Summary of the BNL Workshop on LHC Tune Feedback

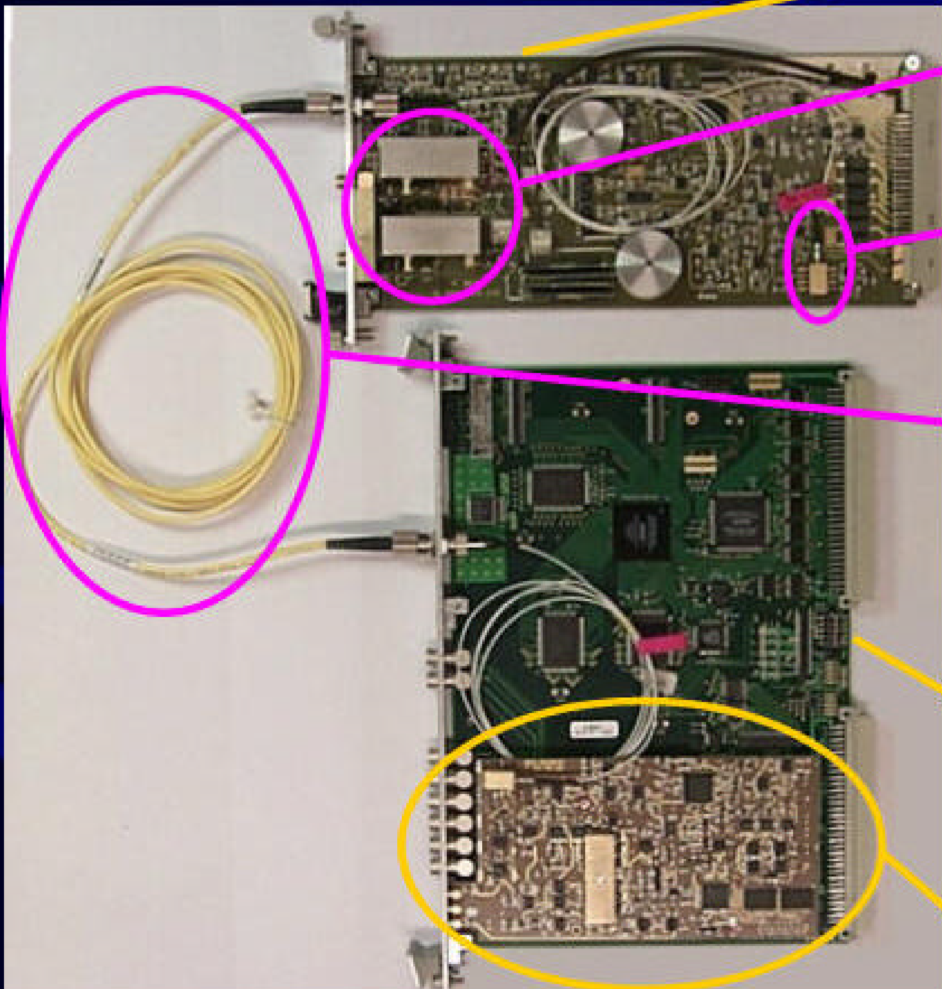
March 9-11, 2005

Peter Cameron

18 Presentations, **LOTS** of Discussion

1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. **Results from the TW Pickup at FNAL - Andreas Jansson**
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, and Chromaticity in Light of LHC Requirements - Pete Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

The LHC BPM Acquisition System



Very Front-End WBTN Card

70MHz Low Pass Filters

Supplied by TRIUMF (Canada)

1310nm Diode Laser Transmitter

⬆ Tunnel

Single-Mode Fibre-Optic Link

⬇ Surface

VME based

Digital Acquisition Board

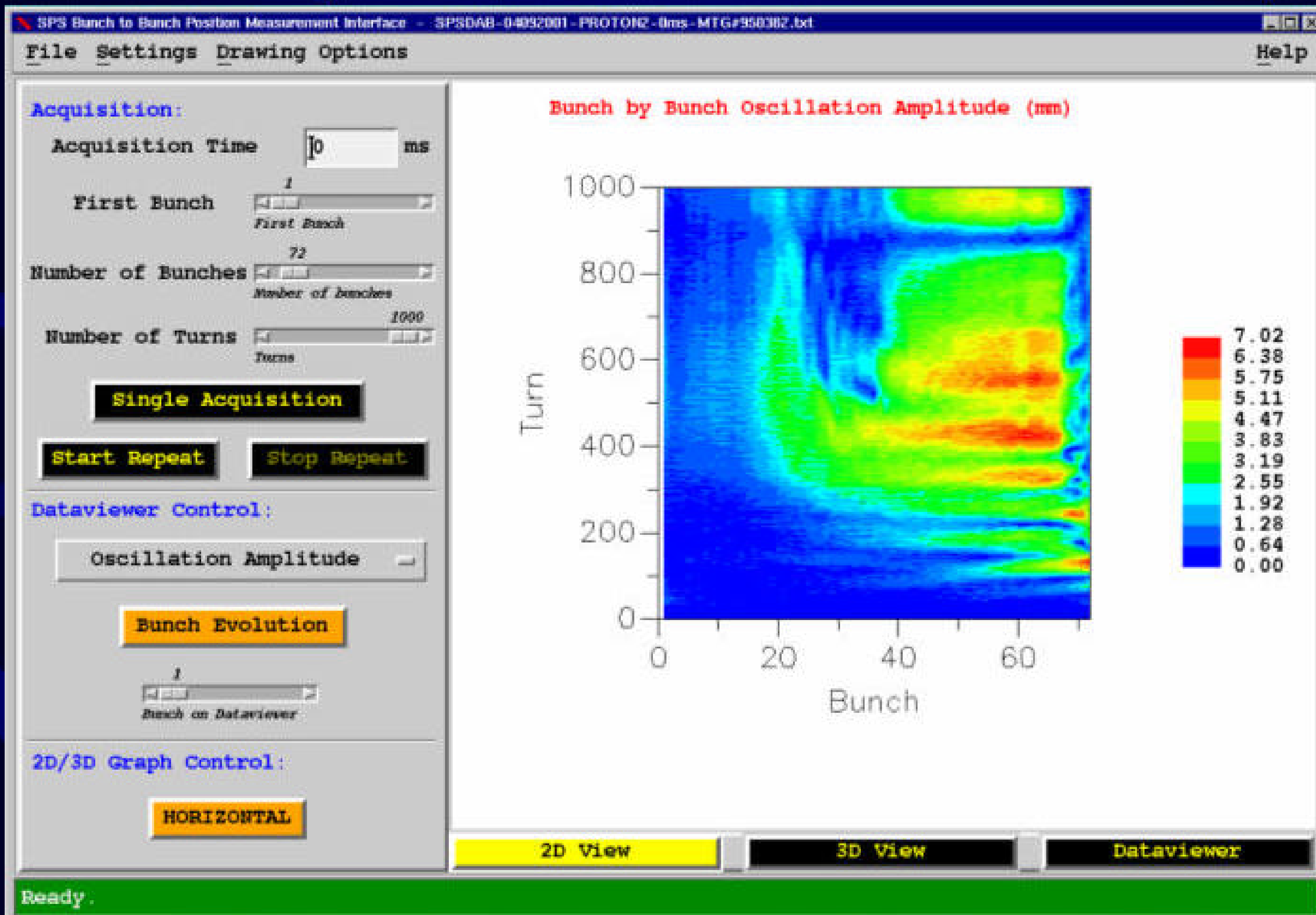
TRIUMF (Canada)

WBTN Mezzanine Card

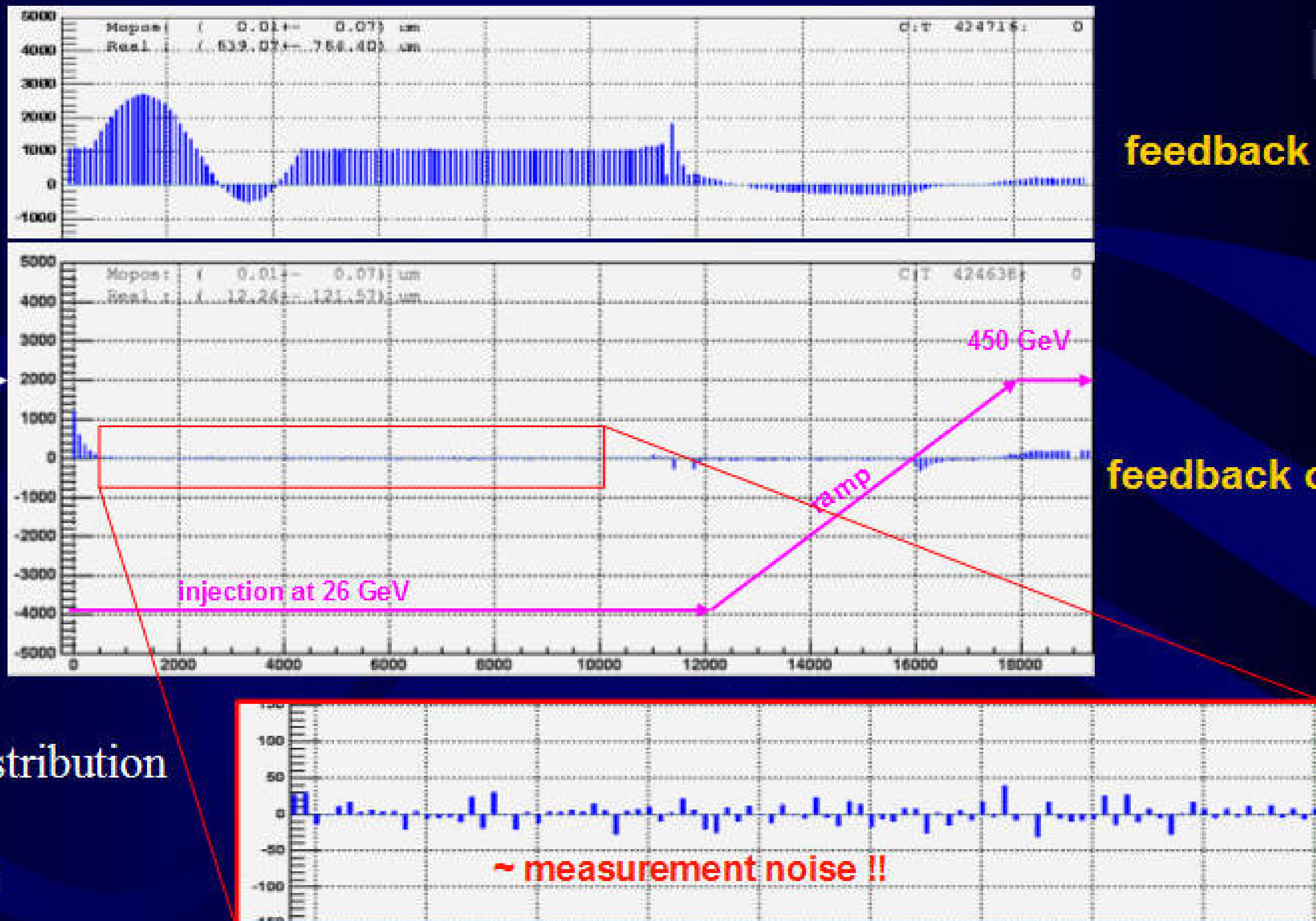
(10bit digitisation at 40MHz)

Bunch-by-bunch Results in the CERN-SPS

System extensively used in SPS for electron cloud & instability studies.



Orbit feedback results from the CERN-SPS



Position distribution
@ 100 Hz
$\sigma = 8.5\ \mu m$

Transverse Diagnostics: Summary

- Clear two step approach:
  1) Day 1 with kicked beams and classical motion analysis
  2) Day N with PLL and more powerful time resolved methods

- This puts a high pressure on getting dedicated machine time in order to commission the PLL early.

- As long as emittance growth is not the major concern, the problems will be:
  - → automation of parameter settings depending on beam conditions
    - filters, gain switches, timings etc
    - phase scans in order to determine the correct PLL lock conditions

- For operational beams the additional problems will be:
  - → lowering the excitation level to an insignificant level
  - → coping with coupling
  - → achieving compatibility with resistive transverse damping

18 Presentations, **LOTS** of Discussion

1. Welcome and Overview – Mike Harrison
2. Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. Results from the TW Pickup at SPS – Maria Elena Castro Carballo
5. Results from the cavity pickup at RHIC – Al Dellapenna
6. Specification for the LHC TW Pickup - Fritz Caspers
7. Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli
8. The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones
9. Direct Diode Detection and Results from SPS - Marek Gasior
10. Results from FNAL - 3D and 21.4MHz - C.Y. Tan
11. Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron
12. 60Hz Lines – C.Y. Tan
13. 60Hz Lines – Pete Cameron
14. Coupling Measurement and Correction - Yun Luo
15. Tune, Coupling, and Chromaticity in Light of LHC Requirements - Pete Cameron
16. AFE and digitizer board – Marek Gasior
17. The DAB board – Rhodri Jones
18. Integration with Magnets - Carl Schultheiss

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

LHC Microwave Schottky Pickups

Fermilab System Specifications

- 1.75 GHz center frequency
- 100 MHz bandwidth
- One Horizontal and Vertical tank each for RR and TeV
- Single Sideband Down Conversion preserves chromaticity information
- Both transverse and longitudinal signals from same pickup
- Bi-directional for both protons and pbars from same pickup
- Gating (single or multiple bunch) for proton or pbar signals for TeV
- Gating for hot or cold pbars in RR

