Tune Feedback at RHIC

Peter Cameron

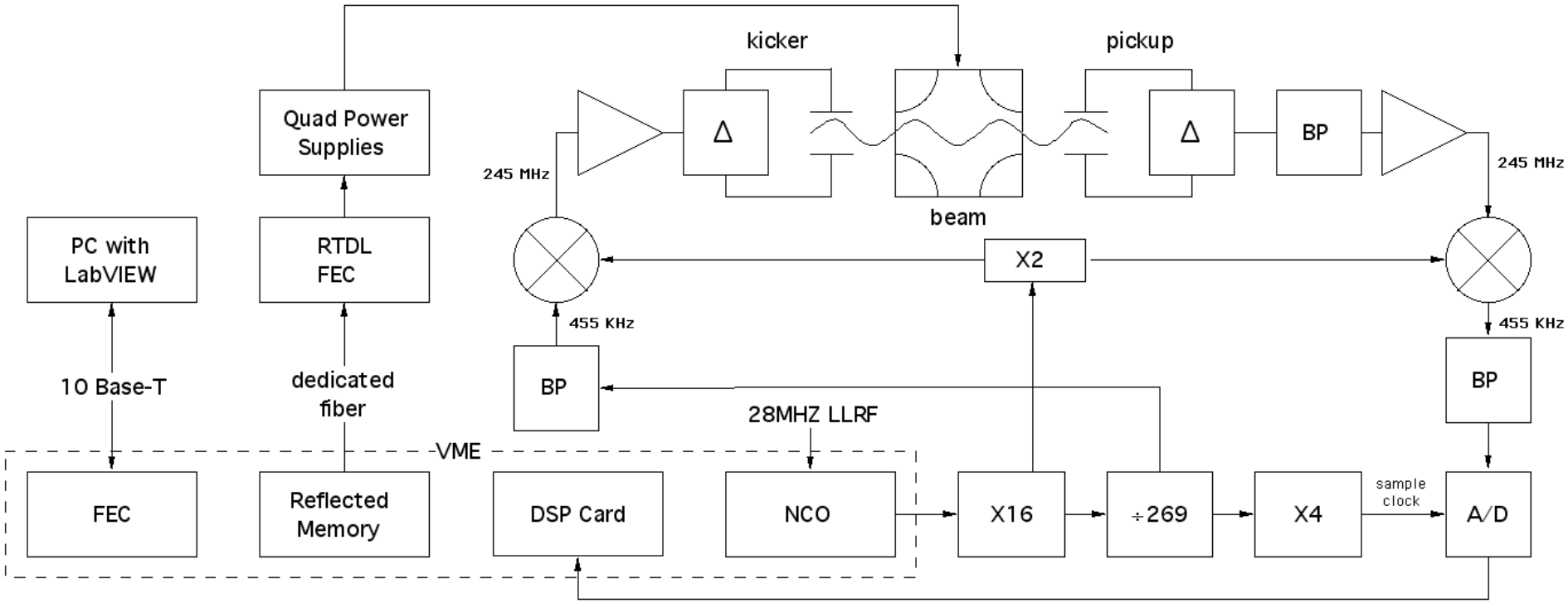
PLL/TF Experience at RHIC

- RHIC 2000 – prototype PLL
- RHIC 2001
  - First generation PLL
  - Tune feedback successful (but not operational) for polarized protons (no transition crossing)
- RHIC 2003
  - Second generation PLL
  - Tune feedback successful (but not operational) for gold and deuterons (transition crossing)
  - Tune feedback successful (but not operational) for polarized protons (no transition crossing)

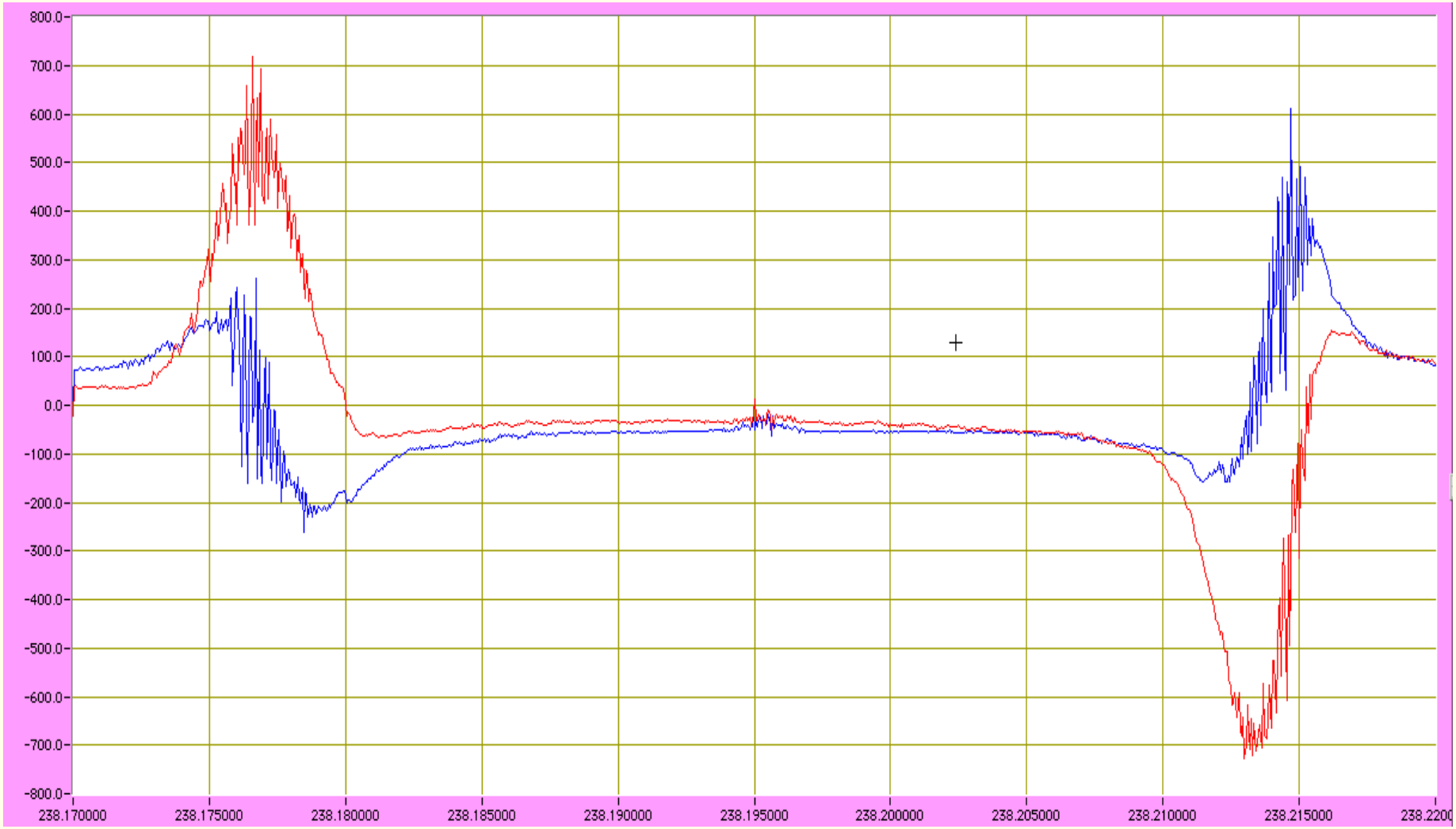
Ramp Control Requirements

- Tune measurement and feedback
  - Avoid resonances (betatron and spin)
- Chromaticity measurement and feedback/feedforward
  - Avoid tails on resonance – not too big
  - Stability - right sign, not too small
- Coupling measurement and feedback/feedforward
  - Control tune
  - Minimize higher order resonance strength
- Accomplish this without excessive emittance growth/halo formation

