# Tune and Chromaticity Tracking in the Tevatron

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# Overview

- What is the Tevatron tune tracker?
- Selected results from some stores. (There are many stores with TT running).
- Planned chromaticity tracker.

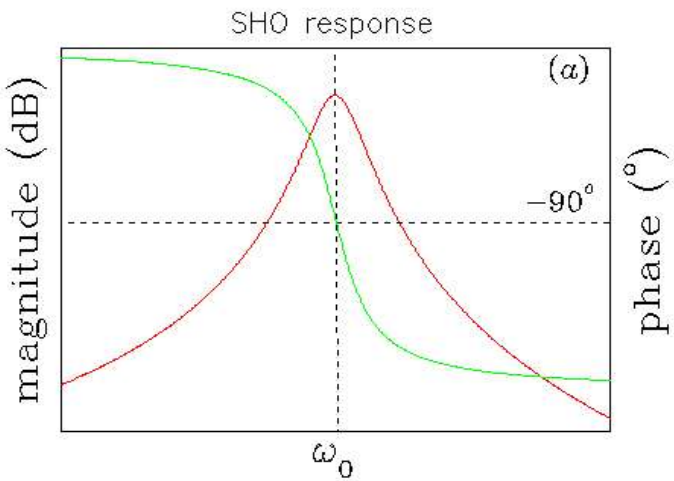
# Tune Tracker

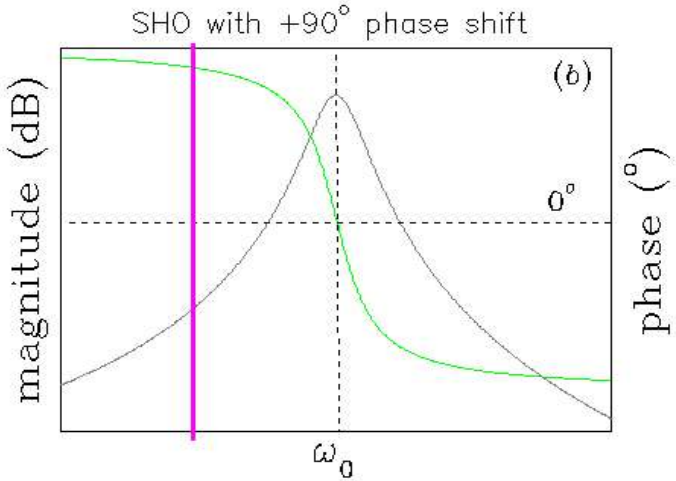
- There are at least two ways to track the tune
  - Tune fitting which is available for 21.4MHz and 1.7 Ghz Schottky. Slow (~1 Hz)
  - Actively exciting the beam and tracking the zero phase response of the beam. This is the PLL method. Fast (100 Khz limited by ethernet bw)

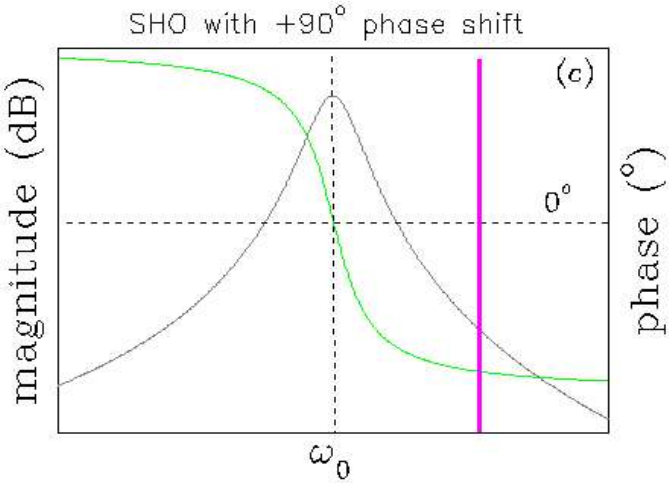
# Tune Tracker Principle (Thought Experiment)

- Young Fermi wants to find the peak a pendulum resonance (SHO).
- He is armed with
  - Sine wave generator to excite the pendulum
  - Phase detector
    - Detect phase of pendulum w.r.t. phase of sine wave