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

LHC Microwave Schottky Pickups

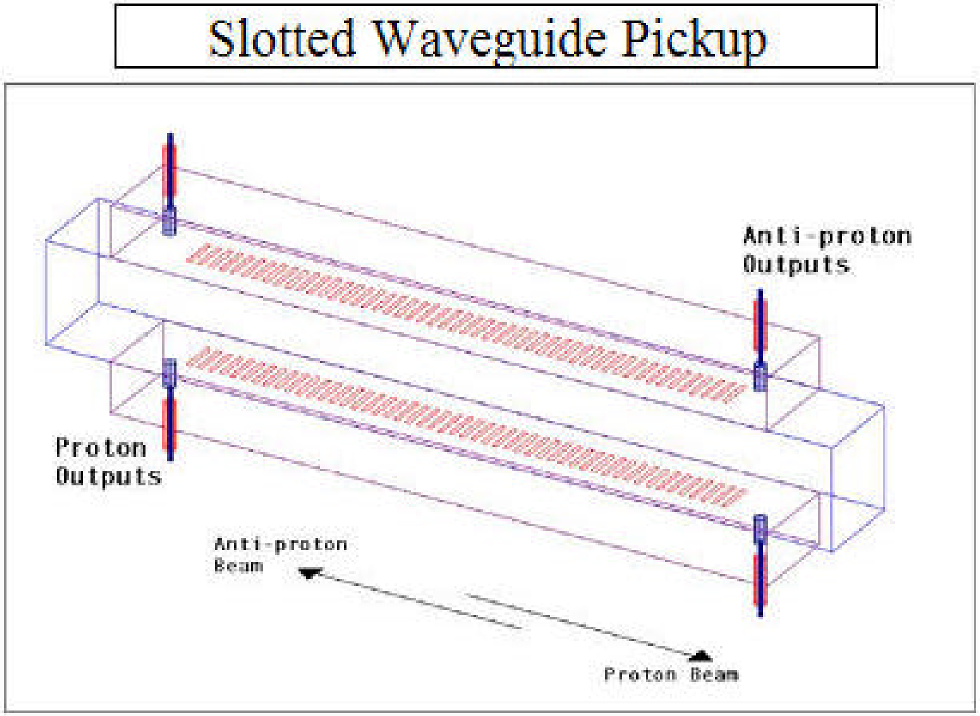
Fermilab System Capabilities

- Continuous on line emittance monitor both TeV and RR
- Longitudinal emittance for RR
- Ability to measure individual or multiple bunches in TeV
- Ability ot measure pbars in presence of protons in TeV
- Ability to measure hot and cold pbars in RR
- Down conversion utilizing RF source allows monitoring up the TeV Ramp
- Single sideband down conversion allows measuring of chromaticity
- Tune measurement for the TeV & RR
- Built in calibration system to monitor gain variation with time

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

LHC Microwave Schottky Pickups

US LARP

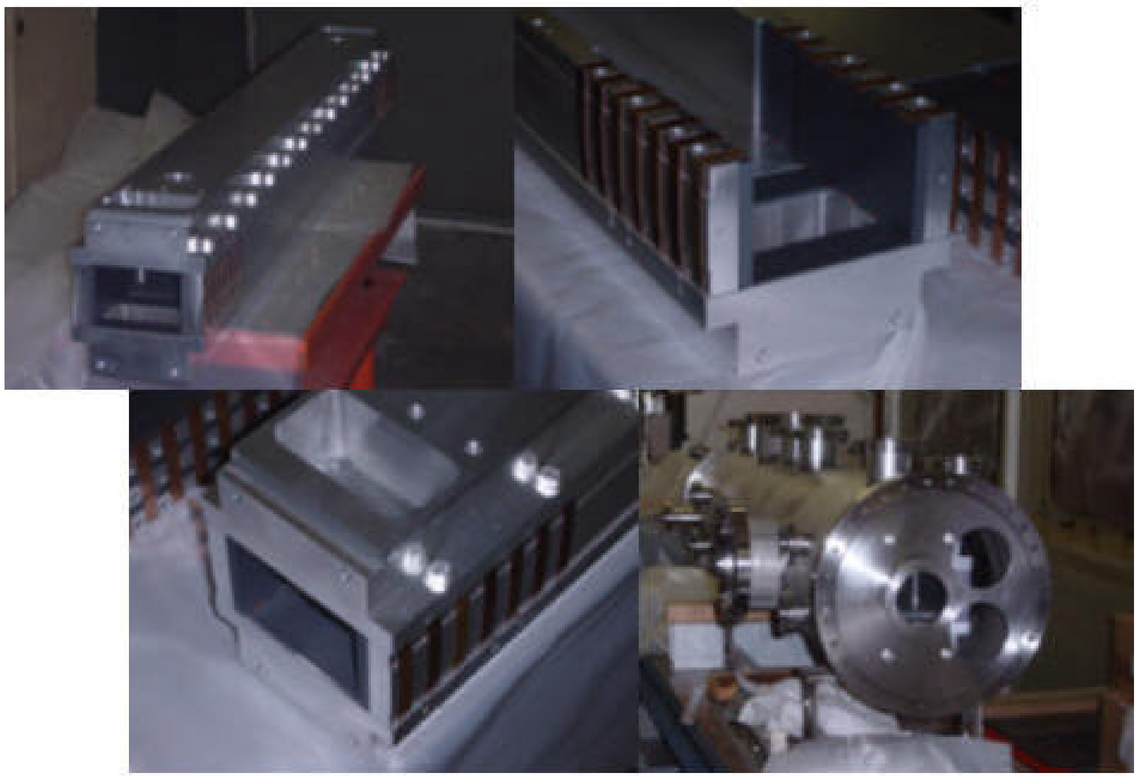


1.7 GHz 109 x 75 mm aperture

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

LHC Microwave Schottky Pickups

Array Assembly

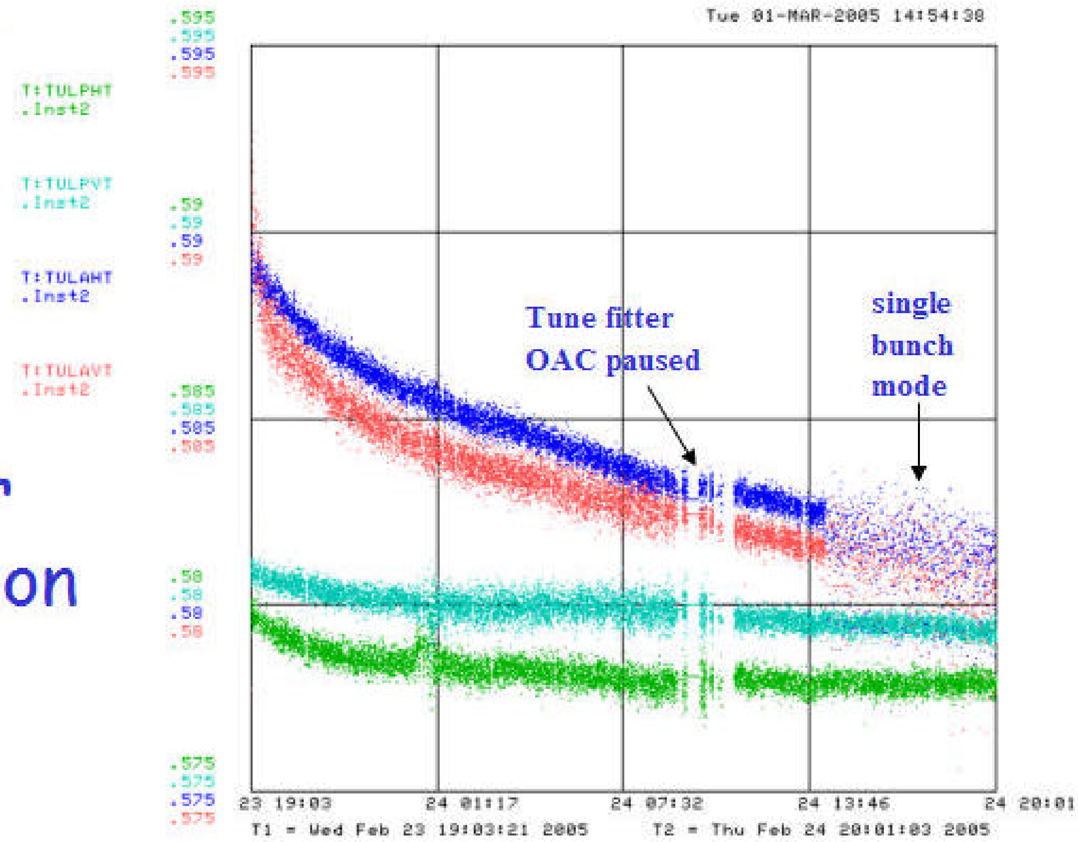


18 Presentations, **LOTS** of Discussion

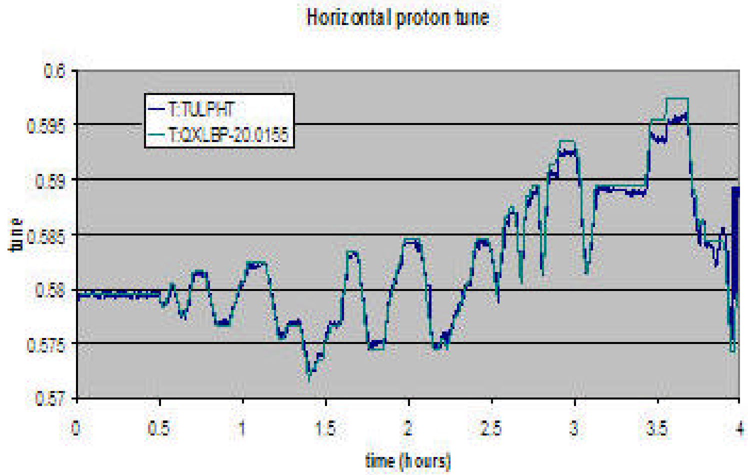
1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. **Results from the TW Pickup at FNAL - Andreas Jansson**
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, and Chromaticity in Light of LHC Requirements - Pete Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

Tune during a store

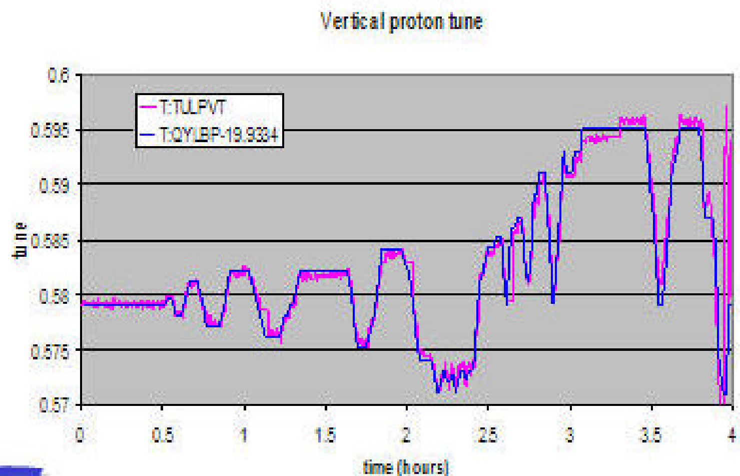
- Clearly see beam-beam effect (on both protons and pbars).
- Plan to implement slow feedback for pbar tunes based on these signals!

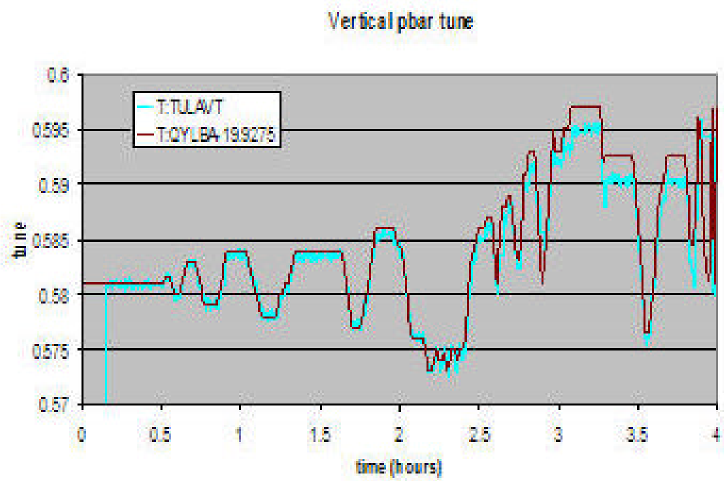


Tune “tracking”

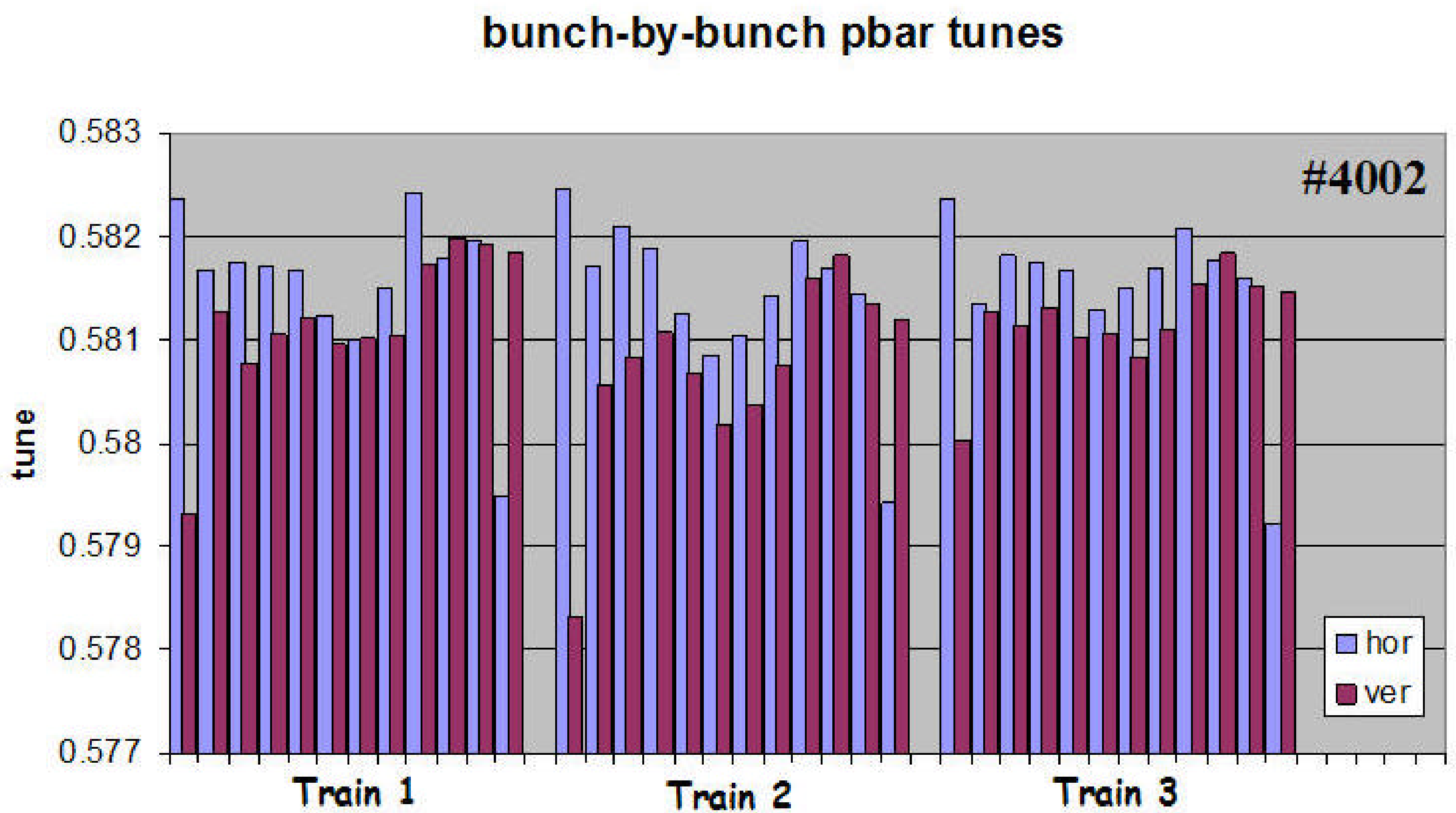


- Measured tune tracks changes in set tunes very well.





