Tune Feedback from an Accelerator Physics / Operations Perspective

Wolfram Fischer

with contributions from many others

BROOKHAVEN NATIONAL LABORATORY

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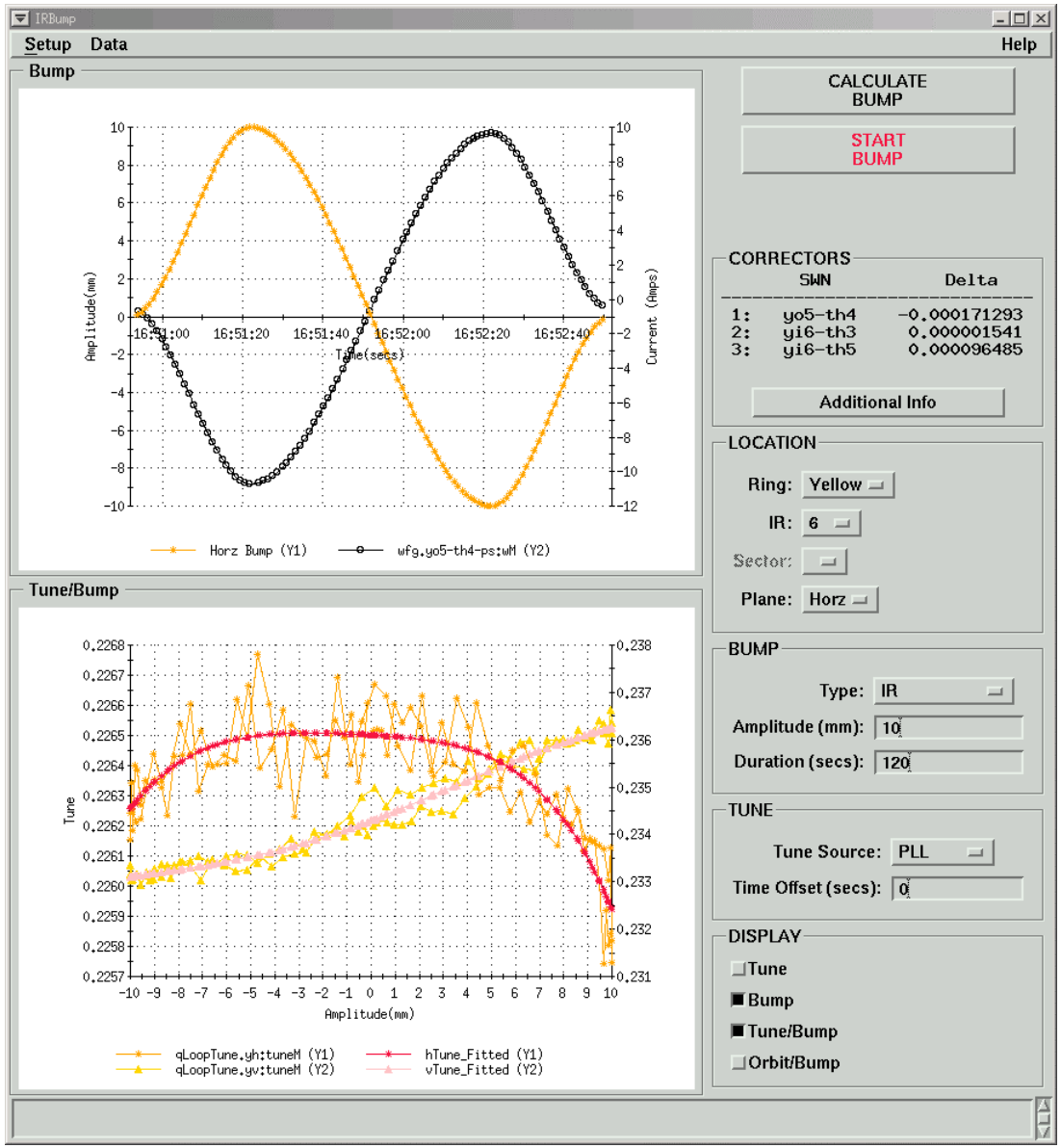
1. Introduction
2. Applications for precision tune measurements
3. Current ramp tuning at RHIC
   Orbit, Losses, Tune, Coupling, Chromaticity, Instabilities
4. Ramps with tune feedback
5. Benefits from tune feedback
6. Summary

- Tune feedback is only one component of ramp control
- Its success depends on other physical quantities (losses, coupling, chromaticity)
- Feedback: Measurement + Correction
- Tune measurement method for feedback in RHIC is faster and more precise than standard method (small kick → free beam oscillations → FFT)
- Measurement valuable by itself
  - May allow observations that are otherwise difficult
  - Can be used for feedforward
- Routine tune feedback requires major commitment



