FY06 RHIC Schottky System Modifications and Experiments Plans

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Outline

- Working Group Seminar announcement
- Basic Concepts of Schottky
- Measurement Requirements - tune and chrom at store
- Tune - linewidths for LFS and HFS
- LFS plan for Run 6
- Complicating factors - coupling (set vs eigentunes), asymmetric rev line, beam out of bucket, gap kicker, beam-beam,...
- Chromaticity - primarily non-linear at store
  - ✓ how to measure with Schottky?
- Emittance calibration
- Beam Experiments
- Conclusions
- Reference and Backup Material

Working Group Seminar
On Interpretation of Schottky Signals

First session: 2:30 pm, Wednesday Nov. 16

Location: 911B LCR

Speaker: Mike Blaskiewicz

Specifics: The plan is to derive longitudinal bunched beam Schottky signals including the effects of synchrotron frequency spread & introducing a good approximation for the Bessel-shaped synchrotron sidebands.

All are welcome to attend. The level of the discussion is expected to be very high. This is NOT an introduction. Expect to have to do work.

Schottky Basics

- "Schottky signals represent the sum of the incoherent signals of all the particles in the beam" (D.Goldberg & G.Lambertson)
- For N particles rms Schottky power is N times the power of 1 particle.
- If coherent motion is introduced (any), the N particle signal will be N times that of a single particle.
- rms coherent power is N^2 times the power of a single particle & N times the power of the Schottky signal!
- Dynamic range: Bunched beams generate intrinsic strong coherent signal.

Table 2. Quantities Obtainable from Schottky Spectra

From LBLTech. Note by Goldberg & Lambertson

Longitudinal (L) or Transverse (T) Signal	Bunched (B) or Unbunched (U)	Observed Quantity	Derived Quantity
L	B, U	Integrated Intensity	Number of particles (N)
T	B, U	Integrated Intensity	$N\sigma_{\perp}^{2}$
T	B, U	Center frequency of betatron band	q of reference particle
T	B, U	Overall Width of Band	At high frequency: $\eta n f_o \Delta p/p$ At low frequency: $\xi f_o \Delta p/p$
L, T	B	Satellite spacing	Synchrotron frequency
L, T	B	Satellite Line Width	Spread in synchrotron frequencies
L	B, U	Overall Width and Shape of Band	$\eta\Delta p/p$ (Even if neither known absolutely, if one is constant, can measure % change in the other), momentum distribution
T	B	Width of central satellite line	Amplitude-dependent tune spread

Table 3: Sources of Coherent Signals in Bunched Beams

Table 3a. Longitudinal Signals

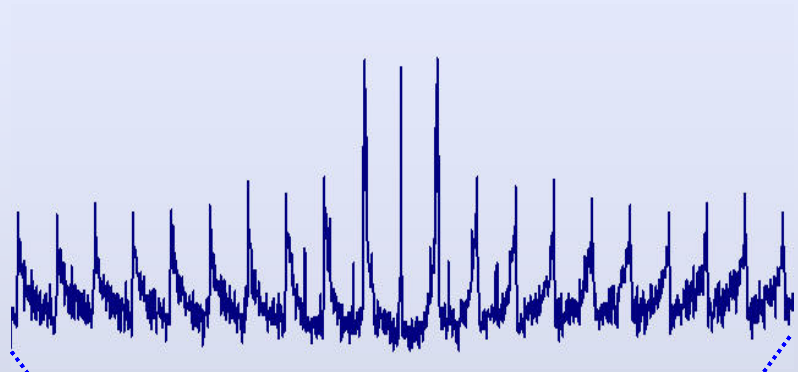
Cause	Frequency	Comments
Intrinsic Signal	nf_o	Intensity may vary with n depending on number of bunches and relative population. Signals roll off at a frequency which is roughly $1/2\pi\sigma_t$, the bunch-cutoff frequency [BCF]. Signal constant with time.
Coherent synchrotron oscillation	nf_o + satellites, up to BCF	If caused by faulty initial matching, signal will de-cohere with time
Intrabunch oscillation	Intrinsic signal pattern centered around oscillation frequency	Oscillation frequency must exceed bunch-cutoff frequency. May either grow or disappear if "self-healing".

Table 3b. Transverse Signals

Cause	Frequency	Comments
Fixed offset, imperfect differencing	nf_o, up to BCF	Signal constant with time; may be easier to cope with since displaced from incoherent signal at $(n\pm q)f_o$
Coherent betatron oscillation	$(n\pm q)f_o$, up to BCF	If caused by faulty initial matching, signal will de-cohere with time
Coherent synchrotron oscillation	satellites centered about nf_o (but no nf_o line), up to BCF	Only observable if pickup in region of non-zero dispersion. If caused by faulty initial matching, signal will de-cohere with time
Intrabunch oscillation	Intrinsic longitudinal signal pattern, centered around oscillation frequency	May either grow or disappear if "self-healing"

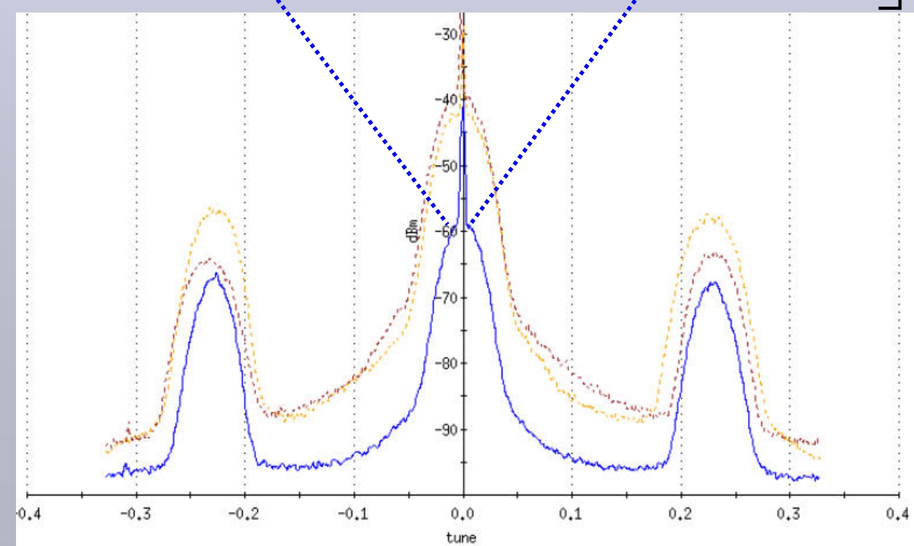
Line Locations and Widths

- Bunched beams: each revolution line splits into an infinite number of synchrotron satellites separated by synchrotron frequency with amplitudes proportional to Bessel functions.



$$d_n = e f_0 a_i \,\mathrm{Re}\left[\sum_{p=-\infty}^{\infty} J_p\left(\left[(n \pm q) - Q\xi/\eta\right]\omega_0 \hat{\tau}_i\right) e^{j\left[\left(\left[(n\pm q)-Q\xi/\eta\right]\omega_0 + p\Omega_s\right)t + p\Psi_i + \varphi_i\right]} \right]$$

- Harmonic bands at nf_0 with betatron bands split into pairs of sidebands at frequencies $(m+-q)f_0$
- Betatron sidebands have similar structure of synchrotron satellites



Line Locations and Widths

- Total line widths (bunched or unbunched)

$$\Delta f = n\eta f_0 \frac{\Delta p}{p} \text{ Longitudinal } \quad \Delta f = \left|-(n \pm q)\eta \pm \xi\right| f_0 \frac{\Delta p}{p} \text{ Transverse}$$

- Individual Lines in bunched beam spectra

$\Delta f_{\|}^{0} = \Delta f_{random}$ Central line width in longitudinal

$\Delta f_{\|} = \Delta f_{\|}^{0} + \mu \Delta f_s$ μ^{th} satellite line width in longitudinal

$\Delta f_s =$ spread of synchrotron frequency due to non-linear synchrotron oscillations (dependent on fraction RF bucket is filled by beam)

$\Delta f_{\perp}^{0} = \Delta f_{\|}^{0} + f_0 \Delta Q_0$ Central line width in Transverse

ΔQ_0 is due to non-linear betatron oscillations, beam-beam tune spread.