Single bunch tunes



Bunch intensities: 15-40 10^9 Emittances: 7-17 π mm mrad

Note characteristic beam-beam signature on first and last bunches in each train!

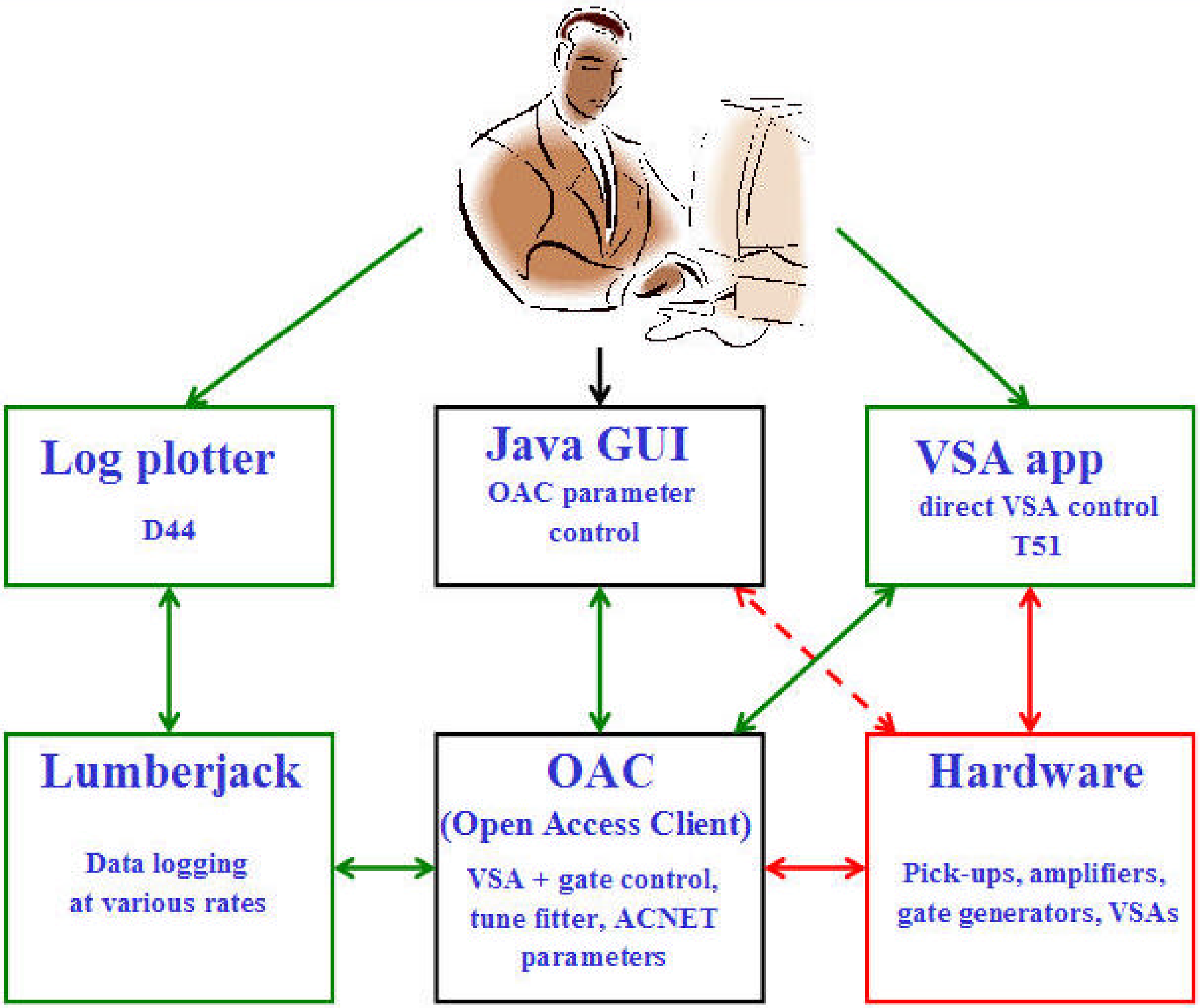
Conclusions

- Can measure tune of a single 15 10^9 pbar bunch to 5 10^{-4}!!!
- Tune measurement is affected by coupling, in a "predictable" way.
- Very good momentum spread agreement.
- Qualitative emittance agreement for pbars, need to understand proton signals better.
- Chromaticity measurement need more work.
- Considering implementing slow tune feedback based on 1.7 GHz Schottky readings.

Comparison - HFS and TW

- High Frequency Schottky
  - must take filling factor into consideration
  - ff ~ bunching freq/cavity freq
  - under most favorable conditions (120 bunch fill pattern), effective Q is ~20
- Travelling wave pickup effective Q is ~20!
  - in addition, this Q is available single bunch, unlike HFS, where Q~1 single bunch
  - bandwidth ~100MHz permits bunch-by bunch measurement
  - also permits abort gap measurement

Software overview



BNL Role in LARP TW Schottky?

- Data Acquisition and Processing
  - Present FNAL architecture is gate before HP DSA
  - Considerable overhead involved in importing system as it stands into LHC operations
  - BNL is learning LHC-standard DAB board for PLL
  - SNS BPM mezannine card for DAB board gives continuous bunch-by-bunch from TW pickup
  - BNL role - provide DAQ and help integrate into LHC Control System
- The SPS TW pickup
  - designed at FNAL, built at CERN, installed in SPS for studies
  - Studies complete, pickup offered to BNL for installation in RHIC
  - closed orbit offset electronics also available
  - Pickup is directional, installation in common beampipe would permit to observe both beams bunch-by-bunch with Q~20

18 Presentations, **LOTS** of Discussion

1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, and Chromaticity in Light of LHC Requirements - Pete Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

Summary of Requirements (3/3)

	Resolution		scenario
	on observable	on tunes	
Q	~ ± 3. 10^{-3}		Commissioning
	± .75 10^{-3}		Tune measurement and/or feedback in operation (injection,ramp, flat top during squeeze)
	±.25 10^{-3}		Nominal (pre-collision and collision)
	≤ ± 1. 10^{-3}		Bunch by bunch
	≤ 10^{-5}		Low-β non-linearities
	≤ 10^{-4}		Pilots, bunch by bunch (detunings)
Q′	±2.5	± 3. 10^{-3}	Commissioning
	±0.5 to ±1.5	±.35 10^{-3}	Nominal, 450 GeV to 7 TeV (measurement and/or feed-back)
|c|	±3 10^{-3}		Commissioning
	±.75 10^{-3}		Nominal beam at Injection, ramp and squeeze
	±.25 10^{-3}		Nominal beam in collision

18 Presentations, **LOTS** of Discussion

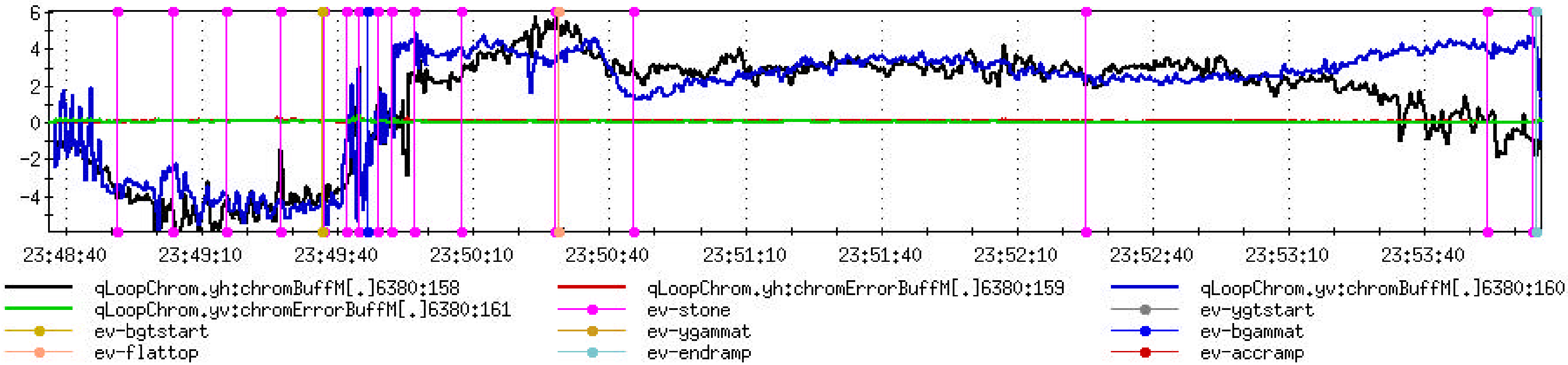
1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, Chromaticity in Light of LHC Requirements - Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

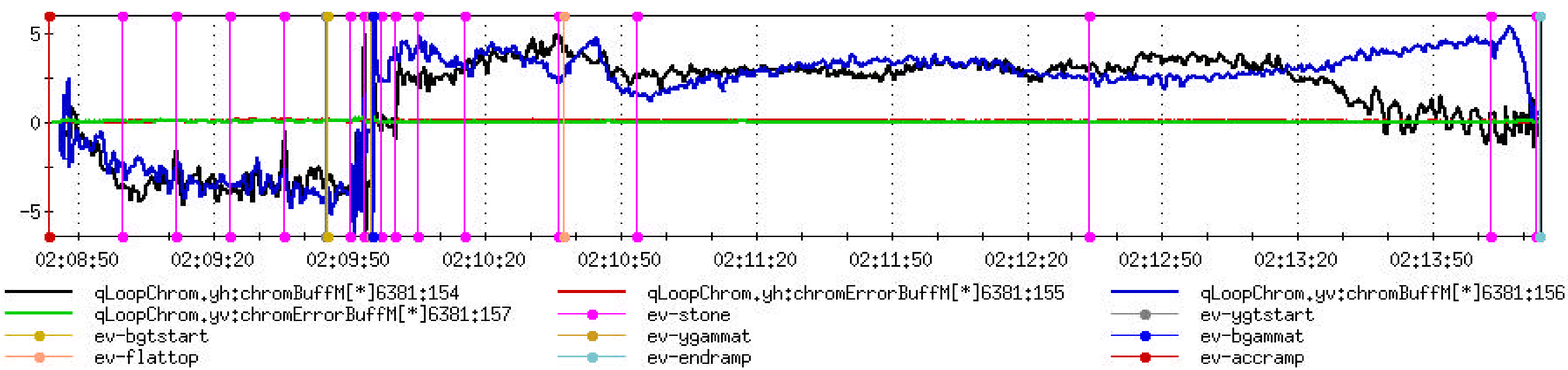
Chromaticity Effect on PLL

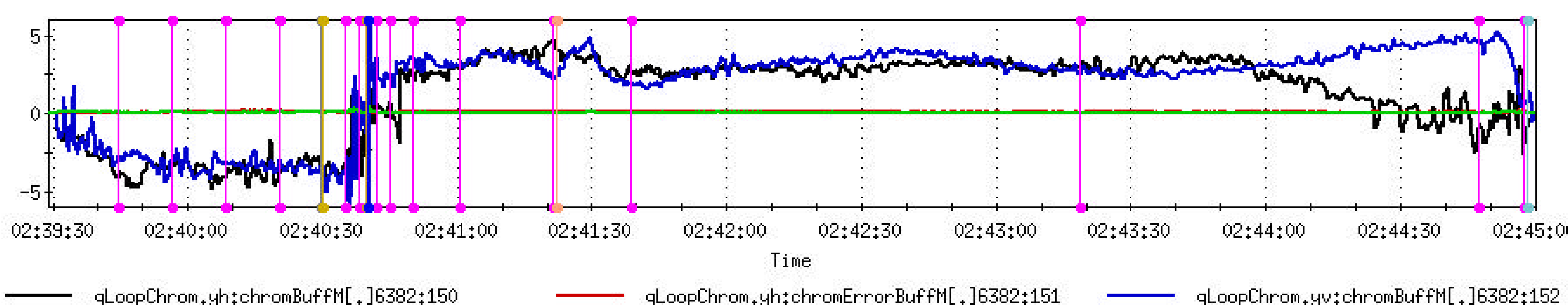
- Conclusion from chromaticity study (and years of experience with beam) is that 245MHz PLL tune measurement comfortably copes with a large range of chromaticity (resonantly excites low δp subset of momentum distribution)
- Chromaticity control is not an issue for 245MHz PLL tune measurement and tune/chrom feedback – further study required for baseband system, but we expect similar behavior
- Chromaticity control is an issue primarily in the usual operational sense – line broadening and resonance overlap

