Tune/Chromaticity/Coupling Measurement and Feedforward/Feedback FY04 Results FY05 Plans

Peter Cameron/Angelika Drees

Outline

FY04 Results at RHIC

- **Tune**
- Chromaticity
- Coupling
- Baseband PLL

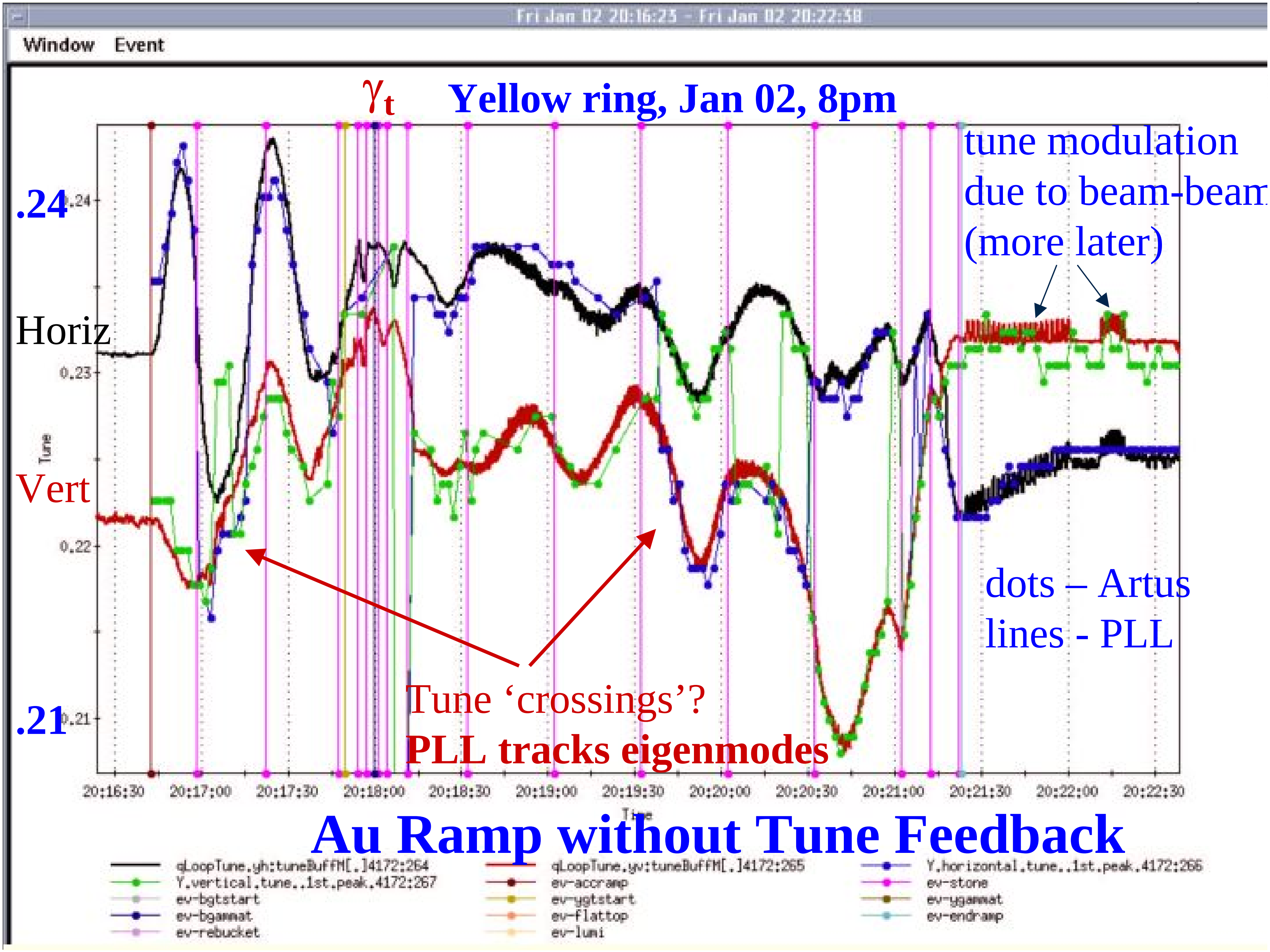
FY04 at CERN

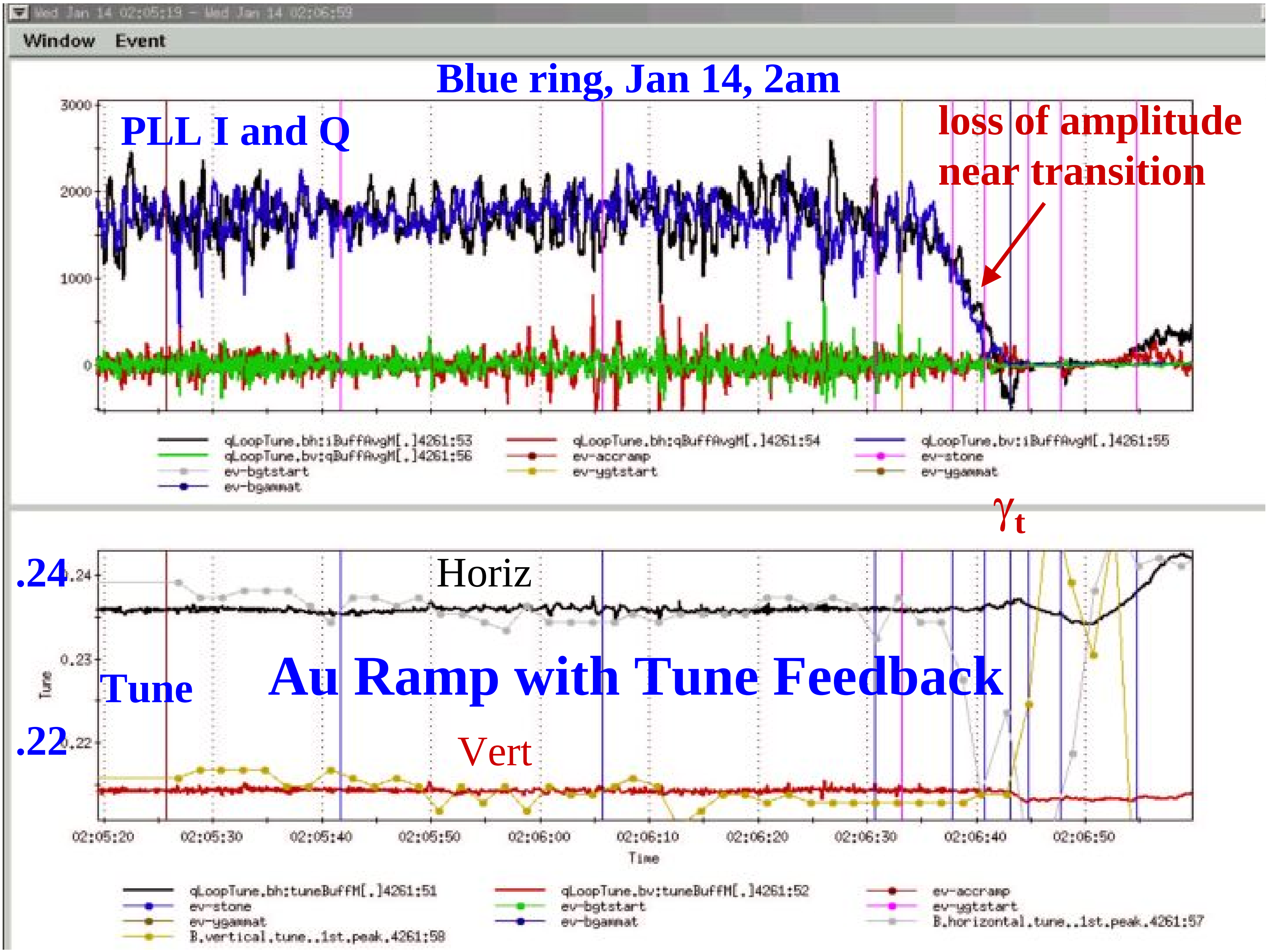
FY05 Plans

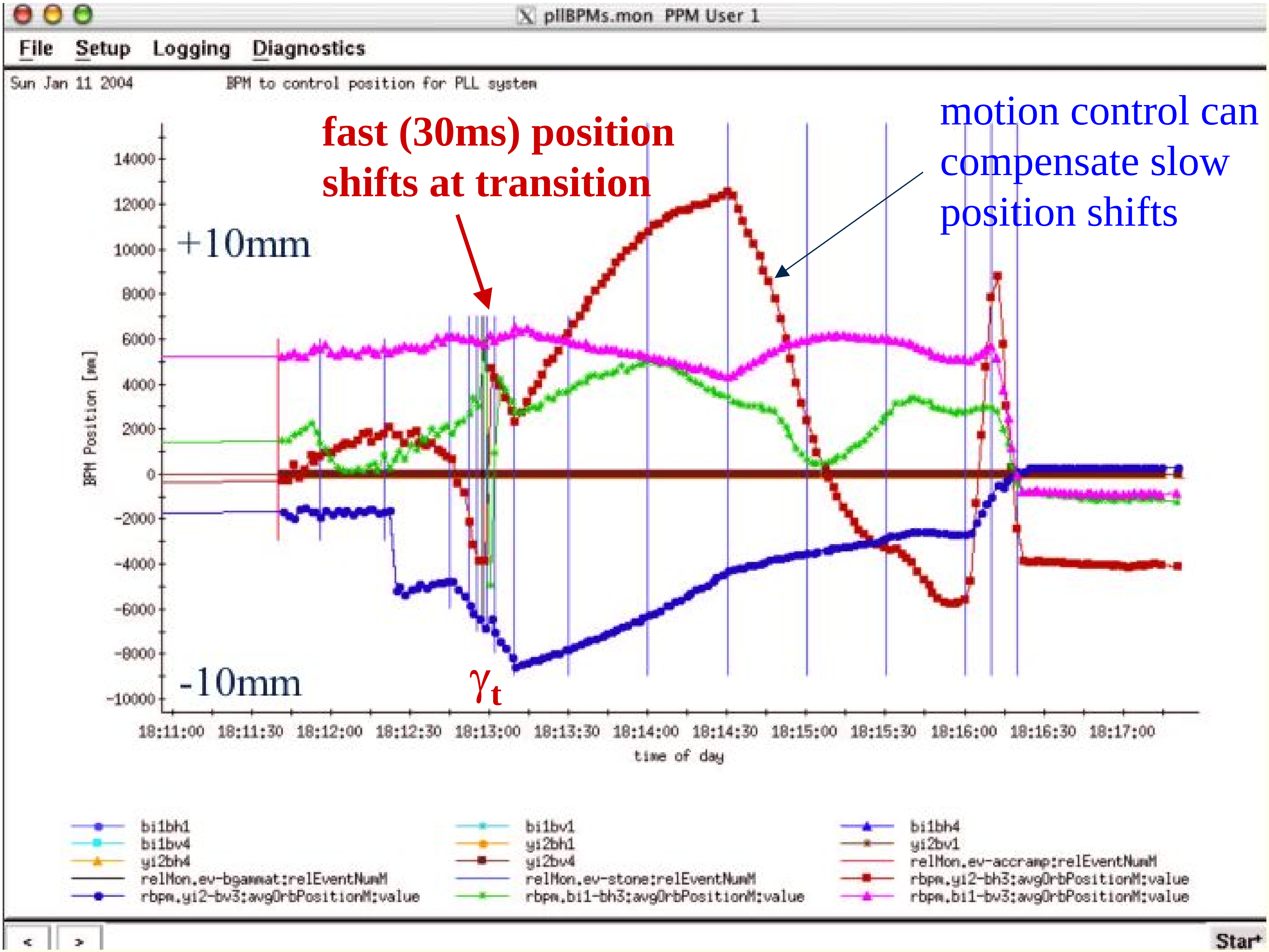
- Baseband PLL
- Coupling Studies
- Chromaticity measurement