$\Delta f_{\perp} = \Delta f_{\perp}^{0} + \mu \Delta f_s$

Table 5: Factors Affecting "Usefulness" of Schottky Spectra

Input signal-to-noise ratio high enough to observe signals in a "reasonable" time.

Frequencies low enough that bands don't overlap.

Frequencies high enough that at least one satellite line observed.

Ability to resolve at least the central satellite lines.

Ability to determine band center.

Ability to determine overall bandwidth.

Ability to detect both longitudinal and transverse signals.

Freedom from coherent signals to avoid

a) spectral contaminants

b) detector damage

Ability to read total incoherent power to determine N and $N\sigma_{\perp}^2$.

Reasonable data acquisition time/hardware

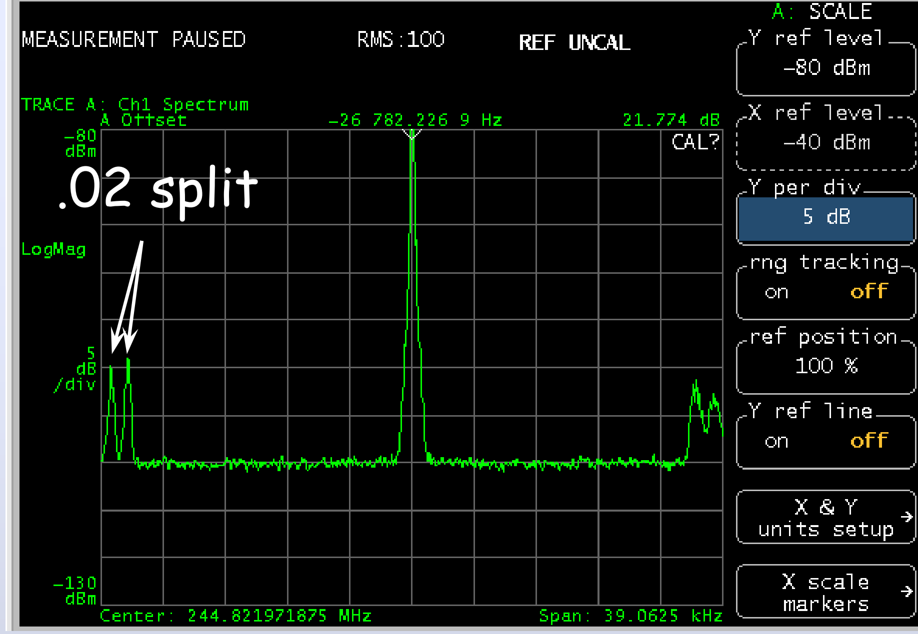
Response either directional or rapid enough to permit separation of p and $\bar{p}$ signals.

Parameters

- Specifications:
  - ✓ $Q_{meas.} \pm 0.001$ at Store
  - ✓ $\xi \pm 1$ at Store
- Basic parameters
  - ✓ f_{rev}= 78.13 - 78.196 kHz (protons)
  - ✓ η = 0.00182 at γ = 106.5
  - ✓ dp/p ~ 0.001 (w/o 200 MHz)

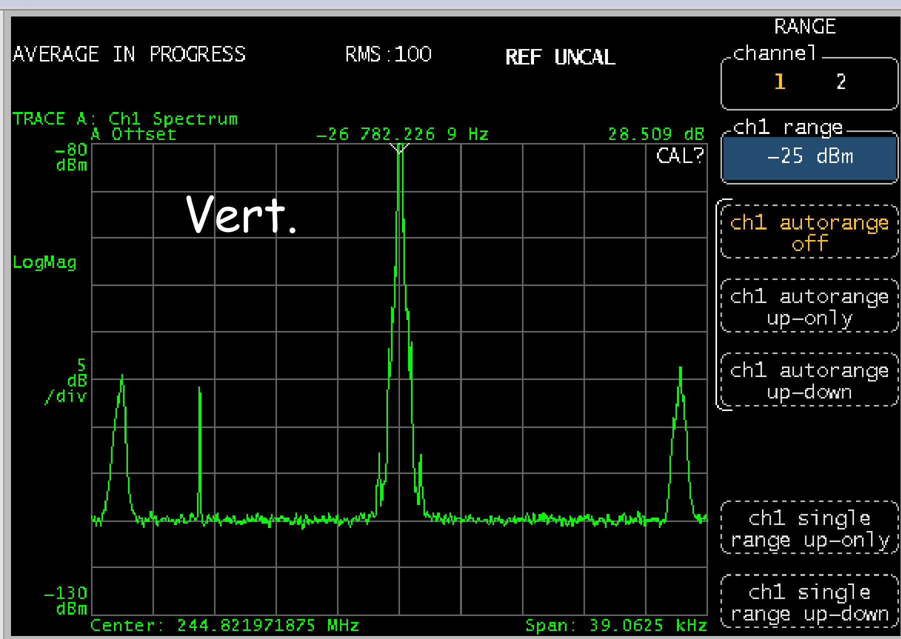
Parameter	LF system	HF system
Freq.	245 MHz	2.07 GHz
n	3133	26473
Line Widths	~440 Hz	~3700 Hz

