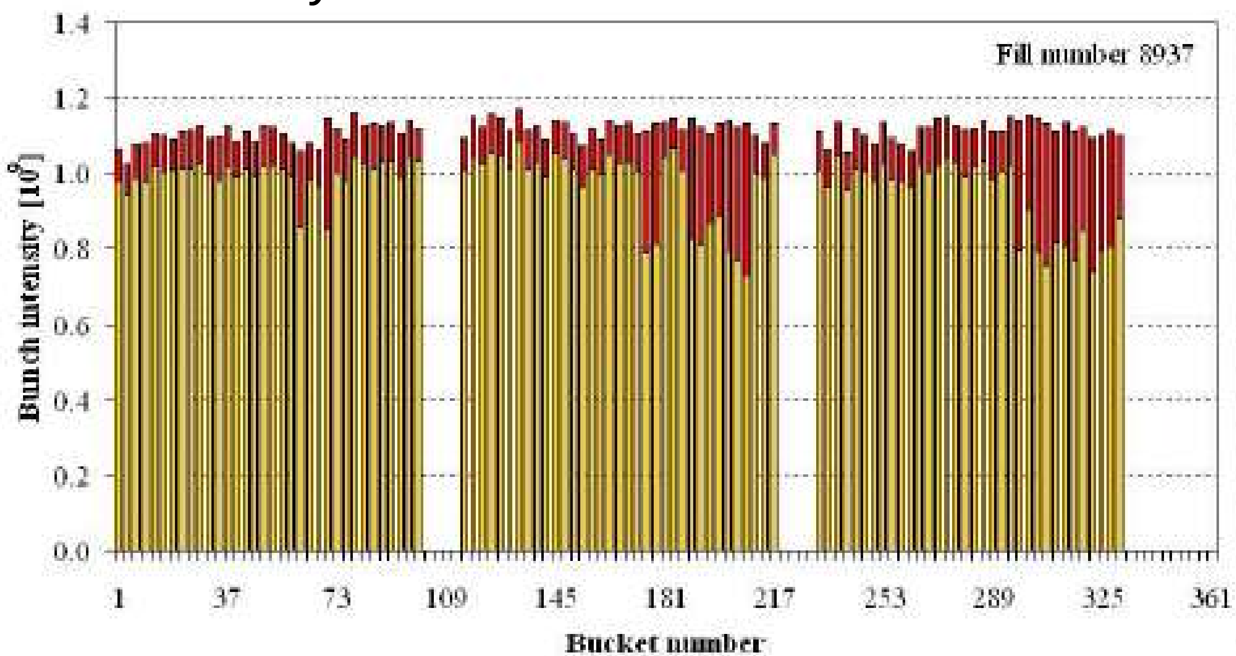
More transition losses close to bunch train ends ….