FY04 tune measurement/feedback

- We continue to have reliable tune measurement during acceleration (excepting transition)
  - independent of coupling (but not tune crossings)
  - independent of chromaticity conditions
  - without measurable emittance growth
- **Feedforward** has been implemented for smoothing ramp tunes w/o Tune Feedback
- Tune **Feedback** attempted with both Au and pp
  - Transition remains a problem with Au
  - **New understanding of coupling effect during TF**


Fri Jan 02 20:16:23 - Fri Jan 02 20:22:38
Window
Event
γt
Yellow ring, Jan 02, 8pm
tune modulation due to beam-beam (more later)
.24
Horiz
Vert
.21
Tune
0.24
0.23
0.22
0.21
dots – Artus
lines - PLL
Tune 'crossings'?
PLL tracks eigenmodes
20:16:30
20:17:00
20:17:30
20:18:00
20:18:30
20:19:00
20:19:30
20:20:00
20:20:30
20:21:00
20:21:30
20:22:00
20:22:30
Time
Au Ramp without Tune Feedback
qLoopTune.yh:tuneBuffM[.]4172:264
qLoopTune.yv:tuneBuffM[.]4172:265
Y.horizontal.tune..1st.peak.4172:266
Y.vertical.tune..1st.peak.4172:267
ev-accramp
ev-stone
ev-bgtstart
ev-ygtstart
ev-ygammat
ev-bgammat
ev-flattop
ev-endramp
ev-rebucket
ev-lumi


Window Event
Blue ring, Jan 14, 2am
PLL I and Q
loss of amplitude
near transition
3000
2000
1000
0
qLoopTune.bh:iBuffAvgM[.]4261:53
qLoopTune.bv:qBuffAvgM[.]4261:56
ev-bgtstart
ev-bgammat
qLoopTune.bh:qBuffAvgM[.]4261:54
ev-accramp
ev-ygtstart
qLoopTune.bv:iBuffAvgM[.]4261:55
ev-stone
ev-ygammat
γ_t
Horiz
.24
0.23
Tune
.22
Au Ramp with Tune Feedback
Vert
02:05:20
02:05:30
02:05:40
02:05:50
02:06:00
02:06:10
02:06:20
02:06:30
02:06:40
02:06:50
Time
qLoopTune.bh:tuneBuffM[.]4261:51
ev-stone
ev-ygammat
B.vertical.tune..1st.peak.4261:58
qLoopTune.bv:tuneBuffM[.]4261:52
ev-bgtstart
ev-bgammat
ev-accramp
ev-ygtstart
B.horizontal.tune..1st.peak.4261:57



pllBPMs.mon PPM User 1
File Setup Logging Diagnostics
Sun Jan 11 2004
BPM to control position for PLL system
fast (30ms) position shifts at transition
motion control can compensate slow position shifts
+10mm
-10mm
γ_t
BPM Position [mm]
14000
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
18:11:00 18:11:30 18:12:00 18:12:30 18:13:00 18:13:30 18:14:00 18:14:30 18:15:00 18:15:30 18:16:00 18:16:30 18:17:00
time of day
bi1bh1
bi1bv4
yi2bh4
relMon.ev-bgammat:relEventNumM
rbpm.yi2-bv3:avgOrbPositionM:value
bi1bv1
yi2bh1
yi2bv4
relMon.ev-stone:relEventNumM
rbpm.bi1-bh3:avgOrbPositionM:value
bi1bh4
yi2bv1
relMon.ev-accramp:relEventNumM
rbpm.yi2-bh3:avgOrbPositionM:value
rbpm.bi1-bv3:avgOrbPositionM:value
Start

Transition Crossing

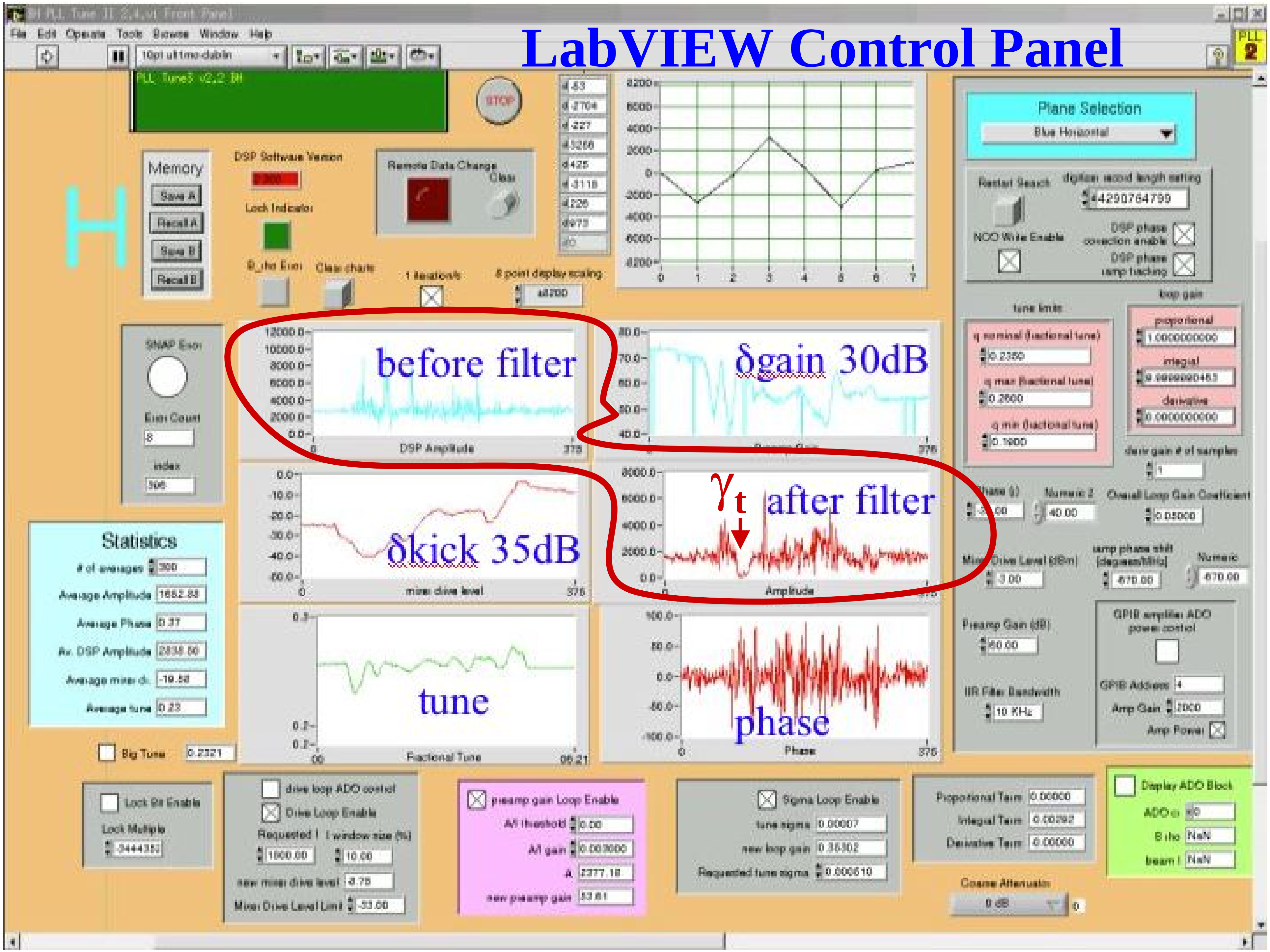
Dynamic Range Problem

- Bunches get short - lots of energy up at 245MHz
- Bunches get short – reduced effectiveness of resonant pickup (τ~400nsec vs 2.25μsec for 6 bunches)
- Fast changes in orbit – big revolution lines
- Fast changes in tune

Available dynamic range ~180dB

- 14 bit digitizer - 84dB
- Feedback on kicker power - 40dB (but not fast enough)
- Feedback on signal path gain - 60dB

LabVIEW Control Panel



Transition Crossing - Conclusions

- The previous slide
  - digitizer counts (**before** 100Hz digital filter) ~ constant
  - signal (**after** filter) driven to zero near transition by AGC
  - near transition all counts come from revolution line
- PLL in present form (245 MHz) fully optimized?
  - No obvious solution to this problem
- Options – where to go from here?
  - Optical notch filter – frequency swing
  - Tracking superconducting filter – R&D project
  - Closed-orbit offset subtraction– processing speed, spectral complexity a problem
  - **Baseband PLL – a real possibility?**

Why Important for LARP?