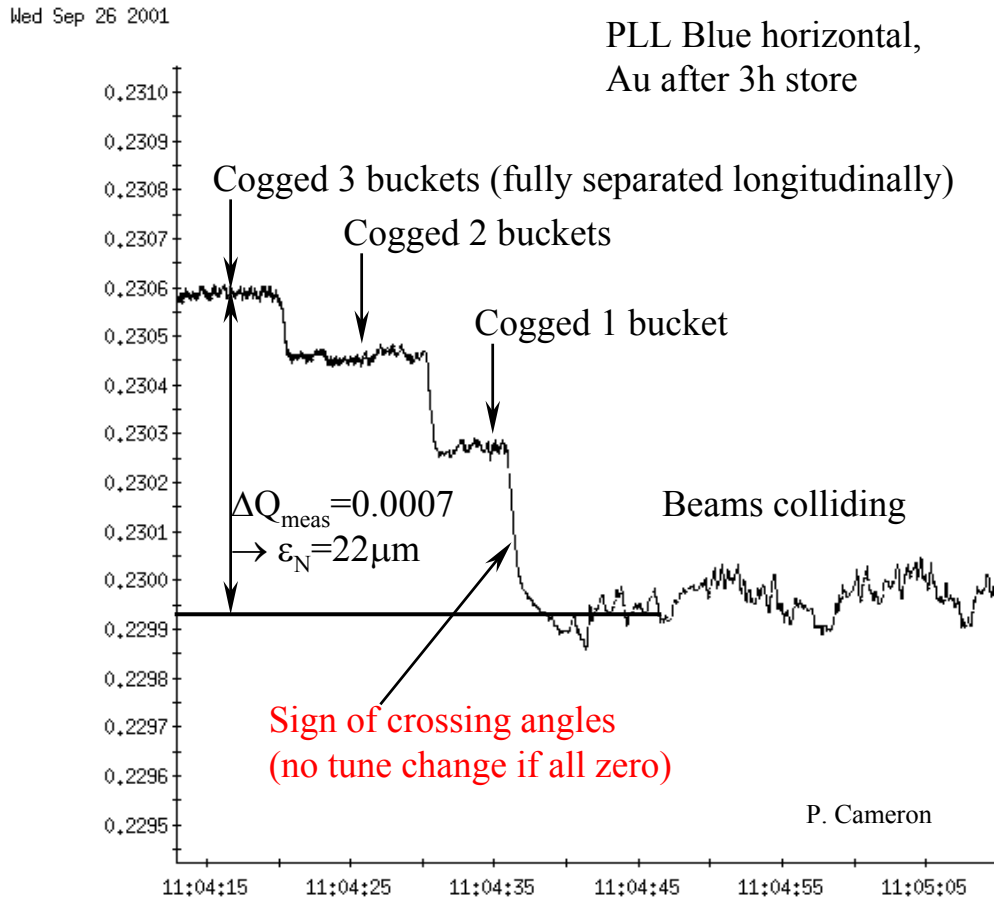
Orbit bumps in interaction region sample nonlinear fields

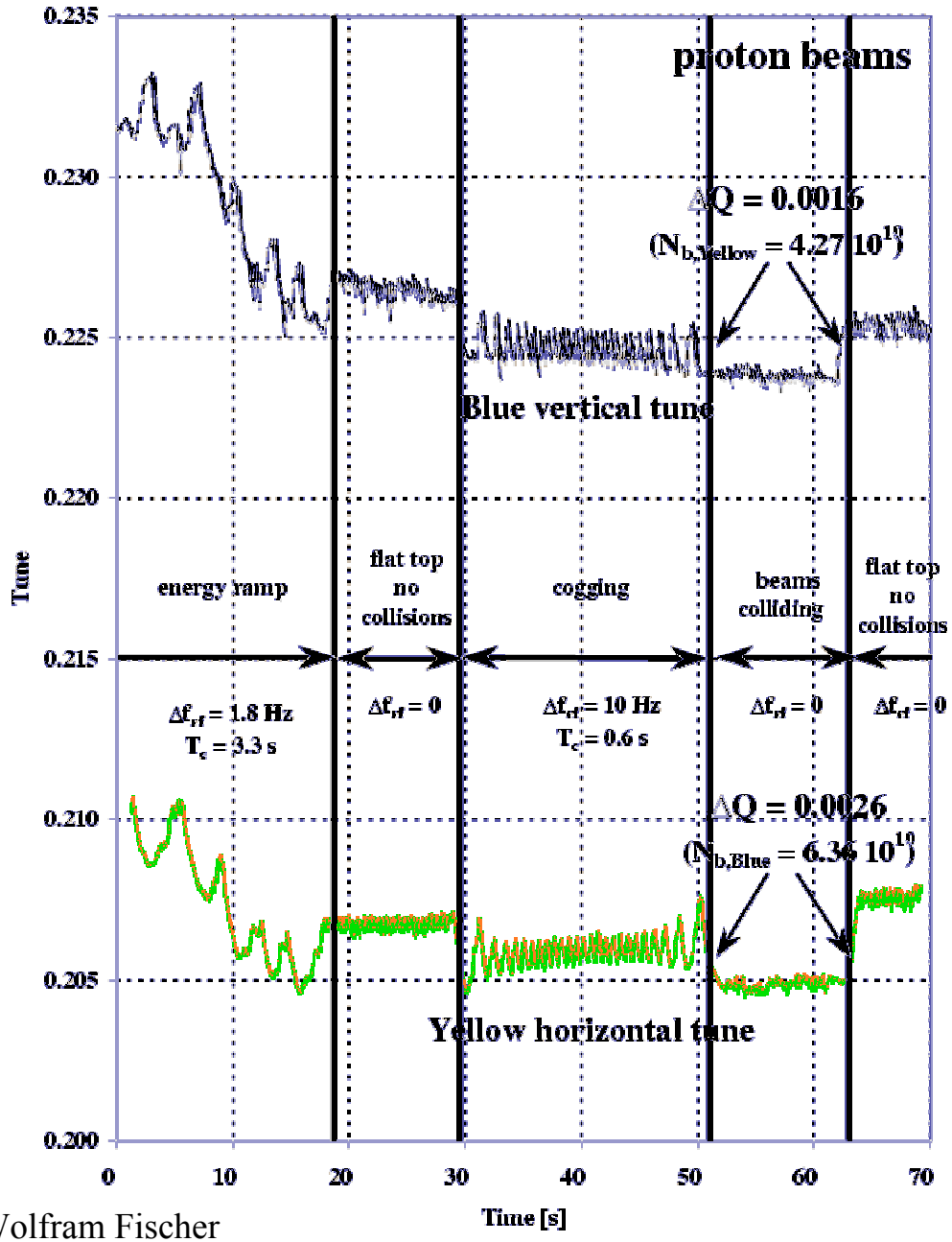
→ From measured tune changes multipoles can be fitted