# How to find the peak from phase



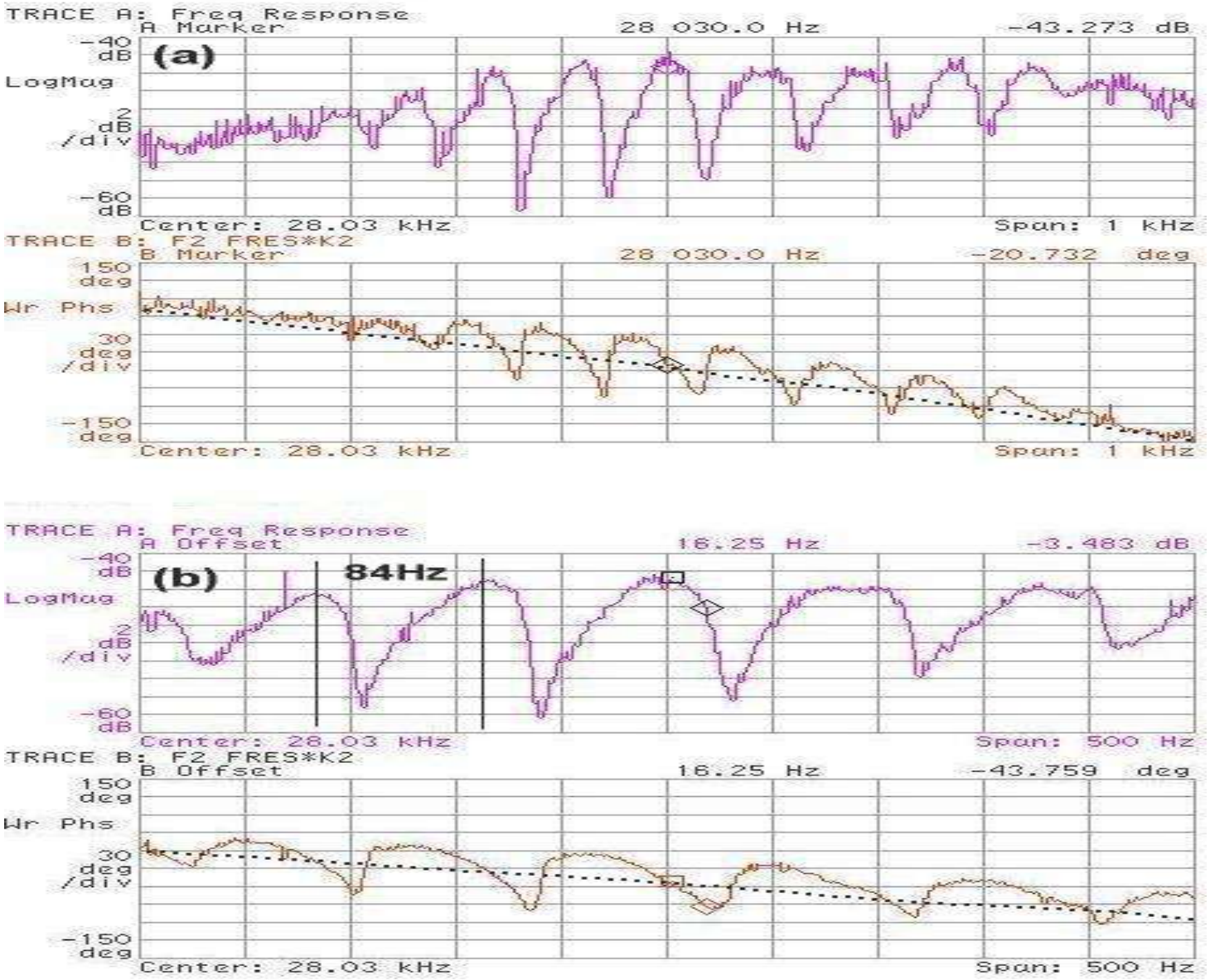



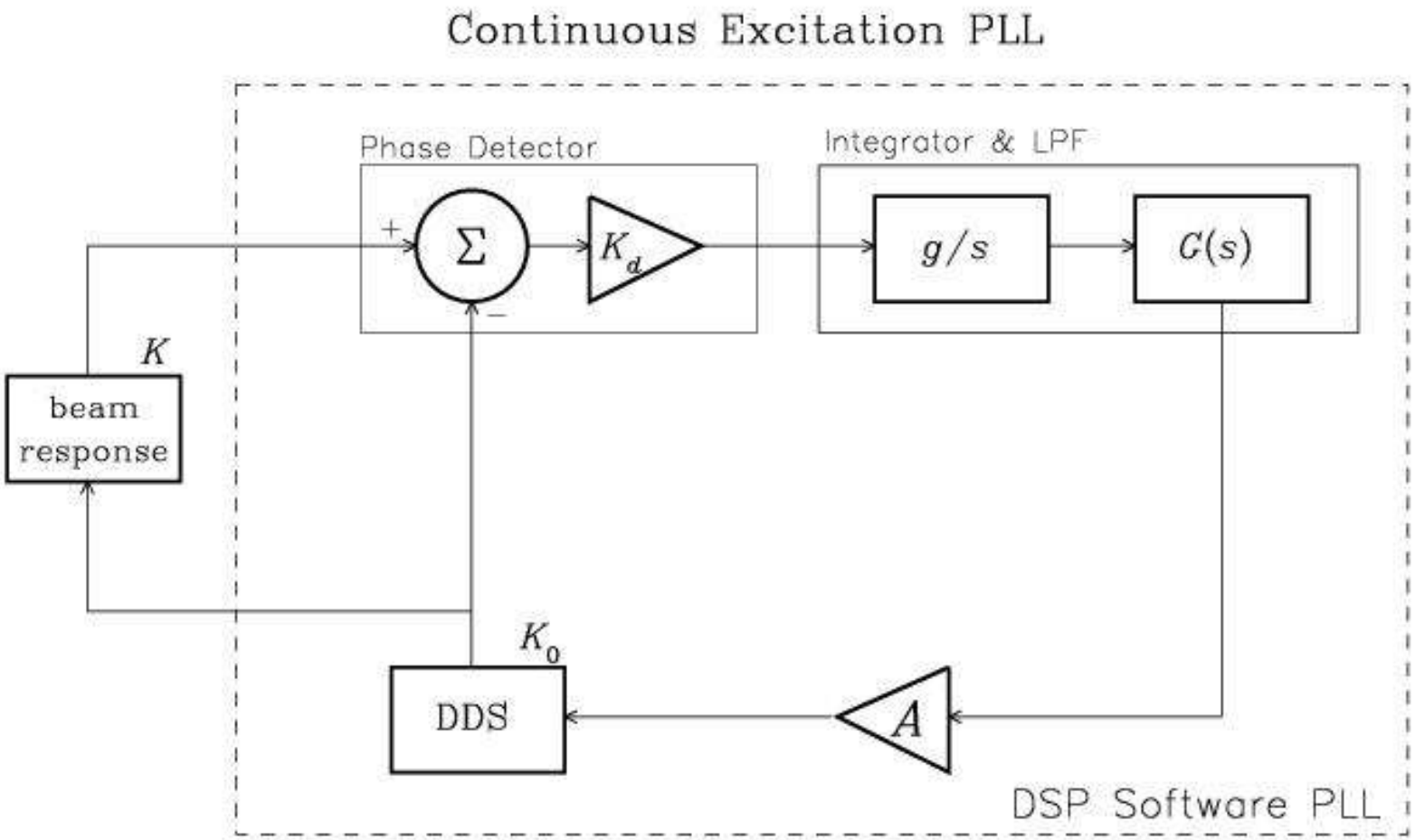