- At RHIC - 28MHz acceleration RF
  - coherent spectrum at 245MHz only when bunches shorten near transition
- AT LHC – 400MHz acceleration RF
  - 245MHz PLL must live in coherent spectrum
  - No transition (fast position/tune changes), **but**
  - As long as one has to live in the coherent spectrum anyhow, many advantages to baseband PLL
    - **focus development effort there for LHC (and perhaps also solve RHIC transition problem)**

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- **Chromaticity**
- Coupling
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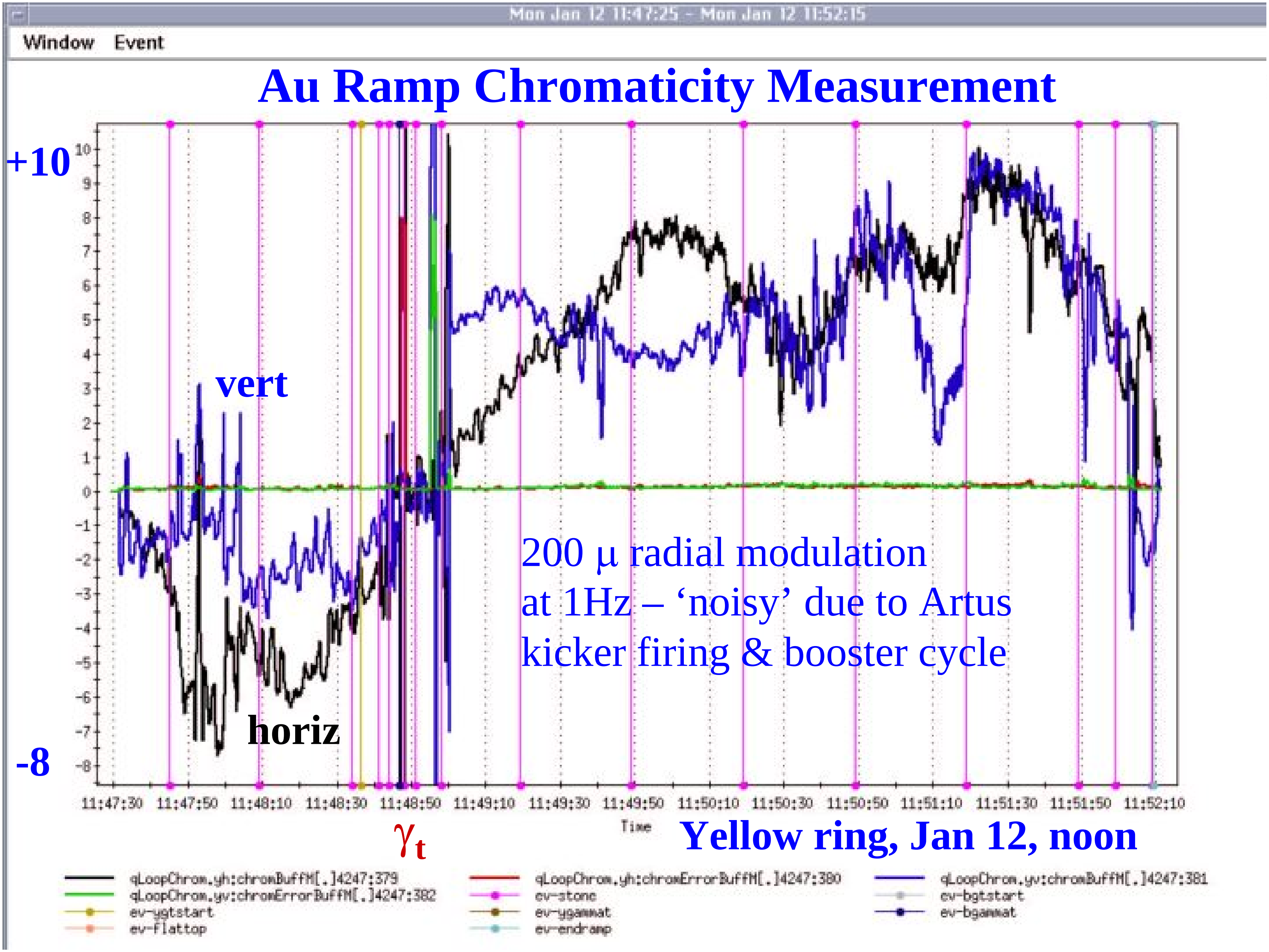
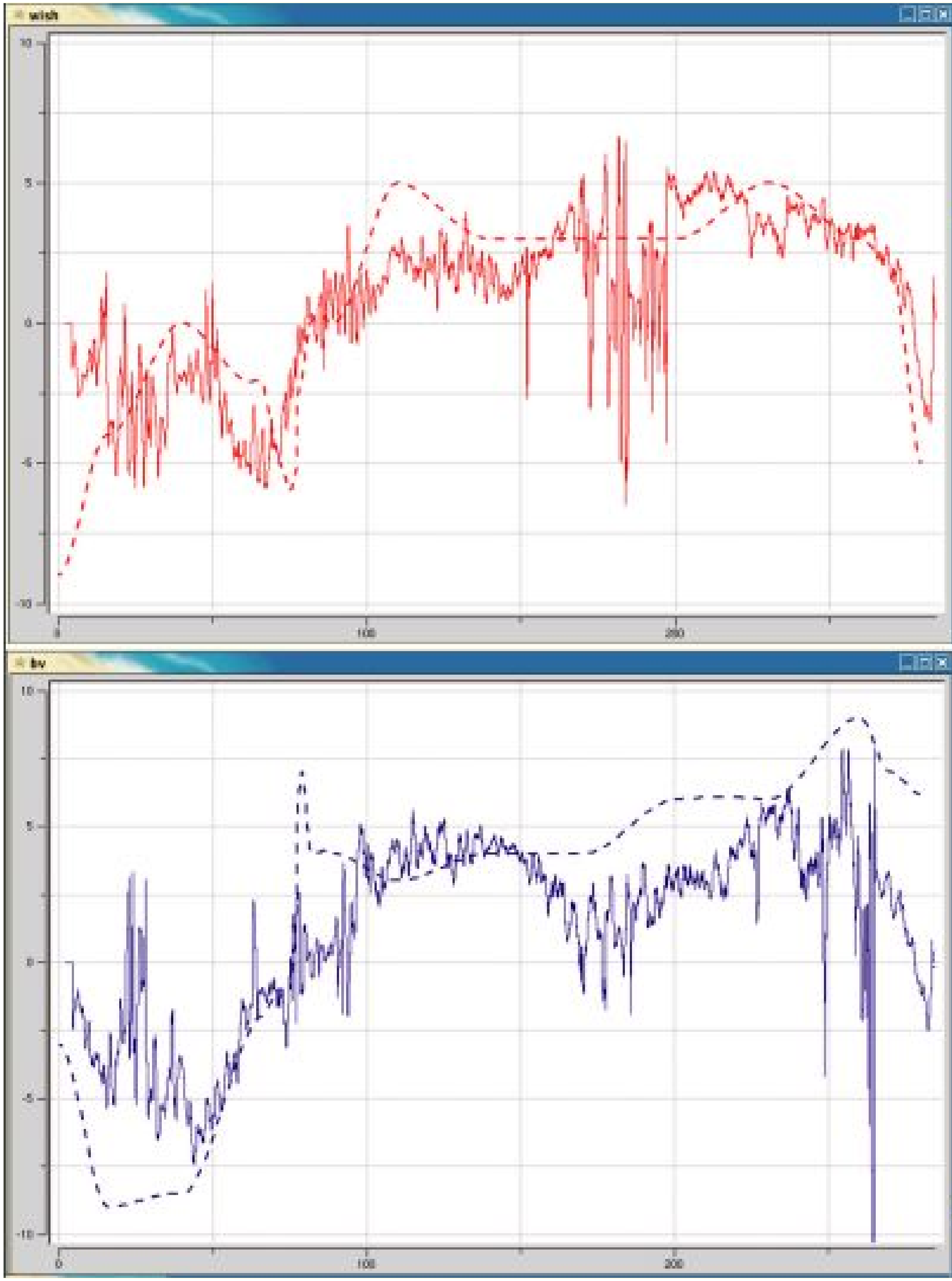
FY04 at CERN

FY05 Plans

- Baseband PLL
- Coupling Studies
- Chromaticity measurement

Au Ramp Chromaticity Measurement





US LARP

Example of feedforward and improvement of magnet model:

Measured horiz and vert chromaticity data and fit, assuming 10 units of b2 in the DX magnets

Summary of Chromaticity

- Radial modulation method gives good data
- Useful data gathered for feedforward and magnet model
- Bandwidth in present form probably not adequate for LHC snapback feedback correction
  - Baseband PLL?
- No testing of phase modulation methods
  - Need ~1KHz PLL BW – not practical?

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- **Coupling**
- Baseband PLL

FY04 at CERN

FY05 Plans

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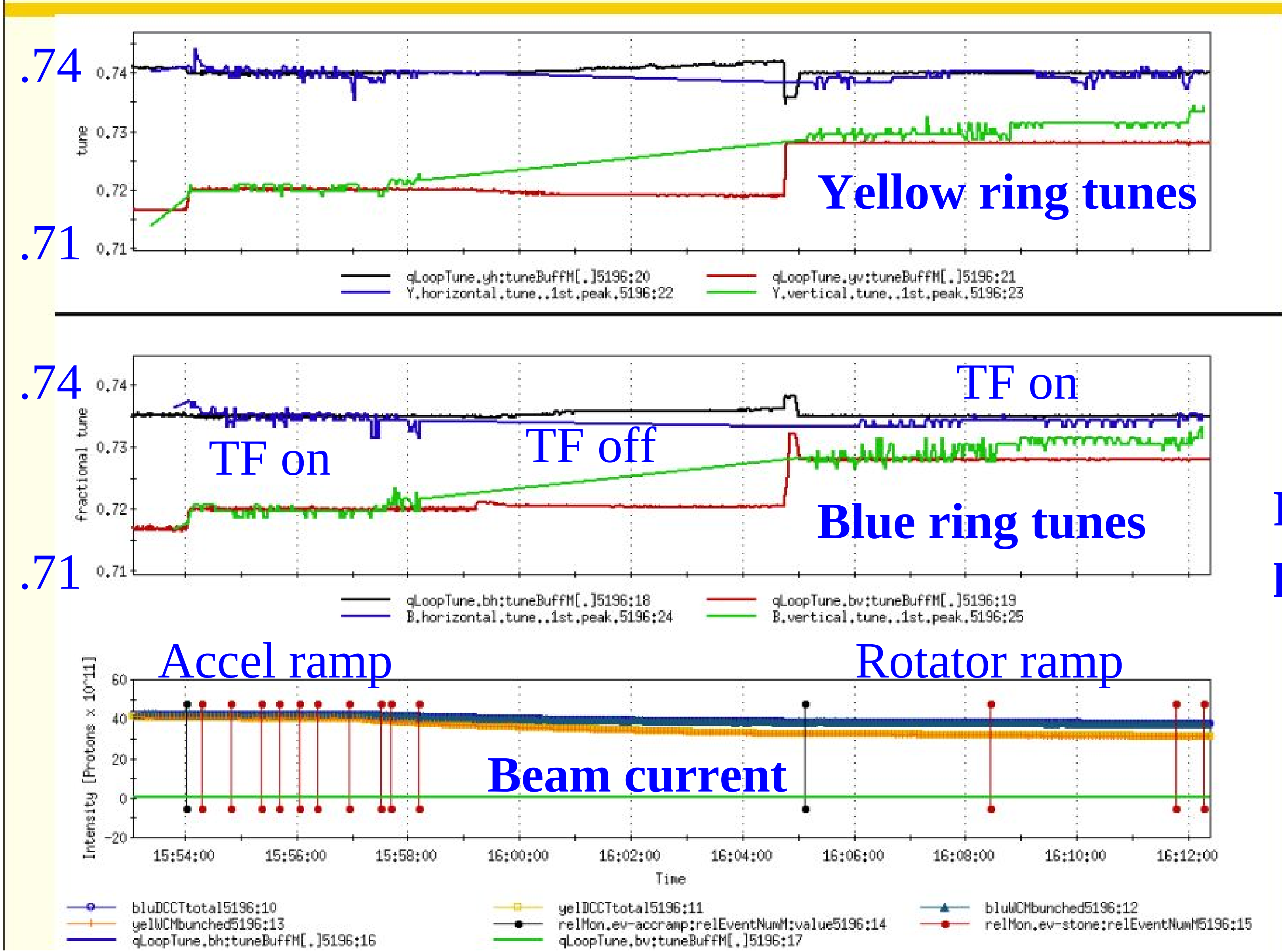
- Coupling Studies
- Chromaticity measurement