Pattern 1



Courtesy of W. Fischer

Pattern 2

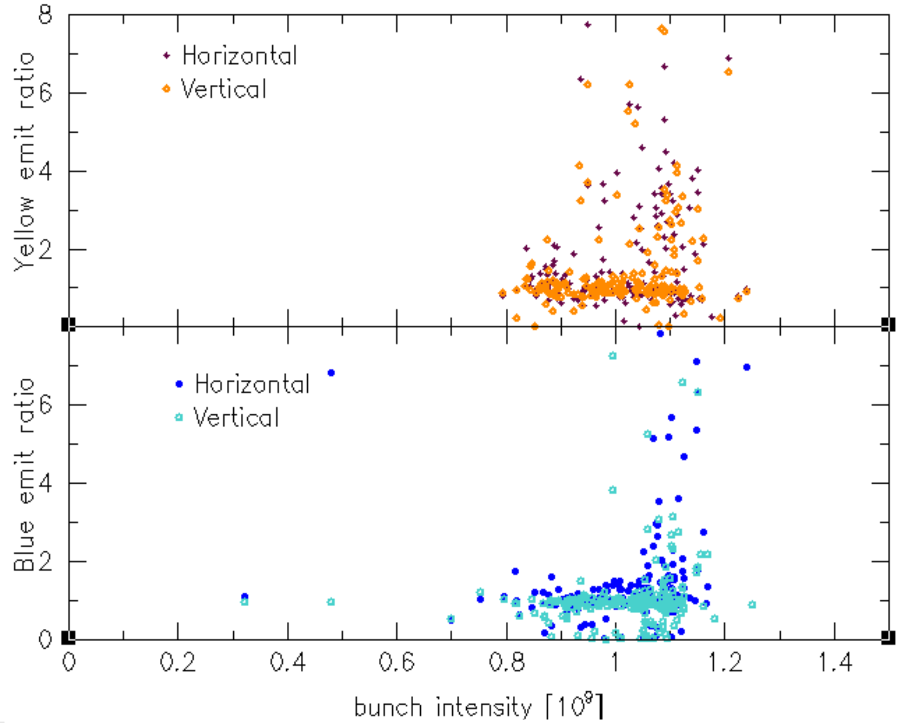


Emittance growth across transition

… but no clear correlation with bucket location in train!