# What I need

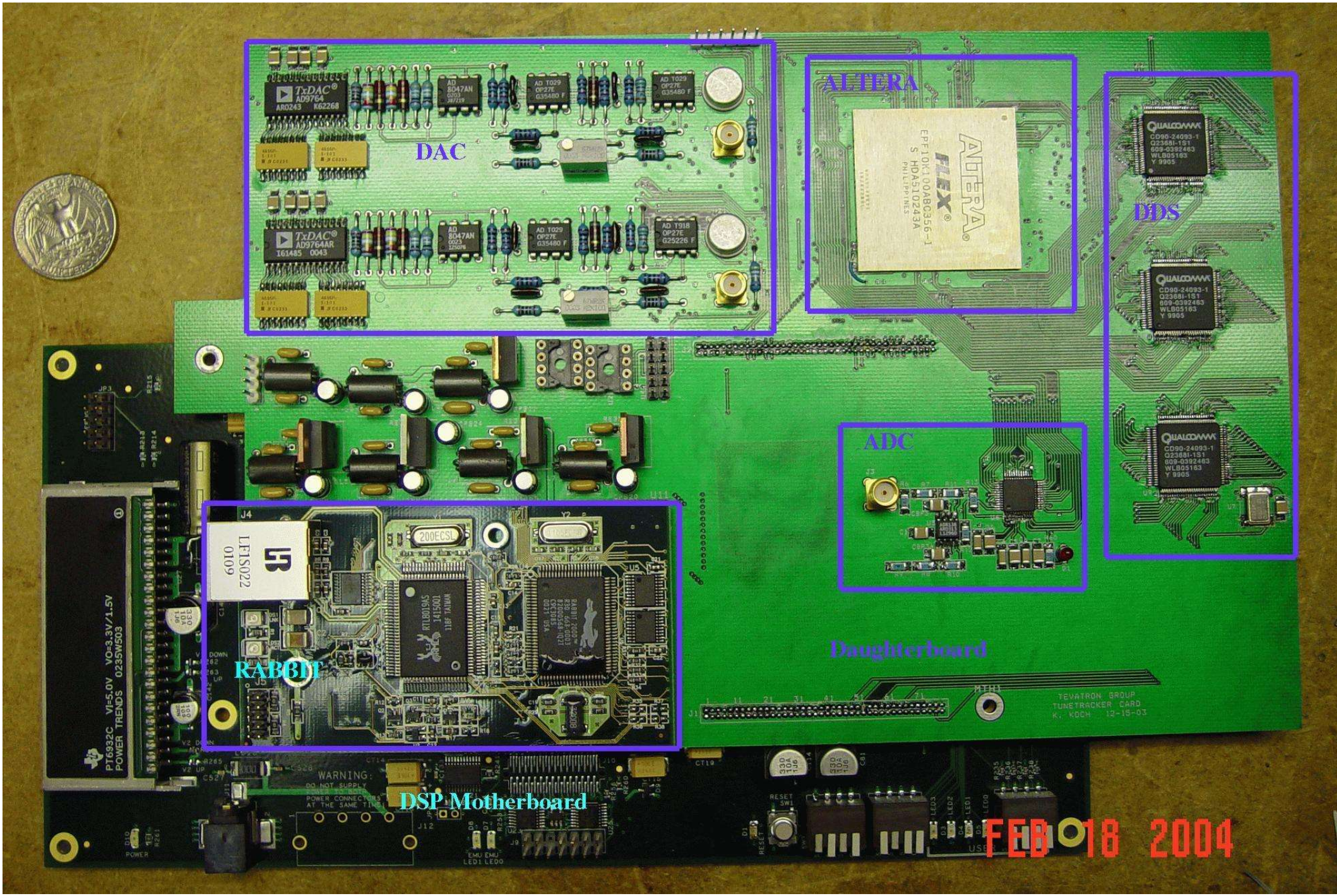
- A detector
  - 21. 4MHz Schottky at A1
- A kicker
  - 1 foot long stripline BPMs converted to kickers at A1
- Can I measure a frequency response?