Tune feedback – from Mei's talk

RHIC Retreat 2004

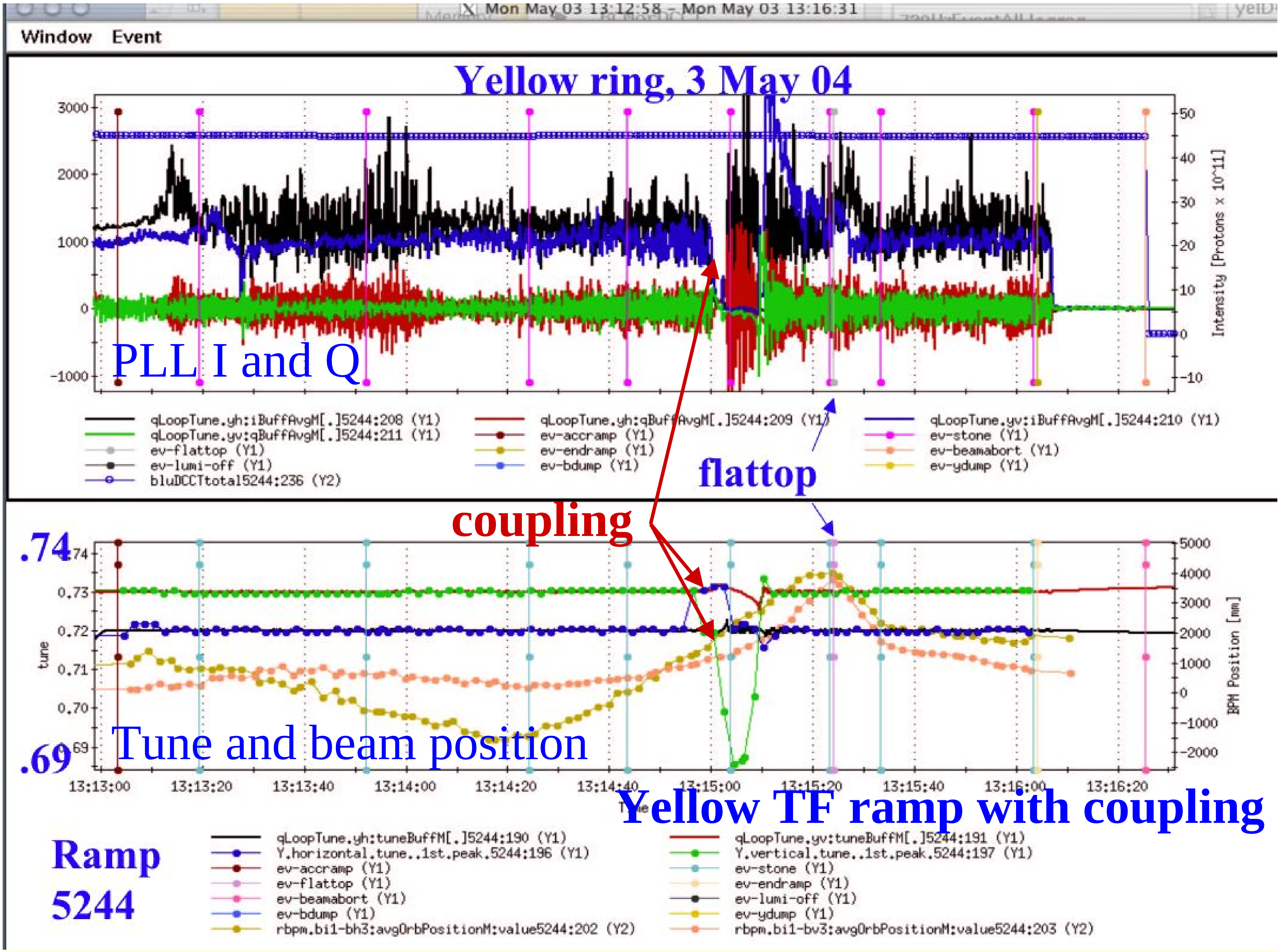


Ramp 5196

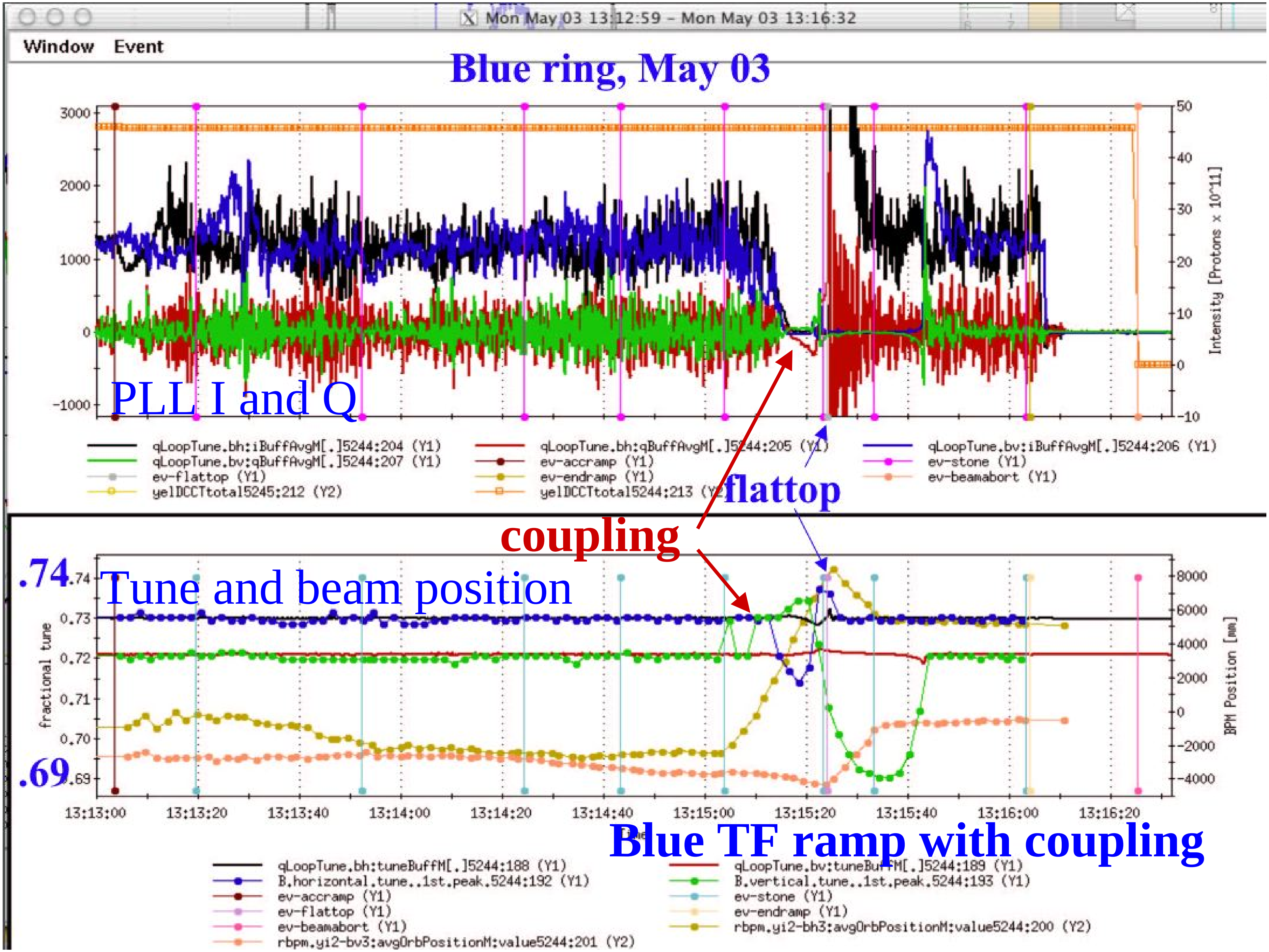
Polarized protons

Effect of Coupling on TF

- Previous slide showed successful ramp w/ TF
  - Coupling was well corrected prior to ramp
- Next two slides show slightly less successful ramps w/ TF
  - Coupling not so well corrected (due to change of Bdot as ramp approaches flattop)
  - Tune excursions during times of large coupling
  - No beam loss, but probable polarization loss