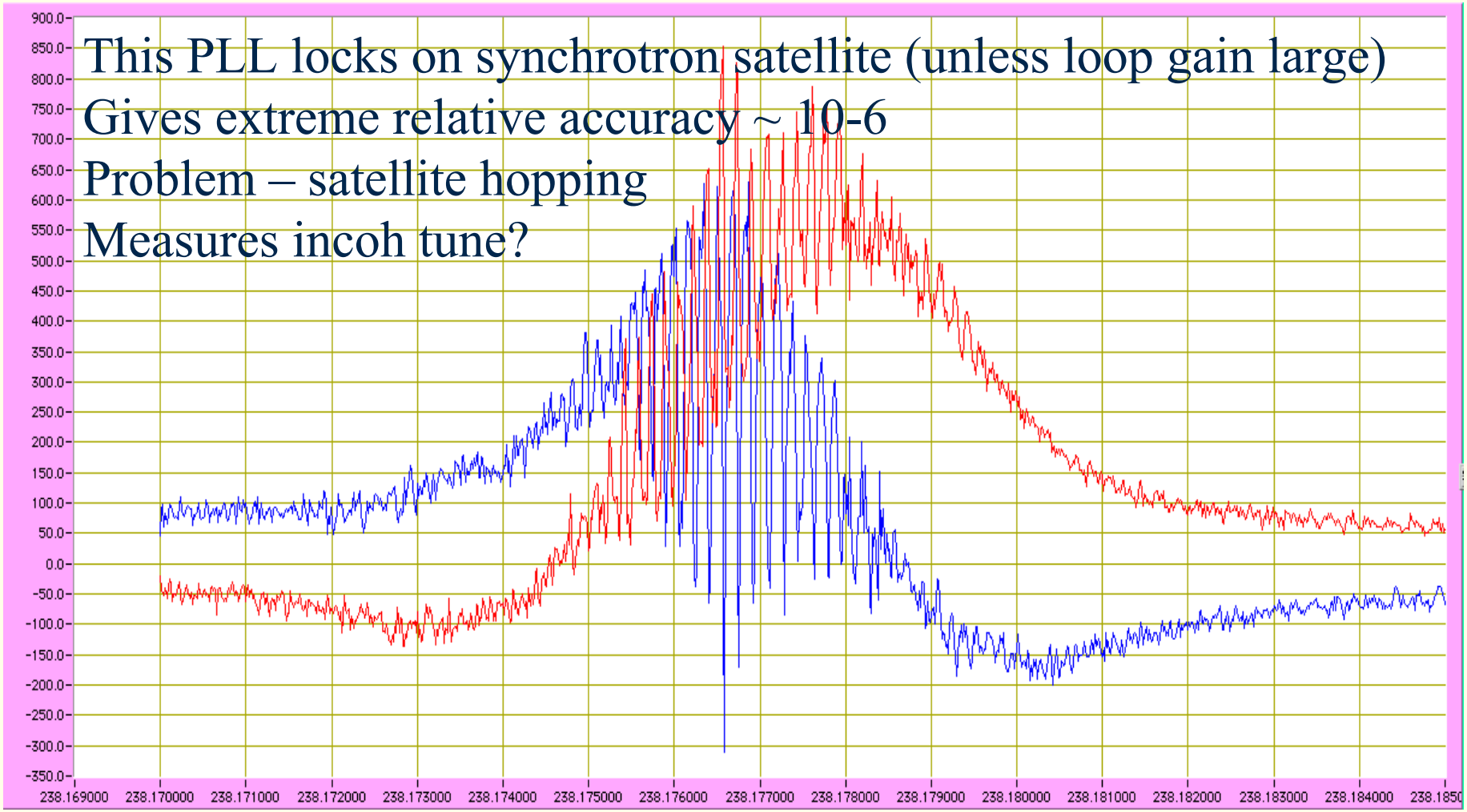
PLL Block Diagram

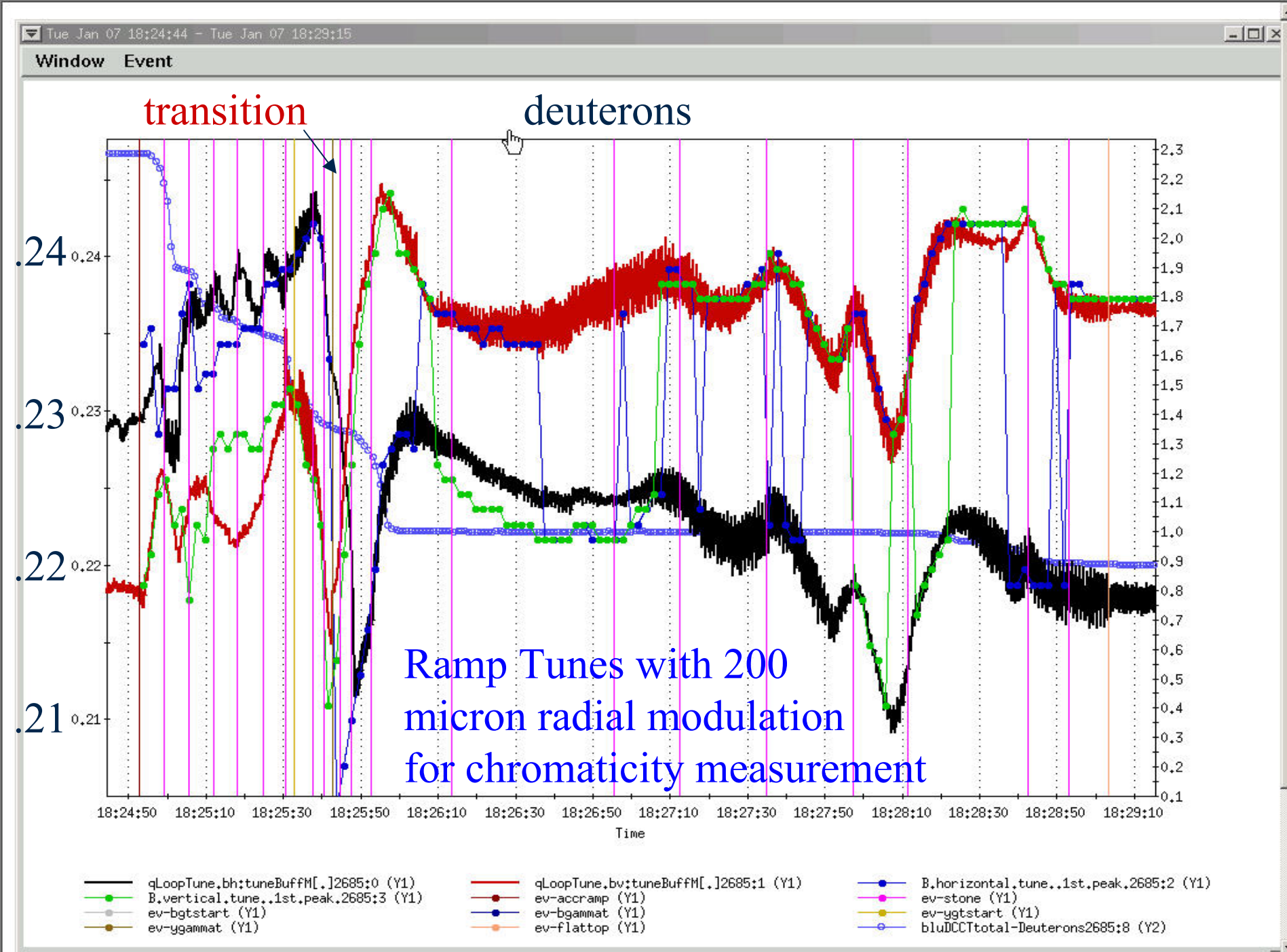


Beam Transfer Function



Zoom on Beam Transfer Function

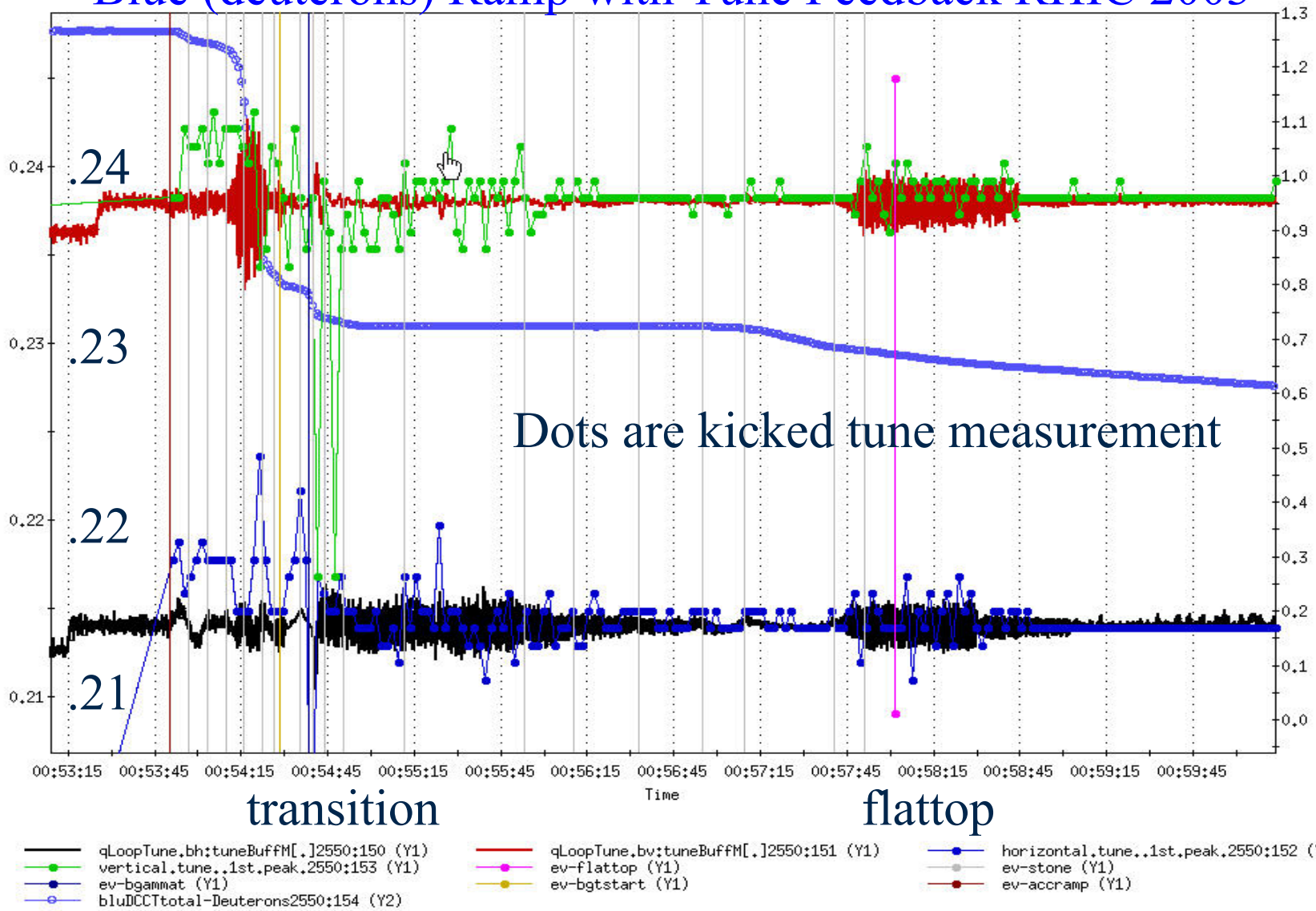



Tue Jan 07 18:24:44 - Tue Jan 07 18:29:15
Window Event
transition
deuterons
.24
.23
.22
.21
0.24
0.23
0.22
0.21
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Ramp Tunes with 200
micron radial modulation
for chromaticity measurement
18:24:50
18:25:10
18:25:30
18:25:50
18:26:10
18:26:30
18:26:50
18:27:10
18:27:30
18:27:50
18:28:10
18:28:30
18:28:50
18:29:10
Time
qLoopTune.bh:tuneBuffM[.]2685:0 (Y1)
B.vertical.tune..1st.peak.2685:3 (Y1)
ev-bgtstart (Y1)
ev-ygammat (Y1)
qLoopTune.bv:tuneBuffM[.]2685:1 (Y1)
ev-accramp (Y1)
ev-bgammat (Y1)
ev-flattop (Y1)
B.horizontal.tune..1st.peak.2685:2 (Y1)
ev-stone (Y1)
ev-ygtstart (Y1)
bluDCCTtotal-Deuterons2685:8 (Y2)

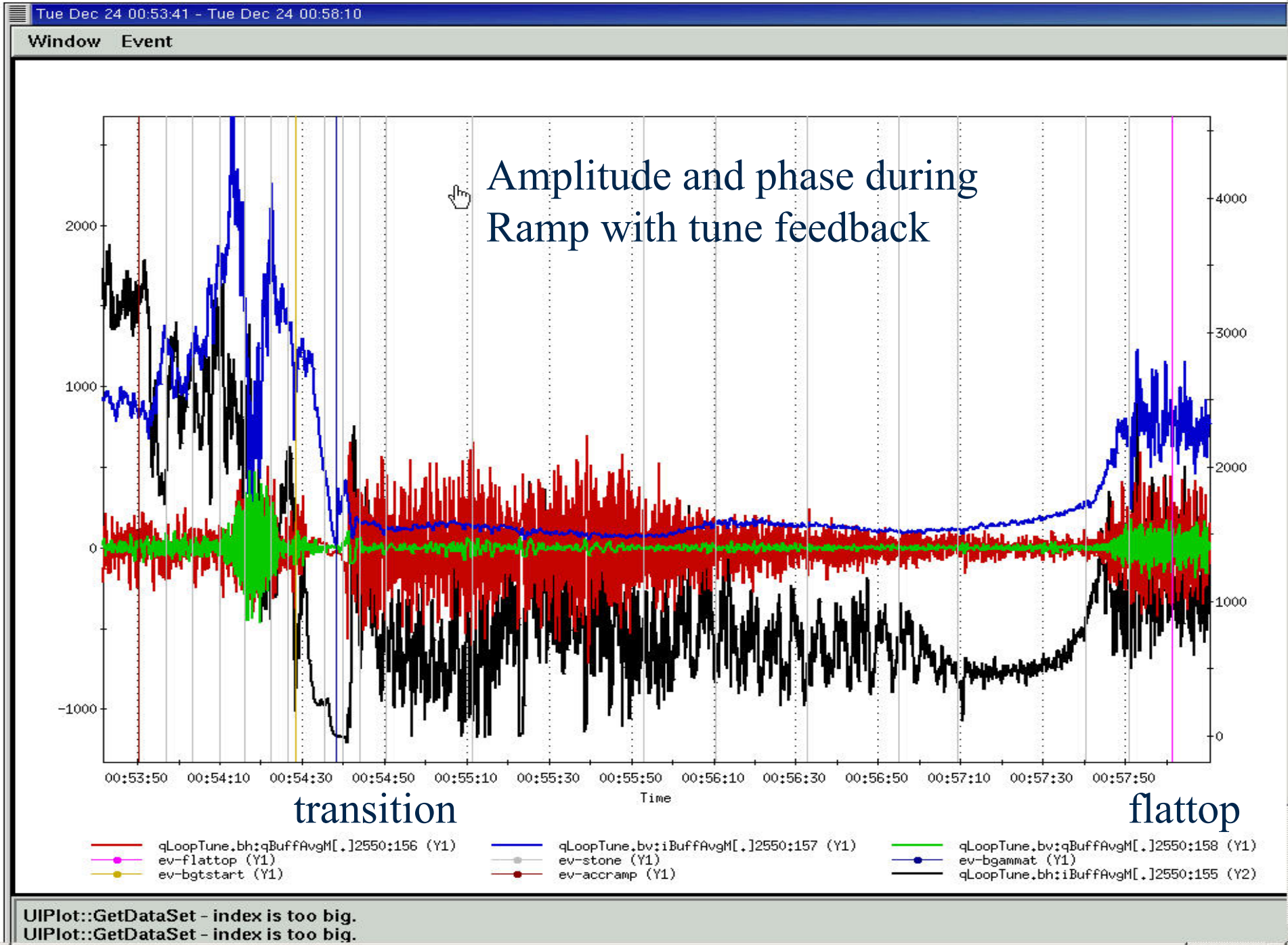
Tue Dec 24 00:53:09 - Tue Dec 24 01:00:13

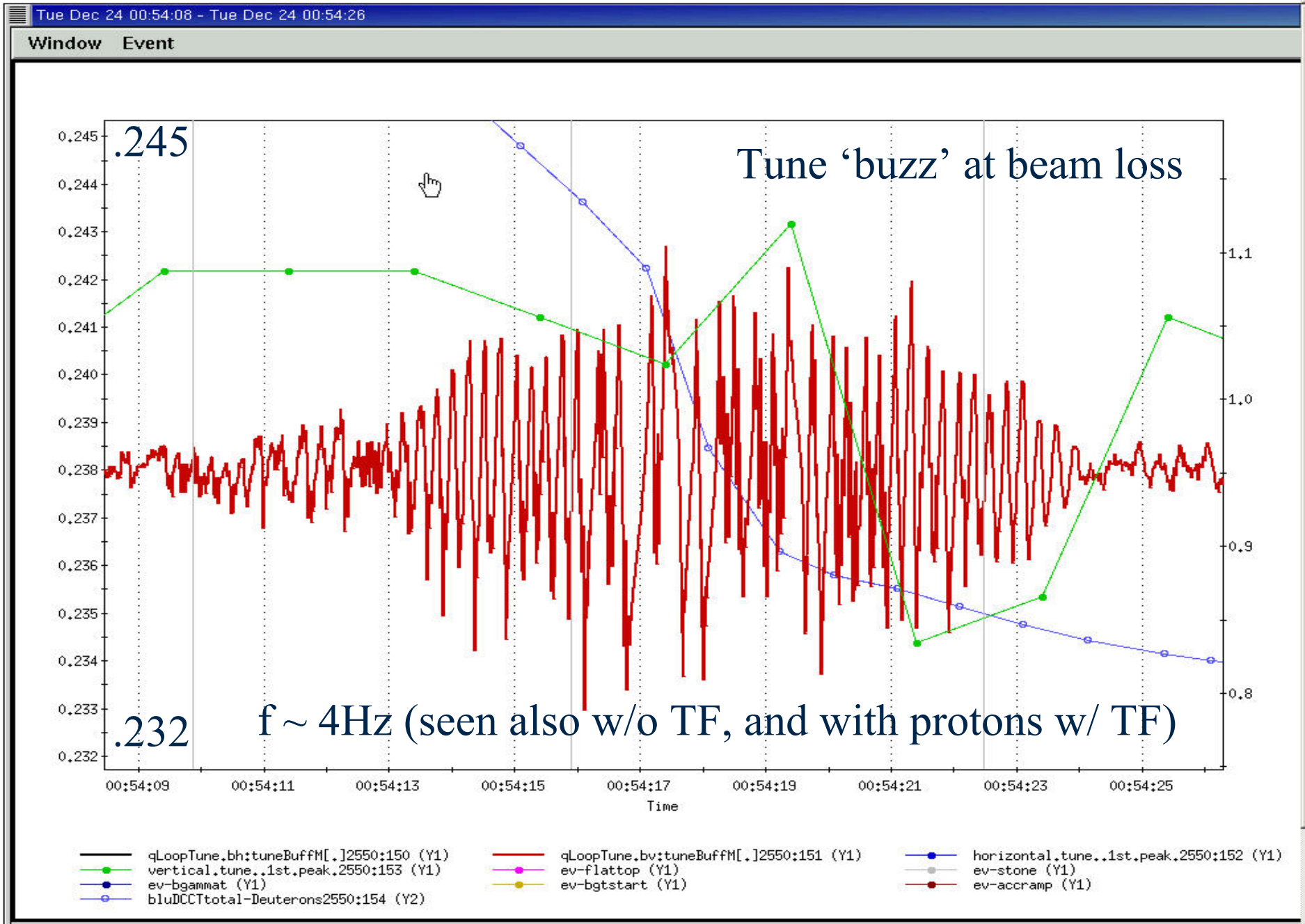
Window Event

Blue (deuterons) Ramp with Tune Feedback RHIC 2003



qLoopTune.bh:tuneBuffM[.] successfully displayed
qLoopTune.bv:tuneBuffM[.] successfully displayed