LF Schottky linewidth - Ions at store after rebucketing, pickup well centered



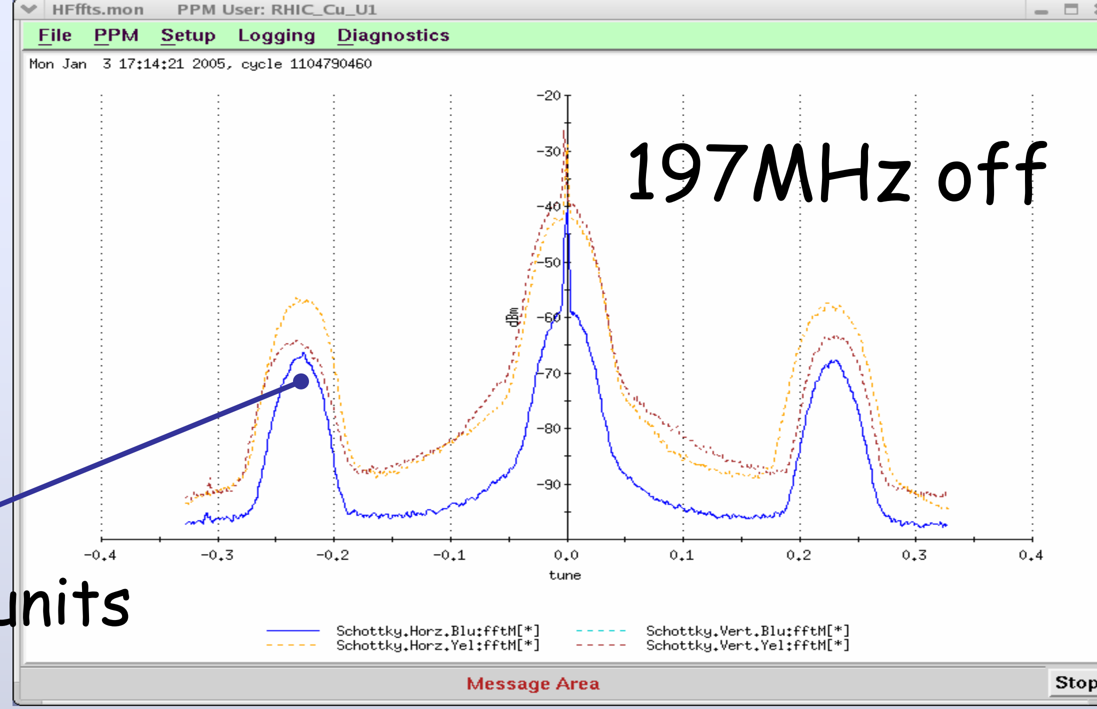
large coupling,
chormaticity large

no coupling,
chormaticity small

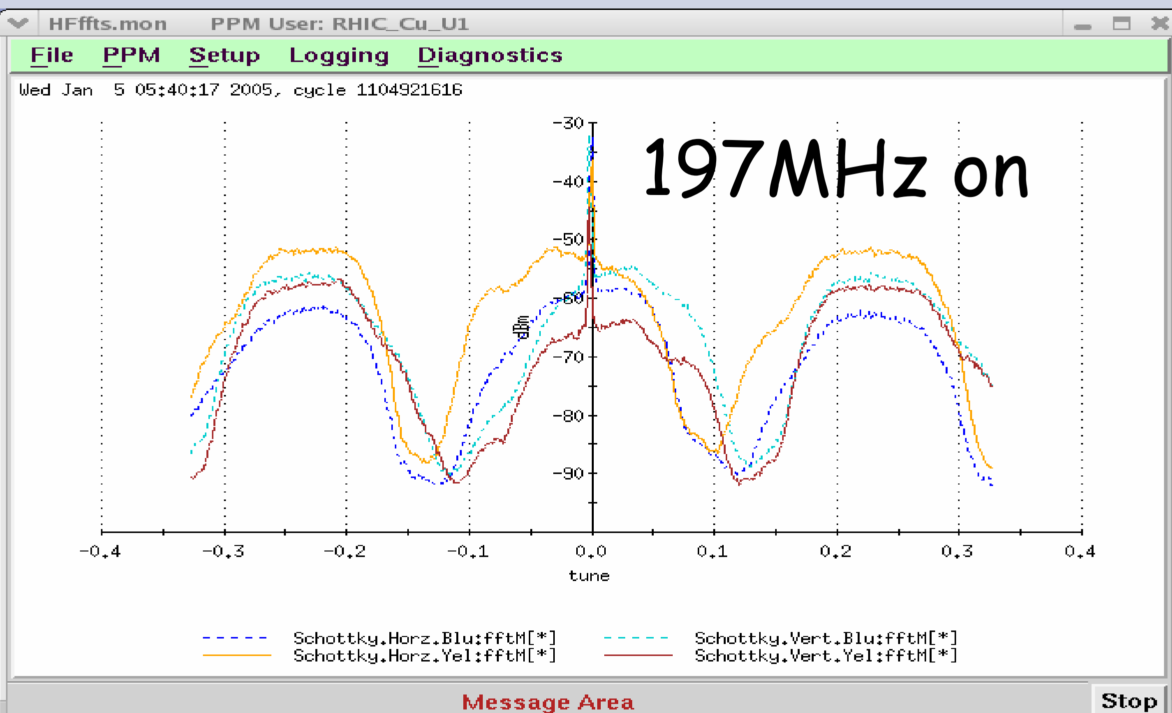


3dB width
~ 800Hz
~ .01 tune units
need .001 measurement
coupling is dangerous!

HF Schottky linewidth - Ions at store

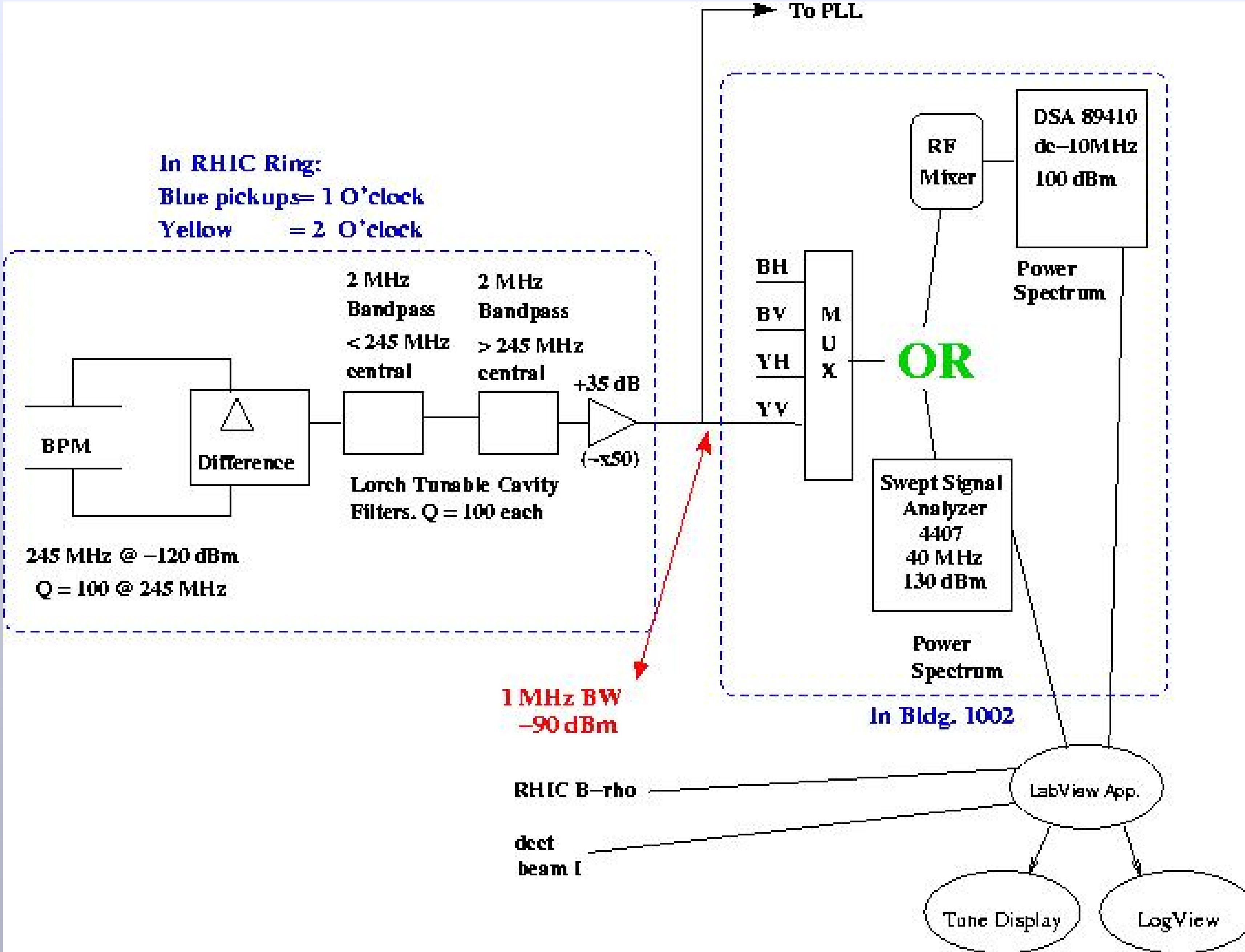


3dB width
~ 3KHz
~ .04 tune units



3dB width
~ 6KHz
~ .08 tune units
asymmetric
rev line ???