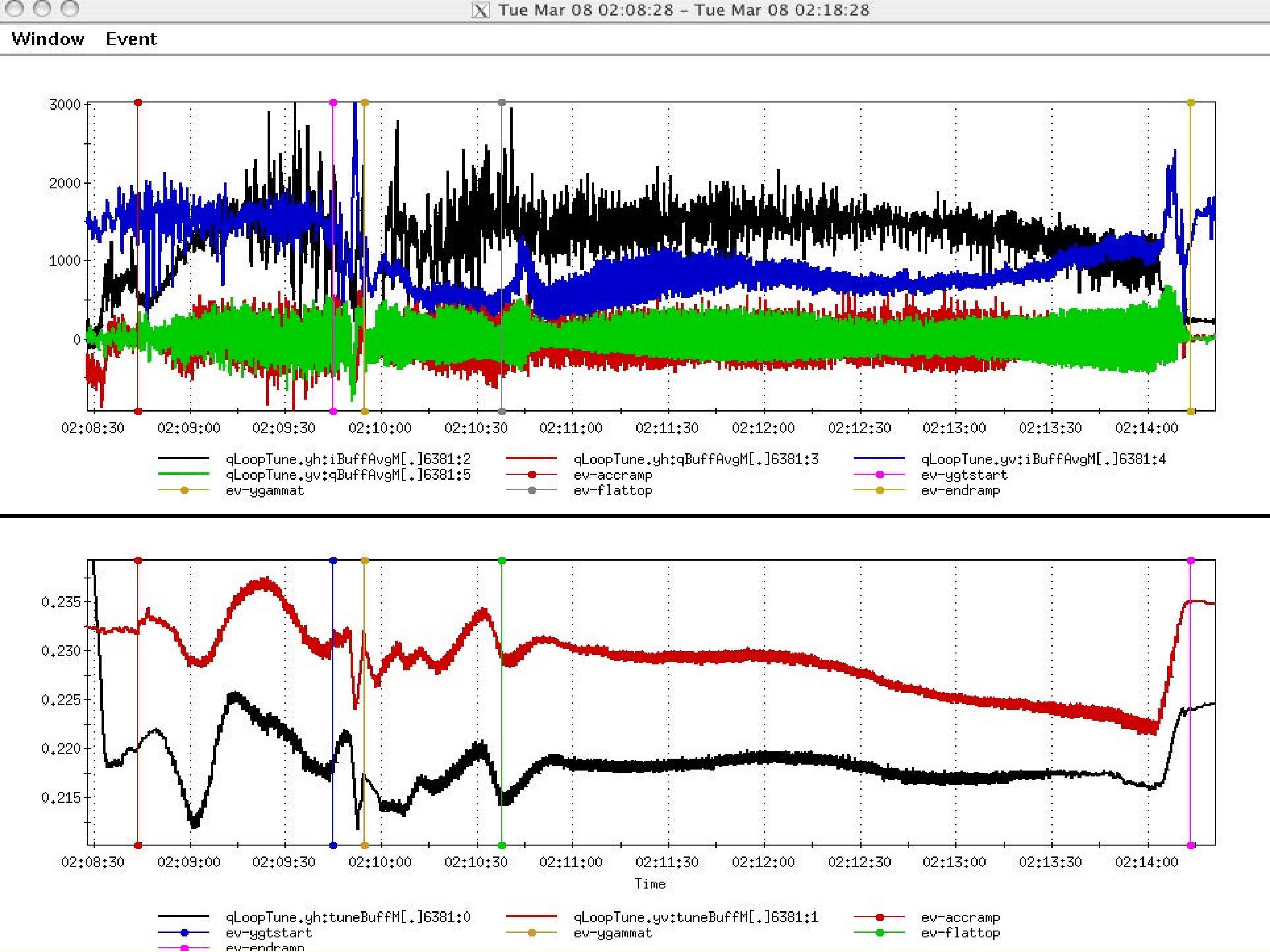
Mon Mar 07 23:48:36 - Tue Mar 08 02:45:00

Window Event

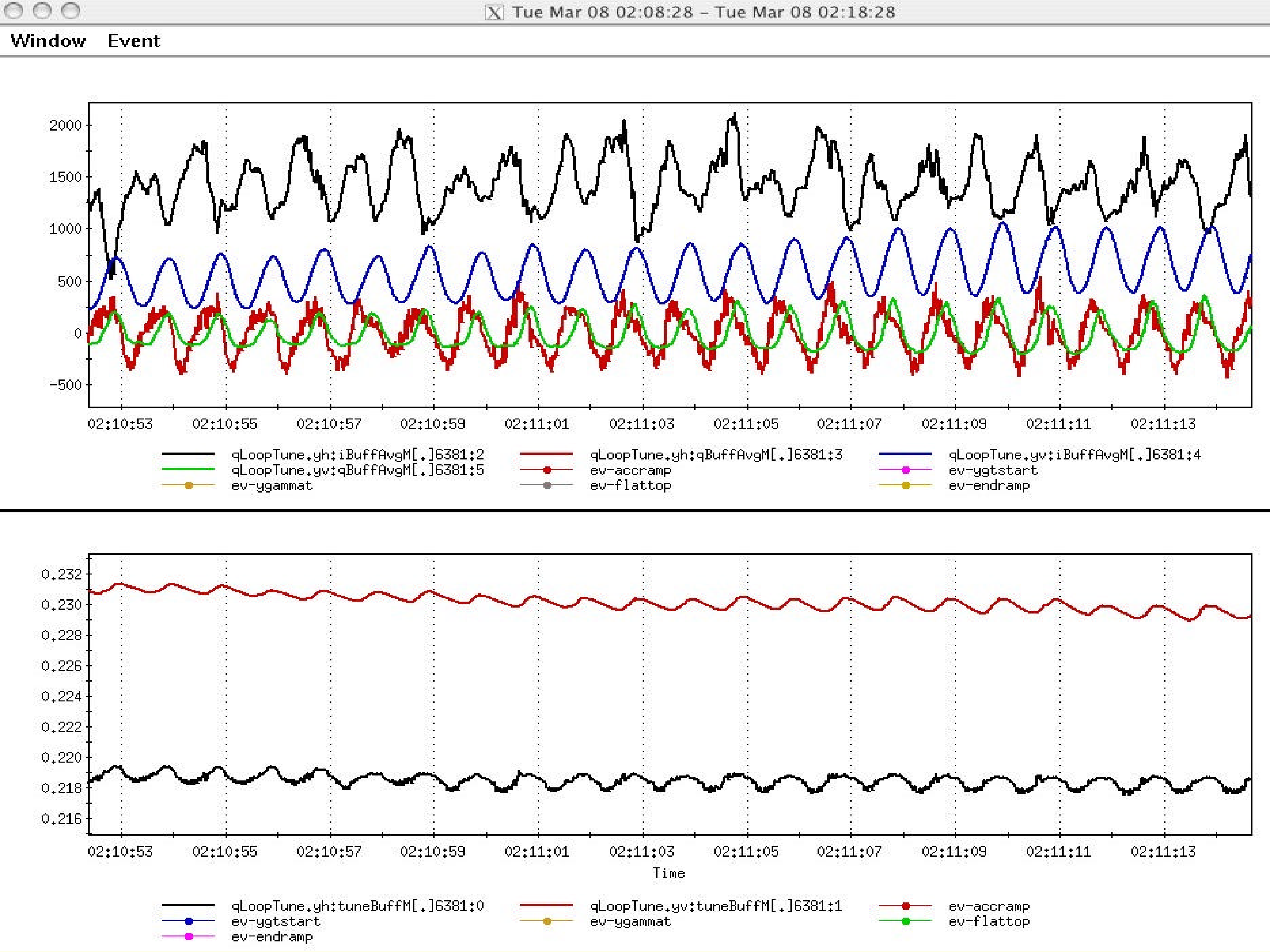








Tue Mar 08 02:08:28 – Tue Mar 08 02:18:28
Window
Event
3000
2000
1000
0
02:08:30
02:09:00
02:09:30
02:10:00
02:10:30
02:11:00
02:11:30
02:12:00
02:12:30
02:13:00
02:13:30
02:14:00
qLoopTune.yh:iBuffAvgM[.]6381:2
qLoopTune.yh:qBuffAvgM[.]6381:3
qLoopTune.yv:iBuffAvgM[.]6381:4
qLoopTune.yv:qBuffAvgM[.]6381:5
ev-accramp
ev-ygtstart
ev-ygammat
ev-flattop
ev-endramp
0.235
0.230
0.225
0.220
0.215
02:08:30
02:09:00
02:09:30
02:10:00
02:10:30
02:11:00
02:11:30
02:12:00
02:12:30
02:13:00
02:13:30
02:14:00
Time
qLoopTune.yh:tuneBuffM[.]6381:0
qLoopTune.yv:tuneBuffM[.]6381:1
ev-accramp
ev-ygtstart
ev-ygammat
ev-flattop
ev-endramp



Tue Mar 08 02:08:28 – Tue Mar 08 02:18:28
Window
Event
2000
1500
1000
500
0
-500
02:10:53
02:10:55
02:10:57
02:10:59
02:11:01
02:11:03
02:11:05
02:11:07
02:11:09
02:11:11
02:11:13
qLoopTune.yh:iBuffAvgM[.]6381:2
qLoopTune.yh:qBuffAvgM[.]6381:3
qLoopTune.yv:iBuffAvgM[.]6381:4
qLoopTune.yv:qBuffAvgM[.]6381:5
ev-accramp
ev-ygtstart
ev-ygammat
ev-flattop
ev-endramp
0.232
0.230
0.228
0.226
0.224
0.222
0.220
0.218
0.216
Time
qLoopTune.yh:tuneBuffM[.]6381:0
qLoopTune.yv:tuneBuffM[.]6381:1
ev-accramp
ev-ygtstart
ev-ygammat
ev-flattop
ev-endramp

Chrom Refinement

- Measurement 'runaway' scenario
  - significant PLL phase error during chrom measurement
  - chrom correction too small
  - tune mod due to chrom larger than previous measurement, phase error larger, chrom error larger
  - repeat
- The fix
  - use more than depth of tune modulation in chrom correction
  - include PLL phase error in chrom correction

Chrom Conclusion

- Chrom spec is actually a spec on ability of tune measurement to track modulation due to chrom, in the presence of other sources of tune modulation (preference is to not have modulation for coupling measurement)
- Baseband sensitivity to chrom may be stronger than what we see in 245MHz system - full momentum distribution is excited
- Inclusion of phase error in chrom correction is essential, will be tested at RHIC asap
- Examine effect of non-lin chrom
- Preliminary indication is that we can meet the spec
- Effect of chrom modulation on orbit feedback must be resolved

Coupling Conclusion

- Coupling correction is essential for tune feedback
- Sufficient attention has not yet been given to this problem
- Coupling must be measured on the ramp
  - best method is to measure eigenmode projections? non-perturbative
- Coupling feedforward is essential, at least until it is under control.
  - Does this require additional PLL receivers?
- Interface between eigenmode buffer from latest ramp to ramp manager for next ramp must be in place - this is a CERN responsibility
- Possibility of coupling feedback merits investigation

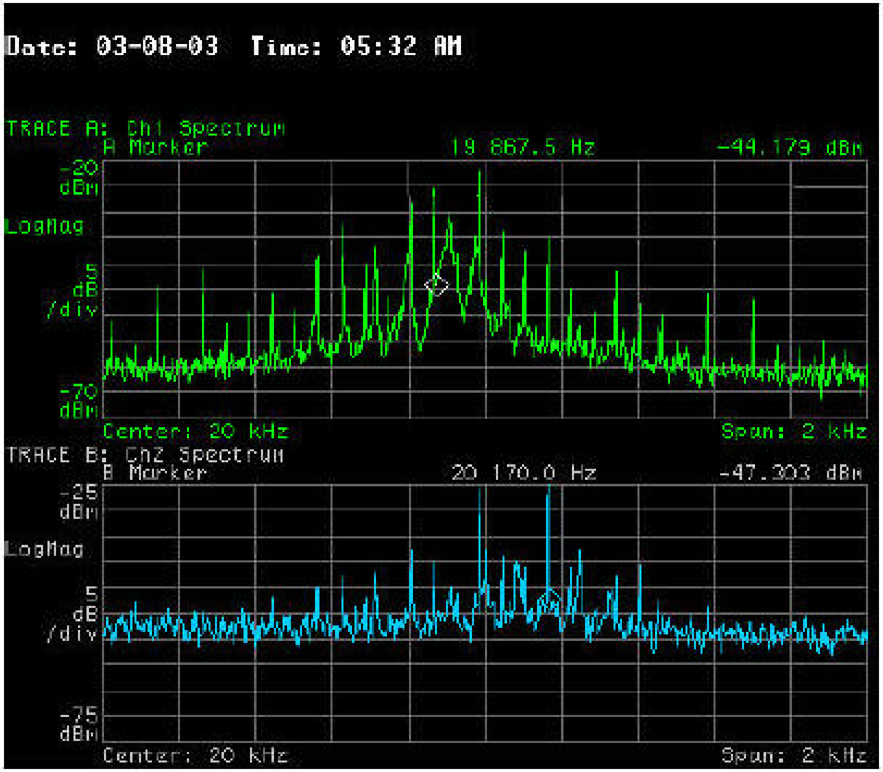
Summary/Action Items

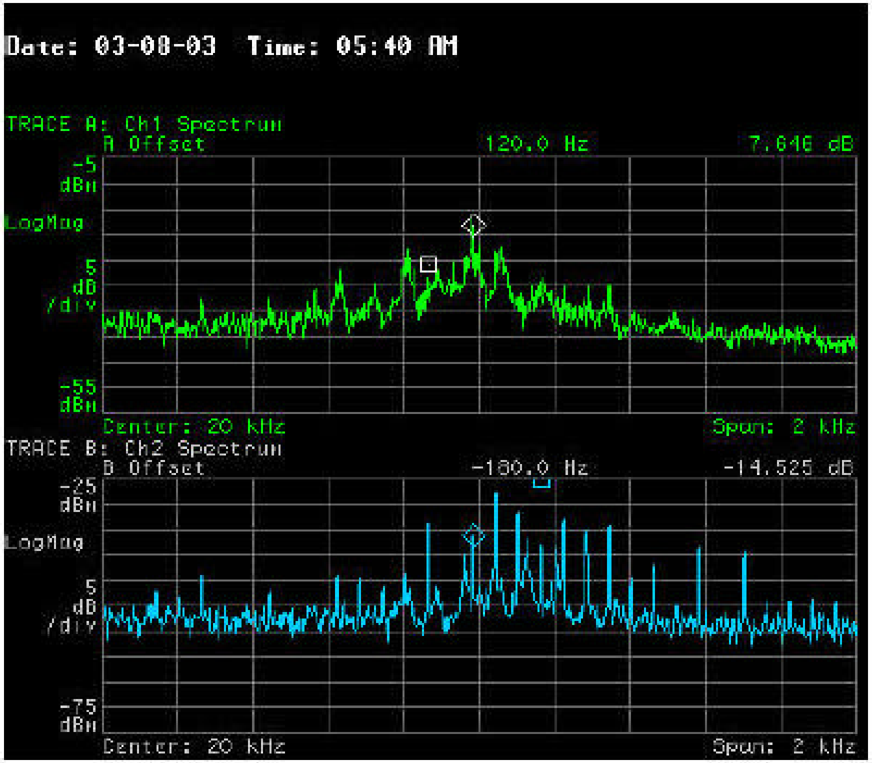
- 60Hz
- Coupling
  - better spec
  - measurement and correction method (robust possible?)
  - interface to Ramp Manager for feedforward
  - feedback?
- Chromaticity
  - include PLL phase error in feedback loop
  - magnitude and effect of non-linear chrom?
- tune - interface to ramp manager for feedforward
- Damper - confirm BBQ resolution < 100nm
- Orbit Correction - confirm 2Hz operation acceptable