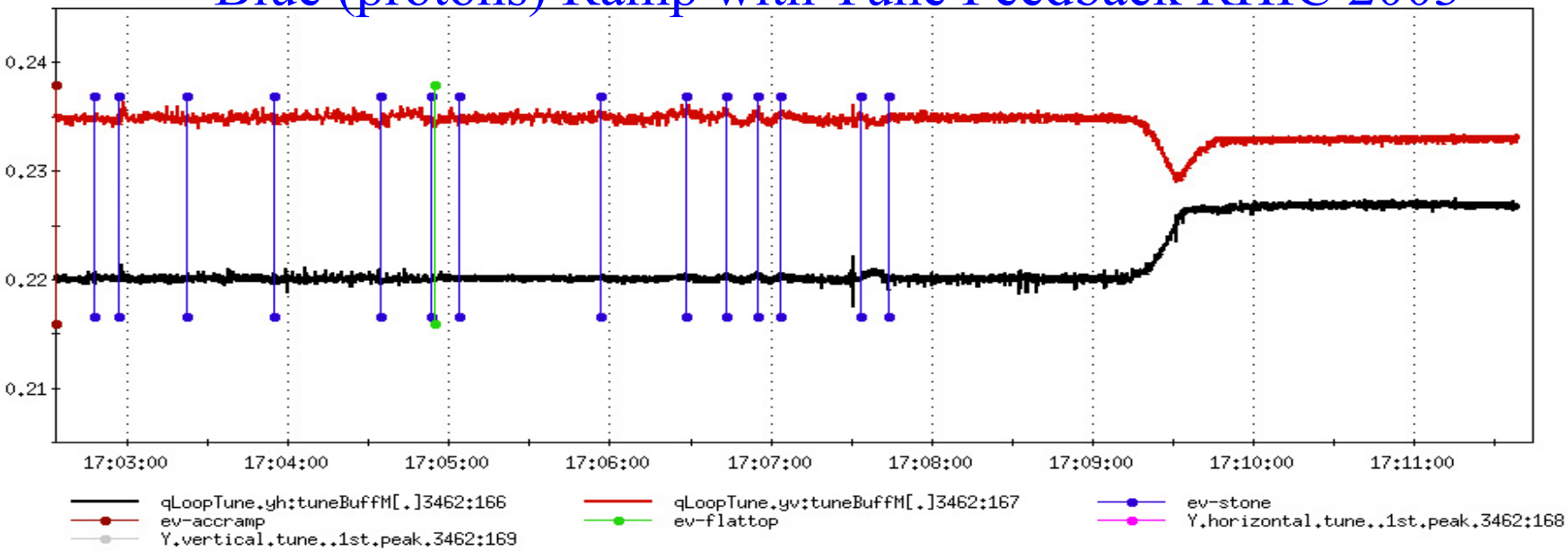

Tue Dec 24 00:53:41 - Tue Dec 24 00:58:10
Window Event
Amplitude and phase during
Ramp with tune feedback
2000
1000
0
-1000
4000
3000
2000
1000
0
00:53:50 00:54:10 00:54:30 00:54:50 00:55:10 00:55:30 00:55:50 00:56:10 00:56:30 00:56:50 00:57:10 00:57:30 00:57:50
Time
transition
flattop
qLoopTune.bh:qBuffAvgM[.]2550:156 (Y1)
ev-flattop (Y1)
ev-bgtstart (Y1)
qLoopTune.bv:iBuffAvgM[.]2550:157 (Y1)
ev-stone (Y1)
ev-accramp (Y1)
qLoopTune.bv:qBuffAvgM[.]2550:158 (Y1)
ev-bgammat (Y1)
qLoopTune.bh:iBuffAvgM[.]2550:155 (Y2)
UIPlot::GetDataSet - index is too big.
UIPlot::GetDataSet - index is too big.

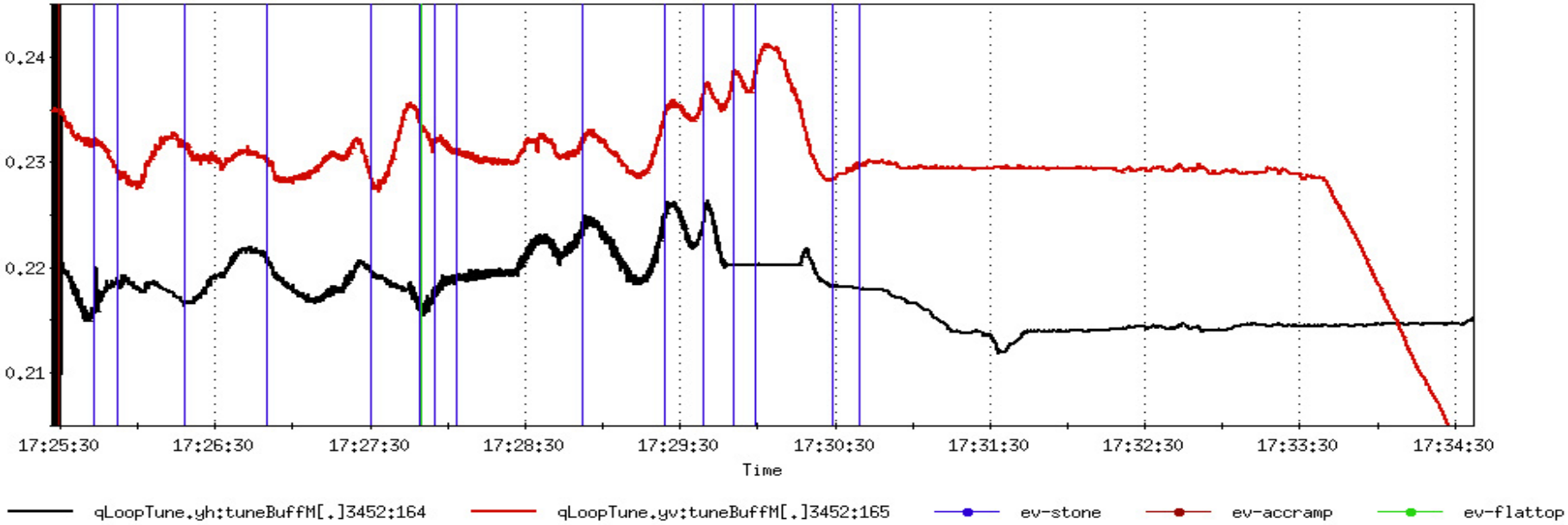

Tue Dec 24 00:54:08 - Tue Dec 24 00:54:26
Window Event
.245
.232
Tune 'buzz' at beam loss
f ~ 4Hz (seen also w/o TF, and with protons w/ TF)
0.245
0.244
0.243
0.242
0.241
0.240
0.239
0.238
0.237
0.236
0.235
0.234
0.233
0.232
1.1
1.0
0.9
0.8
00:54:09
00:54:11
00:54:13
00:54:15
00:54:17
00:54:19
00:54:21
00:54:23
00:54:25
Time
qLoopTune.bh:tuneBuffM[.]2550:150 (Y1)
vertical.tune..1st.peak.2550:153 (Y1)
ev-bgammat (Y1)
bluDCCTtotal-Deuterons2550:154 (Y2)
qLoopTune.bv:tuneBuffM[.]2550:151 (Y1)
ev-flattop (Y1)
ev-bgtstart (Y1)
horizontal.tune..1st.peak.2550:152 (Y1)
ev-stone (Y1)
ev-accramp (Y1)
qLoopTune.bh:tuneBuffM[.] successfully displayed
qLoopTune.bv:tuneBuffM[.] successfully displayed

Fri Apr 11 13:19:26 – Sun Apr 13 23:36:43

Window Event

Blue (protons) Ramp with Tune Feedback RHIC 2003

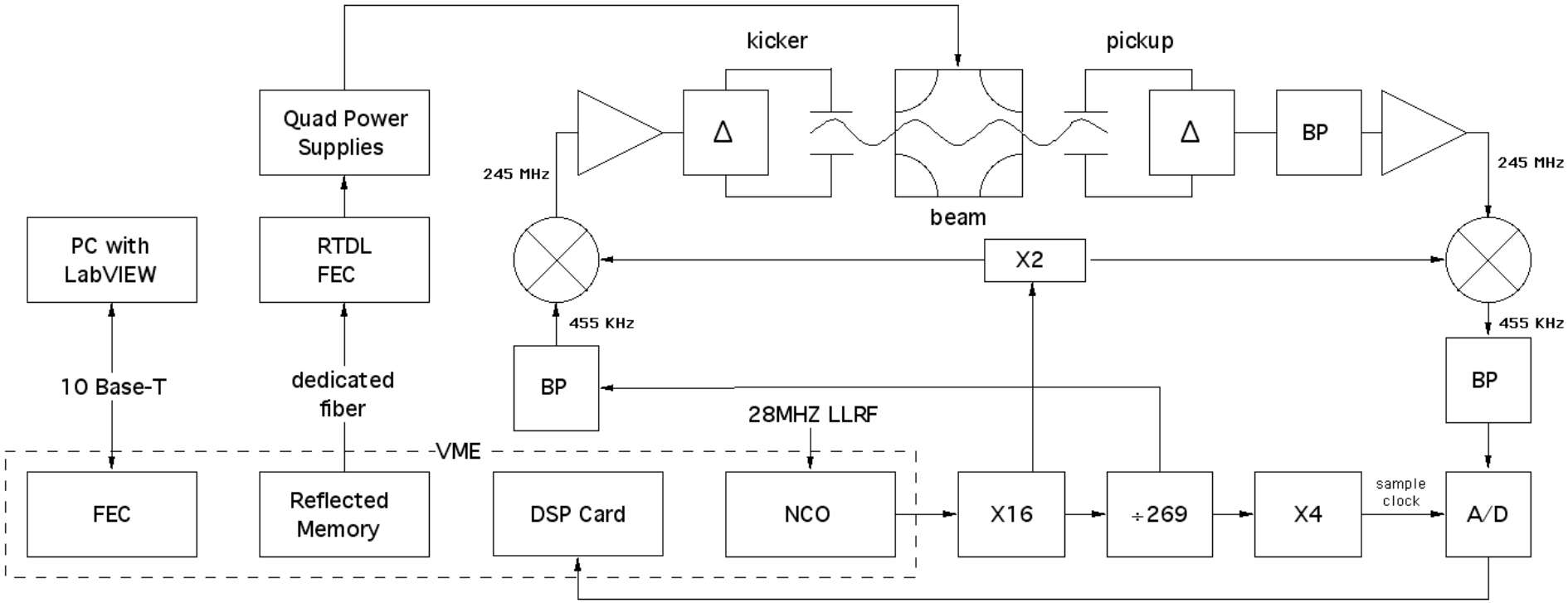


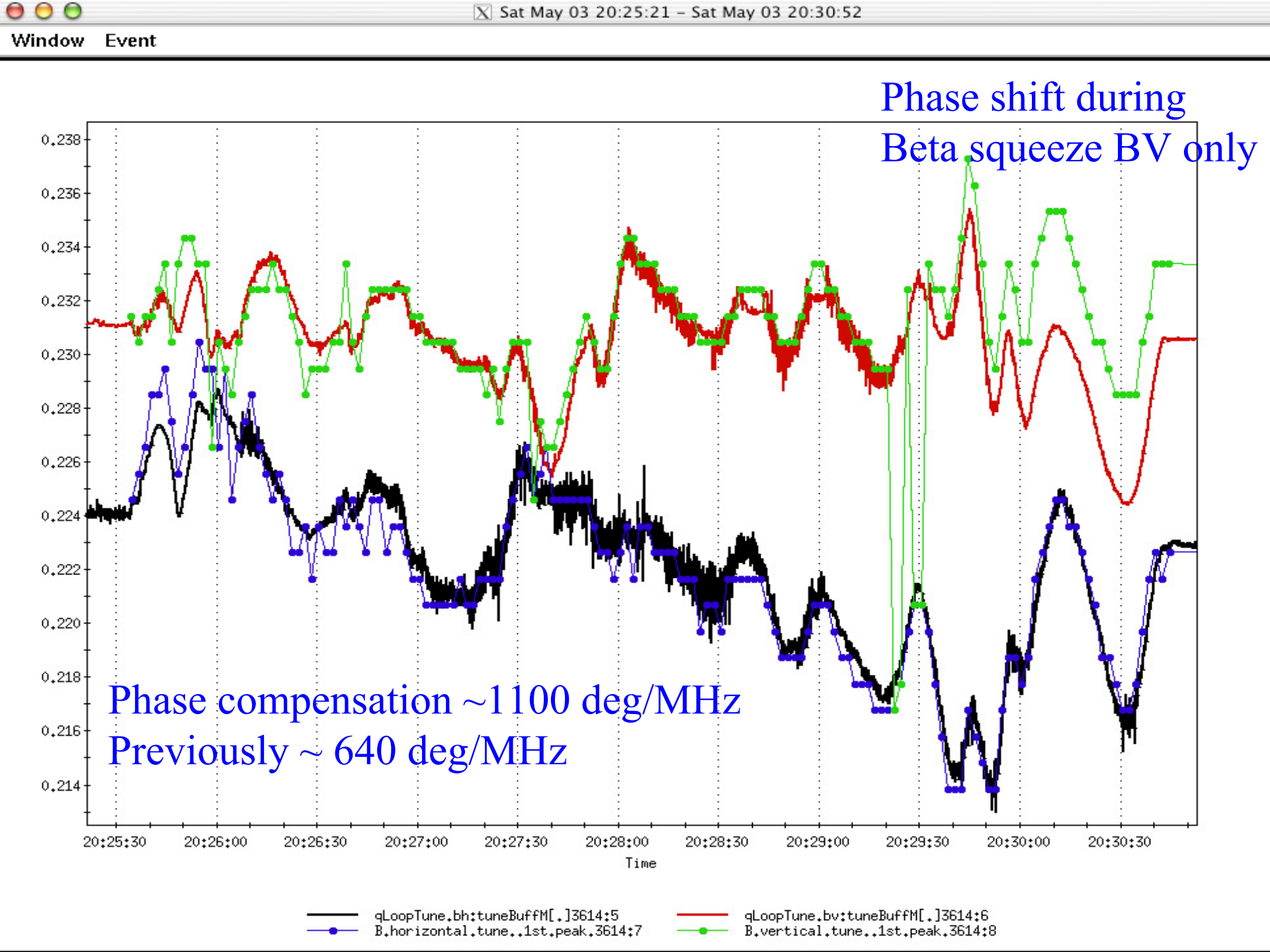


PLL/TF Problem Areas 1

- With TF off, PLL is often confused by tune crossings
- Coupling - phase from the opposite plane leaks in, this despite driving different harmonics H and V
- Coherent spectrum at revolution line (especially near transition) hammers the preamps
    - position feedback on moveable bpm helps somewhat but is not a workable long term solution
    - no active components before mixer and 455KHz filter has been tested, looks promising
- Large position and tune jumps at transition – γ_t quads
- Phase compensation during ramping - anomalous (mixer fix)