“New” Low Frequency Schottky System



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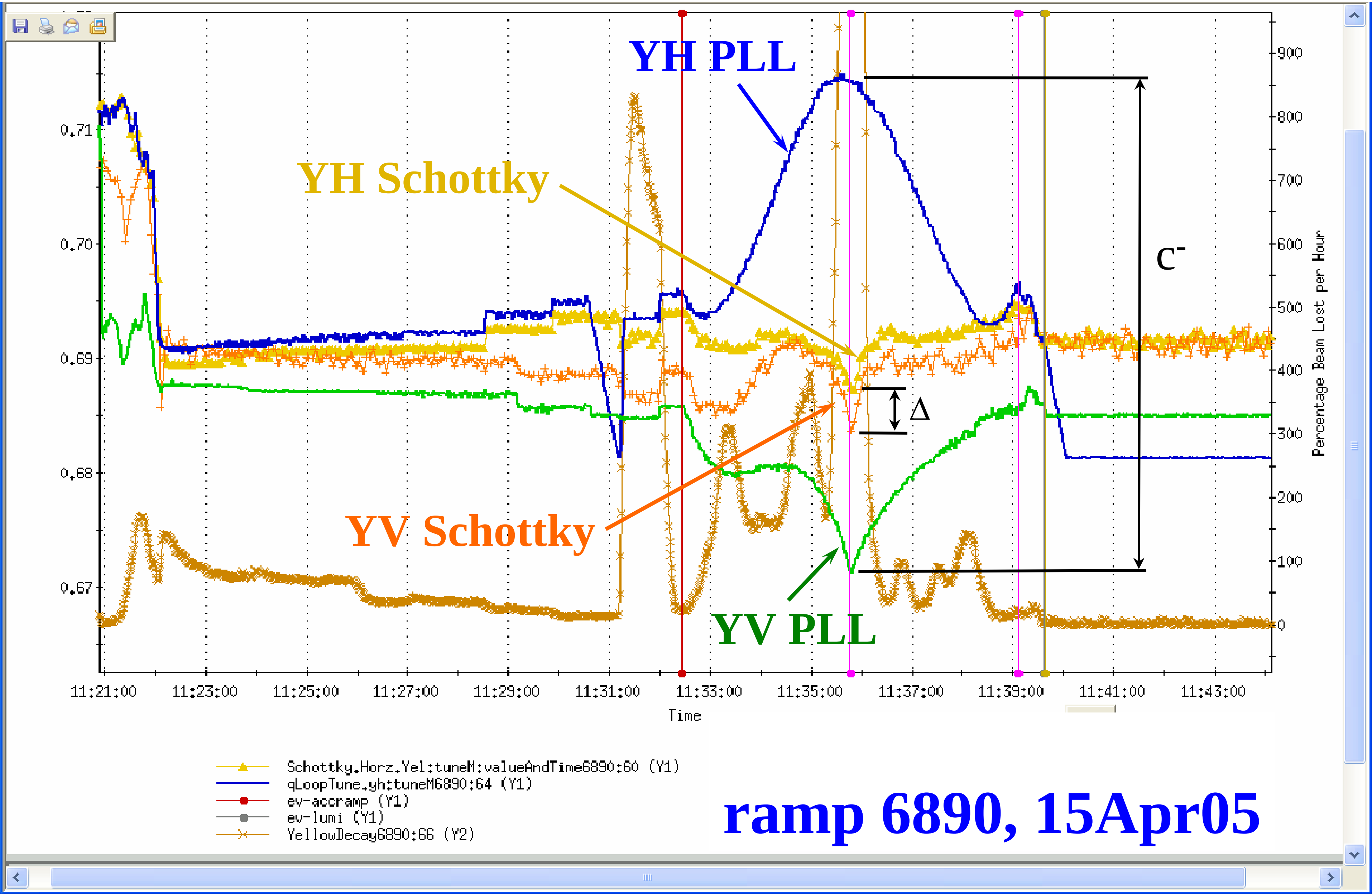
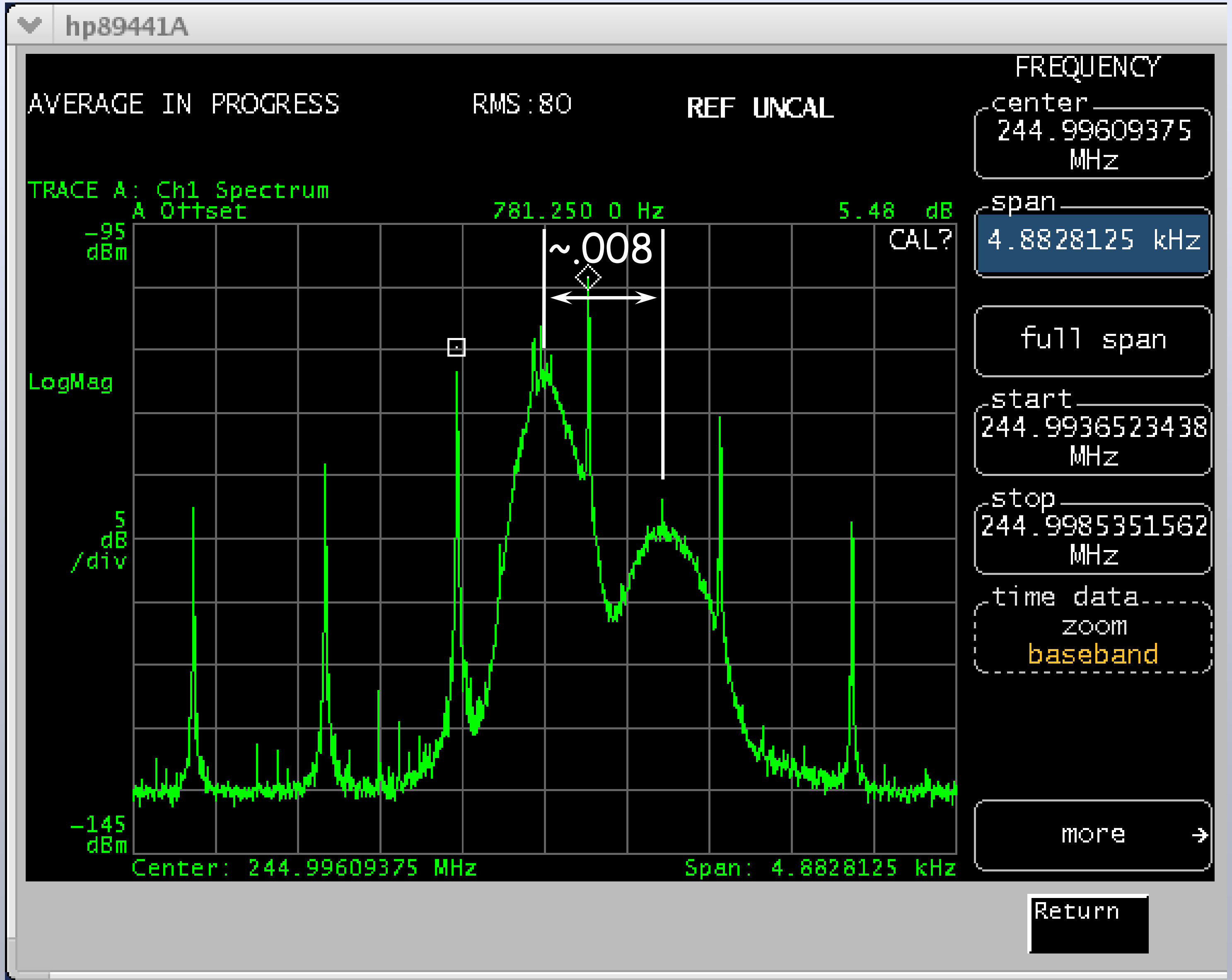
'set' tunes (as measured by Schottky) vs eigentunes (PLL) in the presence of coupling from rotator ramp