18 Presentations, **LOTS** of Discussion

1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, Chromaticity in Light of LHC Requirements - Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

36x0 at 150GeV (VTICK off)





Helix off

Helix on

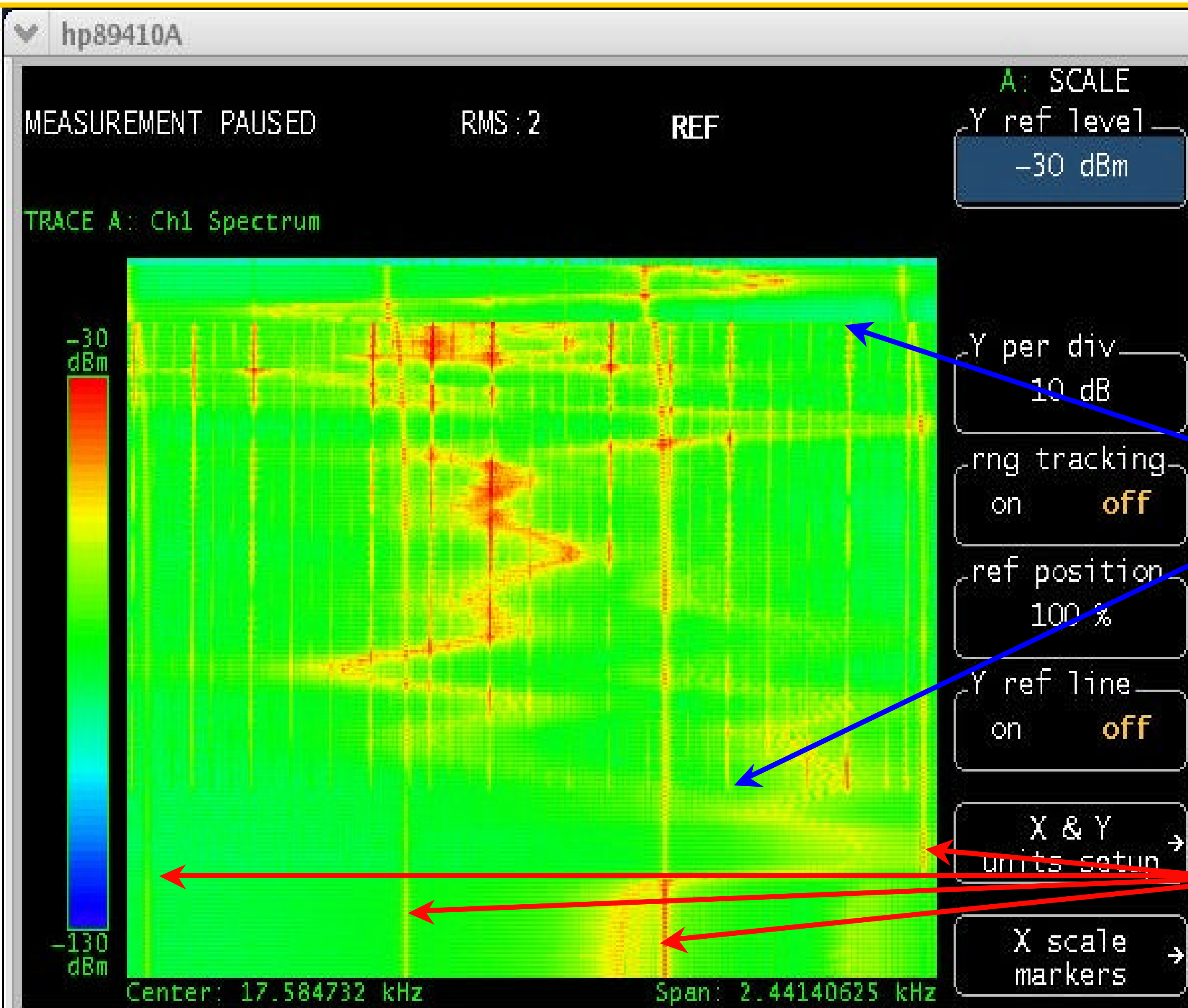
Note: 60Hz lines disappears on helix for horz but not vert. Vert pos changes by approx -4mm and horz by +3mm.Electronics?

Cheng-Yang Tan 08 Mar 2005

18 Presentations, **LOTS** of Discussion

1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, Chromaticity in Light of LHC Requirements - Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

3D Ramp - 1 Jan 05



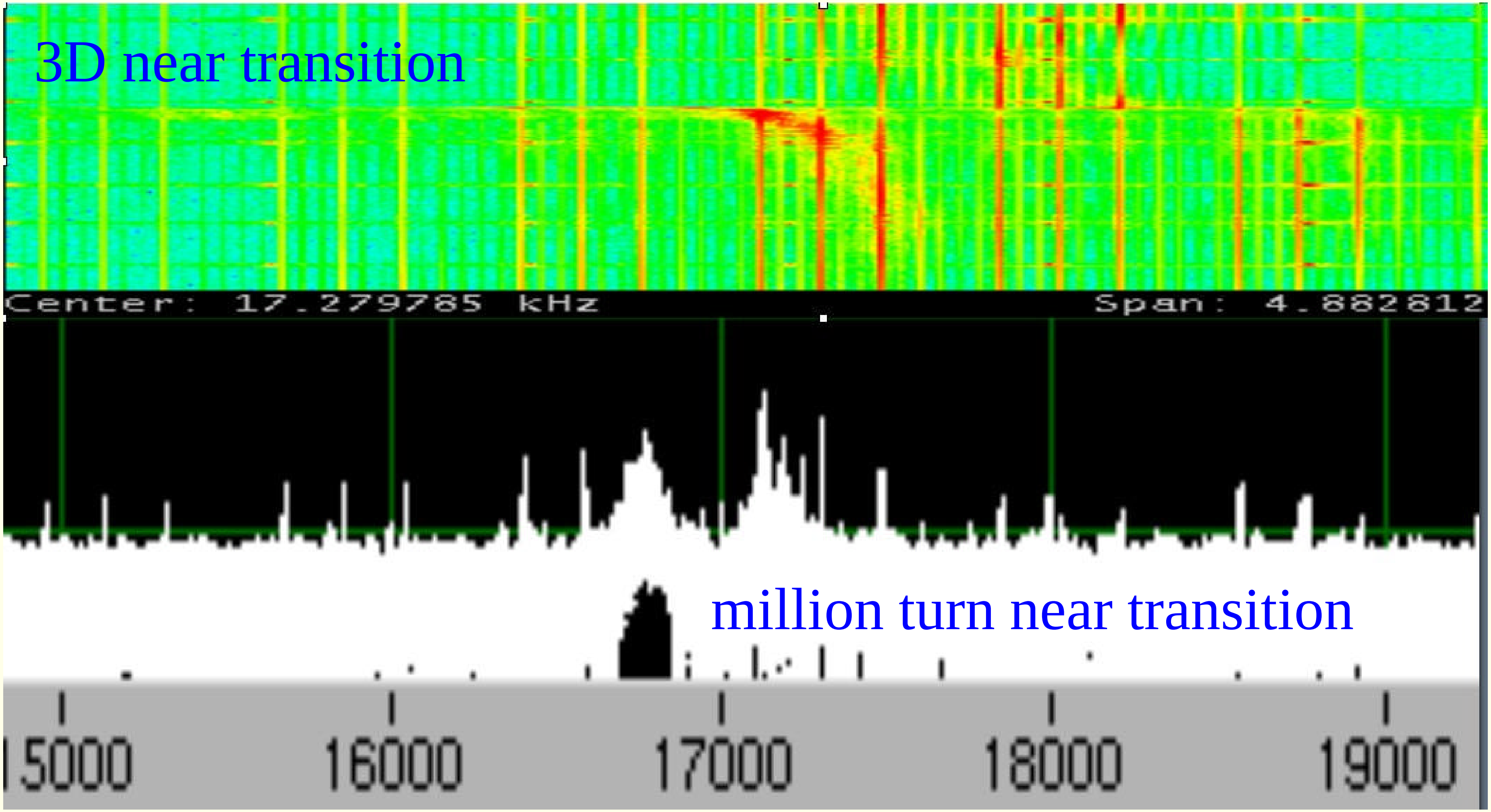
dominant spacing is 360Hz

60Hz onset

60Hz end

IPM every 100 turns? (780 Hz)

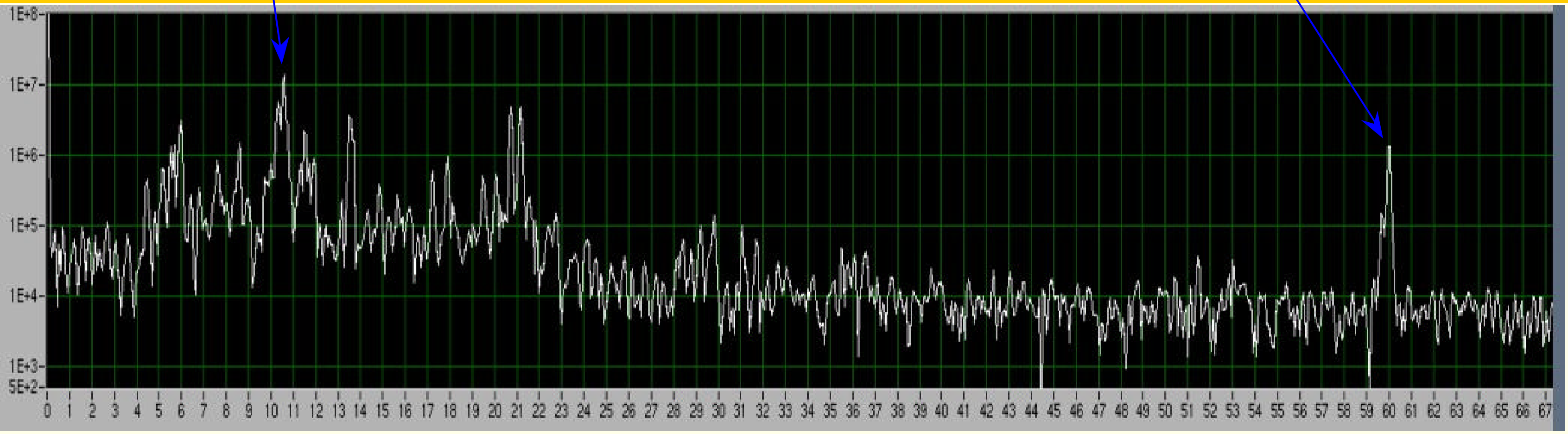
Million Turn BPM 1 - vertical!



estimate ~5m at betatron line

300 micron 10Hz cryostat vibration (0dB)

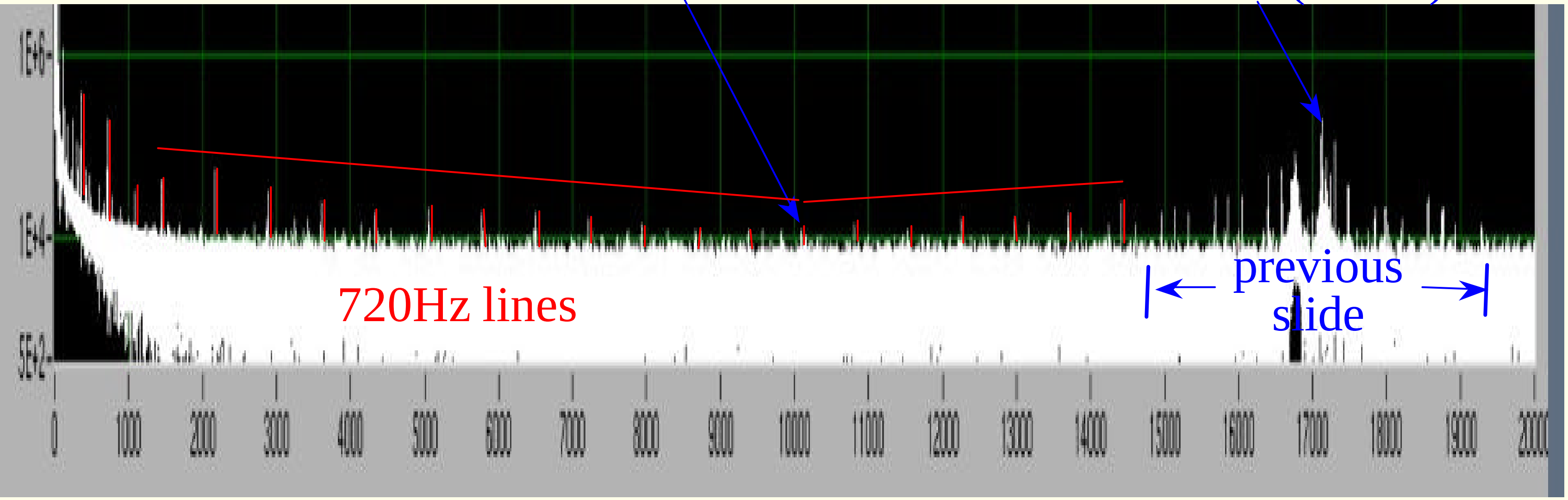
60Hz (-20dB)