→ Nonlinear IR correctors can be used for local compensation

F. Pilat, V. Ptitsyn, J.-P. Koutchouk, S. Binello

- 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





Follow tunes through ramp and flattop manipulations

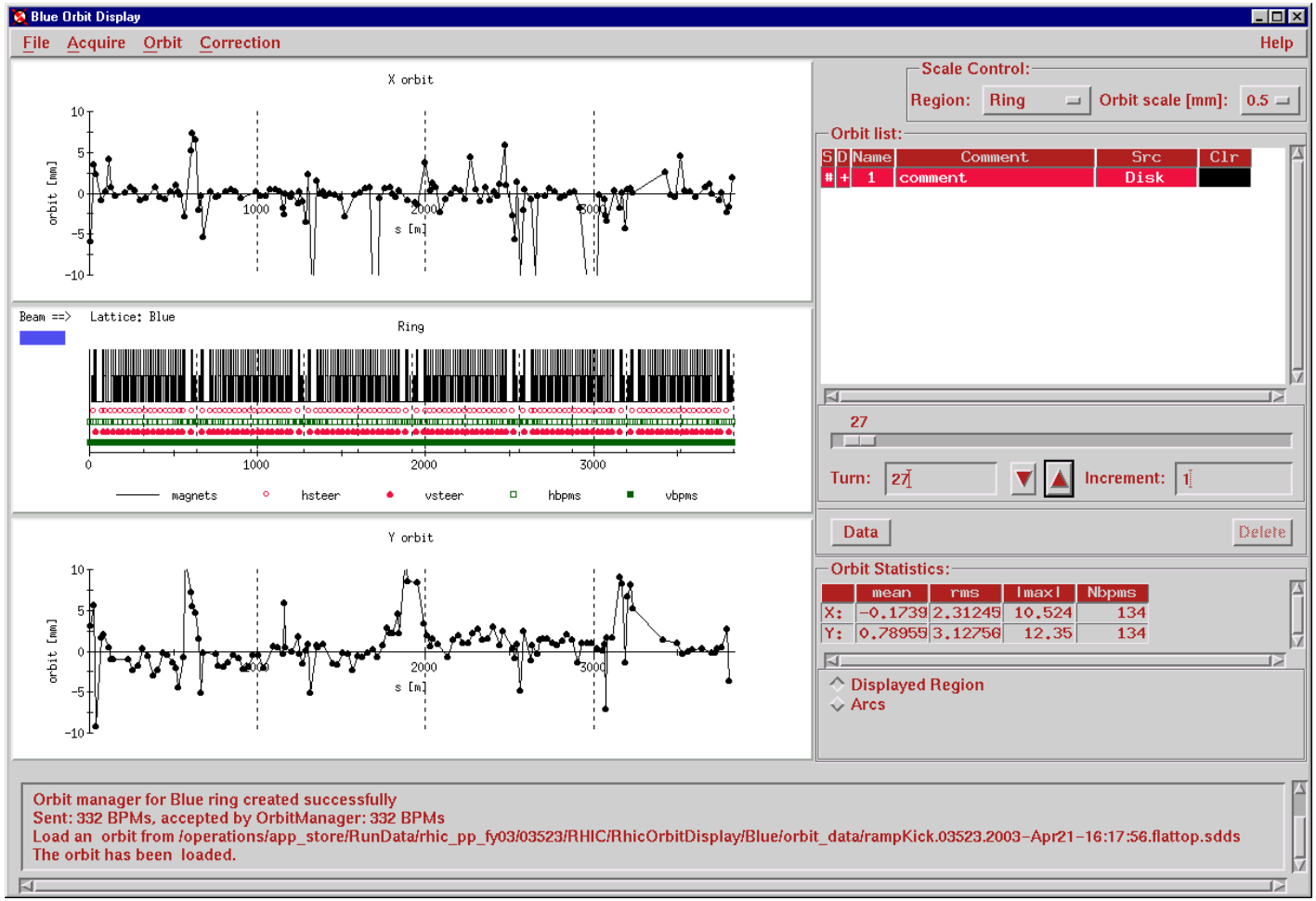
- effect of unequal rf on ramp (tune modulation)