# Can we measure a frequency response?



# In Principle

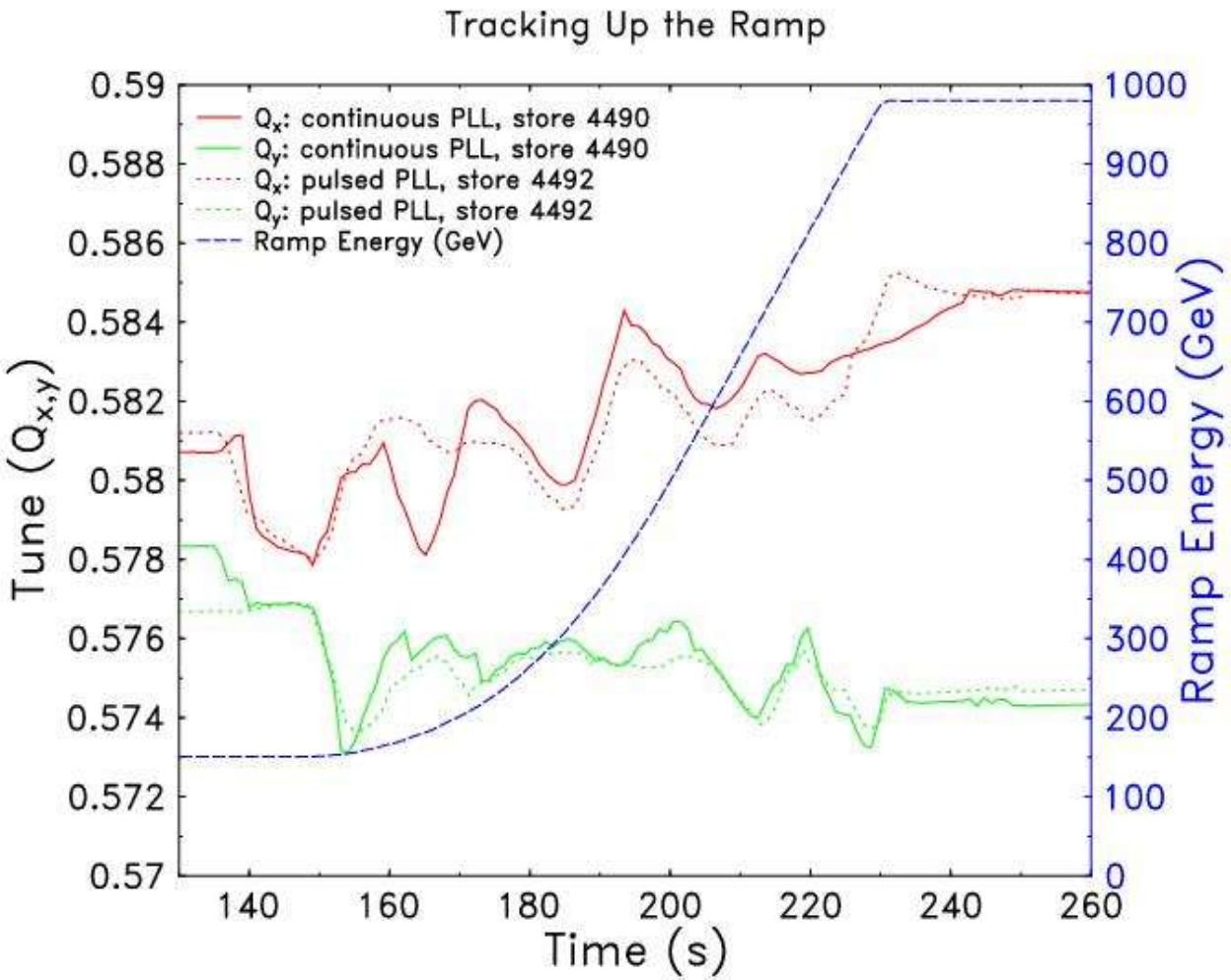



DAC
ALTERA
DDS
ADC
Daughterboard
RABBIT
DSP Motherboard
FEB 18 2004

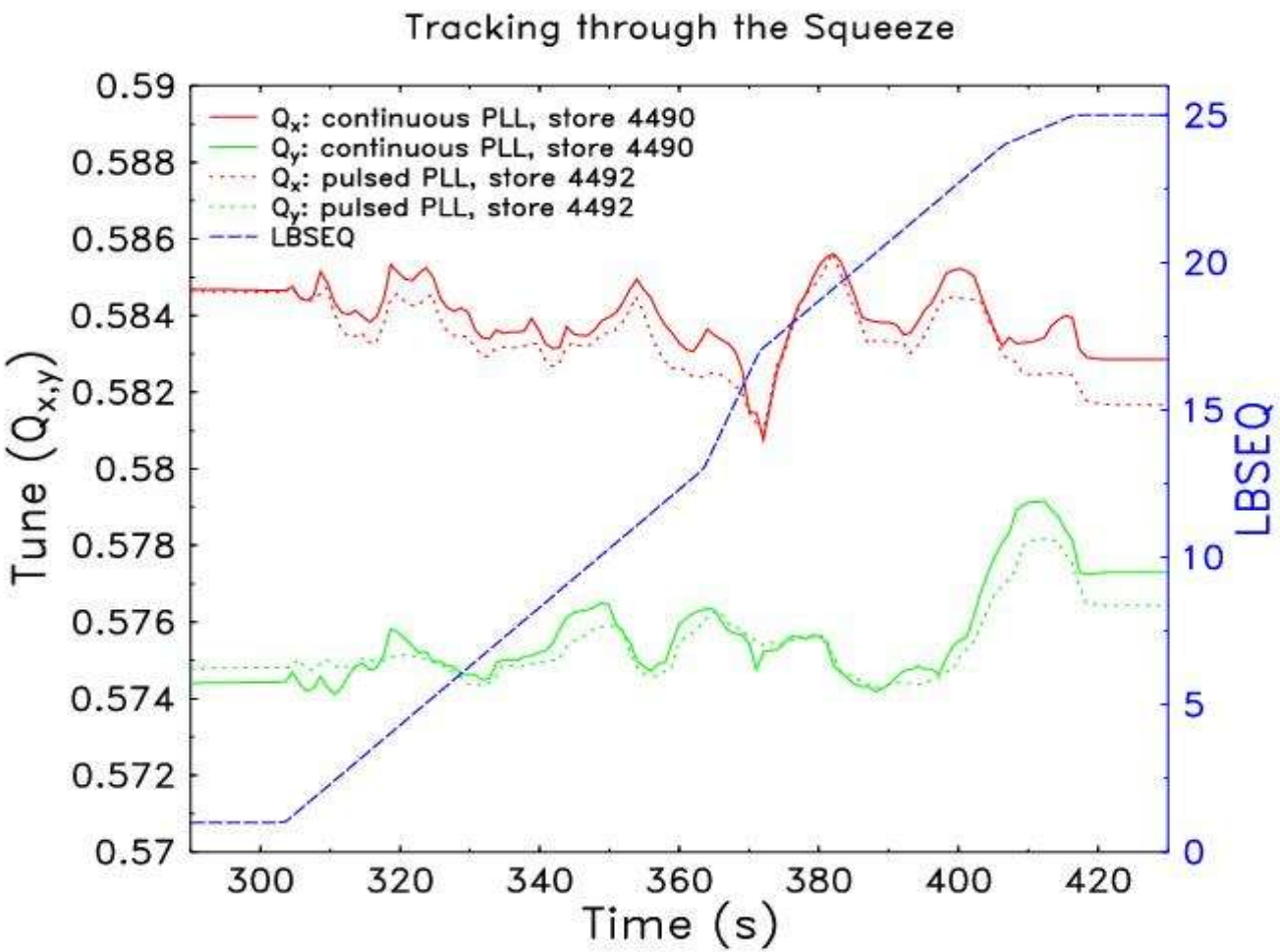
# Tune Tracker Status

- Tune Tracker (TT) at Tevatron declared commissioned on 13 Sep 2005 with first successful tracking of both horz and vert tunes in store 4386.
- As of this date, TT has been on for all stores.
  - The data that has been collected was extremely useful for analysis when things went wrong. E.g. Skew quads not ramping, separator polarity did not switch.