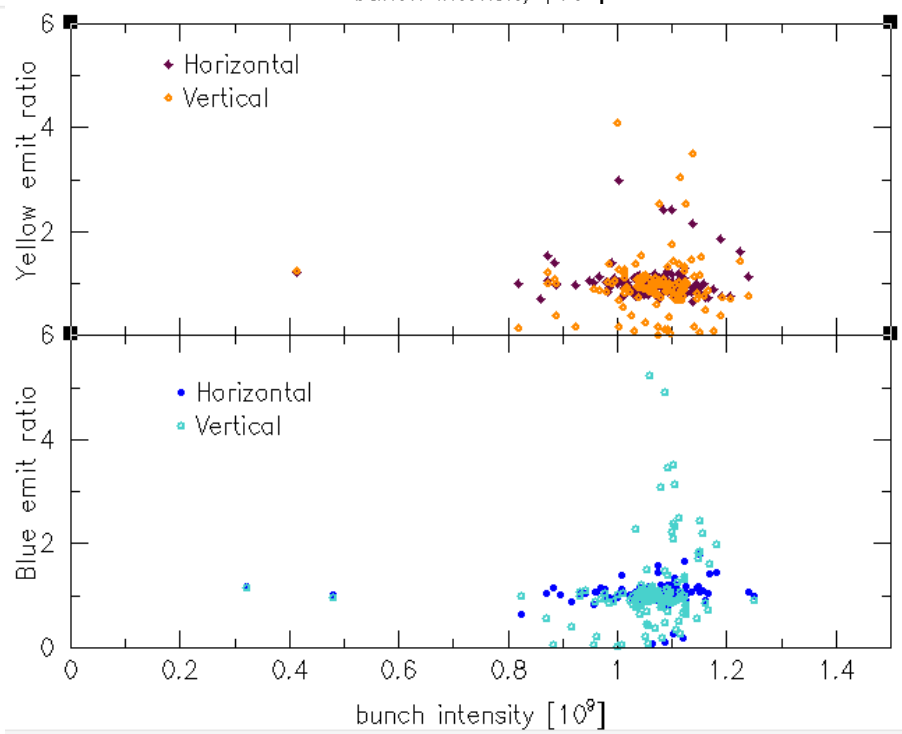
First bunch

Blue shows stronger dependence on intensity



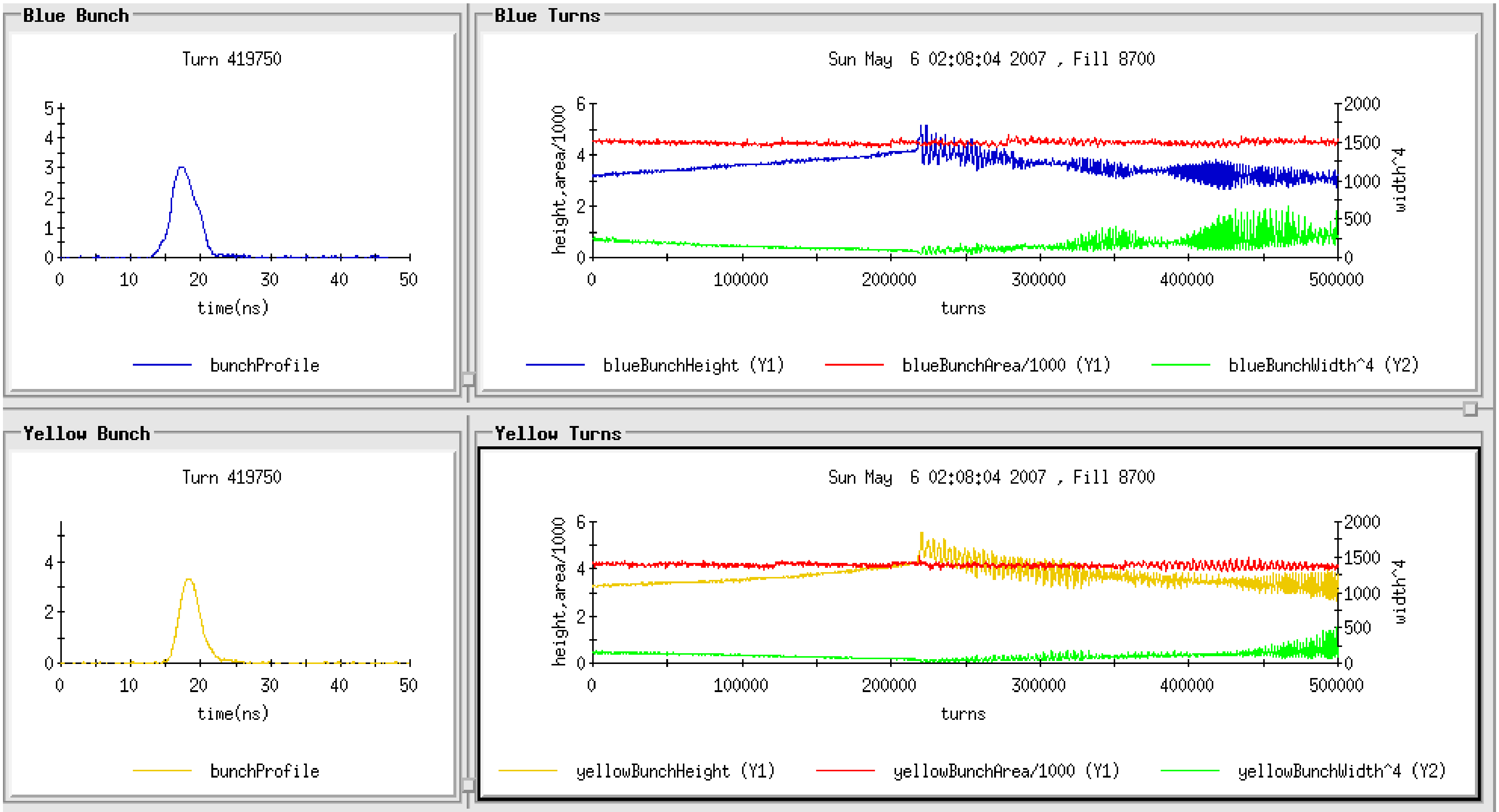
Last bunch

More studies & better diagnostics are required!