- synchronization and cogging at flattop

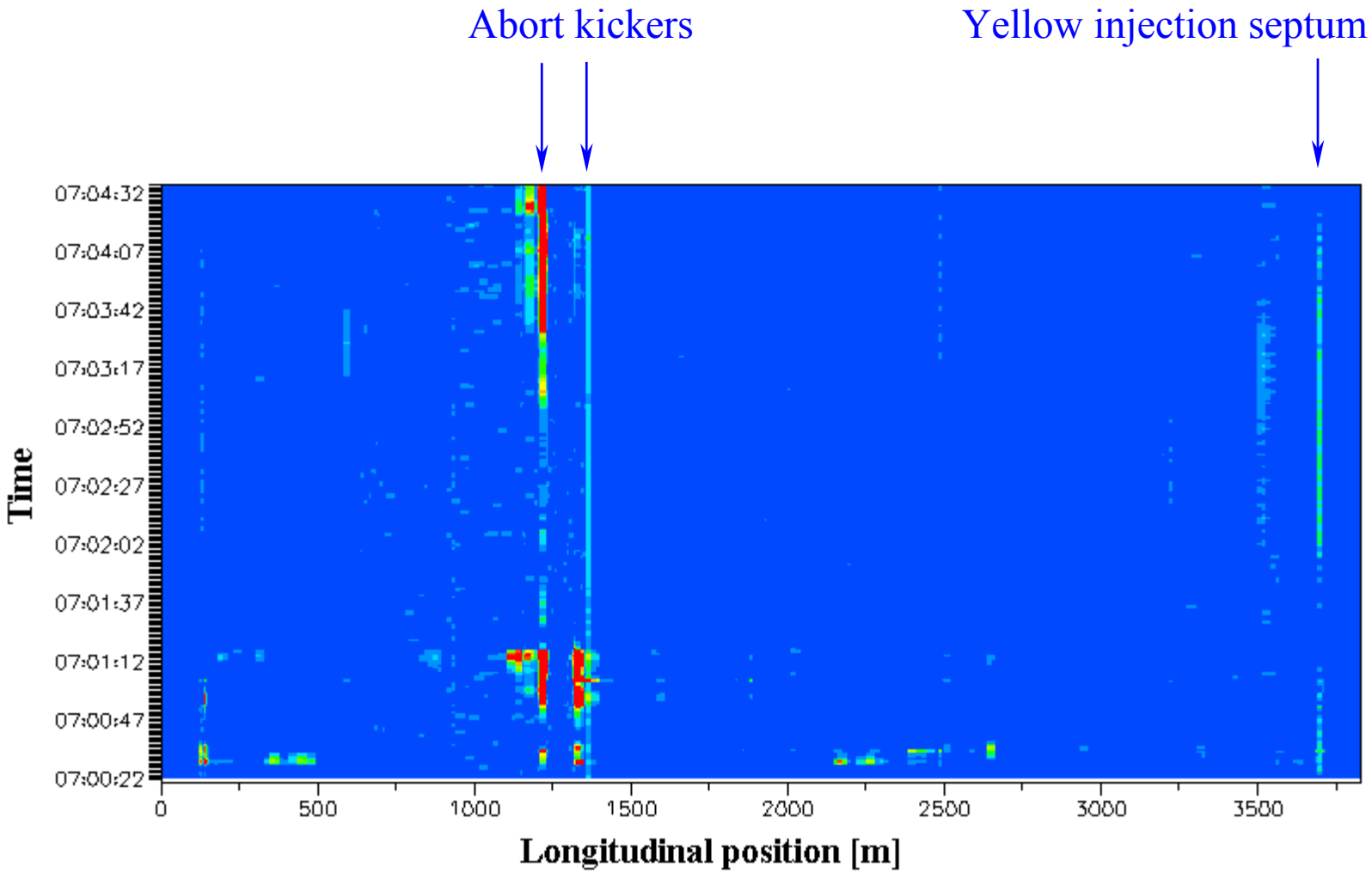
PLL helped to understand and mitigate beam loss effects at beginning of store (effects can in extreme cases lead to lost stores)

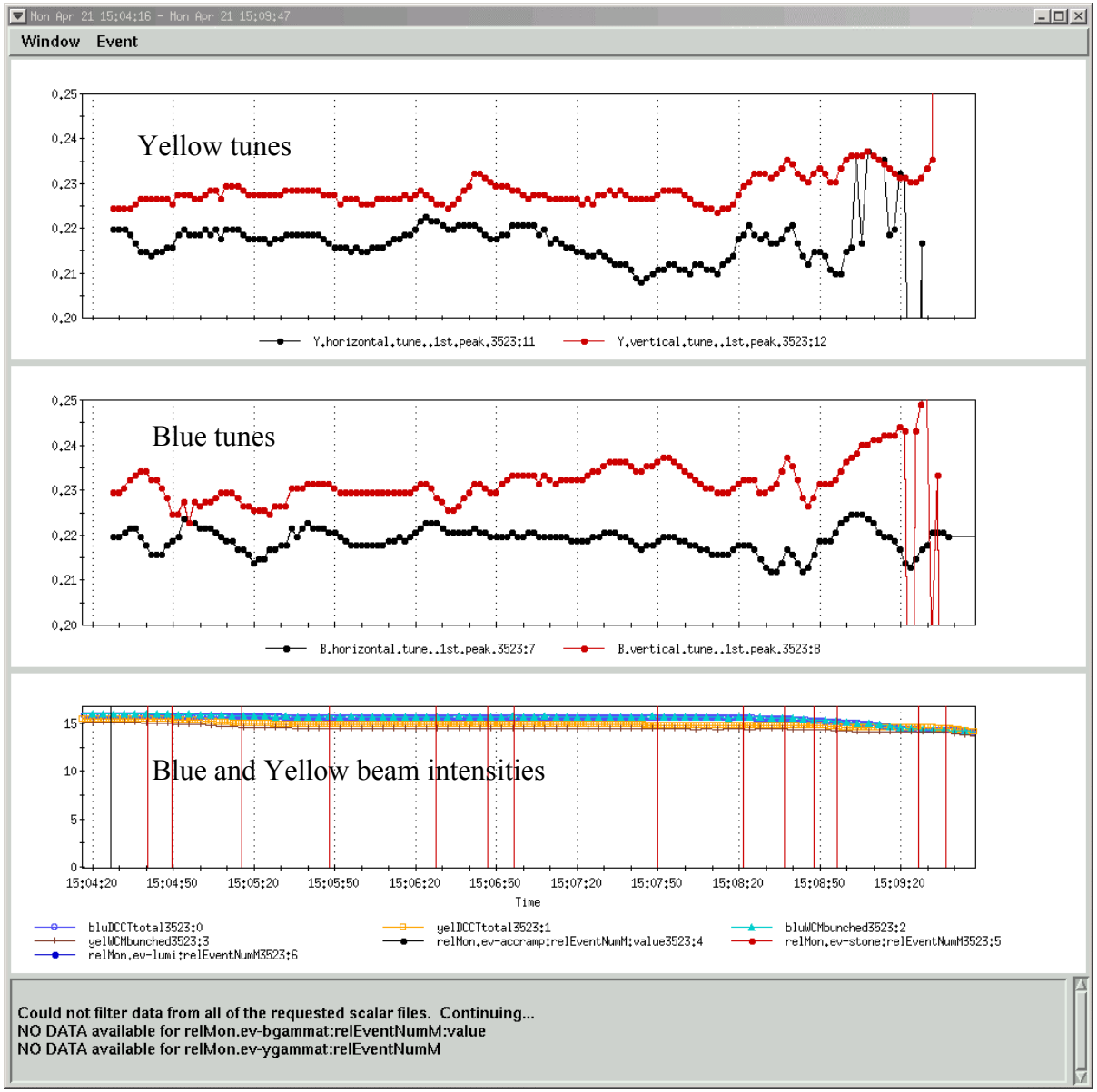
- Measurements on RHIC ramps:
  - Orbit → on every ramp, every 4 sec
  - Losses → on every ramp, every 1 sec
  - Tune → on every ramp, every 4 sec (tune kicker)
    → in principle continuous (PLL)
  - Coupling → in principle at every step stone (from TBT data)
  - Chromaticity → special ramps with radius modulation
    → in principle continuous (PLL)
  - Instabilities → on every ramp, 720 Hz coherence monitor
- Corrections typically on the next ramp (feedforward)
  - At discrete points (stepstones)
- Existing feedbacks for rf phase and radius