Mon May 03 13:12:58 – Mon May 03 13:16:31
Window
Event
Yellow ring, 3 May 04
PLL I and Q
3000
2000
1000
0
-1000
50
40
30
20
10
0
-10
Intensity [Protons x 10^11]
qLoopTune.yh:iBuffAvgM[.]5244:208 (Y1)
qLoopTune.yv:qBuffAvgM[.]5244:211 (Y1)
ev-flattop (Y1)
ev-lumi-off (Y1)
bluDCCTtotal5244:236 (Y2)
qLoopTune.yh:qBuffAvgM[.]5244:209 (Y1)
ev-accramp (Y1)
ev-endramp (Y1)
ev-bdump (Y1)
qLoopTune.yv:iBuffAvgM[.]5244:210 (Y1)
ev-stone (Y1)
ev-beamabort (Y1)
ev-ydump (Y1)
flattop
coupling
.74
.69
0.74
0.73
0.72
0.71
0.70
0.69
tune
5000
4000
3000
2000
1000
0
-1000
-2000
BPM Position [mm]
Tune and beam position
13:13:00
13:13:20
13:13:40
13:14:00
13:14:20
13:14:40
13:15:00
13:15:20
13:15:40
13:16:00
13:16:20
Yellow TF ramp with coupling
Ramp
5244
qLoopTune.yh:tuneBuffM[.]5244:190 (Y1)
Y.horizontal.tune..1st.peak.5244:196 (Y1)
ev-accramp (Y1)
ev-flattop (Y1)
ev-beamabort (Y1)
ev-bdump (Y1)
rbpm.bi1-bh3:avgOrbPositionM:value5244:202 (Y2)
qLoopTune.yv:tuneBuffM[.]5244:191 (Y1)
Y.vertical.tune..1st.peak.5244:197 (Y1)
ev-stone (Y1)
ev-endramp (Y1)
ev-lumi-off (Y1)
ev-ydump (Y1)
rbpm.bi1-bv3:avgOrbPositionM:value5244:203 (Y2)


Mon May 03 13:12:59 - Mon May 03 13:16:32
Window
Event
Blue ring, May 03
PLL I and Q
Intensity [Protons x 10^11]
qLoopTune.bh:iBuffAvgM[.]5244:204 (Y1)
qLoopTune.bv:qBuffAvgM[.]5244:207 (Y1)
ev-flattop (Y1)
yelDCCTtotal5245:212 (Y2)
qLoopTune.bh:qBuffAvgM[.]5244:205 (Y1)
ev-accramp (Y1)
ev-endramp (Y1)
yelDCCTtotal5244:213 (Y2)
qLoopTune.bv:iBuffAvgM[.]5244:206 (Y1)
ev-stone (Y1)
ev-beamabort (Y1)
flattop
coupling
.74
.69
Tune and beam position
fractional tune
BPM Position [mm]
13:13:00
13:13:20
13:13:40
13:14:00
13:14:20
13:14:40
13:15:00
13:15:20
13:15:40
13:16:00
13:16:20
Blue TF ramp with coupling
qLoopTune.bh:tuneBuffM[.]5244:188 (Y1)
B.horizontal.tune..1st.peak.5244:192 (Y1)
ev-accramp (Y1)
ev-flattop (Y1)
ev-beamabort (Y1)
rbpm.yi2-bv3:avgOrbPositionM:value5244:201 (Y2)
qLoopTune.bv:tuneBuffM[.]5244:189 (Y1)
B.vertical.tune..1st.peak.5244:193 (Y1)
ev-stone (Y1)
ev-endramp (Y1)
rbpm.yi2-bh3:avgOrbPositionM:value5244:200 (Y2)

Coupling 17 May 04

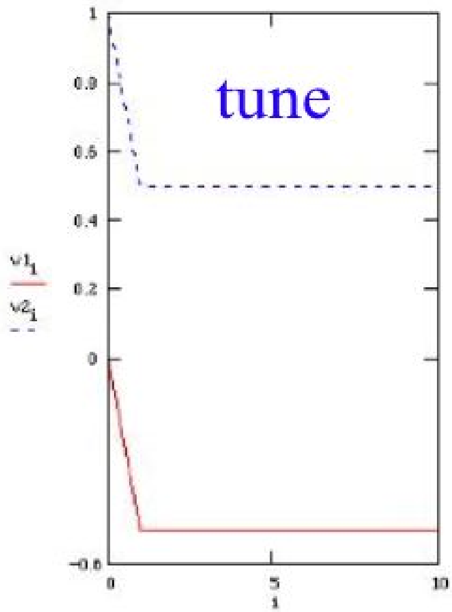
$n := 10$

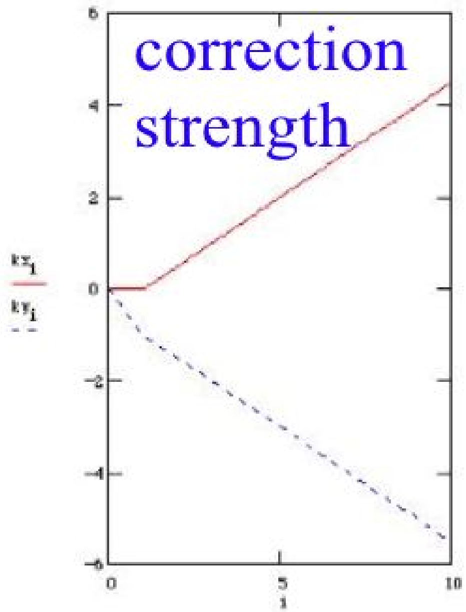
$i := 0 .. n$

$$\begin{bmatrix} v1_0 \\ v2_0 \\ kx_0 \\ ky_0 \end{bmatrix} := \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

coupling terms

$$\begin{bmatrix} v1_{i+1} \\ v2_{i+1} \\ kx_{i+1} \\ ky_{i+1} \end{bmatrix} := \begin{bmatrix} v1_i + -0.5 \cdot (v1_i + v2_i) \\ v2_i + -0.5 \cdot (v1_i + v2_i) \\ kx_i - v1_i \\ ky_i - v2_i \end{bmatrix}$$





Tune Feedback and Coupling

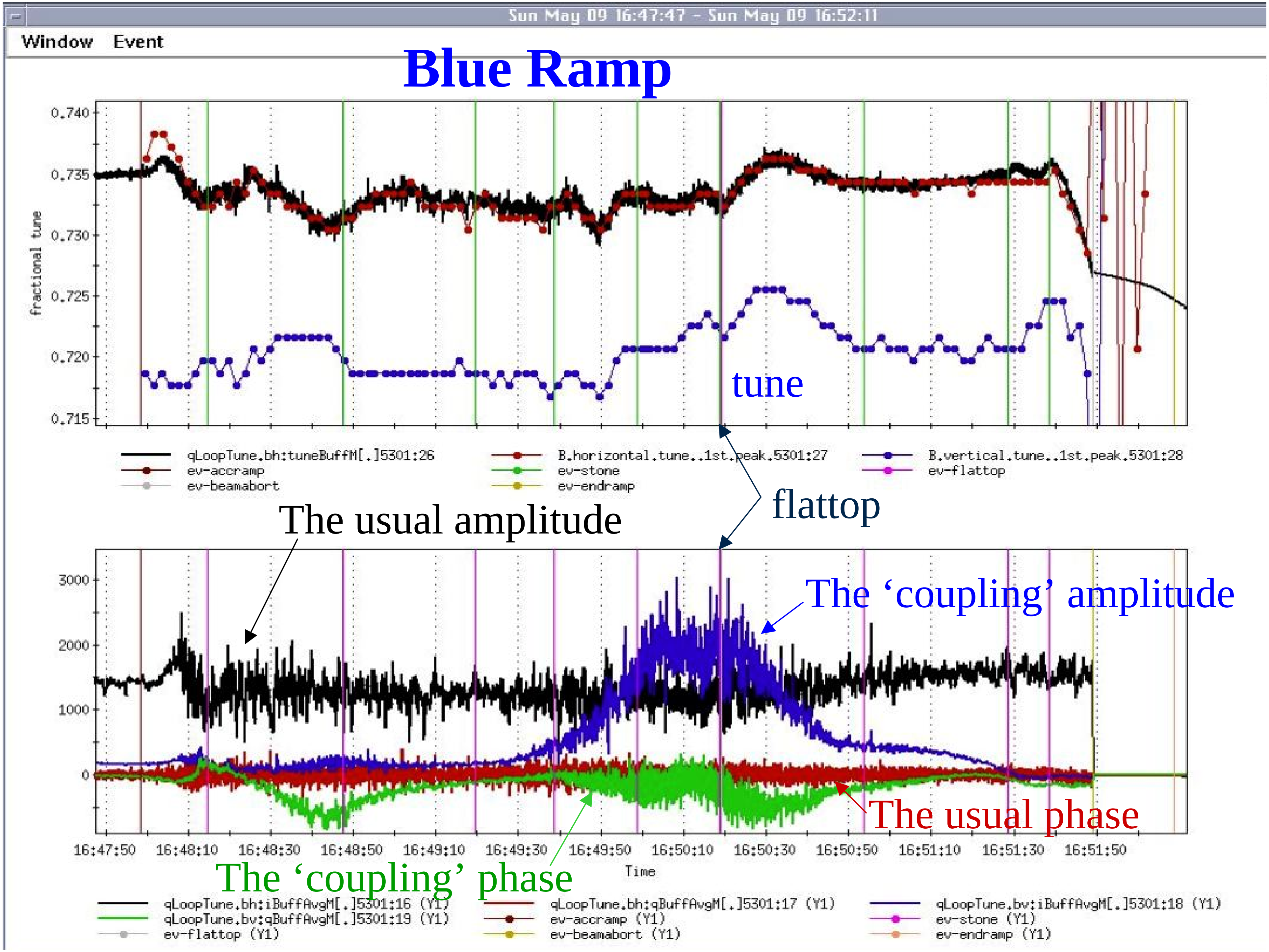
- PLL measures normal modes
  - works fine in the presence of strong coupling
  - tune crossings problematic
- Tune Feedback corrects X and Y
  - not stable in the presence of strong coupling