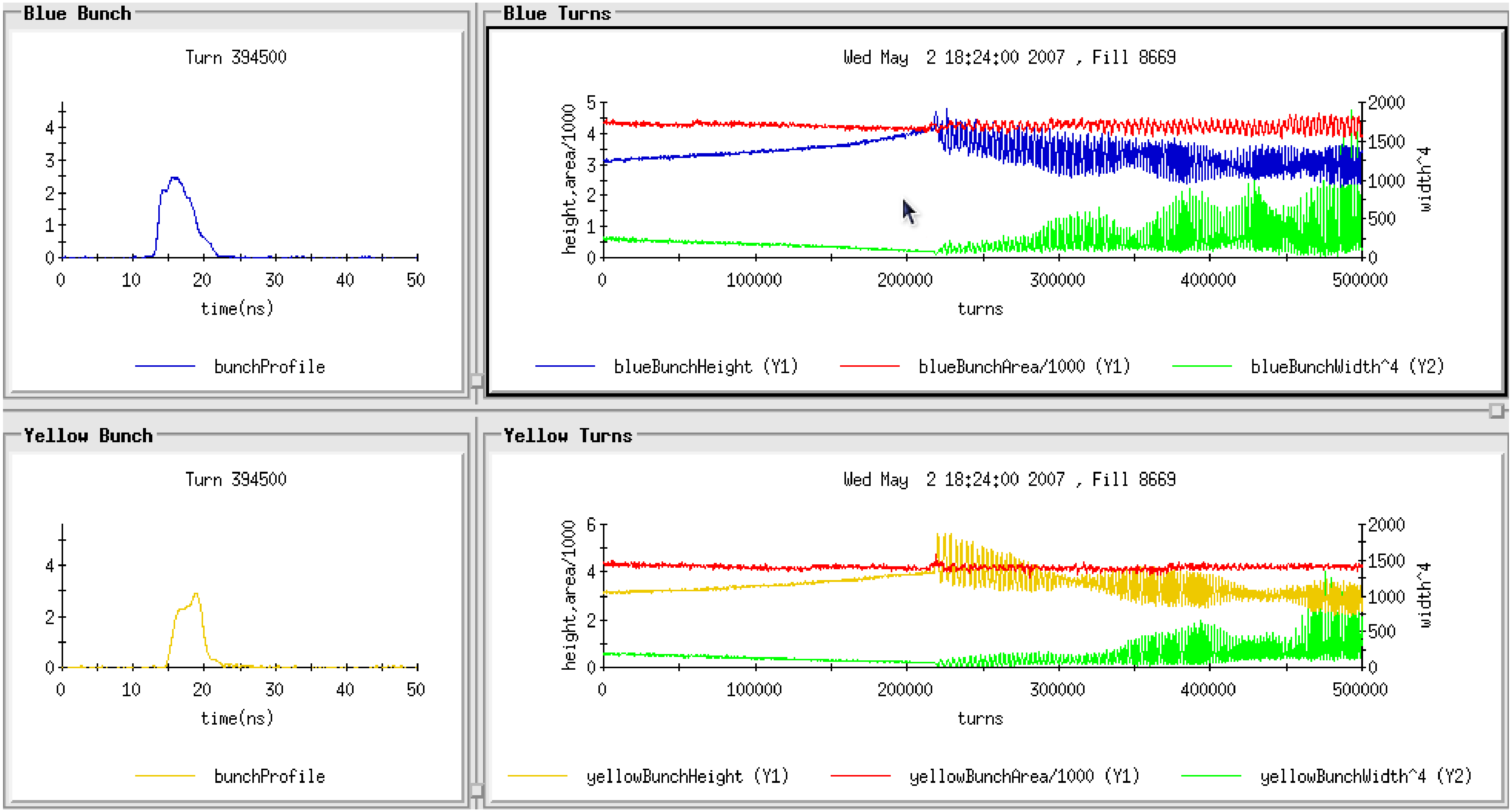
Longitudinal Quad Oscillation - 1

RF Voltage = 300 V, Bunch intensity ~ 1.0×10^{9} ions



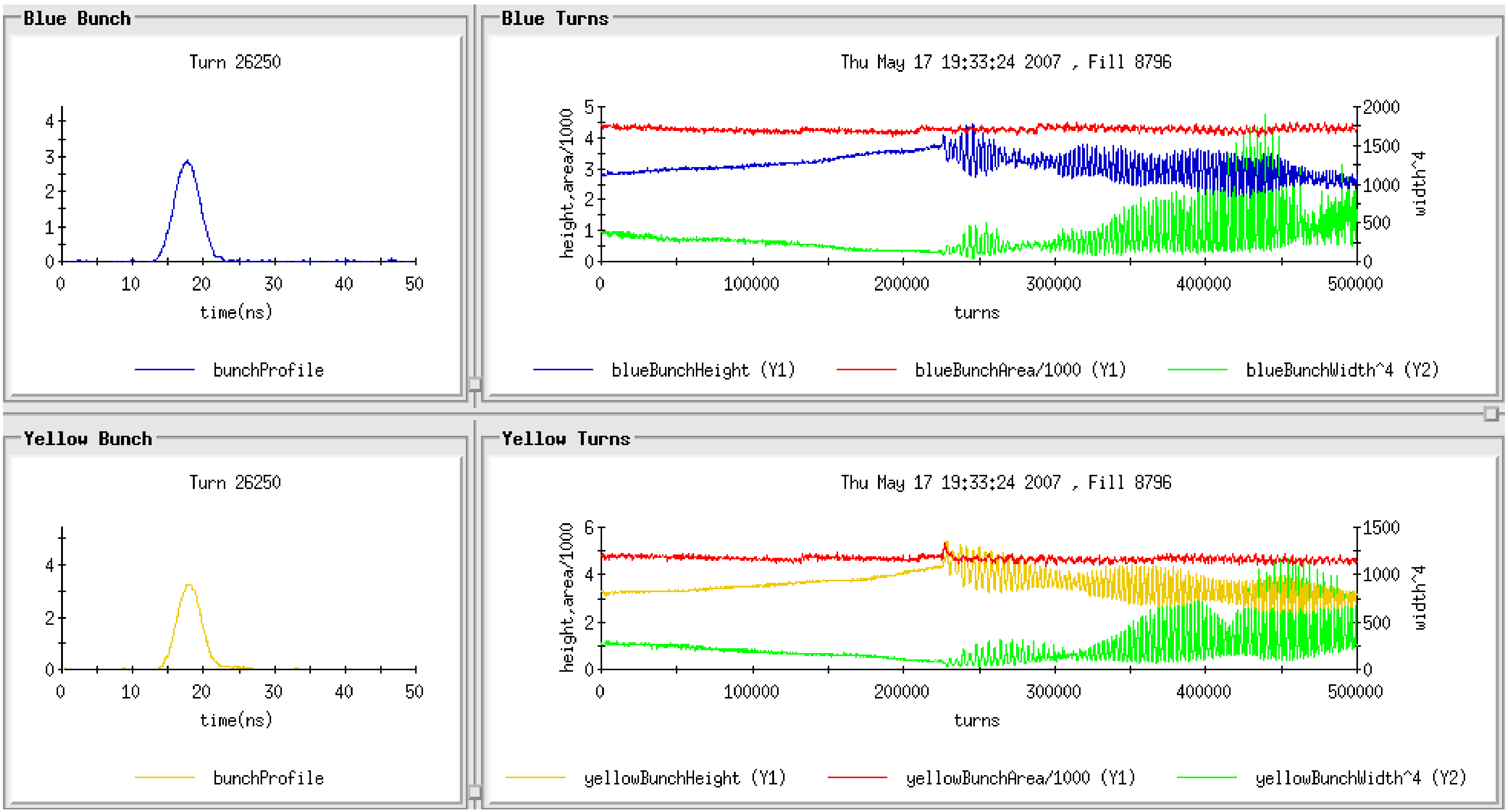
Longitudinal Quad Oscillation - 2

RF Voltage = 300 V, Bunch intensity ~ $1.2x10^9$ ions



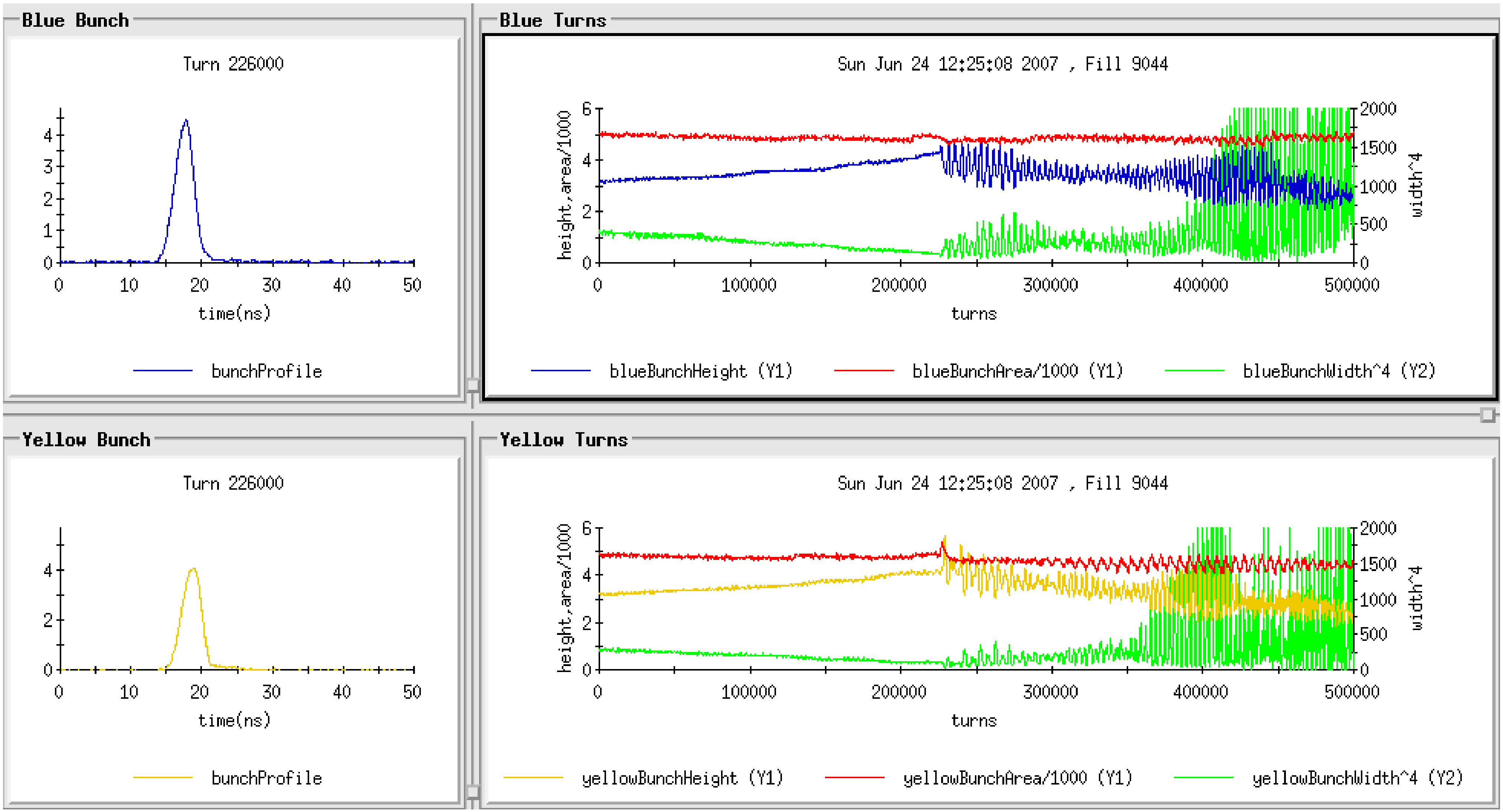
Longitudinal Quad Oscillation - 3

RF Voltage = 200 V, Bunch intensity ~ $1.2x10^9$ ions



Longitudinal Quad Oscillation - 4

RF Voltage = 140 V, Bunch intensity ~ 1.2×10^{9} ions



Conclusions

Lessons learned from RHIC gamma-T jump

- Optics tuning
  - Tune the doublet phase carefully!
    - Minimize second order tune swings