ramp 6890, 15Apr05

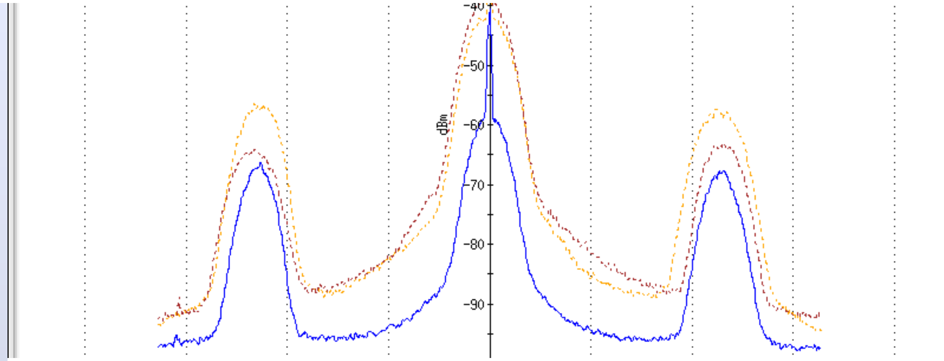
Injection Coupling and Coherent lines from the IPM



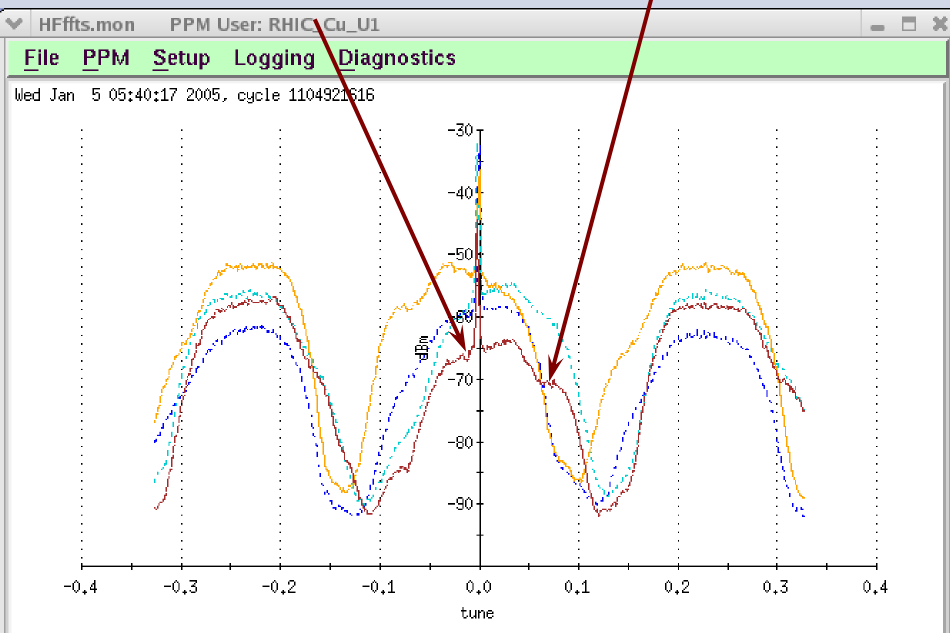
Spectral effects of beam out of bucket, beam offset plus dispersion (transverse mode)

asymmetric rev line (due to beam offset plus dispersion?)