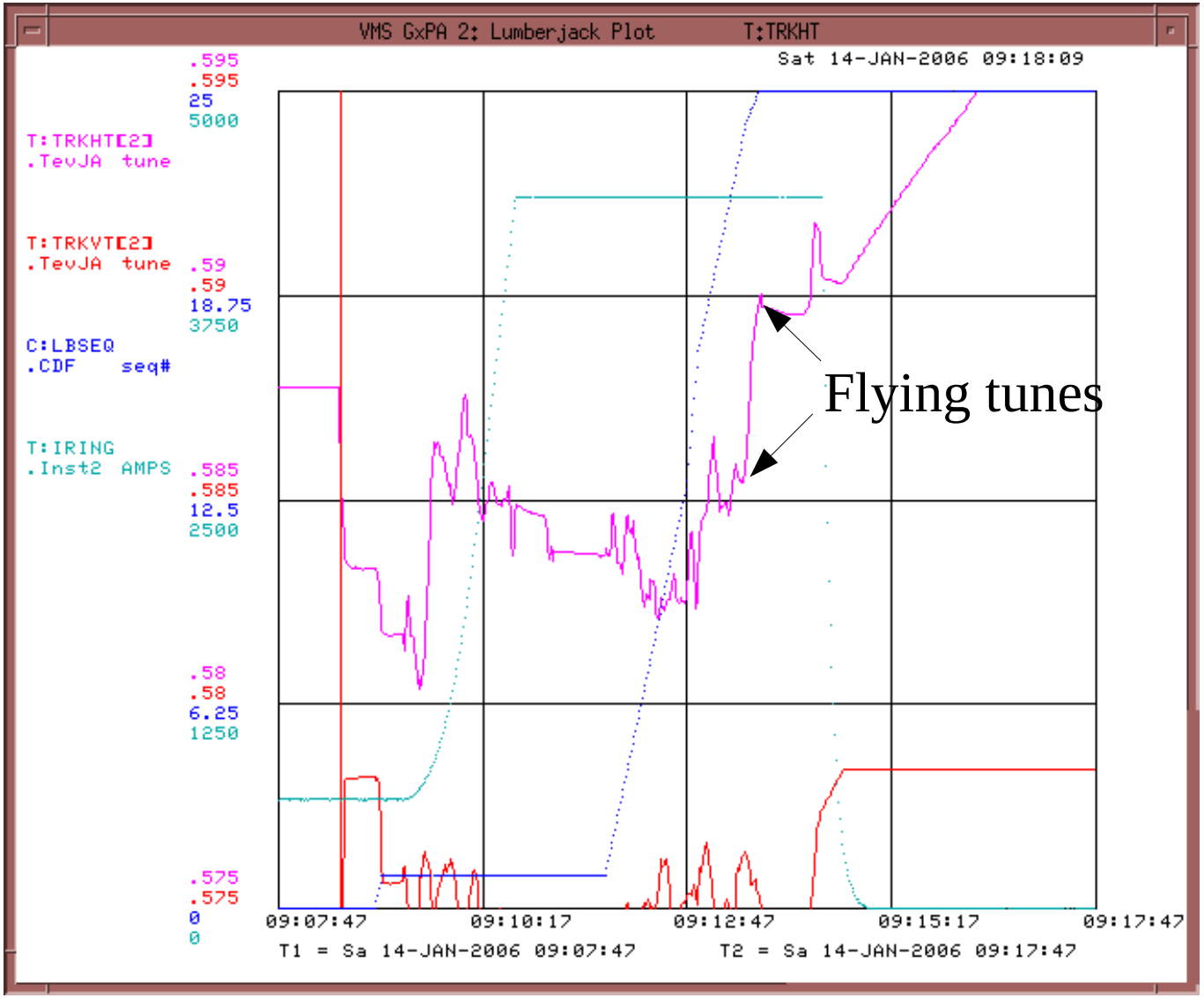
# Normal Store



# Thru' the squeeze



# When Skew Quads Don't Turn On



# Tune Tracker Performance

- TT has performed very well over the past 5-6 months.
  - Very little human intervention. It just works!
- No retuning required even after 2 unscheduled shutdowns of approximately 1 week each.
- However, the beam frequency response changed suddenly in the first week of Feb. Cause is still unknown. Also noticed phase drift over a few weeks.

# Plans

- No tune feedback plans.
  - RHIC has successfully done “feedback” but not during stores.
  - Important for LHC!
- TT will be used as the basis for the chromaticity tracker (CT) using the McGinnis method.
  - LHC evaluating different ways to do chromaticity tracking. SPS experiment planned.