PLL Block Diagram

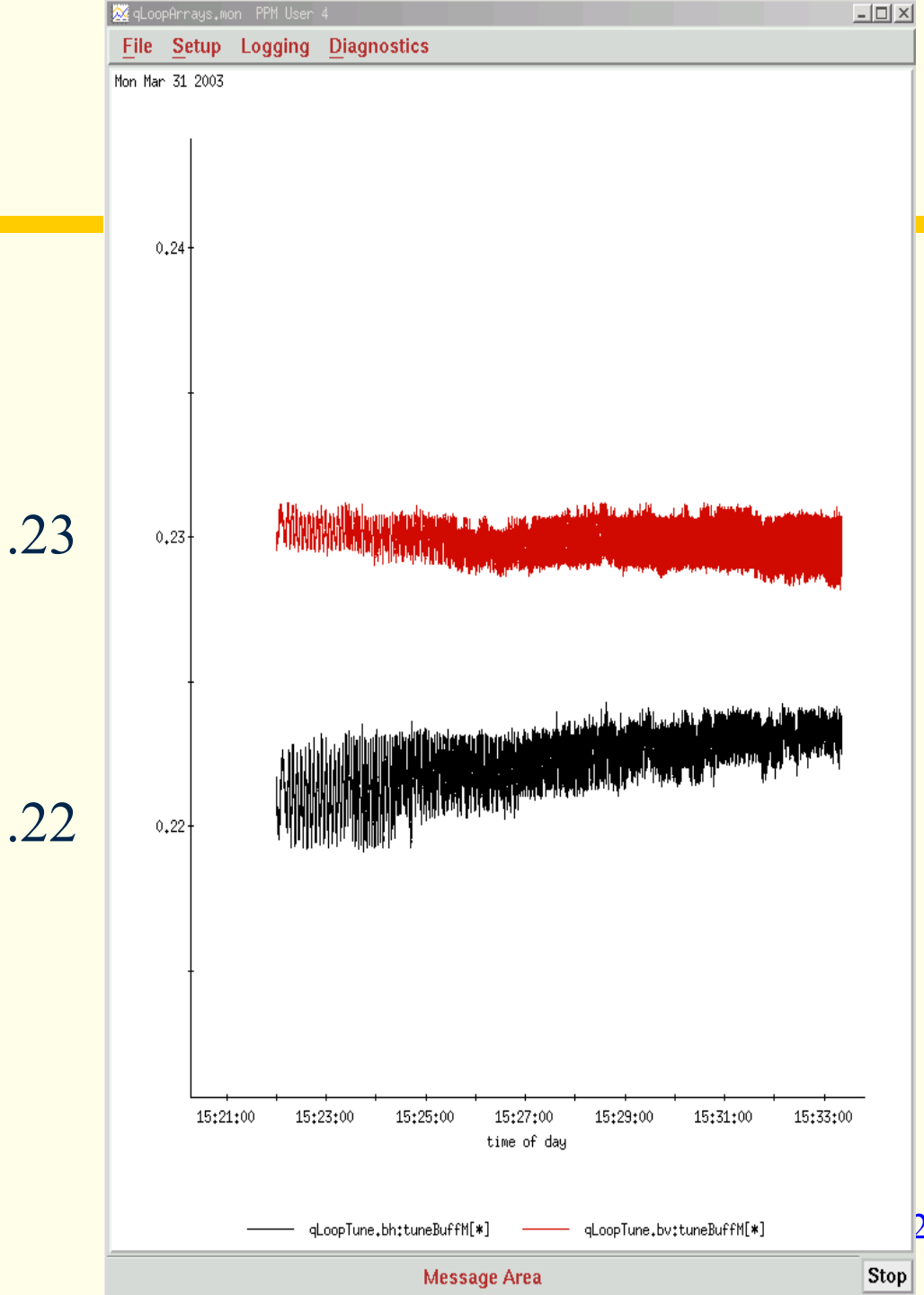



Sat May 03 20:25:21 - Sat May 03 20:30:52
Window Event
Phase shift during
Beta squeeze BV only
Phase compensation ~1100 deg/MHz
Previously ~ 640 deg/MHz
0.238
0.236
0.234
0.232
0.230
0.228
0.226
0.224
0.222
0.220
0.218
0.216
0.214
20:25:30
20:26:00
20:26:30
20:27:00
20:27:30
20:28:00
20:28:30
20:29:00
20:29:30
20:30:00
20:30:30
Time
qLoopTune.bh:tuneBuffM[.]3614:5
B.horizontal.tune..1st.peak.3614:7
qLoopTune.bv:tuneBuffM[.]3614:6
B.vertical.tune..1st.peak.3614:8

PLL/TF Problem Areas 2

- PID loop tuning
  - loop is artificially constrained, usual tuning algorithms do not apply
  - the ‘process’ (the beam transfer function portion) varies considerably
- Magnet transfer function uncertainties

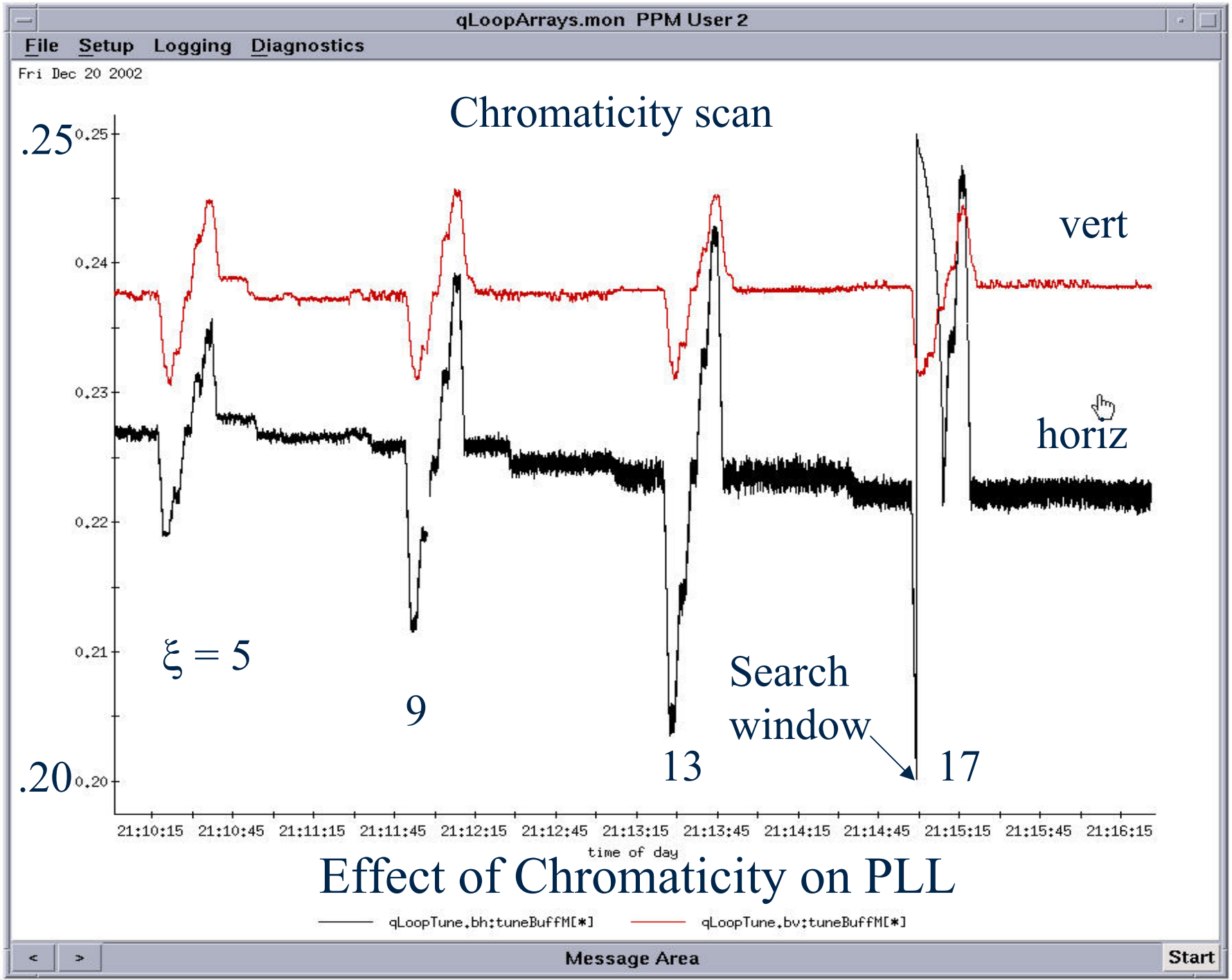
- **NEED a model**

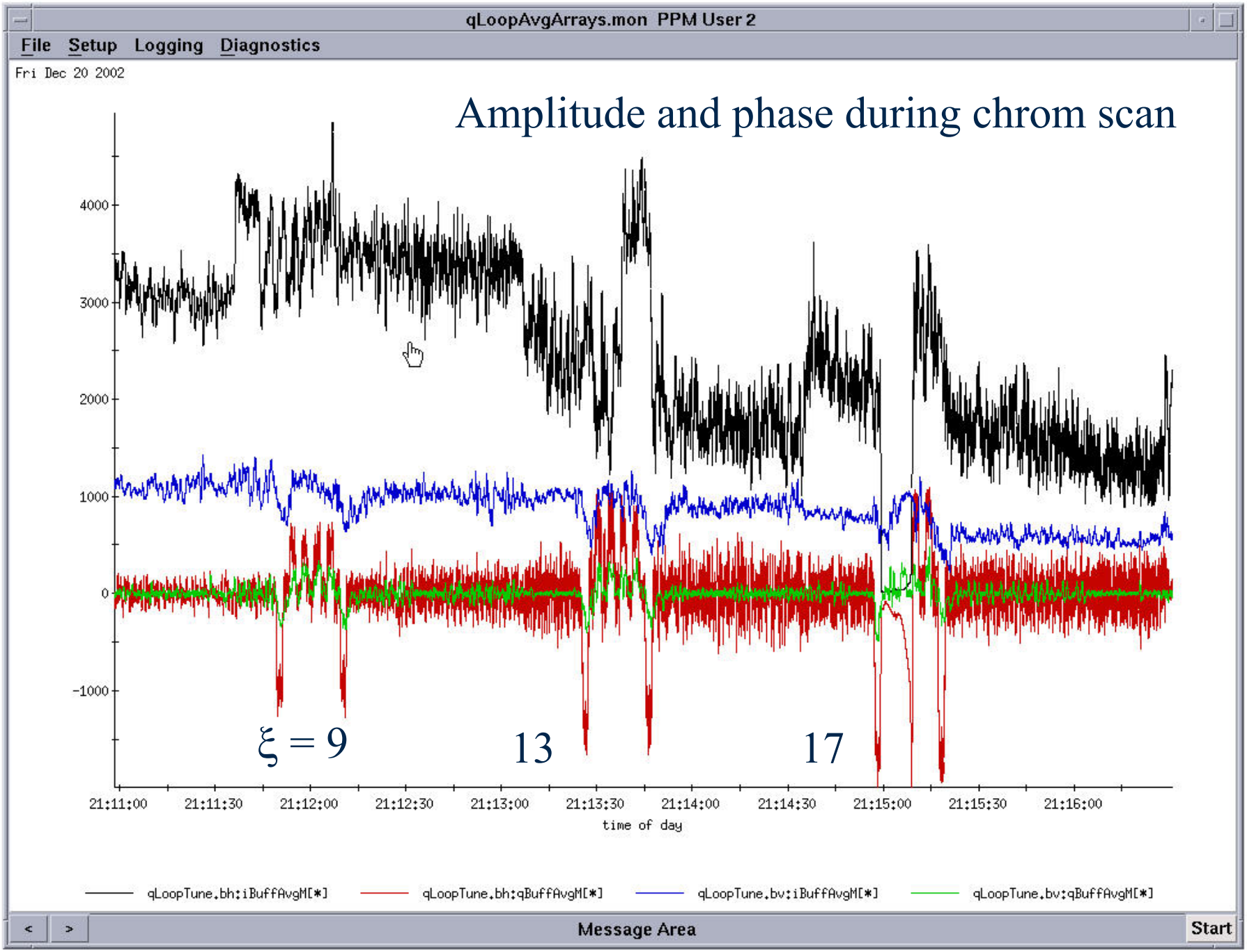


Magnet transfer function uncertainties: ‘constant’ amplitude tune modulation of increasing frequency: measured amplitude increases in vertical, decreases in horizontal, tune shifts.