What We Learned and Did

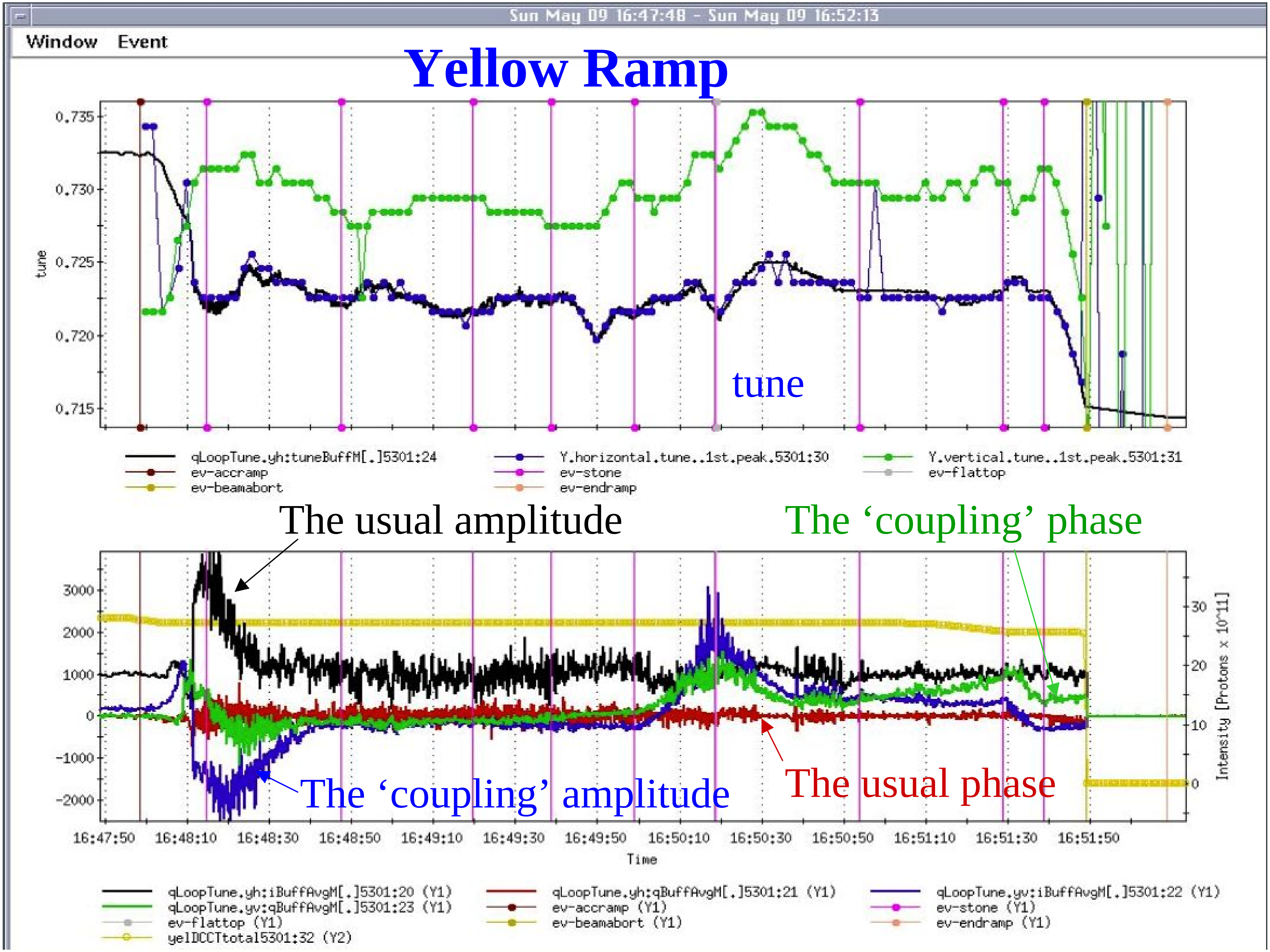
- What we Learned
  - PLL is stable in the presence of coupling (without tune crossings)
  - The system of

    Tune Feedback = PLL + magnet control

    is not stable in the presence of coupling
- What we Did
  - Improved coupling measurement
  - Investigated two correction possibilities:
  - Reconfigured PLL to track projection of eigenmode 1 in both planes


Sun May 09 16:47:47 - Sun May 09 16:52:11
Window Event
Blue Ramp
fractional tune
0.740
0.735
0.730
0.725
0.720
0.715
tune
qLoopTune.bh:tuneBuffM[.]5301:26
ev-accramp
ev-beamabort
B.horizontal.tune..1st.peak.5301:27
ev-stone
ev-endramp
B.vertical.tune..1st.peak.5301:28
ev-flattop
flattop
The usual amplitude
The 'coupling' amplitude
3000
2000
1000
0
The usual phase
16:47:50
16:48:10
16:48:30
16:48:50
16:49:10
16:49:30
16:49:50
16:50:10
16:50:30
16:50:50
16:51:10
16:51:30
16:51:50
Time
The 'coupling' phase
qLoopTune.bh:iBuffAvgM[.]5301:16 (Y1)
qLoopTune.bv:qBuffAvgM[.]5301:19 (Y1)
ev-flattop (Y1)
qLoopTune.bh:qBuffAvgM[.]5301:17 (Y1)
ev-accramp (Y1)
ev-beamabort (Y1)
qLoopTune.bv:iBuffAvgM[.]5301:18 (Y1)
ev-stone (Y1)
ev-endramp (Y1)

Yellow Ramp



Sun May 09 16:47:48 - Sun May 09 16:52:13
Window
Event
tune
0.735
0.730
0.725
0.720
0.715
tune
qLoopTune.yh:tuneBuffM[.]5301:24
ev-accramp
ev-beamabort
Y.horizontal.tune..1st.peak.5301:30
ev-stone
ev-endramp
Y.vertical.tune..1st.peak.5301:31
ev-flattop
The usual amplitude
The 'coupling' phase
3000
2000
1000
0
-1000
-2000
30
20
10
0
Intensity [Protons x 10^11]
The 'coupling' amplitude
The usual phase
16:47:50
16:48:10
16:48:30
16:48:50
16:49:10
16:49:30
16:49:50
16:50:10
16:50:30
16:50:50
16:51:10
16:51:30
16:51:50
Time
qLoopTune.yh:iBuffAvgM[.]5301:20 (Y1)
qLoopTune.yv:qBuffAvgM[.]5301:23 (Y1)
ev-flattop (Y1)
yelDCCTtotal5301:32 (Y2)
qLoopTune.yh:qBuffAvgM[.]5301:21 (Y1)
ev-accramp (Y1)
ev-beamabort (Y1)
qLoopTune.yv:iBuffAvgM[.]5301:22 (Y1)
ev-stone (Y1)
ev-endramp (Y1)

What we learned from what we did

- This method (phase lock to same eigenmode in both planes) gives very clean coupling measurement (amplitude **and** phase)
- Large coupling did indeed exist at the time the system of tune feedback (= PLL + magnet control) became unstable

Coupling summary

- New understanding
  - Coupling not an issue for PLL
  - **Coupling a very serious issue for tune feedback**
- New measurement technique
  - Non-perturbative
  - Excellent S/N
  - Delivers both amplitude and phase of coupling
  - Possibility of coupling correction using this data is being actively investigated – Yun Luo, Steve Peggs, Richard Talman
  - If coupling is not corrected, at the least we BI people can use this information to rotate eigenmodes back to X-Y plane before passing tunes to magnet guys, thereby keeping TF system stable

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FY04 at CERN

FY05 Plans

- Baseband PLL
- Coupling Studies
- Chromaticity measurement

Baseband PLL

- Advantages – Marek Gasior, Rhodri, Hermann,…
  - Filters much easier – helps with dynamic range/rev line problem
  - 24 bit digitizers - 144dB (better than available preamps!) dynamic range
  - Improved CMRR
  - Synchrotron satellites/linewidth - less of an issue
  - Eliminates need for phase compensation - of more interest at RHIC (~700 degrees during ramp)
  - Simplicity – get rid of mixers
  - If resonant, characteristic time is much longer – figure of merit is Q/freq
- Disadvantages
  - Emittance blowup?
  - What else?

Two Approaches to Baseband PLL

- Resonant pickup (primarily BNL)
  - Advantageous with many bunches
  - Improved S/N (emittance blowup/damper floor)
  - Not yet approved by LHC impedance police
- Diode detection (primarily CERN)
  - Advantageous with single bunch - detects all AM sidebands within BW of diode
  - With many bunches, spectrum becomes sparse
  - Concern with emittance growth with many bunches

Resonant Pickup during RHIC 2004

- Resonant pickup at ~100KHz
  - Q ~ 100 gives 20dB improvement in S/N, factor of 10 less excitation amplitude needed (meets requirement of 1 micron LHC damper floor)
  - Double tuned resonant circuit gives ~40dB rejection of nearest revolution line
- Problem remains dynamic range
  - Some (significant?) improvement over 245MHz system
  - Problem is flux density and ferrite de-Q'ing

Resonant pickup summary

- Moderately successful initial results during last hours of RHIC 2004 run
- Plans in progress for SPS and RHIC 2005 testing (see following slides)
- Primary issue to resolve remains dynamic range
- This is being intensively studied in collaboration with CERN

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FY04 at CERN SPS

- June 2004
  - Complete 245MHz system delivered and brought into operation
  - Diode detection pickup undergoing testing with beam
- September 2004
  - Continue operation of 245MHz system with beam
  - Continue testing of diode detection pickup with beam
  - Begin testing of resonant pickup with beam