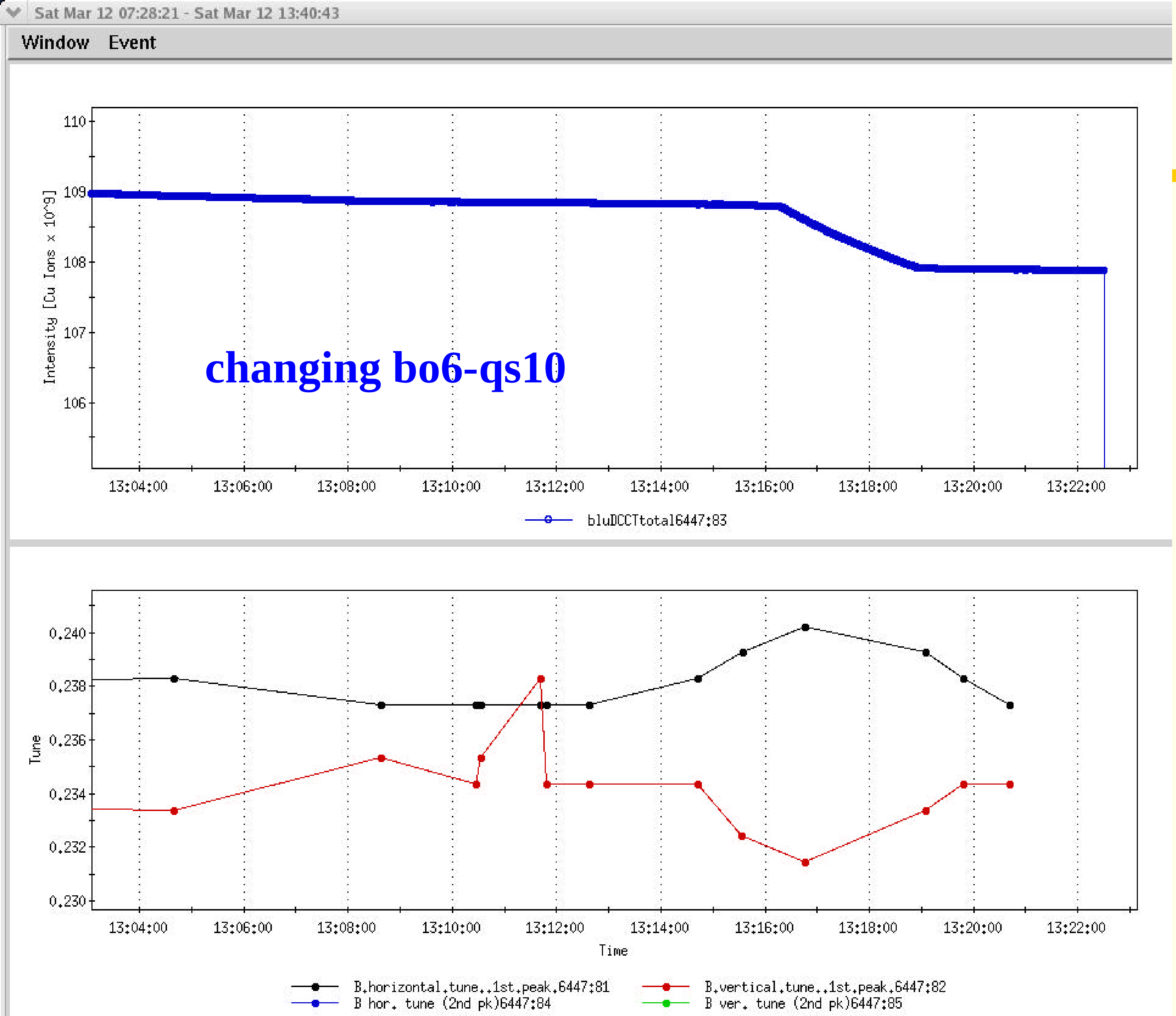
40dB

720Hz x 14 (-60dB)

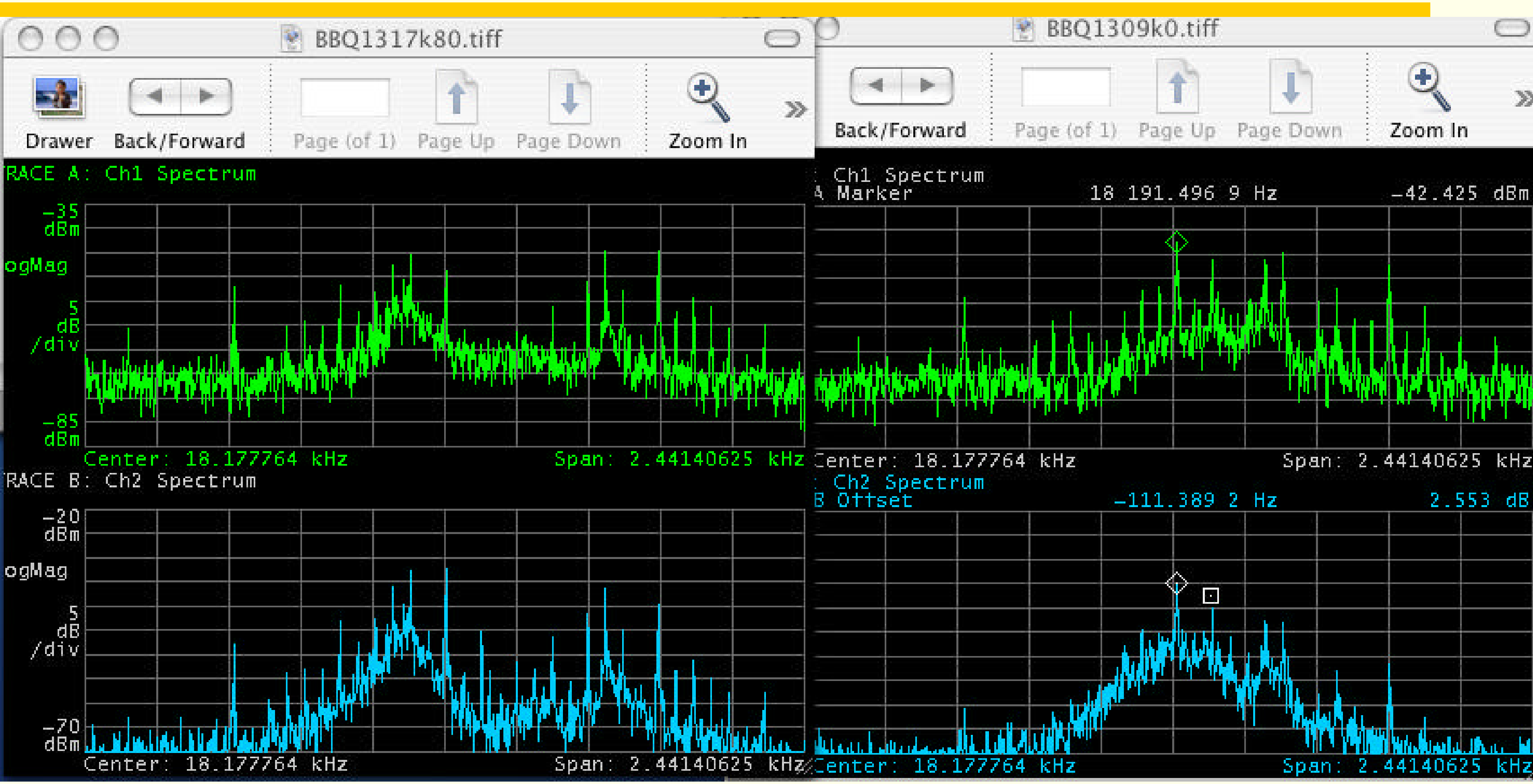
betatron line (-35dB)



the same 40dB


Sat Mar 12 07:28:21 - Sat Mar 12 13:40:43
Window Event
Intensity [Cu Ions x 10^9]
110
109
108
107
106
changing bo6-qs10
13:04:00
13:06:00
13:08:00
13:10:00
13:12:00
13:14:00
13:16:00
13:18:00
13:20:00
13:22:00
bluDCCTtotal6447:83
Tune
0.240
0.238
0.236
0.234
0.232
0.230
Time
B.horizontal.tune..1st.peak.6447:81
B.vertical.tune..1st.peak.6447:82
B hor. tune (2nd pk)6447:84
B ver. tune (2nd pk)6447:85