Ramp Control Requirements

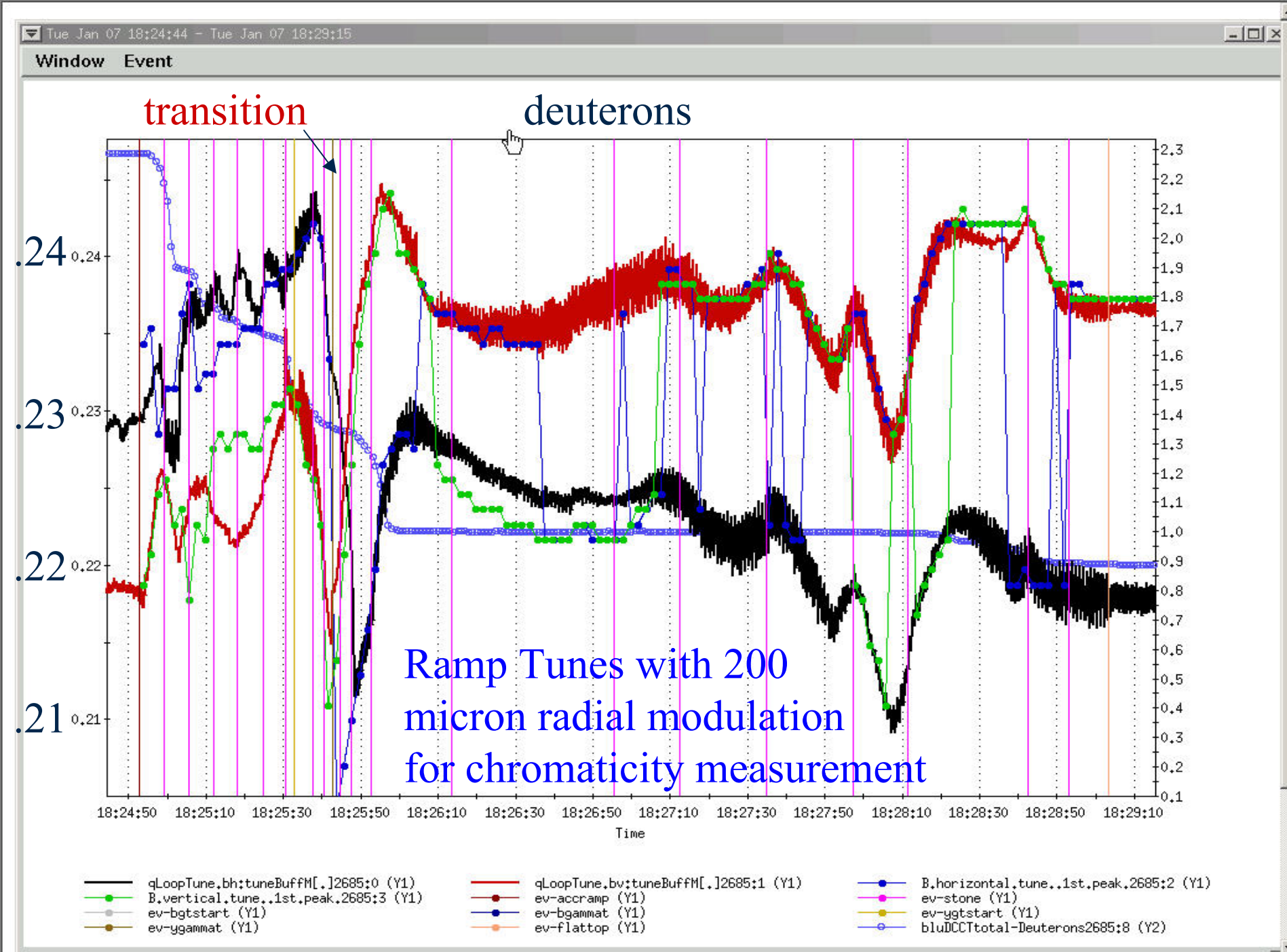
- Tune measurement and feedback
  - Avoid resonances (betatron and spin)
- Chromaticity measurement and feedback/feedforward
  - Avoid tails on resonance
  - Stability (right sign)
- Coupling measurement and feedback/feedforward
  - Control tune
  - Minimize higher order resonance strength
- Accomplish this without excessive emittance growth/halo formation


qLoopArrays.mon PPM User 2
File Setup Logging Diagnostics
Fri Dec 20 2002
Chromaticity scan
.25
0.25
0.24
0.23
0.22
0.21
.20
0.20
vert
horiz
ξ = 5
9
13
Search window
17
21:10:15 21:10:45 21:11:15 21:11:45 21:12:15 21:12:45 21:13:15 21:13:45 21:14:15 21:14:45 21:15:15 21:15:45 21:16:15
time of day
Effect of Chromaticity on PLL
qLoopTune.bh:tuneBuffM[*]
qLoopTune.bv:tuneBuffM[*]
Message Area
Start

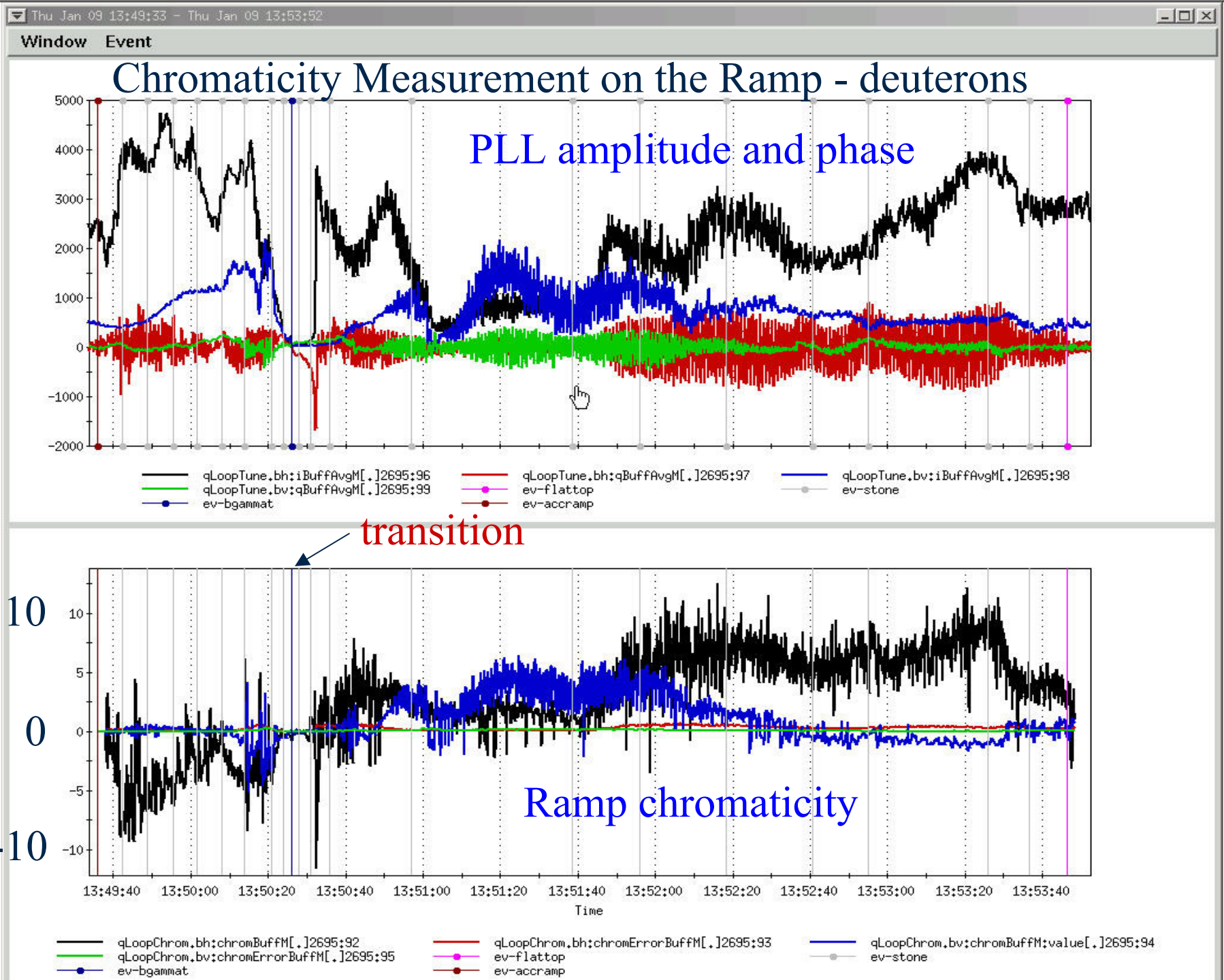

qLoopAvgArrays.mon PPM User 2
File Setup Logging Diagnostics
Fri Dec 20 2002
Amplitude and phase during chrom scan
4000
3000
2000
1000
0
-1000
ξ = 9
13
17
21:11:00
21:11:30
21:12:00
21:12:30
21:13:00
21:13:30
21:14:00
21:14:30
21:15:00
21:15:30
21:16:00
time of day
qLoopTune.bh:iBuffAvgM[*]
qLoopTune.bh:qBuffAvgM[*]
qLoopTune.bv:iBuffAvgM[*]
qLoopTune.bv:qBuffAvgM[*]
Message Area
Start

Chromaticity Effect on PLL

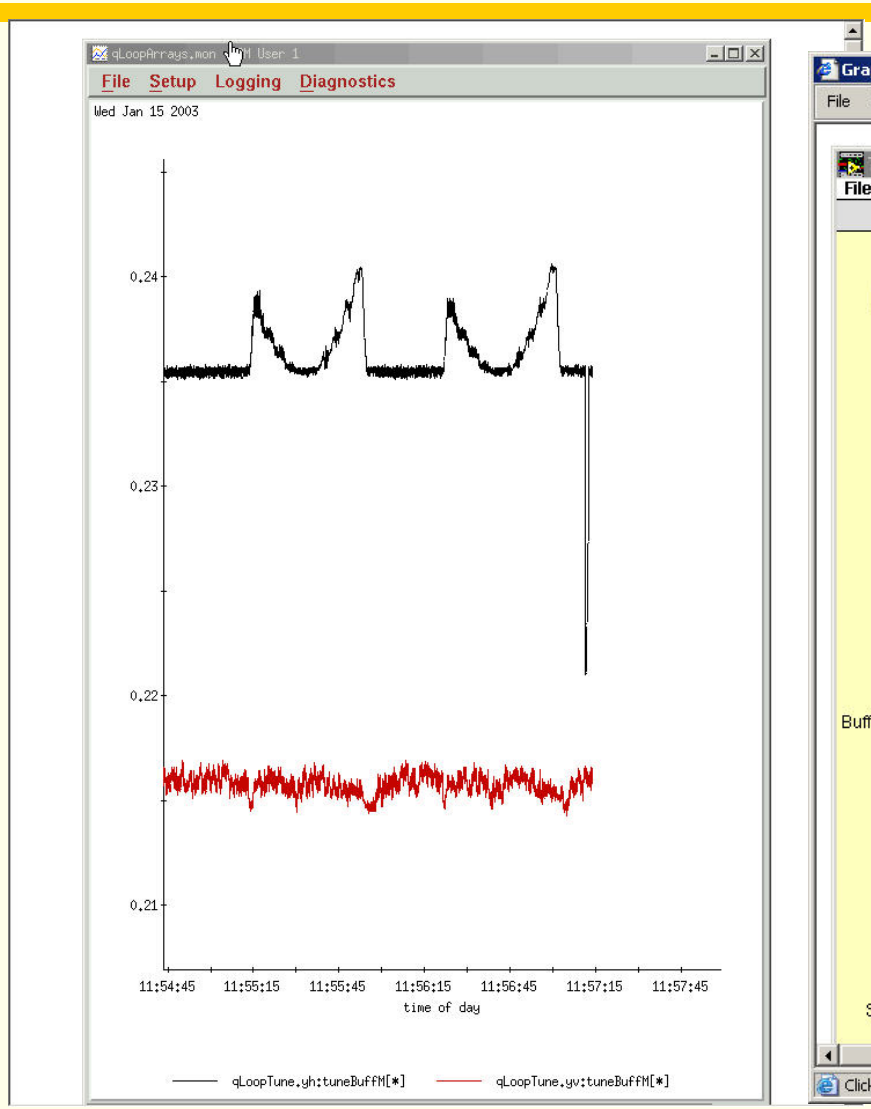
- Conclusion from the chromaticity study is that PLL tune measurement can cope with a large range of chromaticity
- Chromaticity control is not a primary issue for PLL tune measurement and tune feedback
- Chromaticity control is an issue primarily in the usual operational sense