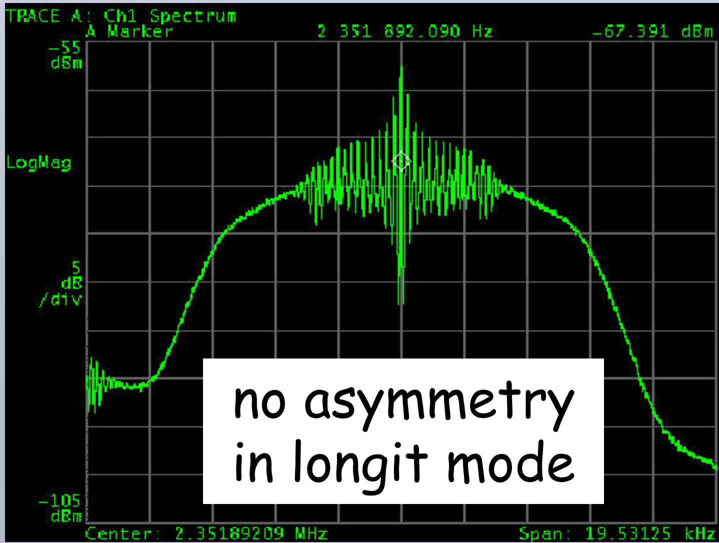
beam out of bucket



197 MHz off

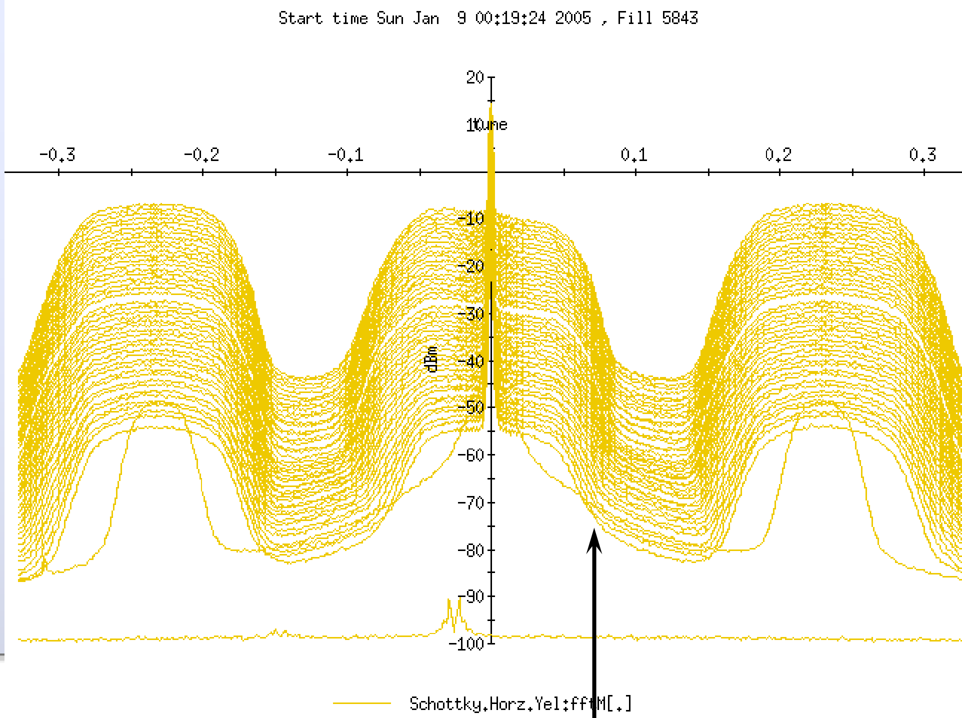


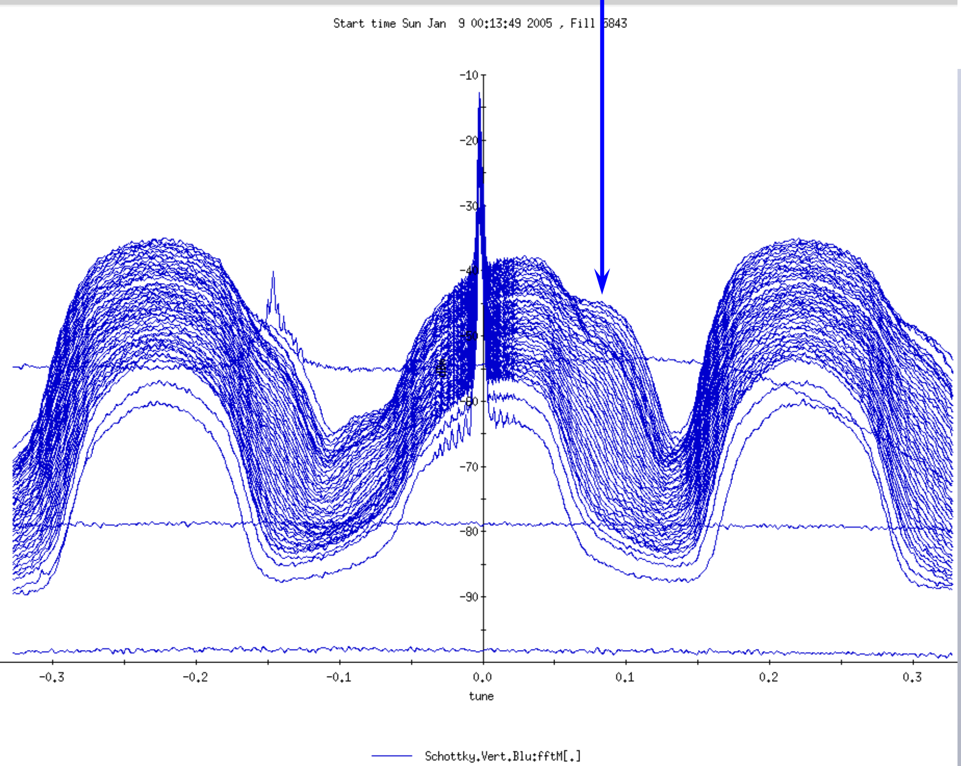
197 MHz on



Beam out of bucket - Jan 9th

out of bucket beam survives in blue

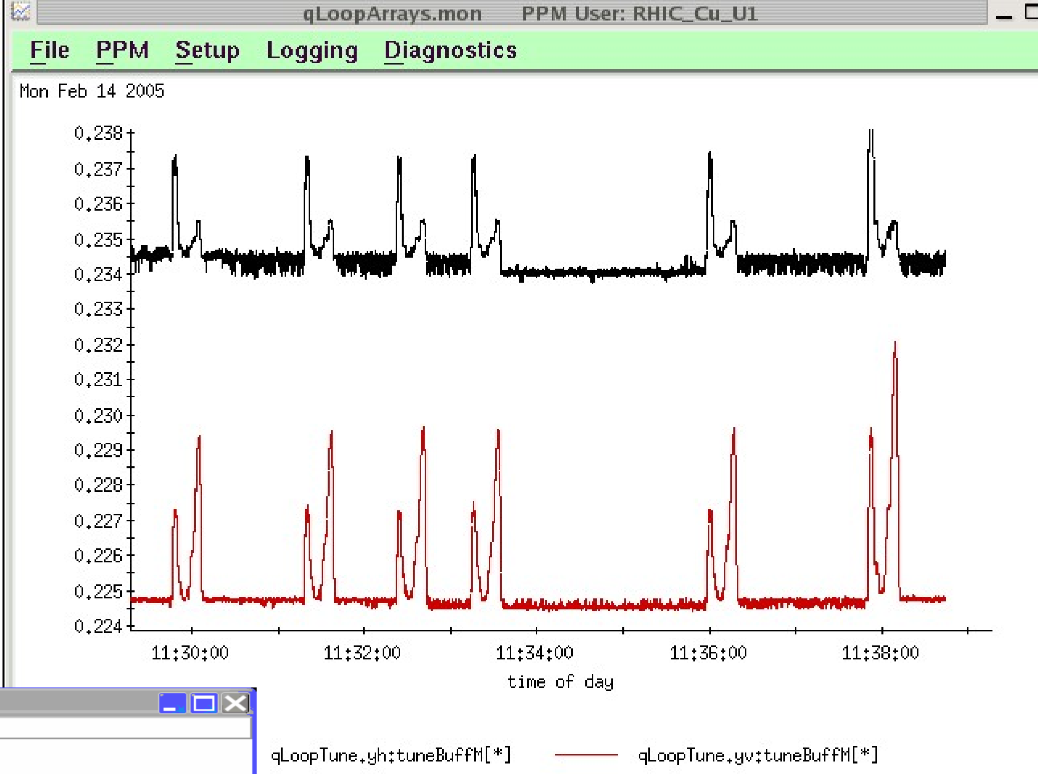




not so in yellow

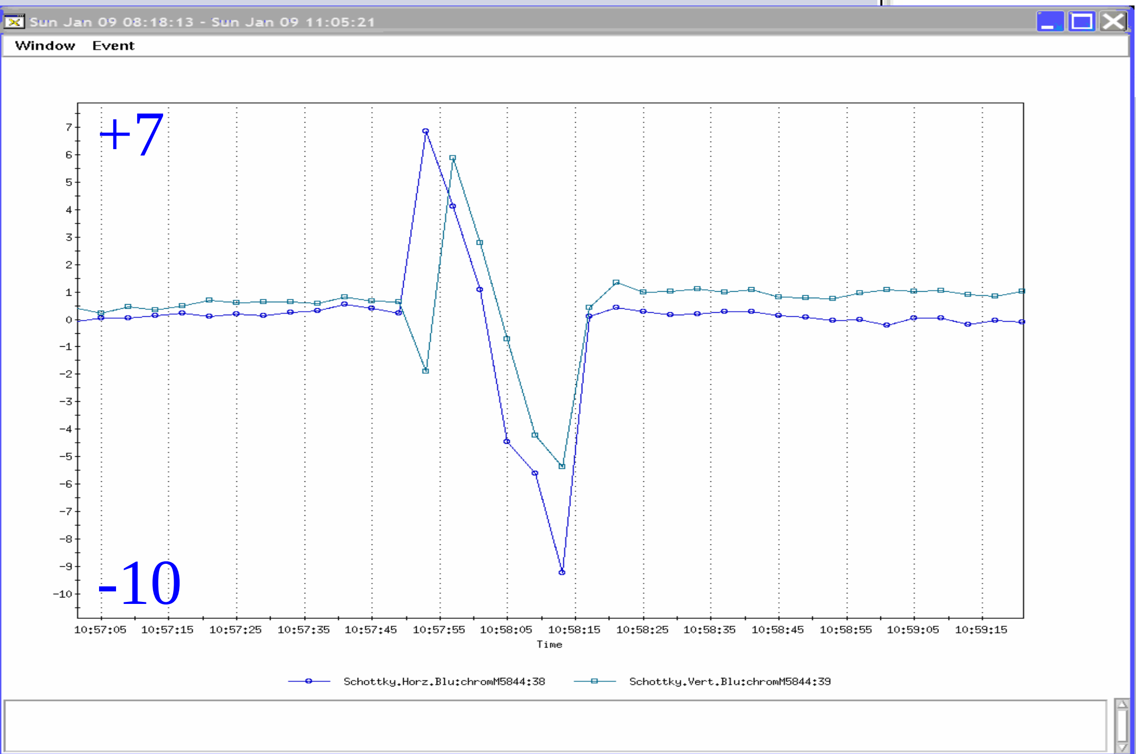
momentum aperture larger in blue?
RF bucket (lineshape) different in yellow?

non-lin chrom at store



PLL tune measurement during radial shift

chrom measurement



HF Schottky chrom measurement during radial shift.