    - Mitigate beta beats, which can deviate the chromaticity jump during transition crossing. Could be the root cause of RHICs transverse instability

- Electron cloud impact

- Longitudinal quadrupole oscillation
  - RF phase jump synchronization is critical
  - Explore RF gymnastics for better matching
    - The advantage of lowering rf voltage in RHIC is not obvious. More systematic studies are required!
  - Bunch oscillation damper: solution at AGS & RHIC

PROS & CONS
of a first order transition jump

PROS

1) Highest Packing Fraction (smallest footprint) and/or
2) smoothest possible optics
3) As few as 3 main quad types & 2 dipole types
4) RHIC OK with unoptimized optics, at medium intensity
5) MI will show an optimized jump at high intensity
6) More beam studies OK!

CONS

1) Pass through transition!
2) Fast pulsed power supply families
3) Careful orbit & tune control
4) Transverse instability – electron cloud?
5) Longitudinal quadrupole oscillations
6) Need better design of chromaticity jump

Q: Should PS2 jump, or avoid, transtition?

The answer should not be based in religion.

Collaboration

AGS (worlds highest intensities) has a 2nd order jump

RHIC has worlds 1st first order jump

J-PARC will teach us about Imaginary γ_T performance

MI will show us an optimized first order jump, with high intensity beams from Project-X

The transition problem is one place that global intellectual resources – and beam time – can be applied to PS2 design.

LARP is a potential vehicle!