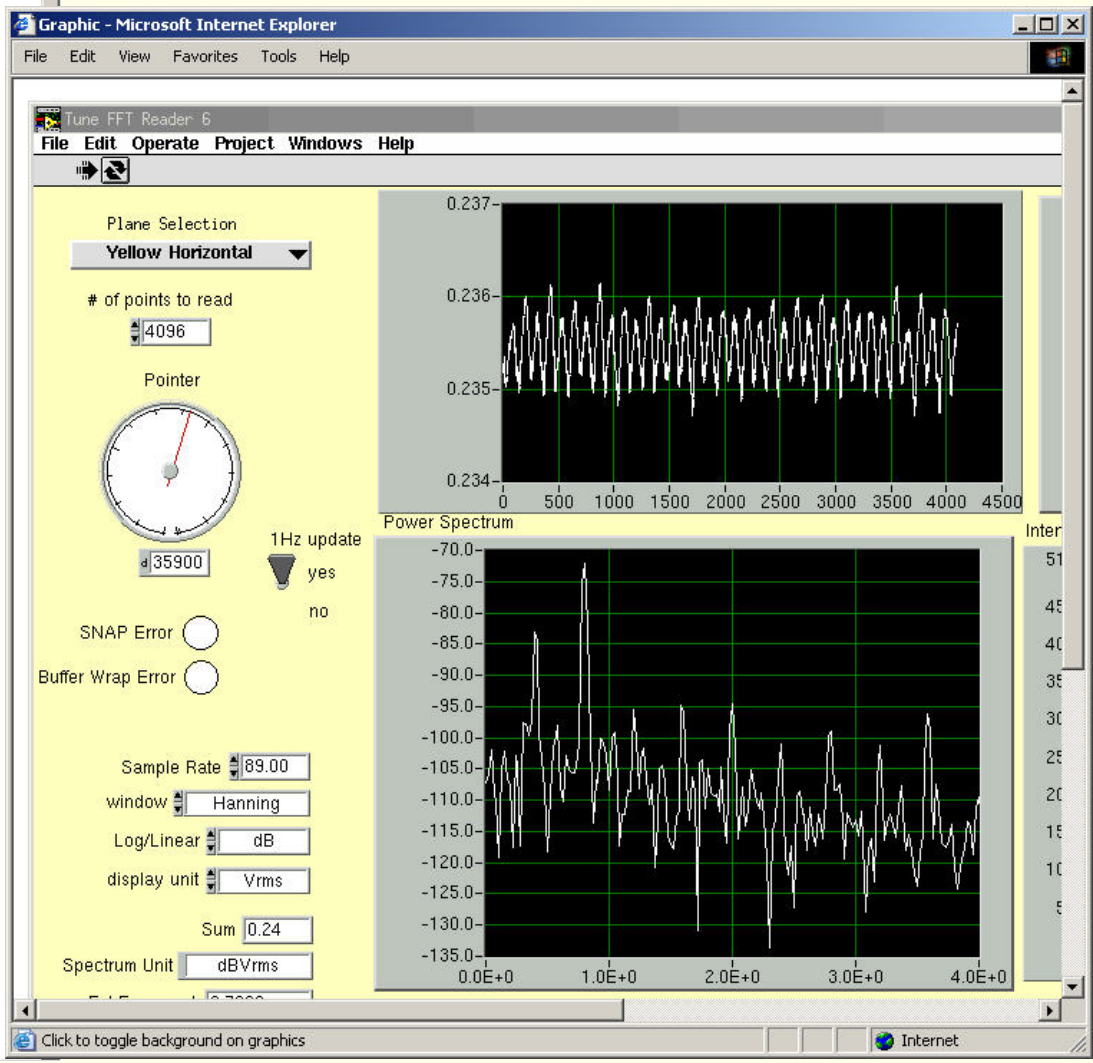

Tue Jan 07 18:24:44 - Tue Jan 07 18:29:15
Window Event
transition
deuterons
.24
.23
.22
.21
0.24
0.23
0.22
0.21
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Ramp Tunes with 200
micron radial modulation
for chromaticity measurement
18:24:50
18:25:10
18:25:30
18:25:50
18:26:10
18:26:30
18:26:50
18:27:10
18:27:30
18:27:50
18:28:10
18:28:30
18:28:50
18:29:10
Time
qLoopTune.bh:tuneBuffM[.]2685:0 (Y1)
B.vertical.tune..1st.peak.2685:3 (Y1)
ev-bgtstart (Y1)
ev-ygammat (Y1)
qLoopTune.bv:tuneBuffM[.]2685:1 (Y1)
ev-accramp (Y1)
ev-bgammat (Y1)
ev-flattop (Y1)
B.horizontal.tune..1st.peak.2685:2 (Y1)
ev-stone (Y1)
ev-ygtstart (Y1)
bluDCCTtotal-Deuterons2685:8 (Y2)

Chromaticity Measurement on the Ramp - deuterons



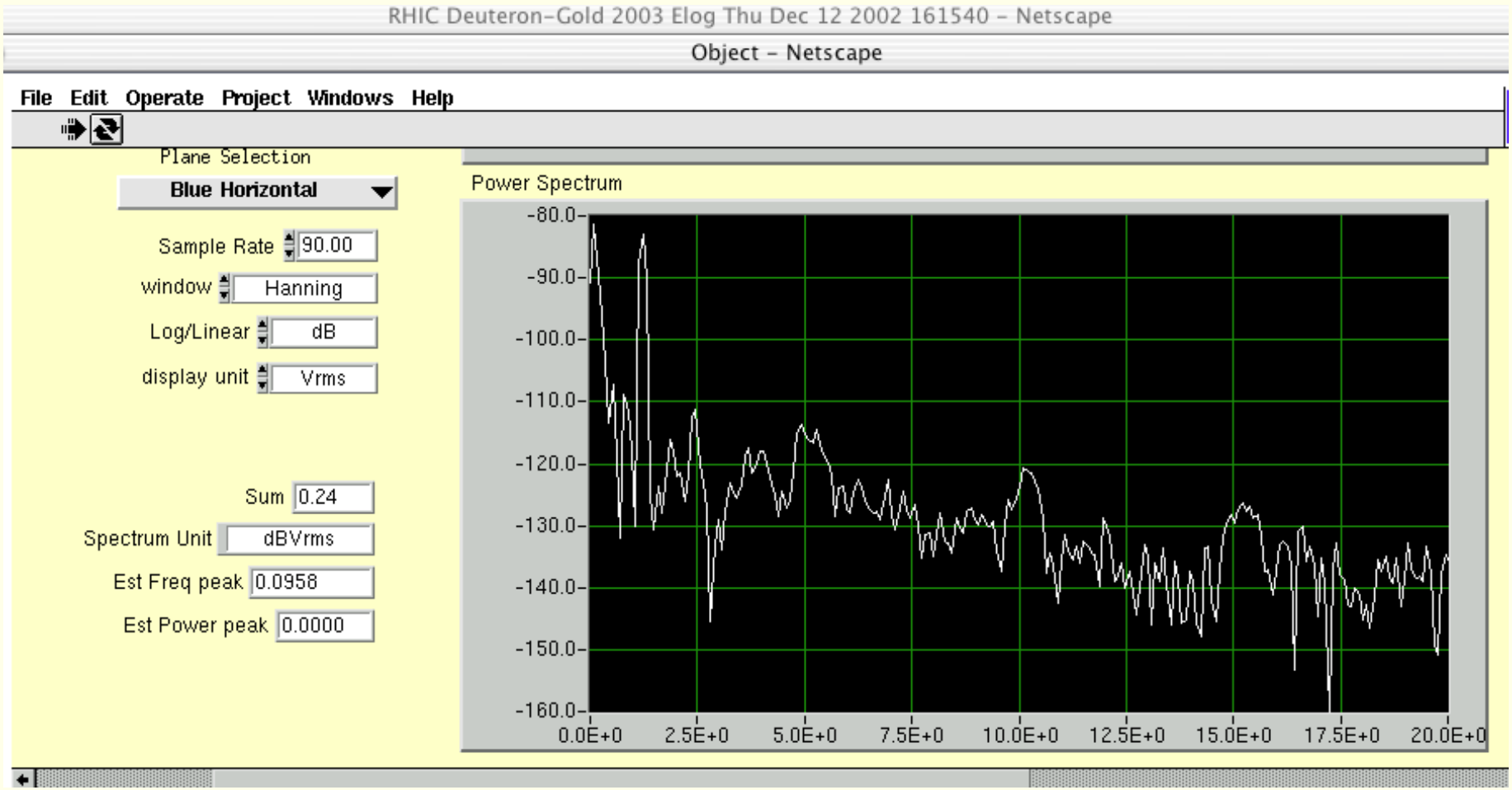
Non-linear chromaticity – .5Hz, .4mm





Filter, filter, filter,…

FFT of RHIC PLL output, 30dB S/N on a few 10^9 debunched deuterons with 100 micron 1.2Hz radial modulation