If chrom were linear this would be flat.

Big effect.

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Experiments

- Lots of parasitic "getting familiar" with signals (LF mostly, and HF).
- Comparisons of Schottky (HF/LF) tunes and tune spreads to PLL and Artus measurements.
- Understanding emittance measurements - absolute emittance calibration from rev line
- non-lin chrom measurement from Schottky
- Tune ripple measurements
- Coupling measurements (how well are coupling lines resolved?)
- Synchrotron radiation measurement?
- Understanding tune spread measurements
- Beam-beam effects? Gap-cleaning effects?

Conclusions

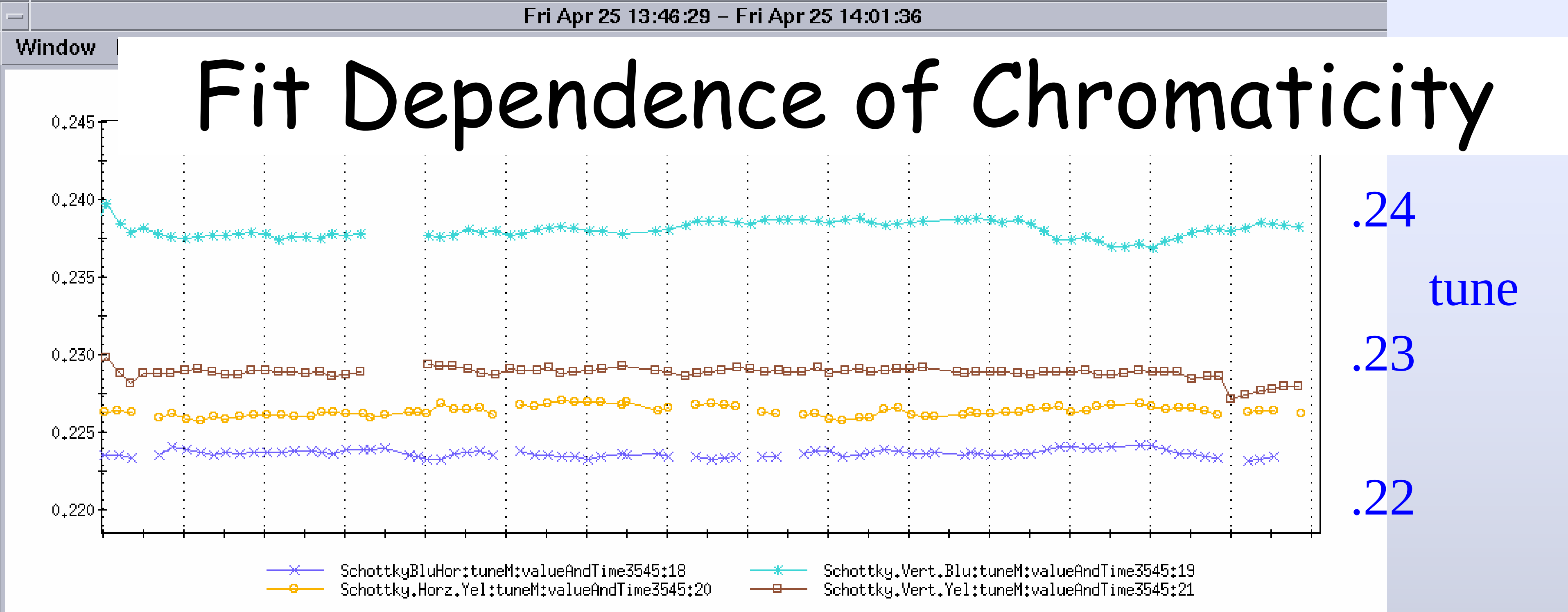
- MOST THINGS you want to know about the beam are available (without perturbation!) in the Schottky spectrum, if you can figure out how to get it out.
- New LF Schottky system needs commissioning time.
- A significant amount of the "experiments" time needs to be used to develop confidence in the improved Schottky data
- To ensure Schottky data is not "corrupted" by other coherent phenomena, coordination is needed. (with Gap cleaning, IPM, Stochastic cooling, …)
- To get a first pass at setup and calibrations we need a few hours at the beginning of the run (dedicated "quiet" operations time).

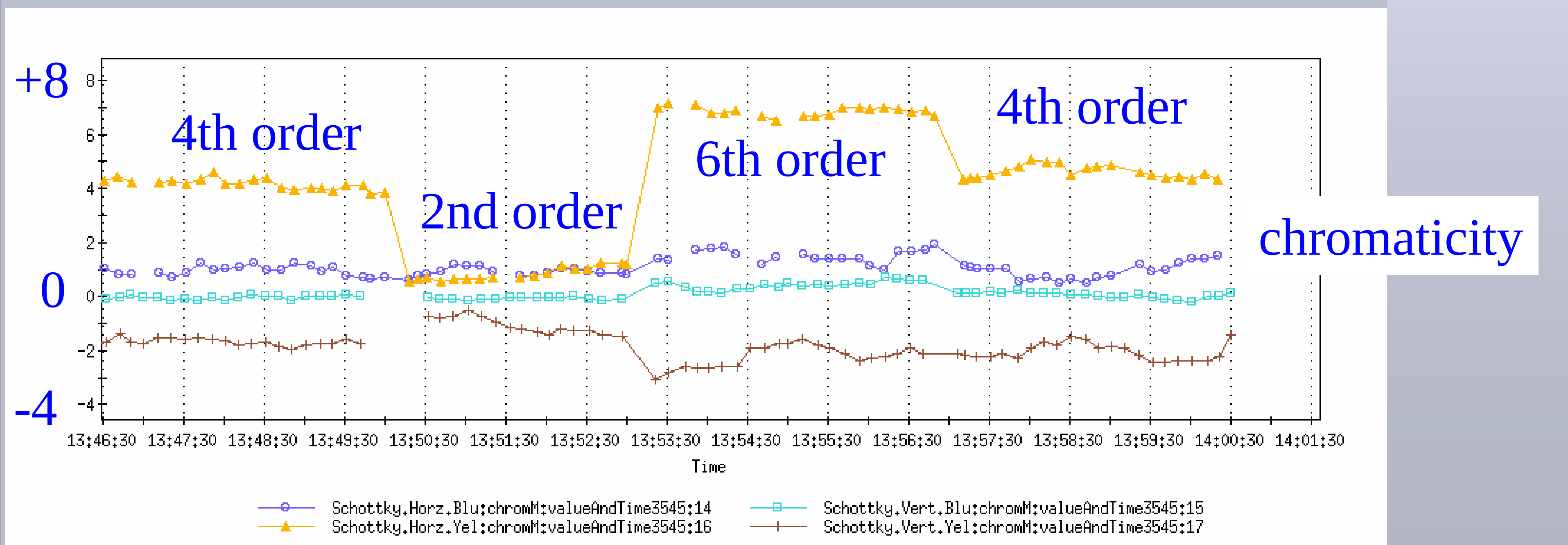
Backup, Reference material,,,,

Standard References

- D. Boussard lectures: http://preprints.cern.ch/cernrep/1987/1987-003_v2/1987-003_v2.html
- R.Siemann USPAS lectures: (1992S) Topics in Experimental Accelerator Physics
- W. Mackay USPAC lectures: (2005S) Accelerator Physics Supplementary Notes
- D.A.Goldberg & G.R. Lambertson: Schottky Monitors for the Tevatron Collider, LBL internal tech. note no. BECON-61, LBID-1129