Effect of Coupling on Spectrum

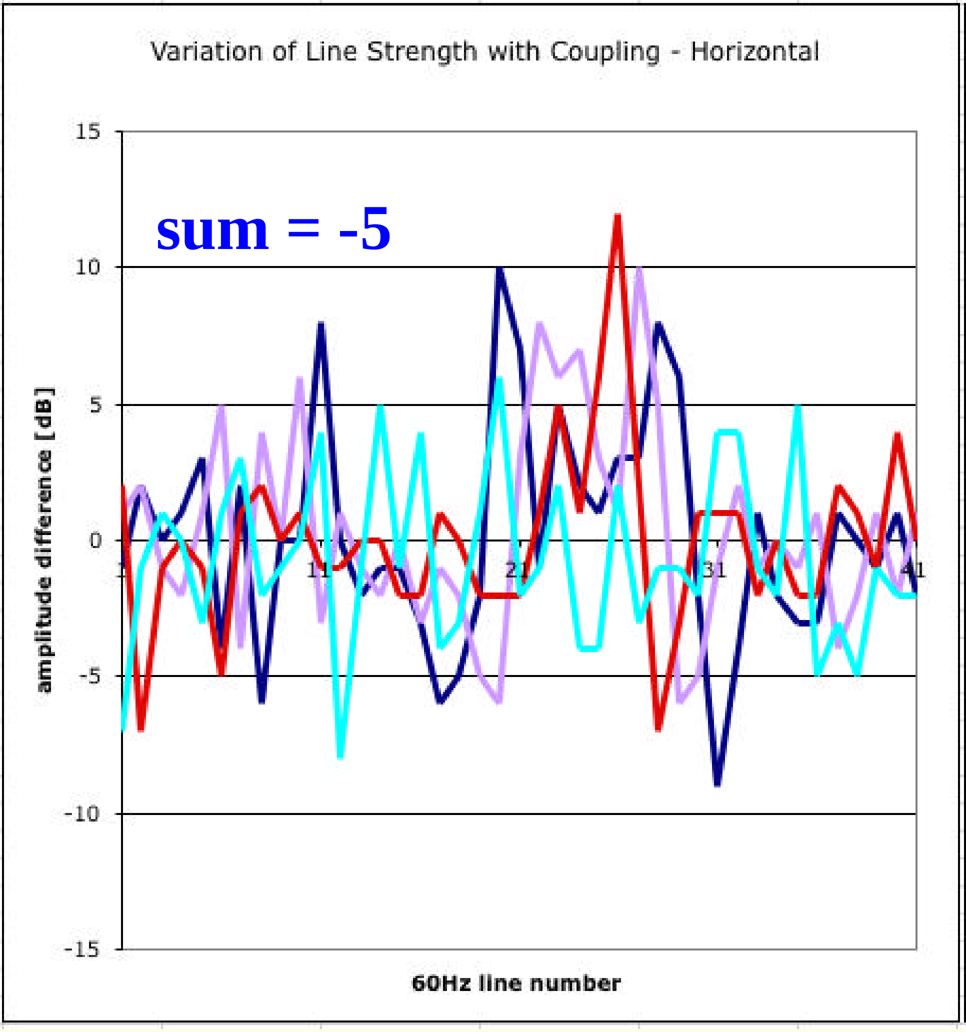


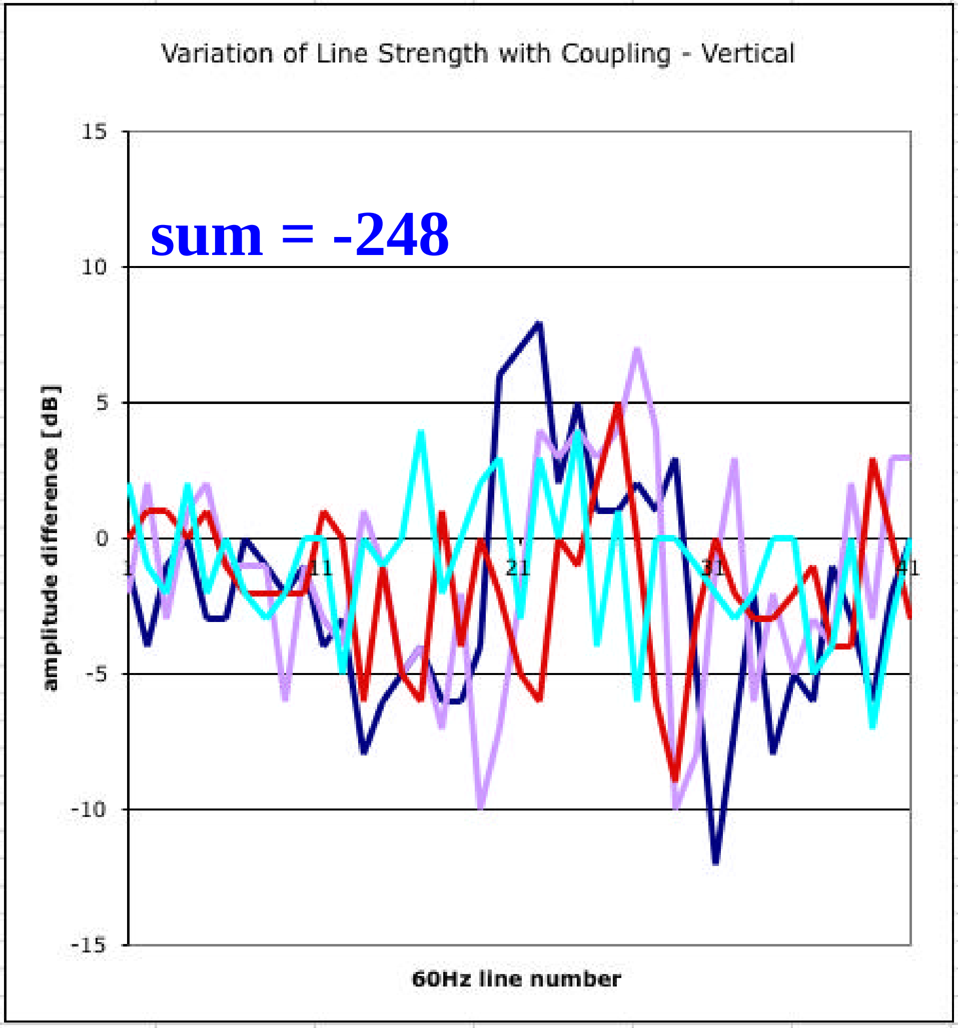
k = -.0008

k = 0

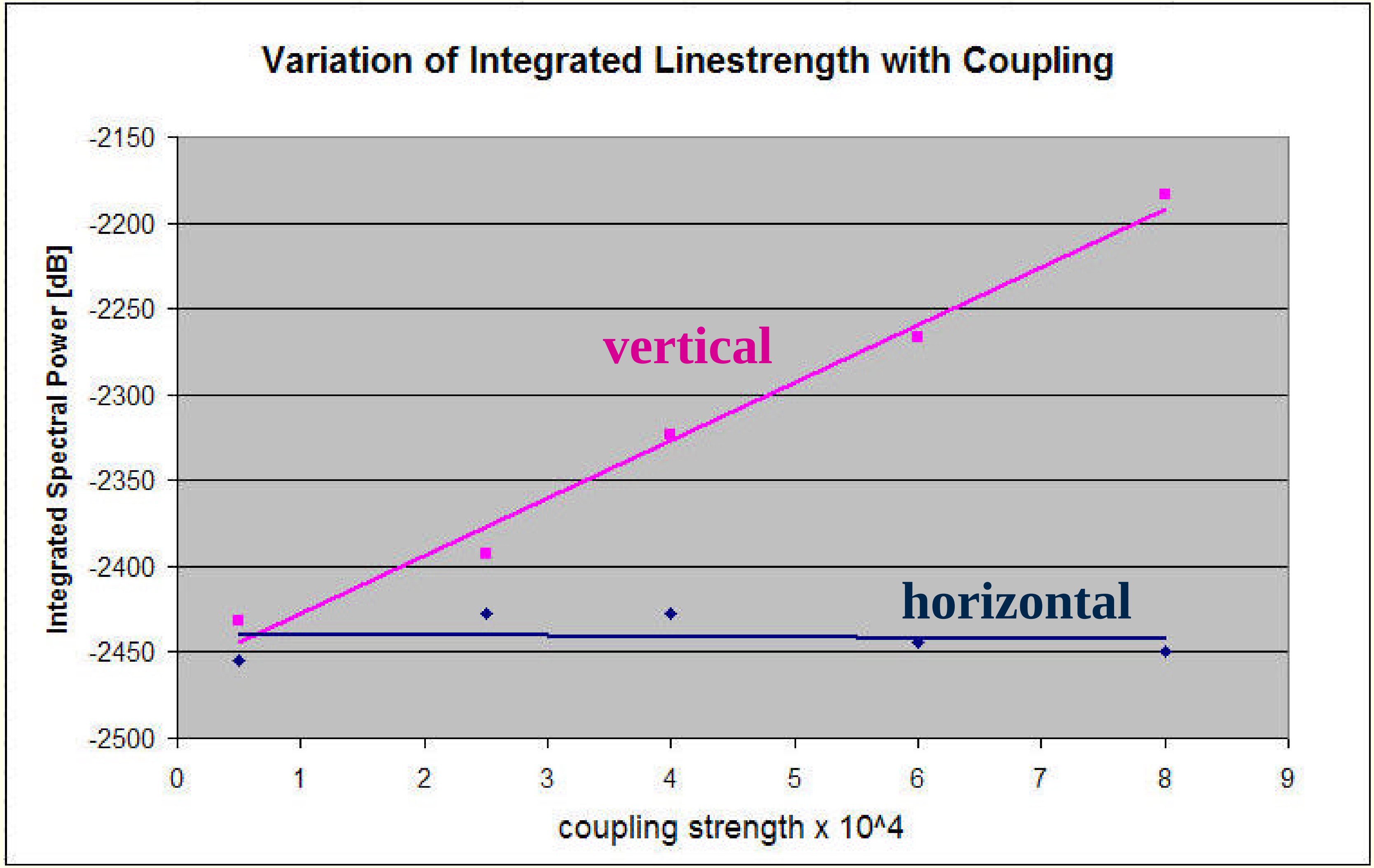
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1		k80 H	k60 H	k40 H	k25 H	k0 H		diff86	diff 64	diff425	diff250		k80 V	k60 V	k40 V	k25 V	k0 V		diff86	diff64	diff425	diff250
2																						
3	line						line					line						line				
4	1	-67	[illegible]	-67	-65	-72	1	-1	1	2	-7	1	-64	-65	-67	-67	-65	1	-1	-2	0	2
5	2	-68	-66	-64	-71	-72	2	2	2	-7	-1	2	-66	-70	-68	-67	-68	2	-4	2	1	-1
6	3	-61	-61	-62	-63	-62	3	0	-1	-1	1	3	-63	-64	-67	-66	-68	3	-1	-3	1	-2
7	4	-67	-66	-68	-68	-68	4	1	-2	0	0	4	-68	-68	-67	-67	-65	4	0	1	0	2
8	5	-69	-66	-65	-66	-69	5	3	1	-1	-3	5	-66	-69	-67	-66	-68	5	-3	2	1	-2
9	6	-68	-72	-67	-72	-71	6	-4	5	-5	1	6	-63	-66	-67	-68	-68	6	-3	-1	-1	0
10	7	-66	-64	-68	-67	-64	7	2	-4	1	3	7	-65	-65	-66	-68	-70	7	0	-1	-2	-2
11	8	-66	-72	-68	-66	-68	8	-6	4	2	-2	8	-63	-64	-65	-67	-70	8	-1	-1	-2	-3
12	9	-52	-52	-52	-52	-53	9	0	0	0	-1	9	-48	-50	-56	-58	-60	9	-2	-6	-2	-2
13	10	-72	-72	-66	-65	-65	10	0	6	1	0	10	-65	-66	-67	-69	-69	10	-1	-1	-2	0
14	11	-72	-64	-67	-68	-64	11	8	-3	-1	4	11	-59	-63	-66	-65	-65	11	-4	-3	1	0
15	12	-60	-60	-59	-60	-68	12	0	1	-1	-8	12	-54	-57	-61	-61	-66	12	-3	-4	0	-5
16	13	-59	-61	-62	-62	-63	13	-2	-1	0	-1	13	-53	-61	-60	-66	-66	13	-8	1	-6	0
17	14	-60	-61	-63	-63	-58	14	-1	-2	0	5	14	-53	-59	-60	-61	-62	14	-6	-1	-1	-1
18	15	-52	-53	-53	-55	-56	15	-1	0	-2	-1	15	-43	-48	-53	-58	-58	15	-5	-5	-5	0
19	16	-57	-60	-63	-65	-61	16	-3	-3	-2	4	16	-47	-51	-55	-61	-57	16	-4	-4	-6	4
20	17	-53	-59	-60	-59	-63	17	-6	-1	1	-4	17	-42	-48	-55	-54	-56	17	-6	-7	1	-2
21	18	-47	-52	-54	-54	-57	18	-5	-2	0	-3	18	-36	-42	-44	-48	-48	18	-6	-2	-4	0
22	19	-45	-47	-52	-54	-53	19	-2	-5	-2	1	19	-33	-37	-47	-47	-45	19	-4	-10	0	2
23	20	-60	-50	-56	-58	-52	20	10	-6	-2	6	20	-45	-39	-46	-48	-45	20	6	-7	-2	3
24	21	-48	-41	-38	-40	-42	21	7	3	-2	-2	21	-32	-25	-27	-32	-35	21	7	-2	-5	-3
25	22	-61	-62	-54	-53	-54	22	-1	8	1	-1	22	-54	-46	-42	-48	-45	22	8	4	-6	3
26	23	-64	-59	-53	-48	-46	23	5	6	5	2	23	-45	-43	-40	-40	-40	23	2	3	0	0
27	24	-63	-61	-54	-53	-57	24	2	7	1	-4	24	-58	-53	-49	-50	-46	24	5	4	-1	4
28	25	-61	-60	-57	-51	-55	25	1	3	6	-4	25	-51	-50	-47	-45	-49	25	1	3	2	-4
29	26	-64	-61	-60	-48	-46	26	3	1	12	2	26	-53	-52	-48	-43	-42	26	1	4	5	1
30	27	-56	-53	-43	-41	-44	27	3	10	2	-3	27	-46	-44	-37	-37	-43	27	2	7	0	-6
31	28	-68	-60	-55	-62	-63	28	8	5	-7	-1	28	-56	-55	-51	-57	-57	28	1	4	-6	0
32	29	-51	-45	-51	-54	-55	29	6	-6	-3	-1	29	-41	-38	-48	-57	-57	29	3	-10	-9	0
33	30	-44	-46	-51	-50	-52	30	-2	-5	1	-2	30	-36	-41	-49	-52	-53	30	-5	-8	-3	-1
34	31	-53	-62	-63	-62	-58	31	-9	-1	1	4	31	-45	-57	-58	-58	-60	31	-12	-1	0	-2
35	32	-62	-66	-64	-63	-59	32	-4	2	1	4	32	-56	-63	-60	-62	-65	32	-7	3	-2	-3
36	33	-44	-43	-44	-46	-47	33	1	-1	-2	-1	33	-39	-41	-47	-50	-52	33	-2	-6	-3	-2
37	34	-57	-59	-59	-59	-61	34	-2	0	0	-2	34	-53	-61	-63	-66	-66	34	-8	-2	-3	0
38	35	-54	-57	-58	-60	-55	35	-3	-1	-2	5	35	-51	-56	-61	-63	-63	35	-5	-5	-2	0
39	36	-56	-59	-58	-60	-65	36	-3	1	-2	-5	36	-55	-61	-64	-65	-70	36	-6	-3	-1	-5
40	37	-61	-60	-64	-62	-65	37	1	-4	2	-3	37	-57	-58	-62	-66	-70	37	-1	-4	-4	-4
41	38	-66	-66	-68	-67	-72	38	0	-2	1	-5	38	-65	-68	-66	-70	-70	38	-3	2	-4	0
42	39	-60	-61	-60	-61	-62	39	-1	1	-1	-1	39	-57	-63	-66	-63	-70	39	-6	-3	3	-7
43	40	-69	-68	-70	-66	-68	40	1	-2	4	-2	40	-68	-70	-67	-67	-70	40	-2	3	0	-3
44	41	-67	-69	-68	-68	-70	41	-2	1	0	-2	41	-70	-70	-67	-70	-70	41	0	3	-3	0
45								6	16	1	-28								-83	-56	-70	-39
46																						
47									**-5**											**-248**		

Coupling Cameron - difference





coupling 60Hz plot



60Hz Conclusions

- 60Hz **IS** on the beam
- Statement of excellent sensitivity of BBQ (and million turn BPM)
- It is at baseband, will show up everywhere in the spectrum - we can't escape it
- High Priority - Carl Schultheiss - 720Hz balancing circuit
- Filtering is difficult
- Possible solution - park tune between lines (effective only with TF on)

18 Presentations, **LOTS** of Discussion

1. **Welcome and Overview – Mike Harrison**
2. **Overview of LHC Diagnostics and Diagnostics Commissioning - Rhodri Jones**
3. Results from the TW Pickup at FNAL - Andreas Jansson
4. **Results from the TW Pickup at SPS – Maria Elena Castro Carballo**
5. **Results from the cavity pickup at RHIC – Al Dellapenna**
6. **Specification for the LHC TW Pickup - Fritz Caspers**
7. **Design and Expected Performance of the LHC TW Pickup - Ralph Pasquinelli**
8. **The LHC Tune/Chromaticity/Coupling Specification - Rhodri Jones**
9. **Direct Diode Detection and Results from SPS - Marek Gasior**
10. **Results from FNAL - 3D and 21.4MHz - C.Y. Tan**
11. **Results from BNL - Homodyne, 3D, and 245MHz - Pete Cameron**
12. **60Hz Lines – C.Y. Tan**
13. **60Hz Lines – Pete Cameron**
14. **Coupling Measurement and Correction - Yun Luo**
15. **Tune, Coupling, Chromaticity in Light of LHC Requirements - Cameron**
16. **AFE and digitizer board – Marek Gasior**
17. **The DAB board – Rhodri Jones**
18. **Integration with Magnets - Carl Schultheiss**

BBQ Advantages / Disadvantages

Advantages

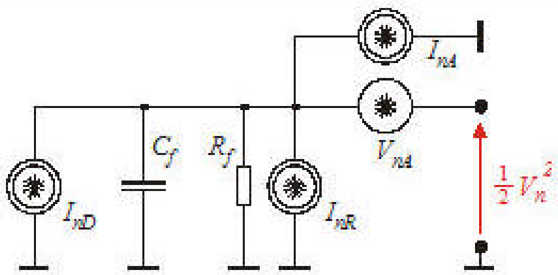
- Sensitivity
- Virtually impossible to saturate
- Simplicity
- No resonant PU, no movable PU, no hybrid, no mixers
- It can work with any PU
- Base-band operation guaranties the independence of the machine filling pattern
- Signal conditioning / processing in the base-band is easy (powerful components for low frequencies)
- Flattening out the beam dynamic range (small sensitivity to the bunch number)

Disadvantages

- Operation in the low frequency range
- It is sensitive to the "bunch majority"