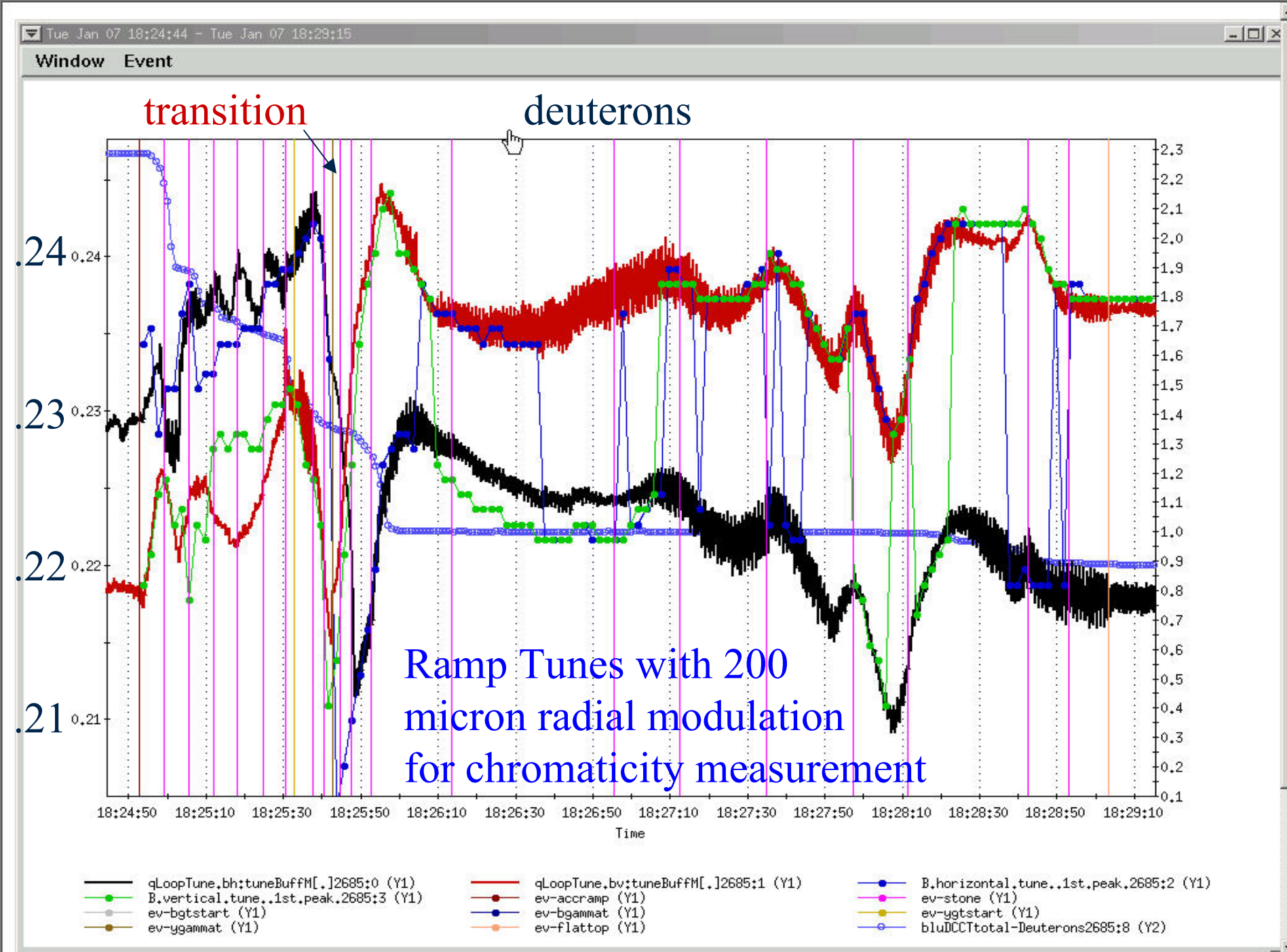


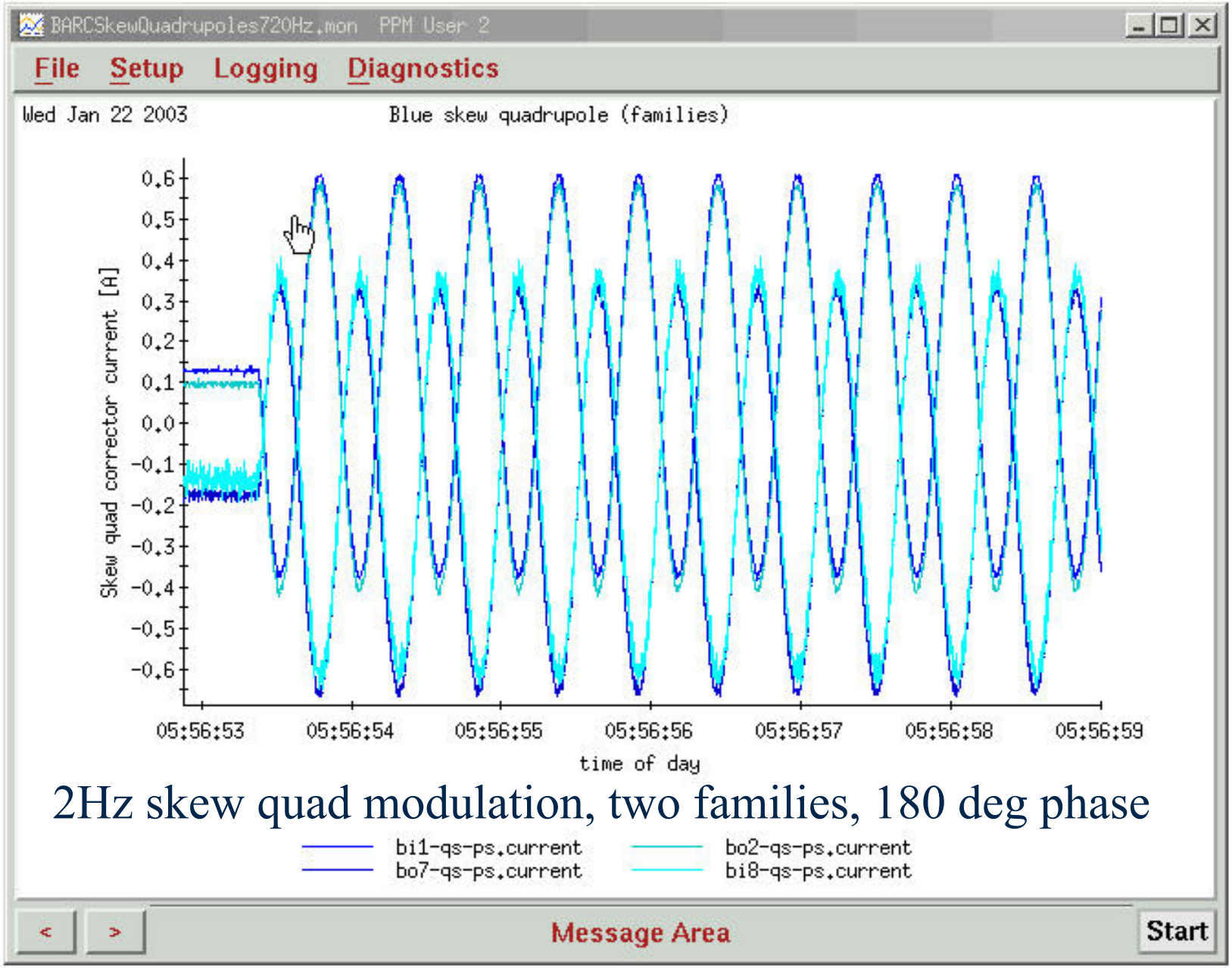
Chromaticity Measurement with PLL

- Works well when utilized
- Hesitancy to use on a regular basis because of concern with beam loss due to radial modulation (and it is just more complexity in a complex environment – requires specialists)
- Decoherence of kicked tune excitation is the primary tool used during normal operations

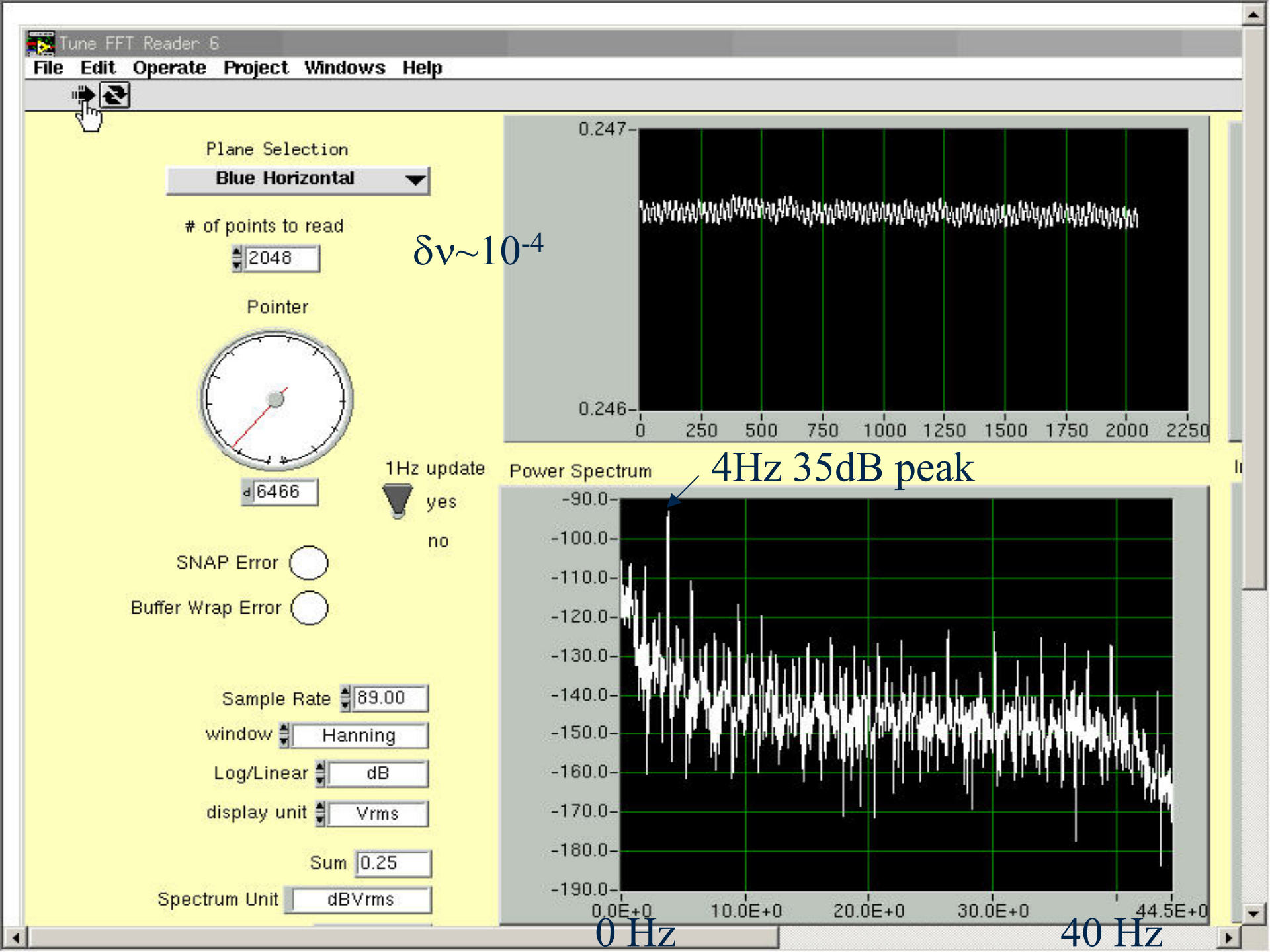
Ramp Control Requirements

- Tune measurement and feedback
  - Avoid resonances
- Chromaticity measurement and feedback/feedforward
  - Avoid tails on resonance
  - Stability (right sign)
- Coupling measurement and feedback/feedforward
  - Control tune
- Accomplish this without excessive emittance growth/halo formation


Tue Jan 07 18:24:44 - Tue Jan 07 18:29:15
Window Event
transition
deuterons
.24
.23
.22
.21
0.24
0.23
0.22
0.21
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Ramp Tunes with 200
micron radial modulation
for chromaticity measurement
18:24:50
18:25:10
18:25:30
18:25:50
18:26:10
18:26:30
18:26:50
18:27:10
18:27:30
18:27:50
18:28:10
18:28:30
18:28:50
18:29:10
Time
qLoopTune.bh:tuneBuffM[.]2685:0 (Y1)
B.vertical.tune..1st.peak.2685:3 (Y1)
ev-bgtstart (Y1)
ev-ygammat (Y1)
qLoopTune.bv:tuneBuffM[.]2685:1 (Y1)
ev-accramp (Y1)
ev-bgammat (Y1)
ev-flattop (Y1)
B.horizontal.tune..1st.peak.2685:2 (Y1)
ev-stone (Y1)
ev-ygtstart (Y1)
bluDCCTtotal-Deuterons2685:8 (Y2)



2Hz skew quad modulation, two families, 180 deg phase


Tune FFT Reader 6
File Edit Operate Project Windows Help
Plane Selection
Blue Horizontal
# of points to read
2048
δν~10-4
Pointer
6466
1Hz update
yes
no
SNAP Error
Buffer Wrap Error
Sample Rate 89.00
window Hanning
Log/Linear dB
display unit Vrms
Sum 0.25
Spectrum Unit dBVrms
0.247
0.246
0 250 500 750 1000 1250 1500 1750 2000 2250
Power Spectrum
4Hz 35dB peak
-90.0 -100.0 -110.0 -120.0 -130.0 -140.0 -150.0 -160.0 -170.0 -180.0 -190.0
0.0E+0 10.0E+0 20.0E+0 30.0E+0 44.5E+0
0 Hz
40 Hz

Tune FFT Reader 6

File Edit Operate Project Windows Help

Plane Selection

Blue Horizontal

# of points to read

2048

Pointer

26292

1Hz update

yes

no

SNAP Error

Buffer Wrap Error

Sample Rate 89.00

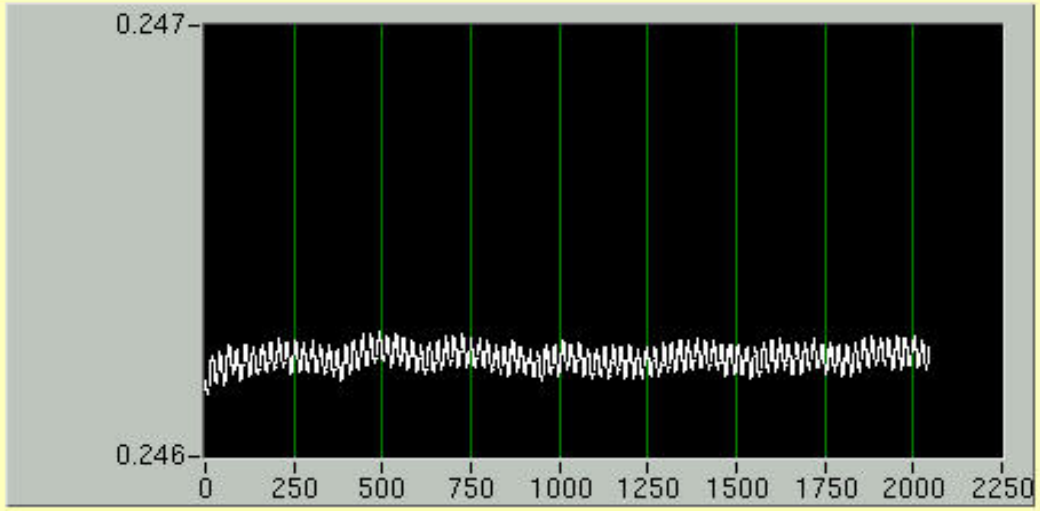
window Hanning

Log/Linear dB

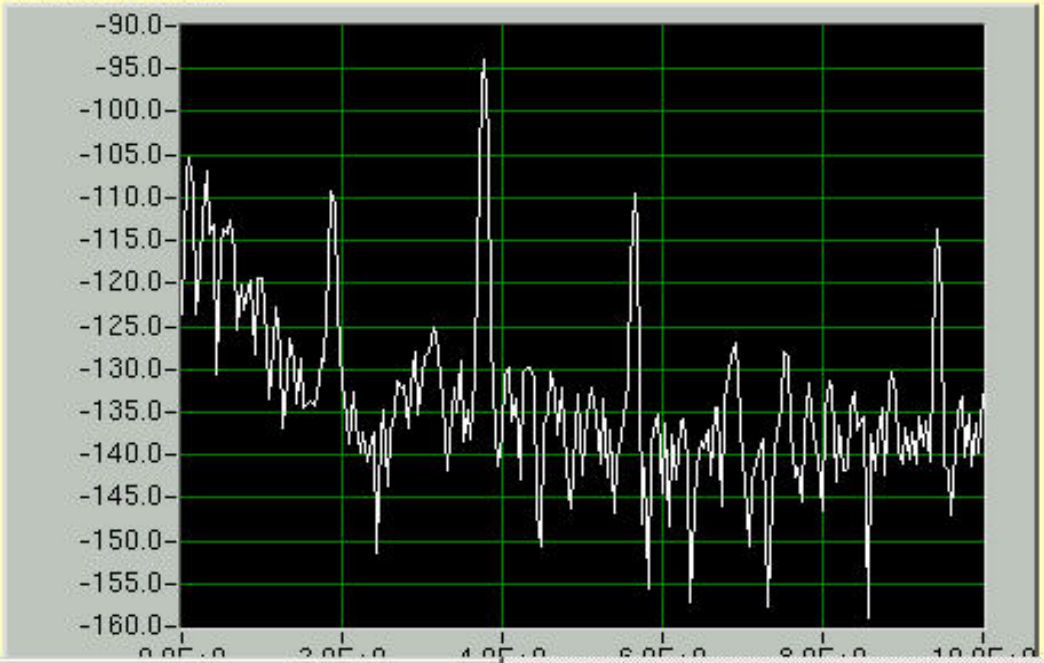
display unit Vrms

Sum 0.25

Spectrum Unit dBVrms



Power Spectrum



Intensi

550
500
450
400
350
300
250
200
150
100
50
0

Coupling on the ramp

- Potential exists to measure and correct coupling with PLL
- This was given some study time, more required to firmly establish the method
- Wolfram's method (analyze BPM data when tune kicker fires) offers another viable approach