- Horizontal and vertical orbit measured every 4sec,
- Corrected at stepstones (feedforward)
- Orbit corrections also changes the tunes



V. Ptitsyn, T. Satogata

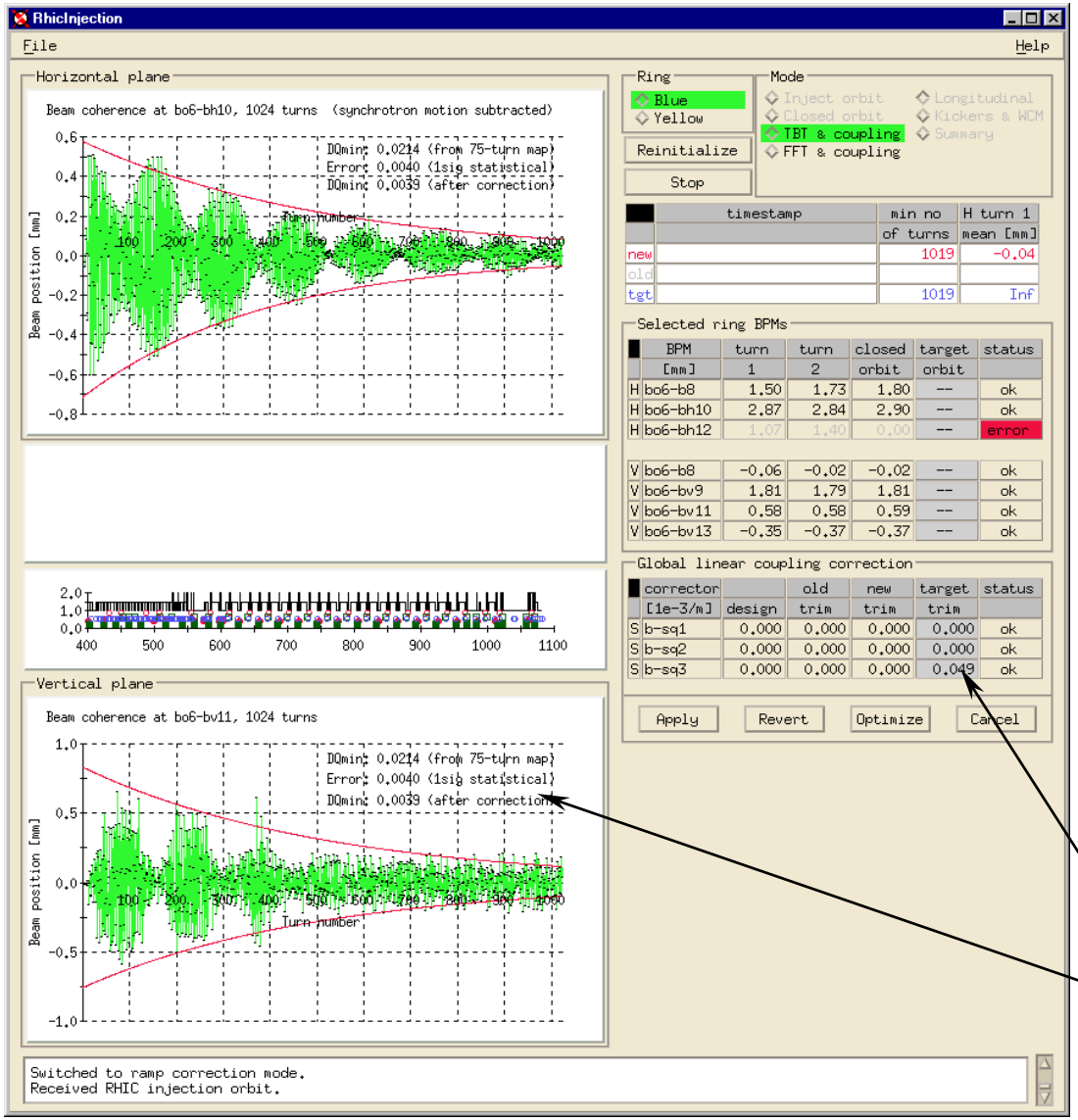

Abort kickers
Yellow injection septum
Time
07:04:32
07:04:07
07:03:42
07:03:17
07:02:52
07:02:27
07:02:02
07:01:37
07:01:12
07:00:47
07:00:22
0
500
1000
1500
2000
2500
3000
3500
Longitudinal position [m]