Fit Dependence of Chromaticity

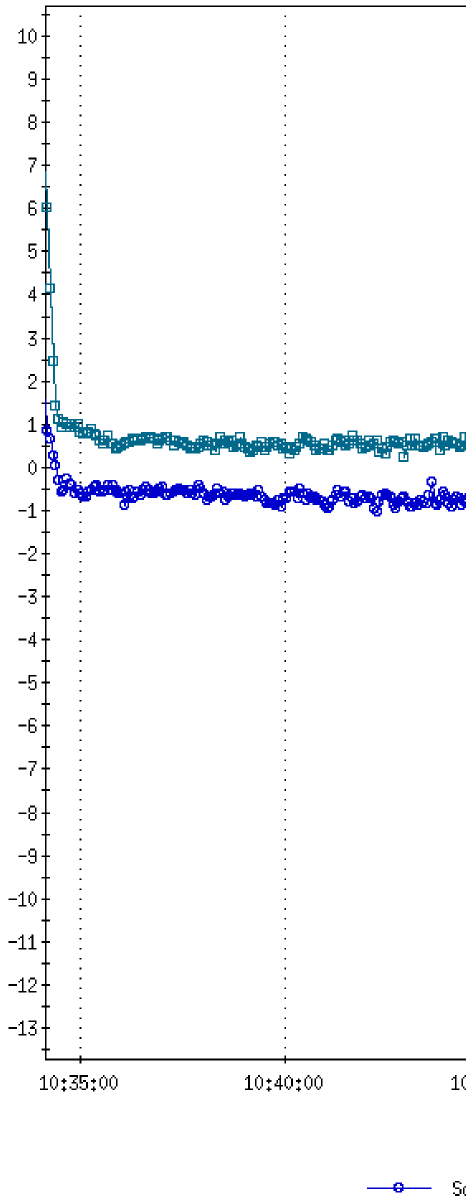


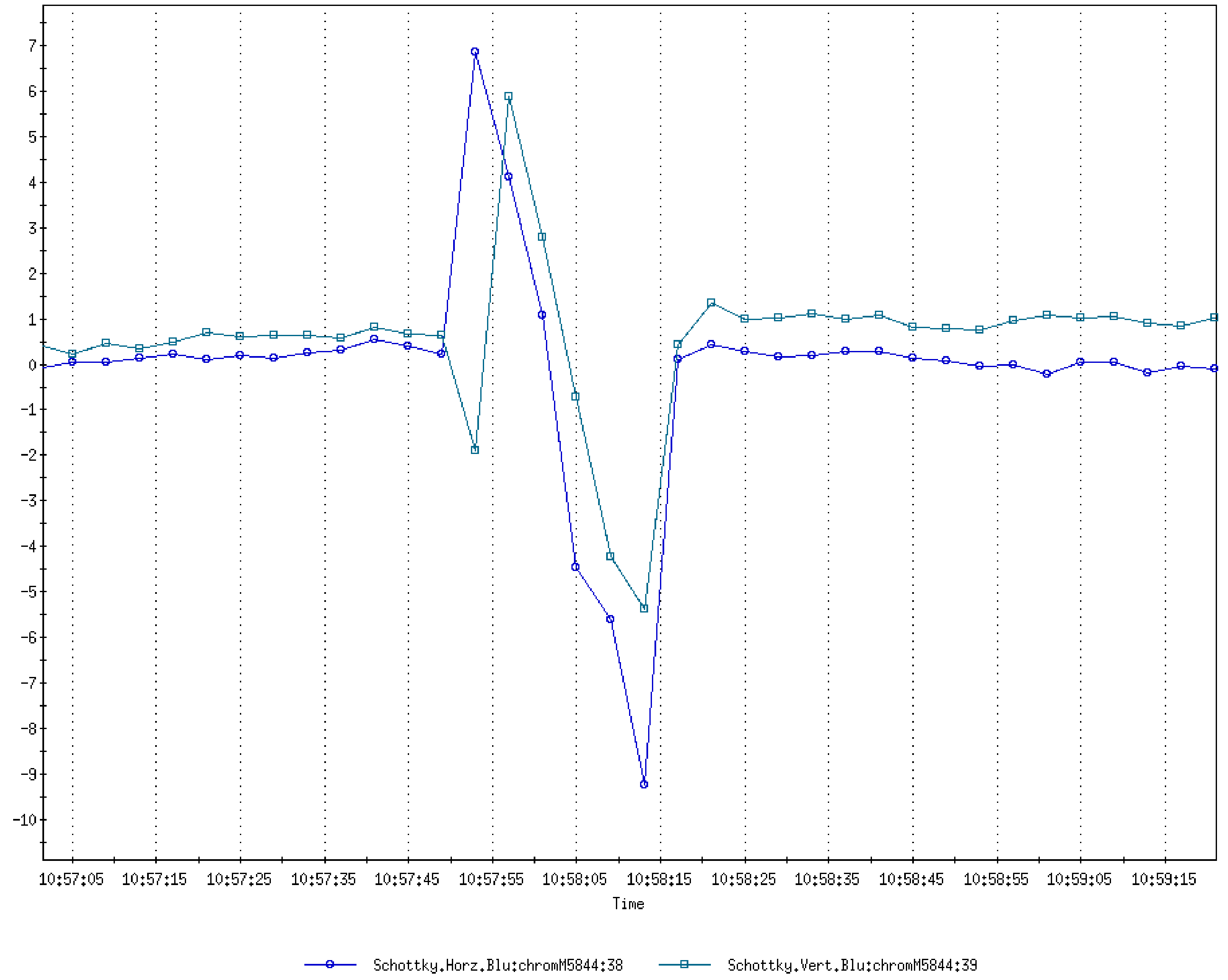


Improvement to chromaticity calculation

- adjust pickup position so that rev line asymmetry is removed
- remove rev line coherence by successive iteration fitting
  - this gives incoherent rev line shape, uncontaminated by any transverse effects!
- scale rev line so 3dB power is same as betatron power
- subtract betatron line from rev line
- do polynomial fit to this difference
- coefficients are 1st, 2nd, 3rd,... order chroms (?)
- this ignores other effects (beam out of bucket,...)

Non-linear Chromaticity





Emittance Calibration

- adjust pickup position so that asymmetry is removed
- sweep pickup position around this null to get a series of spectra from which power vs position data can be extracted
- remove rev line coherence from these spectra by successive iteration fitting
- comparison of power in betatron line with position dependence of power in rev line gives absolute (albeit dependent on assumptions of lineshape) calibration of emittance