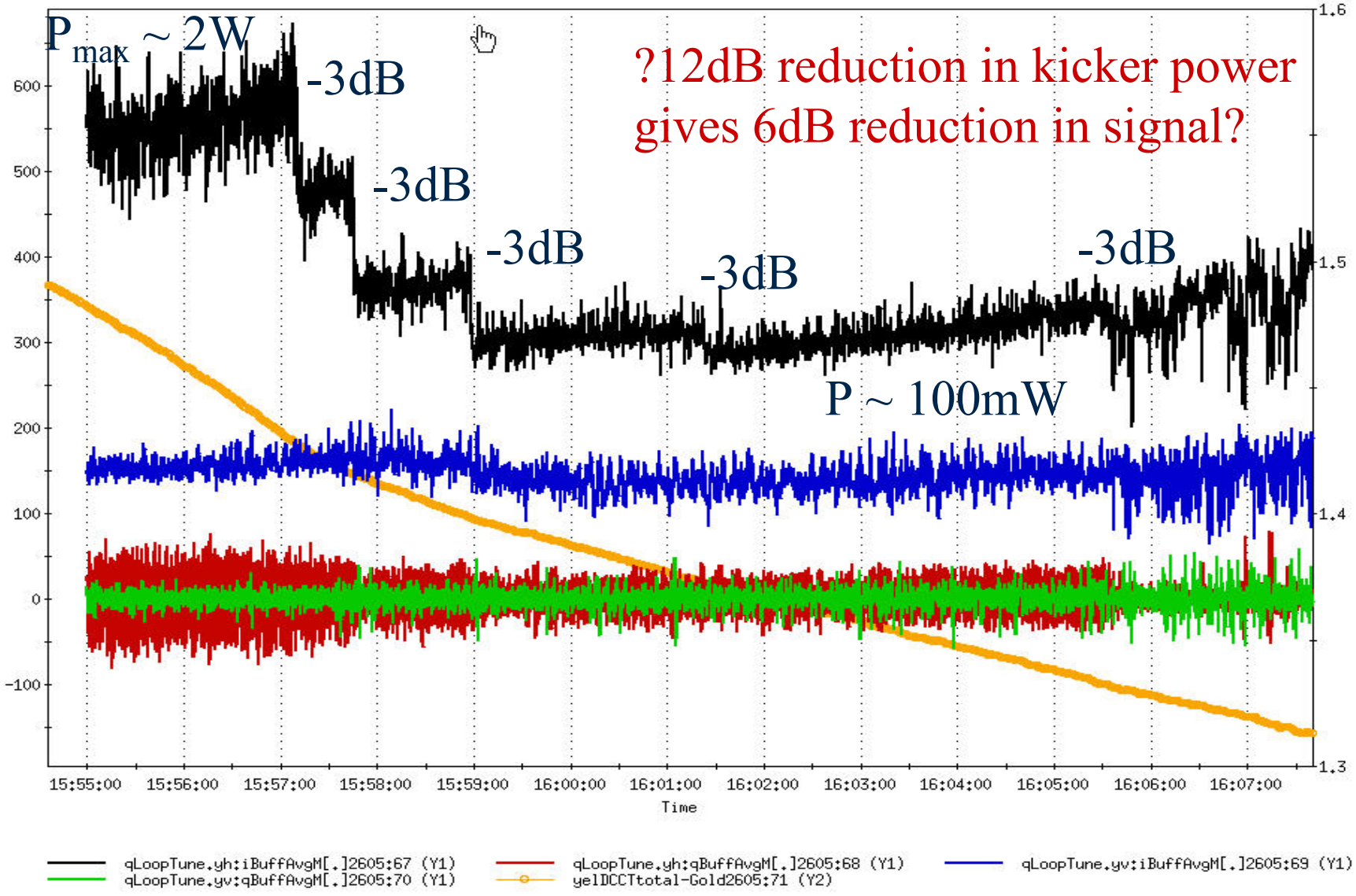
Ramp Control Requirements

- Tune measurement and feedback
  - Avoid resonances
- Chromaticity measurement and feedback/feedforward
  - Avoid tails on resonance
  - Stability (right sign)
- Coupling measurement and feedback/feedforward
  - Control tune
  - Minimize higher order resonance strength
- Accomplish this without excessive emittance growth/halo formation

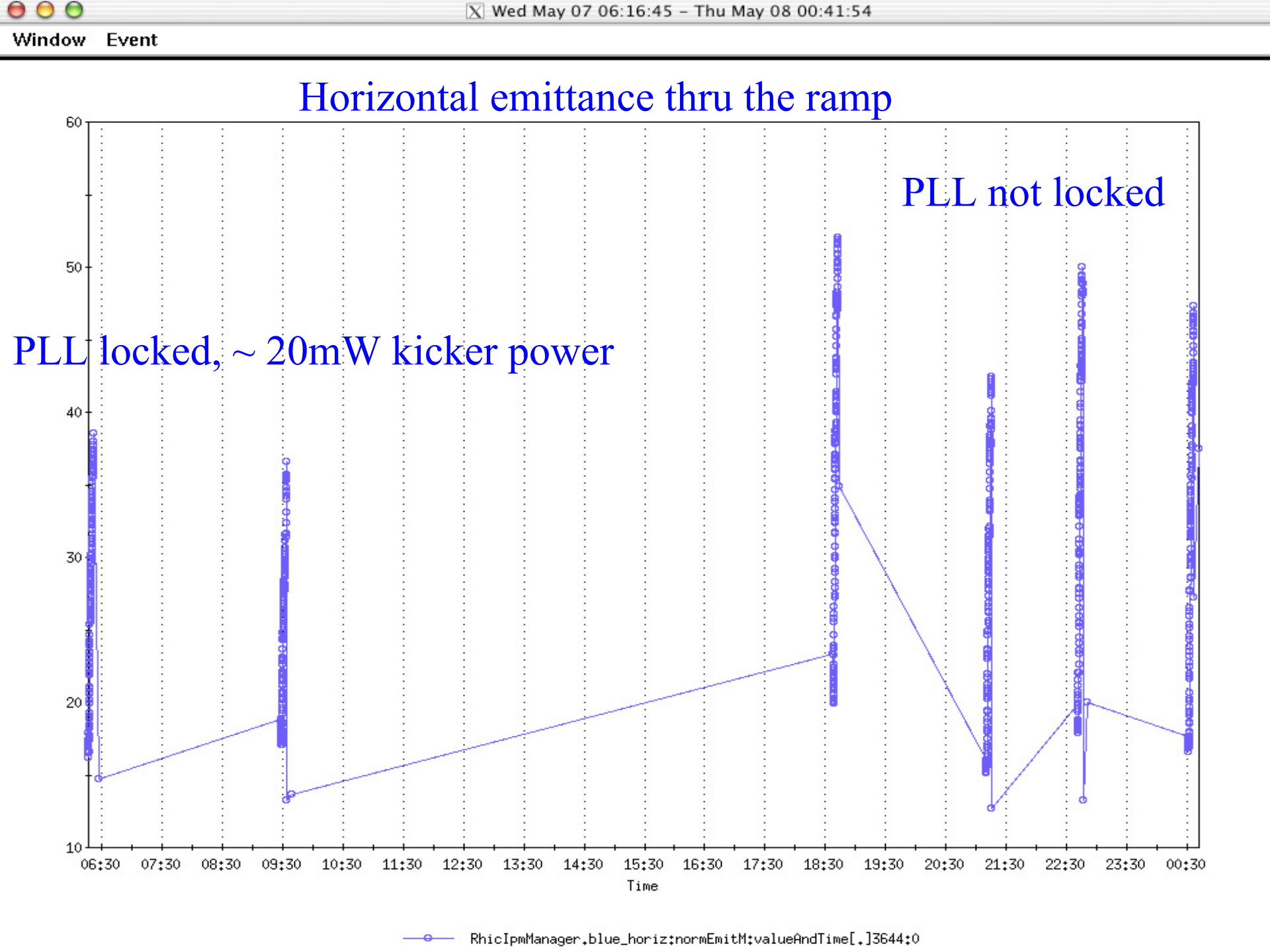
Sun Dec 29 15:54:35 - Sun Dec 29 16:07:40

Window Event

PLL amplitude for kick reduced in 3dB steps

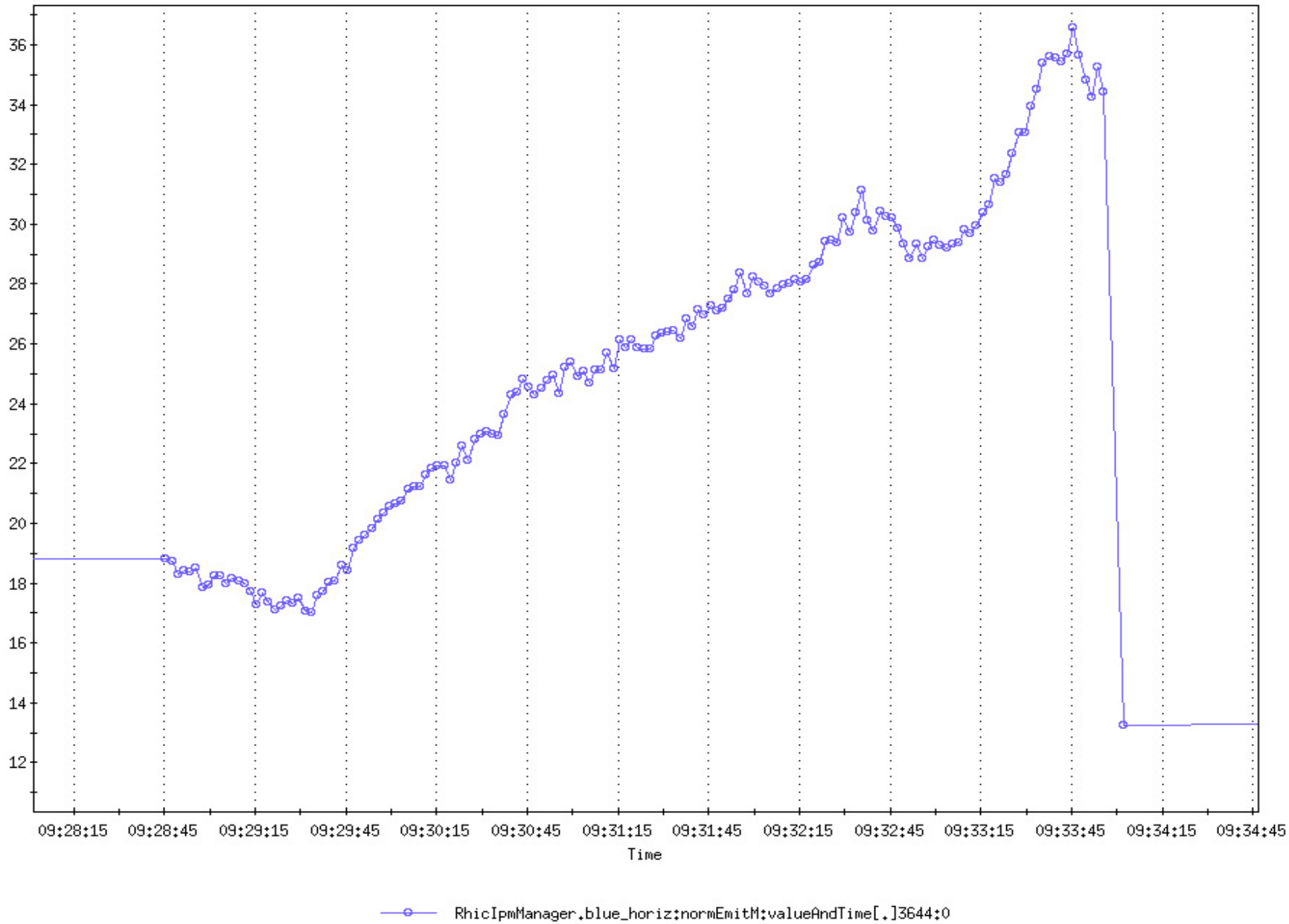


qLoopTune.yh:iBuffAvgM[.] successfully displayed
qLoopTune.yh:qBuffAvgM[.] successfully displayed


Wed May 07 06:16:45 - Thu May 08 00:41:54
Window
Event
Horizontal emittance thru the ramp
PLL not locked
PLL locked, ~ 20mW kicker power
60
50
40
30
20
10
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
00:30
Time
RhicIpmManager.blue_horiz:normEmitM:valueAndTime[.]3644:0

Wed May 07 09:28:01 – Wed May 07 09:34:46

Window Event



Summary of TF in RHIC 2003

- dAu run - after commissioning problems sorted out, seven ramps attempted, all 'successful'
  - But deuteron beam survival worse with TF on!
  - Resonance between TF and power supplies? Radial loop? Too much loop gain in PLL? Bad chrom? Beam-beam? (no TF after cogged ramps)
- Polarized Protons - after commissioning, ~ 75% success
- Operator overhead/overload is significant
  - New systems in the heat of commissioning
  - Example – feedforward from magnet currents

Possible Specifics of LHC PLL/TF

- Short single bunch during commissioning – a useful resonant pickup is difficult
  - This suggests system will be more like LEP PLL – emittance growth a problem
  - Pickup sensitivity must be maximized
    - high impedance capacitive?
    - travelling wave?
    - else????
  - Moveable pickup with centering feedback is necessary (but may not be sufficient) to avoid saturation
- Attempt to minimize effects of coupling in frequency domain at RHIC were not completely successful – comes thru the beam
  - This suggests kicking two separate bunches for H and V is not a complete solution

Collaboration with CERN/FNAL/LBNL Ramp Control

- Single channel RHIC PLL system (mixers, AFE, digitizer, NCO, software) is at CERN
- Hands-on understanding of parameter space travel
- Investigation of chrom (radial & phase mod,…)
- Investigation of coupling (skew quad mod,…)
- Beam modeling, PLL modeling, TF modeling
- Beam experiments? travel
- New Pickup – separate item
- Plans for PLL/TF during RHIC 2004?

Conclusion

- BNL has beam, and has many operating systems which will be required (with improvements) for LHC
- BNL has great interest in benefiting from the expertise at CERN, FNAL, LBNL,…
- LARP offers the possibility of the financial and organizational support needed to make this a reality