→ Observe measured tunes (FFT from TBT data after kick) and beam losses along the ramp

→ Change tune at stepstones for next ramp

R. Michnoff, A. Drees



- Beam kicked with tune kicker near stepstones
- TBT used to construct N-turn map
- Coupling correction based on eliminating off-diagonal sub-matrices of N-turn map
- Method routine at injection (single button correction, a few seconds)
- Under test for ramps and at store

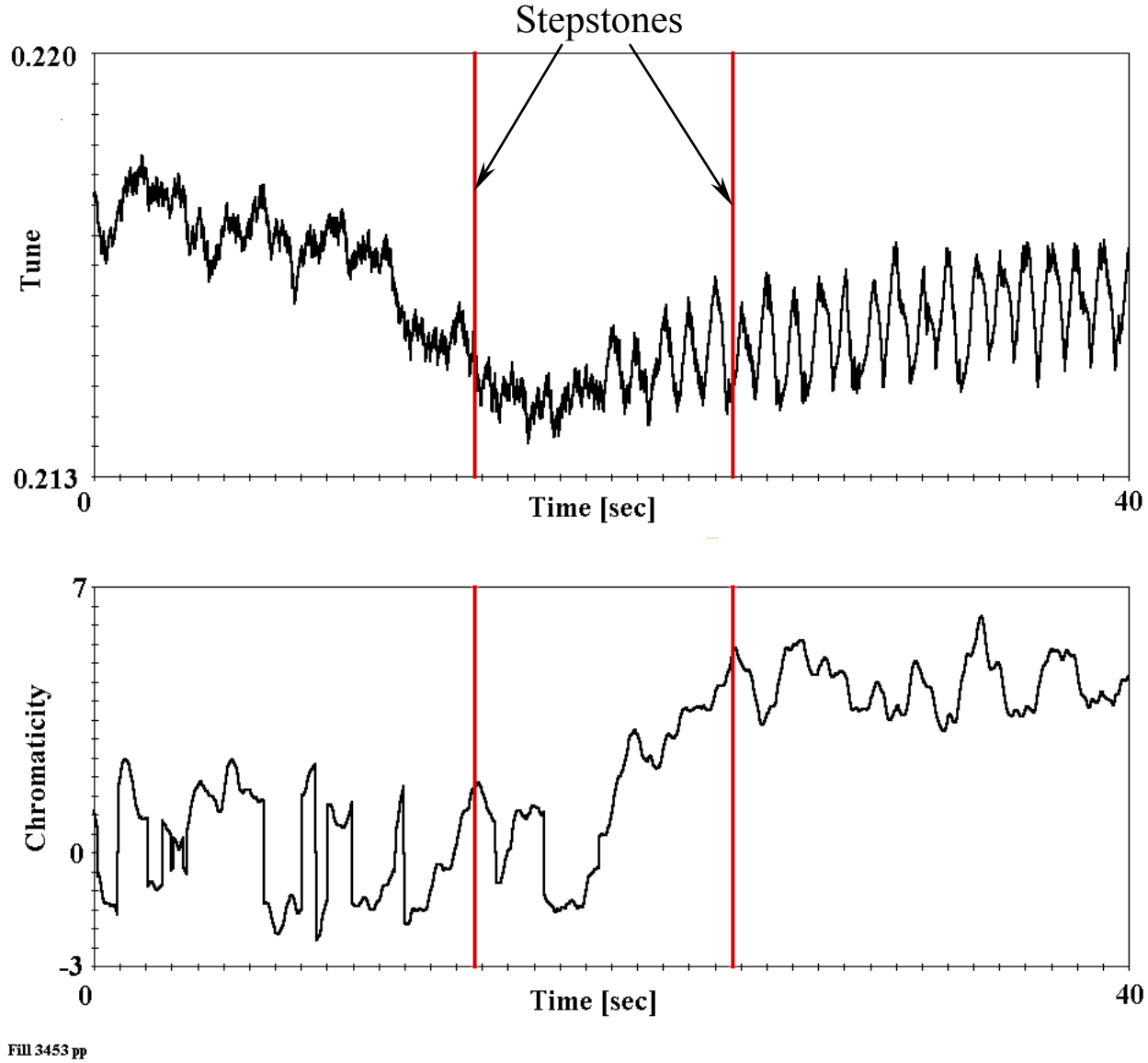
Computed corrector strengths

Computed ΔQ_{min}

W. Fischer, T. Satogata, J. van Zeijts

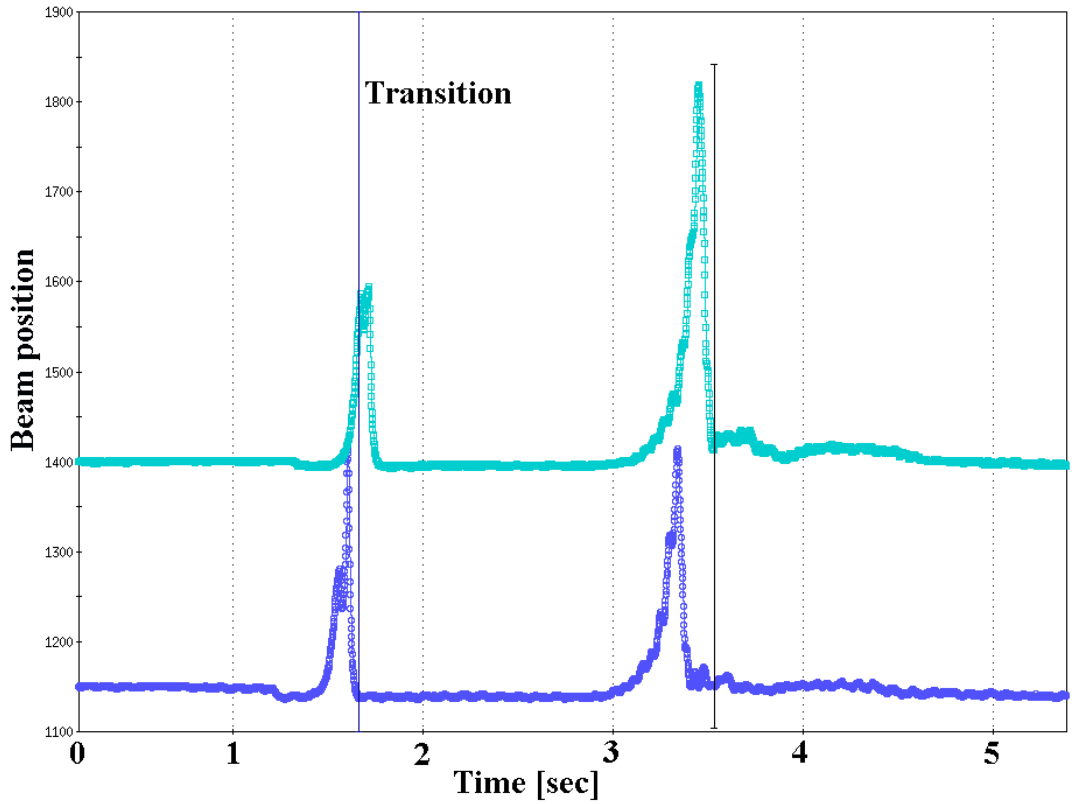
[W. Fischer, "Robust linear coupling correction with *N*-turn maps", accepted for PRSTAB; PAC03]