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FY05 Plans - 1

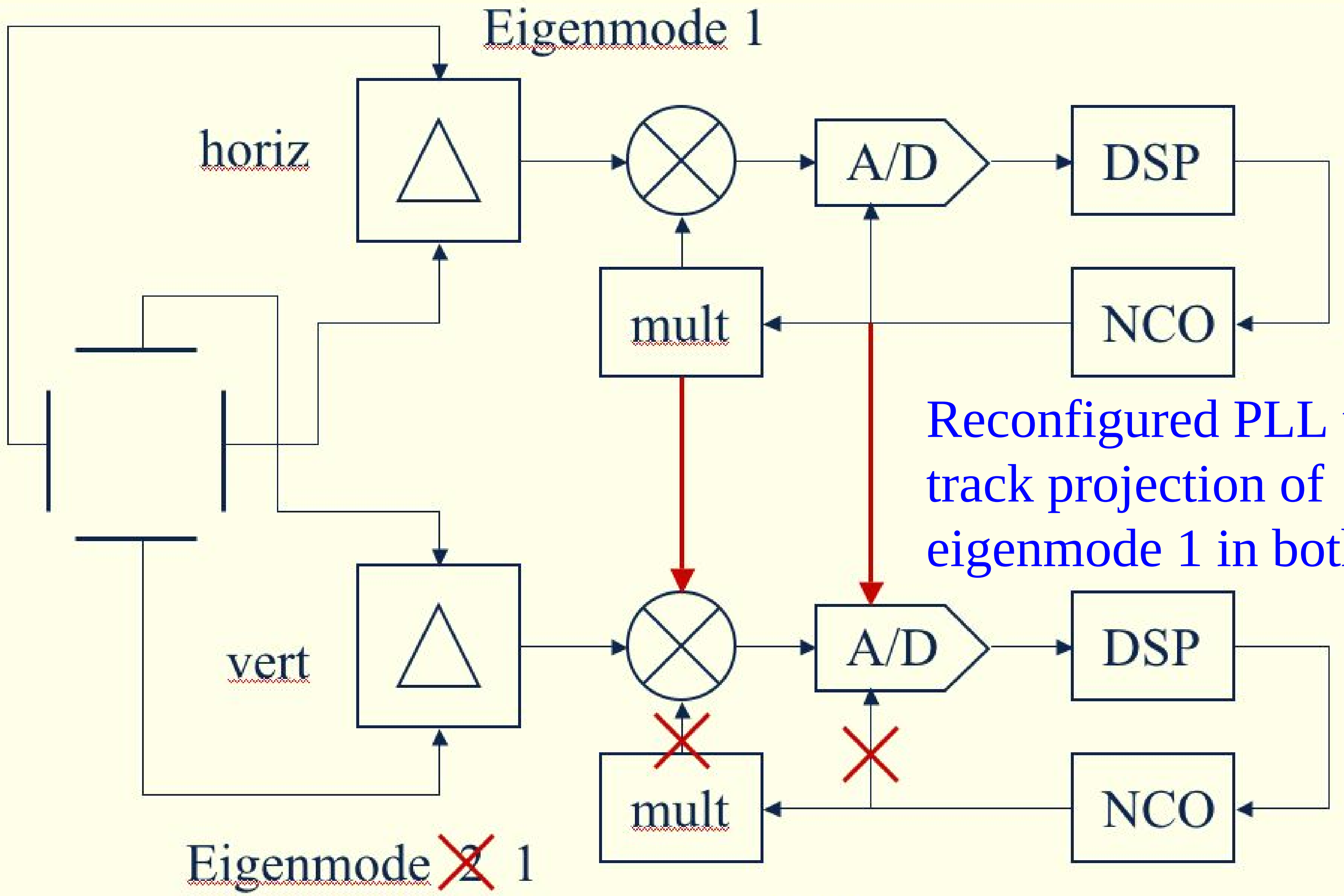
- SPS beam goes away for ~18 months in October
- There will be a strong CERN presence at RHIC during this time
- Status of PLL/TF at RHIC
  - Model in reasonably good shape, ramps are under control – less push from RHIC management for 'next generation' PLL and tune feedback
  - Consequently, significant portion of burden for this effort will fall on the LHC team
  - Need co-operation from RHIC for essential beam time and infrastructure support

FY05 Plans - 2

- 245MHz as-is except four additional 245MHz DAQ channels for coupling measurement
- Baseband PLL
  - Add motion control on 1m pickups
  - Fabricate and install resonant electronics
  - Fabricate and install diode detection electronics
  - Kickers, kicker amplifiers, amplifier control,…
  - DAQ – digitizers, DSPs, DSP code, LabVIEW code, Controls interface,…
  - Studies – coupling, chrom, emittance blowup, …