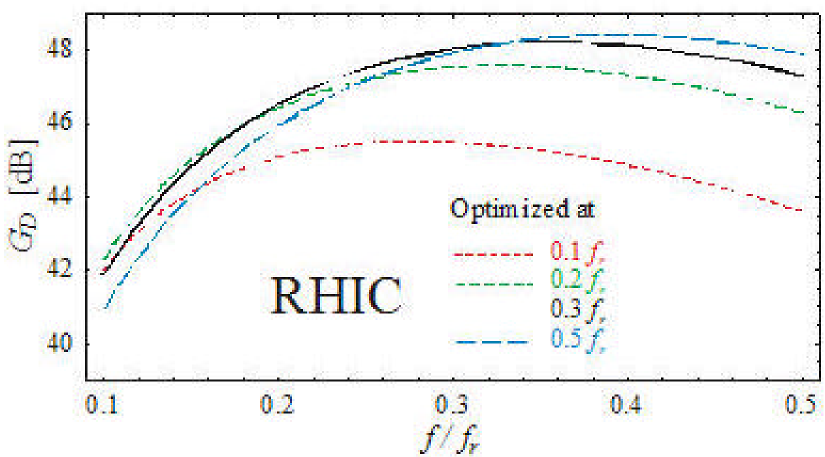
More measurements and other plots from the presented measurements can be seen on the BBQ web site

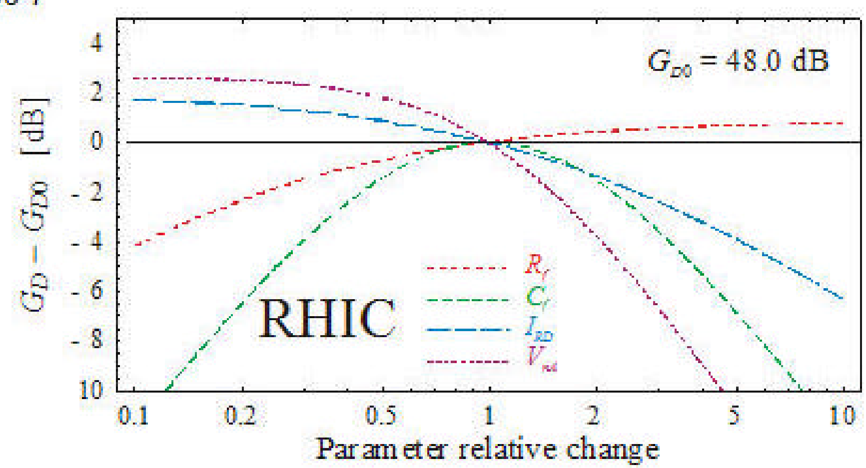
www.cern.ch/gasior/pro/3D-BBQ/3D-BBQ.html

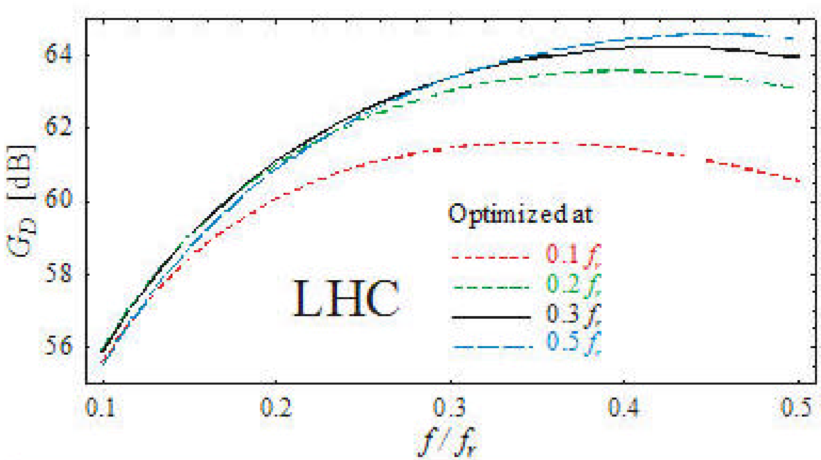


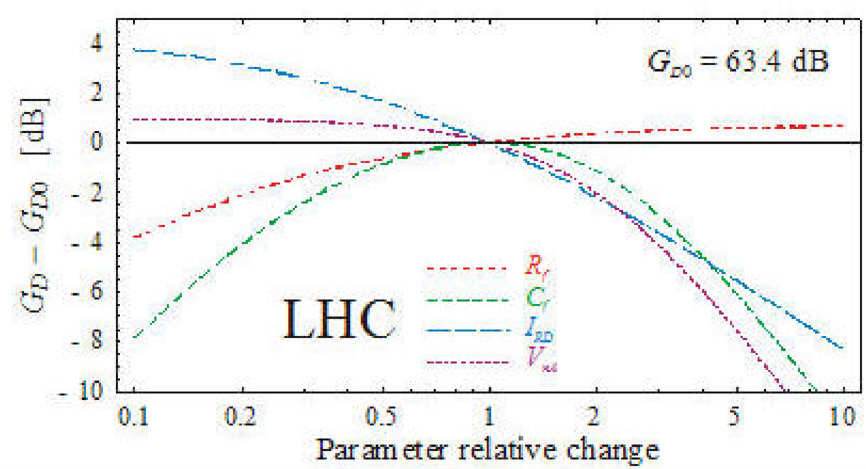
$$G_D = \frac{V_{nC}\,\dfrac{T}{2\sqrt{\pi}\,\sigma}\cdot\dfrac{C_{pu}}{C_{pu}+C_f}\cdot\dfrac{\sin(\pi q)}{\pi q}}{\sqrt{V_{nA}^2+\dfrac{T^2}{(2\pi q\,C_f)^2}\left(2e\,I_{RD}+\dfrac{4k\Theta}{R_f}+I_{nA}^2\right)}}$$

$\tau = 100\,T$

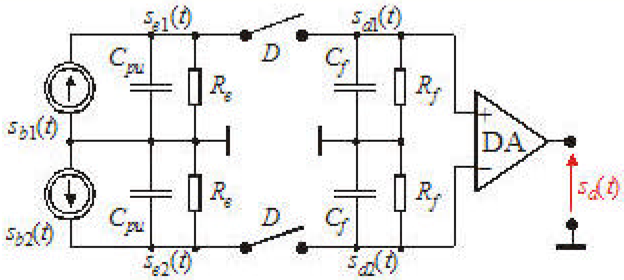




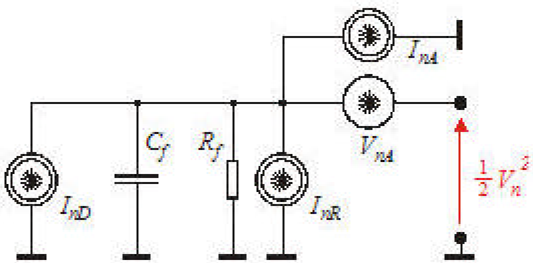




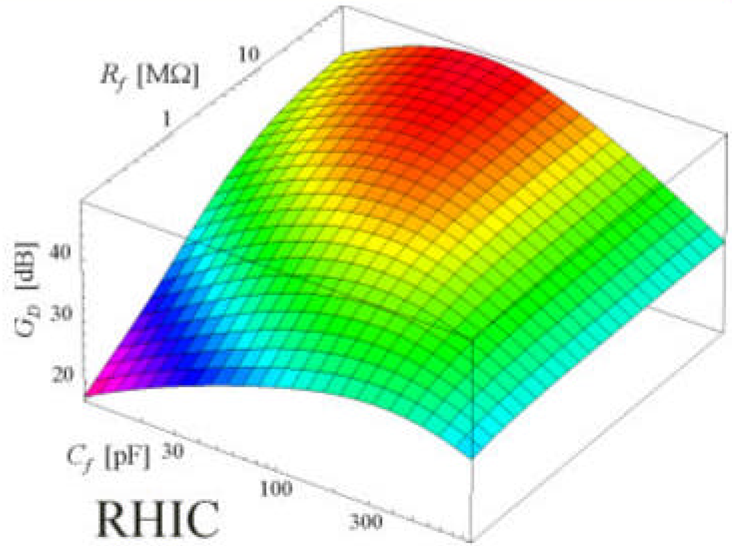
Direct Diode Detection – SNR



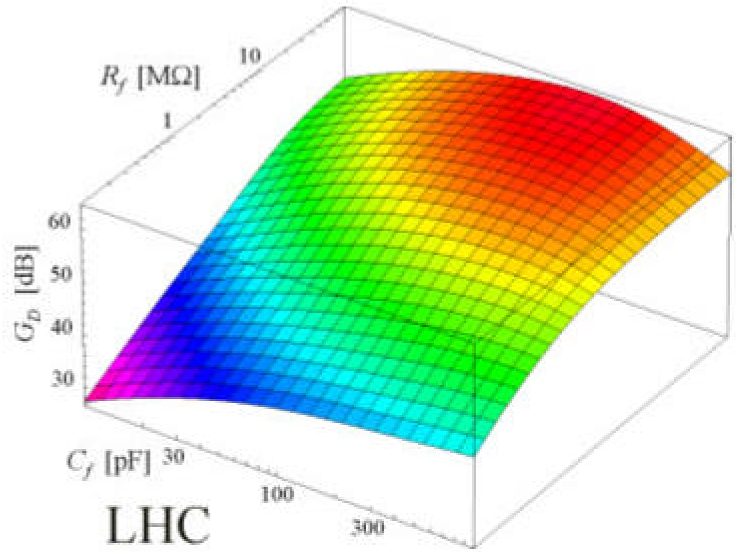
$$G_S = \frac{T}{\sqrt{2\pi}\sigma} \cdot \frac{C_{pu}}{C_{pu}+C_f} \cdot \left| \frac{\tau\left(1-\exp\left(-\mathrm{j}2\pi q - T/\tau\right)\right)}{1+\mathrm{j}2\pi q} \right|$$



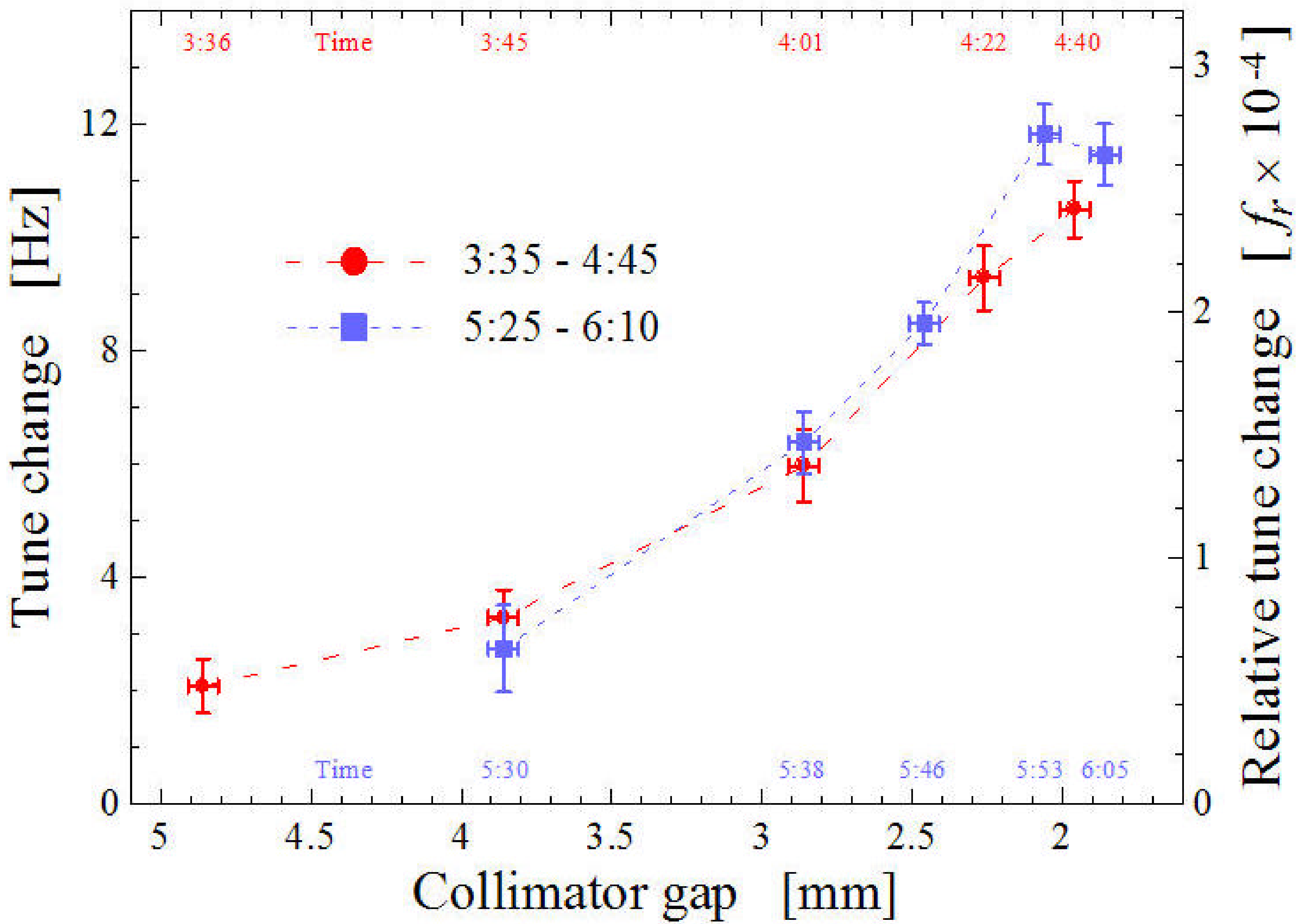
$$G_D = \frac{\dfrac{V_{nC}T}{\sqrt{\pi}\sigma} \cdot \dfrac{R_f C_f C_{pu}}{C_{pu}+C_f} \left| \dfrac{1-\exp\left(-\mathrm{j}2\pi q - T(R_f C_f)^{-2}\right)}{1+\mathrm{j}2\pi q} \right|}{\sqrt{V_{nA}^2 + \dfrac{T^2 R_f^2 \left(2eI_{RD} + \dfrac{4k\Theta}{R_f} + I_{nA}^2\right)}{T^2 + (2\pi q R_f C_f)^2}}}$$



$\tau = 100\ T$



SPS BBQ Measurements – LHC Collimator Impedance



Smallest frequency error is 0.37 Hz (9 ppm of f_r)

Largest frequency error is 0.77 Hz (18 ppm of f_r)

Error average is 0.54 Hz (13 ppm of f_r)

SPS f_r is 43376

Acquisition Architecture