Chromaticity correction on ramp



- Radius modulated with frequency of 1 Hz and amplitude of 0.2 mm
- Tune modulation observed with PLL
- Chromaticity computed from tune momentum changes and
- Measurement only on selected ramps

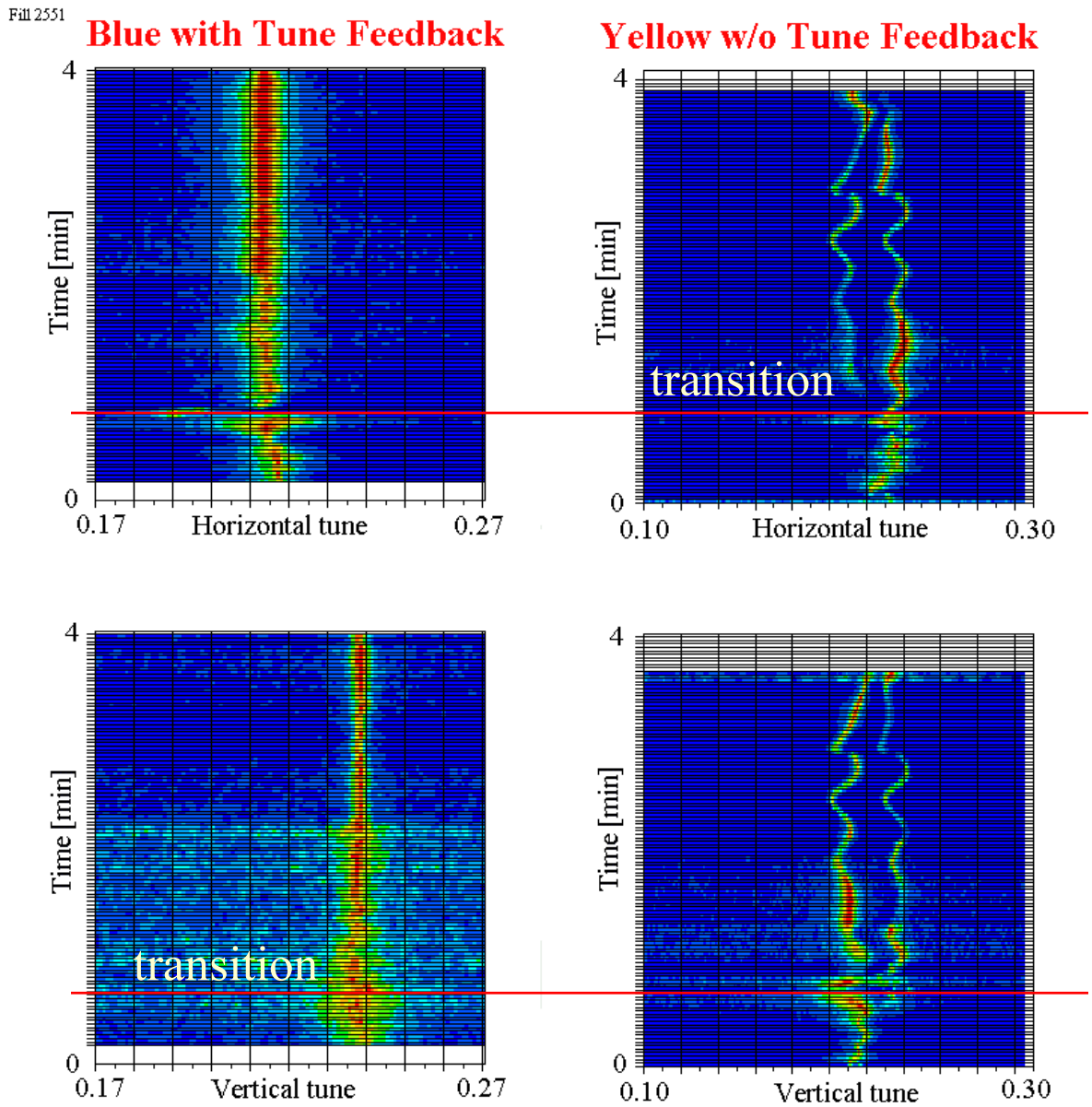
S. Tepikian, P. Cameron



R. Michnoff

- Observation at 720Hz provides information on coherent motion (for example head-tail due to slow chromaticity change at transition leads to instability)
- Chromaticity changes, octupoles, and beam-beam interaction used for stabilization (feedforward)
- Large tune spread requires good tune and coupling control (tunes need to be in the middle between limiting resonances)