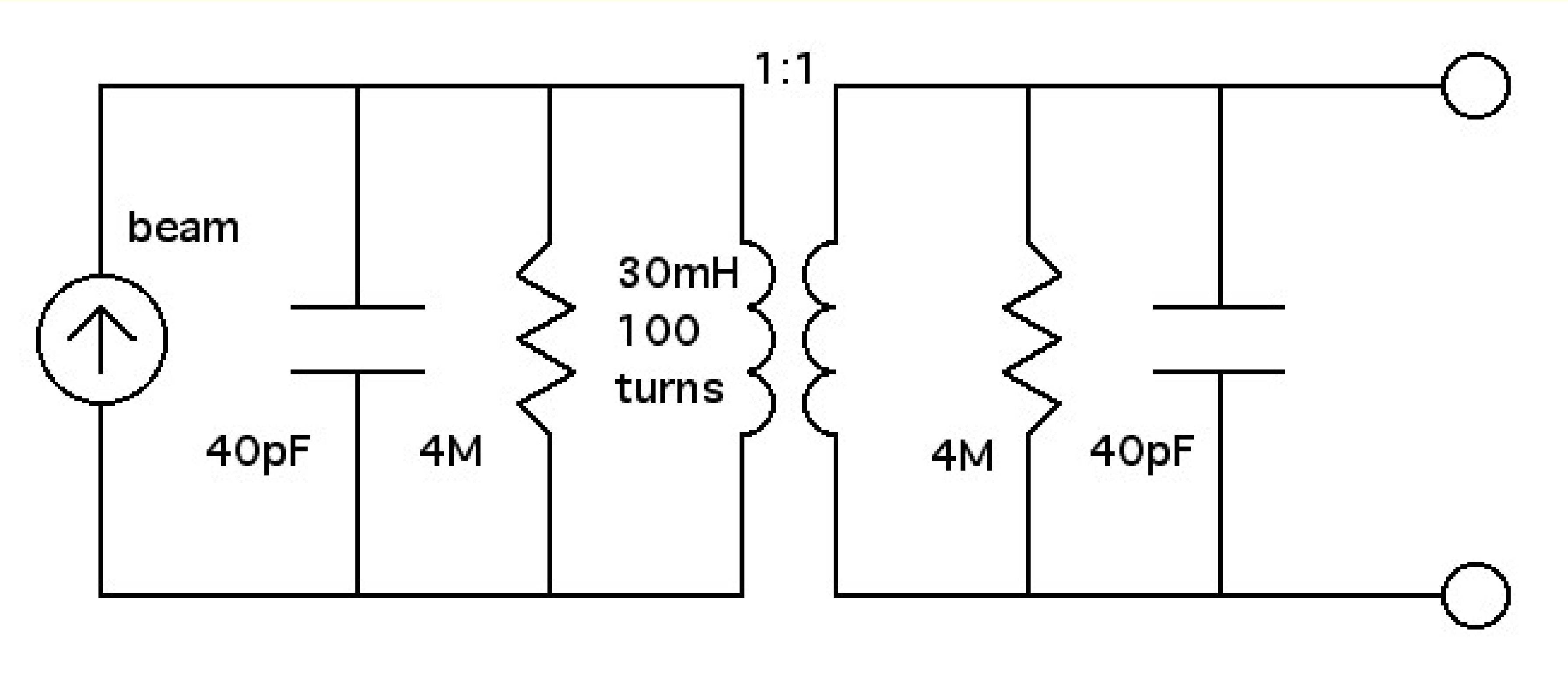
Extra Slides

Coupling Measurement

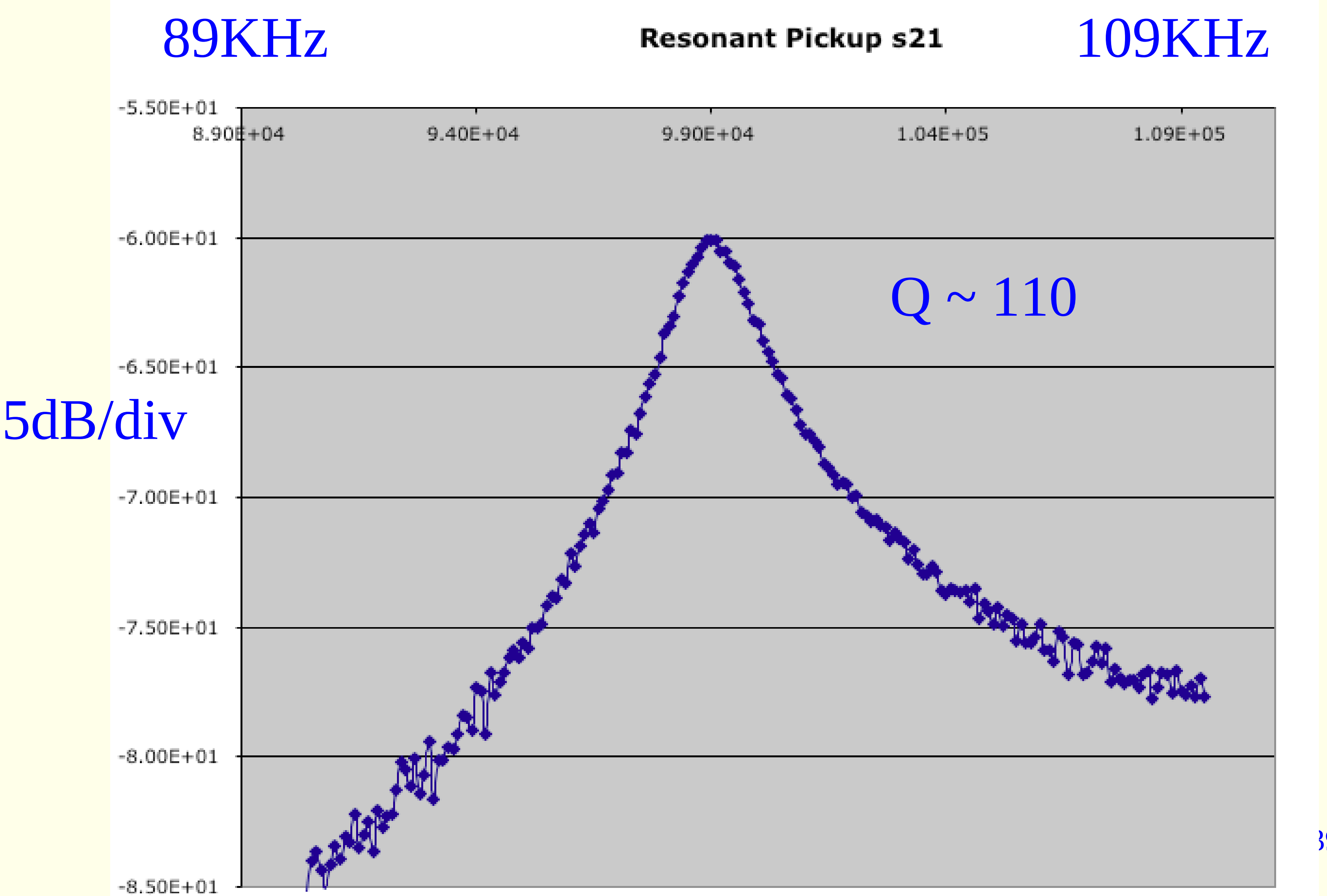


Reconfigured PLL to track projection of eigenmode 1 in both planes

Resonant Pickup circuit

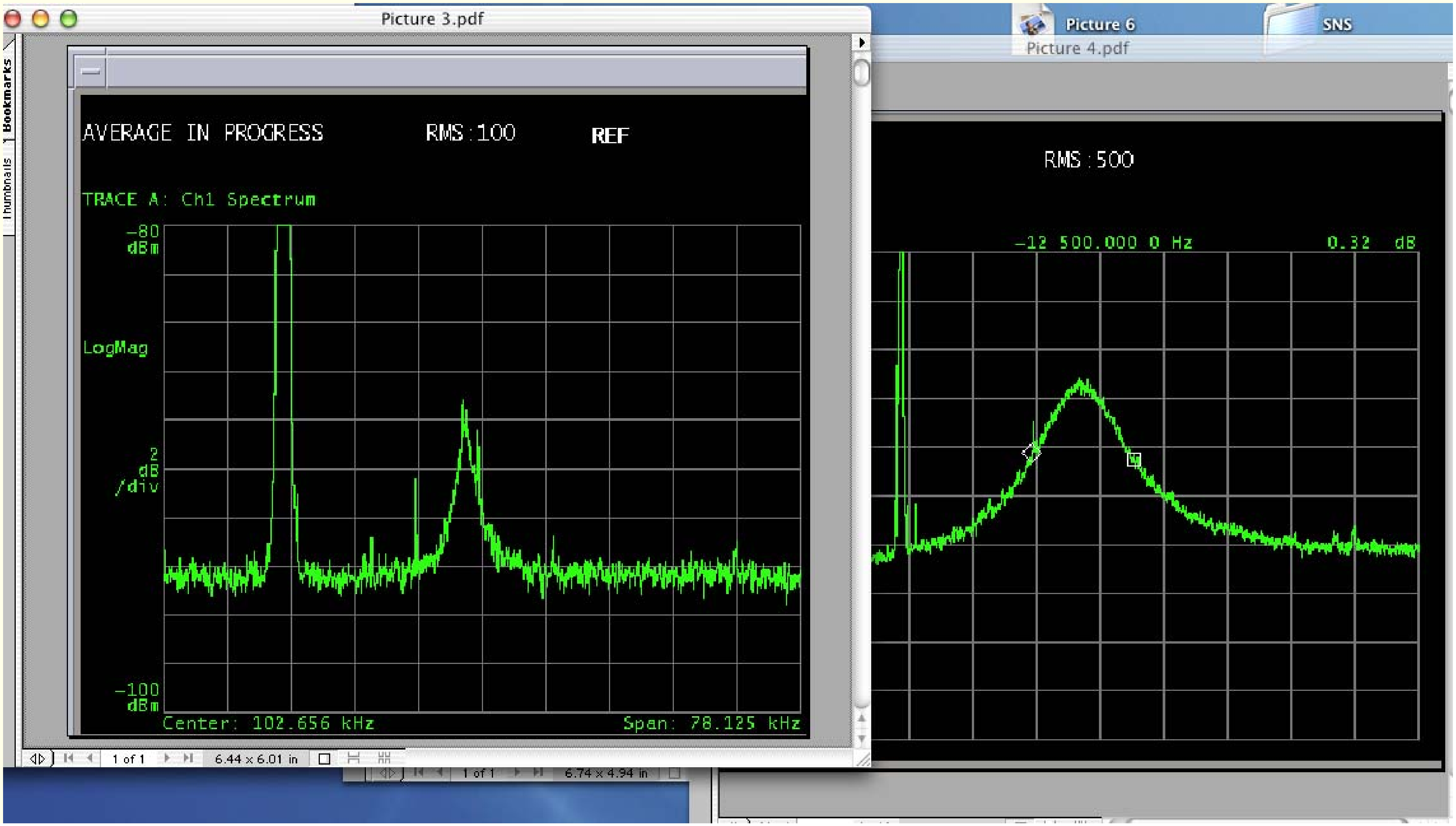


Bench S21 measurement



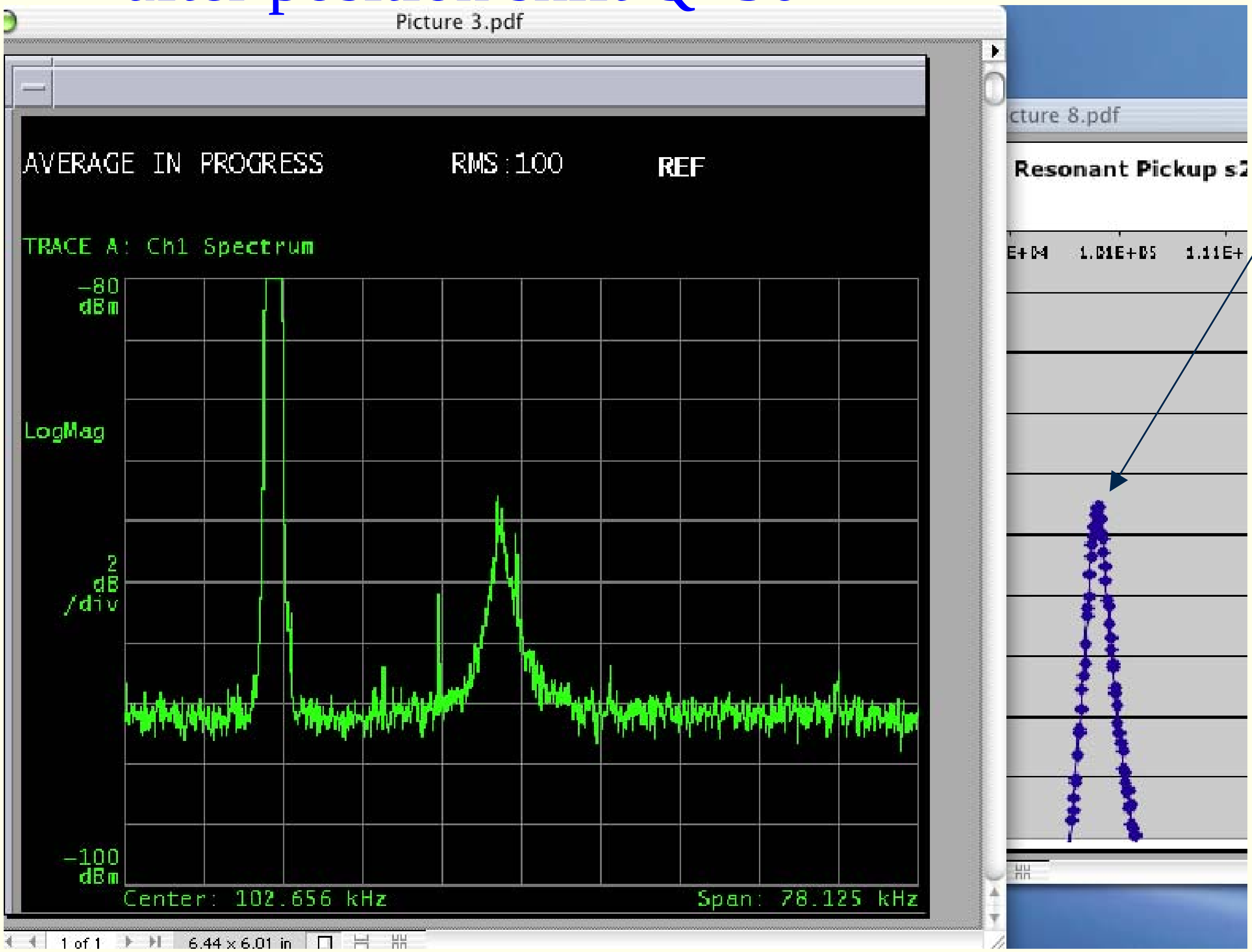
Beam-dependent Q

after position shift Q~50 before Q~9



Comparison with Bench S21

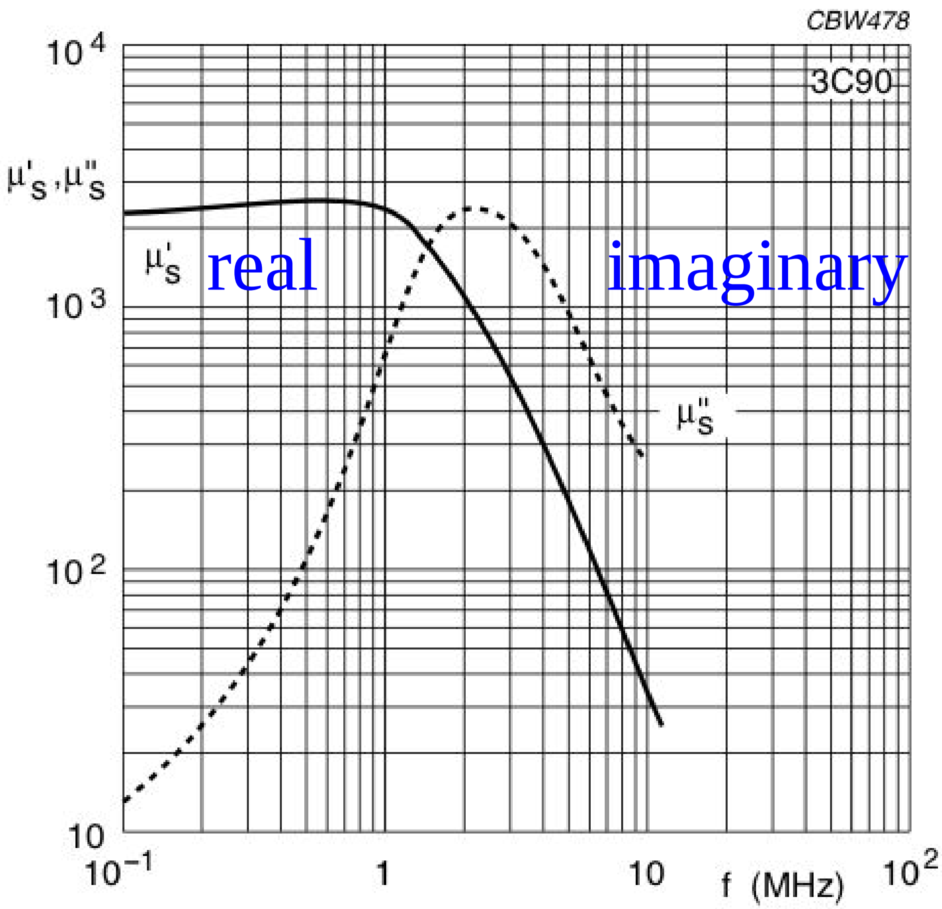
after position shift Q~50



bench S21

H and V scales are the same

Flux Density in toroid



Max recommended ~10G

Three concerns

- Sum mode ~500G
- Rev line diff mode ~200G
- Signal – single bunch S/N ~40dB with 1 micron excitation

Solutions

- Add capacitance – reduces S/N, electronics out of tunnel?
- More ferrite – x10
- Motion control – transition!