- Feedforward procedure, relies on reproducibility
- Time consuming
- Need to know the response coefficients Δ/Δ_{set} for each corrected quantity at each stepstone (or increase number of iterations)
- Interaction between orbit, tune, coupling and chromaticity, instability changes
- All these disadvantages would be overcome by feedback systems for all quantities
- Need to evaluate trade-off between time invested in making feedbacks work and time saved in ramp tuning

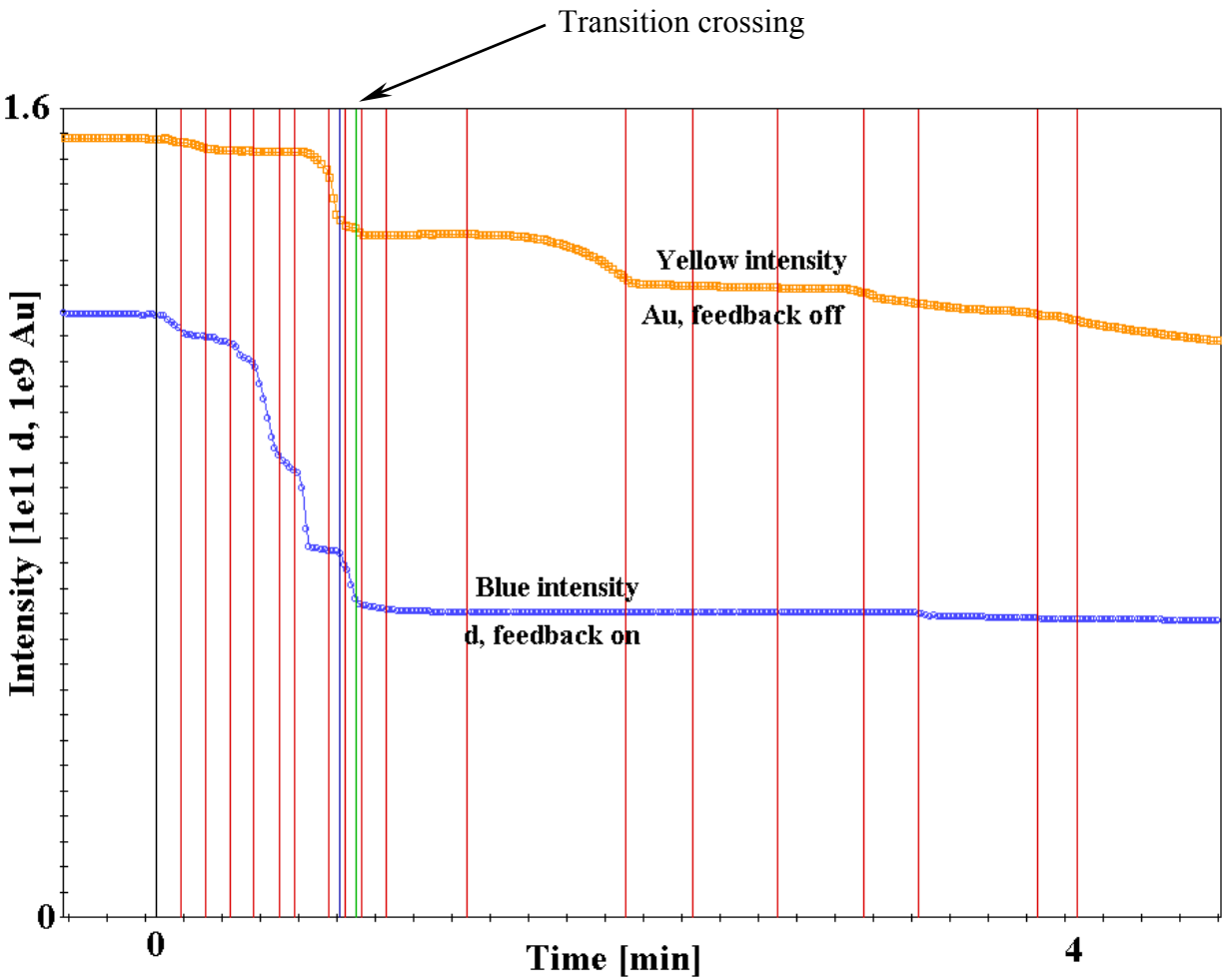


Tune feed back during energy ramp

Tune measurement:
P. Cameron

Magnet control:
C. Schultheiss,
J. van Zeijts

Blue : deuterons
Yellow: gold



So far we saw on ramps with tune feedback
- Larger than usual beam losses
- Emittance growth

→ Prevents routine use of tune feedback
→ These ramps still provide very valuable information that can be used in ramp tuning

- For the tune feedback to work
  - Losses must not exceed certain limits
  - ΔQ_{min} must be smaller than the ΔQ of set points
  - Chromaticity must be small enough to allow PLL to lock
- A substantial investment in ramp development has to be made before tune feedback is usable
- Tune feedback is very helpful when new ramps are implemented

1. Tune feedback should be viewed in the context of ramp tuning
   → Consider orbits, losses, tunes, coupling, chromaticities, instabilities
2. Commissioning of tune feedback requires large commitment of resources
   → But commissioning can be done in steps, benefits can be realized at every step:
   - PLL tune measurement is a very valuable tool
   - Occasional tune feedback ramp is very valuable
   - Routine tune feedback is very valuable