# The McGinnis Method

- Classical method: measures change in RF frequency (i.e. $\Delta p/p$) to betatron frequency change.
- $$\Delta Q = -\frac{C}{\eta}\frac{\Delta f}{f}$$
- McGinnis method: Phase modulate the RF frequency. This couples to transverse plane because of chromaticity.
  - Novelty: Phase demodulate the betatron frequency to obtain chromaticity

# The McGinnis Method (cont'd)

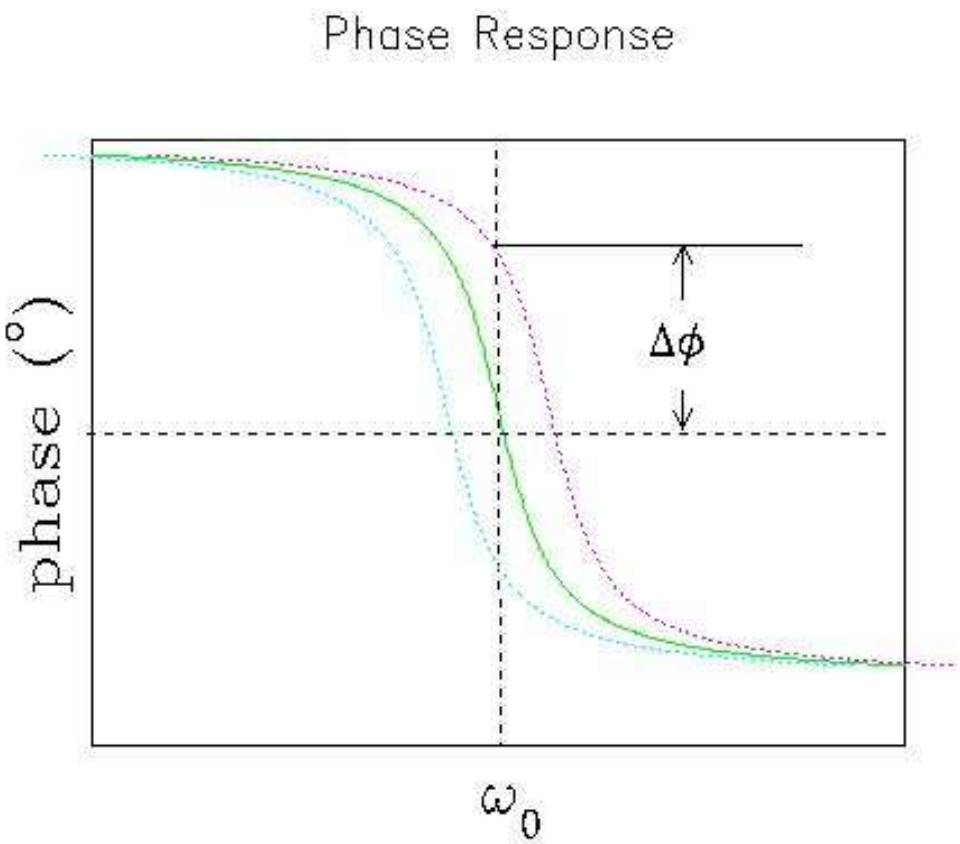
- The McGinnis formula for calculating chromaticity when using the VSA as a phase demodulator:
- $$\chi = \eta \left| \frac{\sqrt{2}|Z|h}{\Delta\phi_{mod}} - (k - Q_0) \right|$$
-

| | | | | | |
|---|---|---|---|---|---|
| $\chi$ | = | chromaticity | $h$ | = | harmonic number |
| $\eta$ | = | slip factor | $k$ | = | revolution harmonic |
| $Z$ | = | demod. height in radrms | $Q_0$ | = | fractional betatron tune |
| $\Delta\phi_{mod}$ | = | size of modulation | | | |

# McGinnis Method (cont'd)

- McGinnis method requires that:
  - RF be phase modulated.
  - TT supplies the carrier frequency (i.e. Betatron tune) for phase demodulation.
  - Phase demodulated height is related to the chromaticity.

# Why we need the TT




TT will lock at $\omega_0$. If modulation is outside the bw of the TT, it will not follow the modulation and thus, $\Delta\phi$ can be measured w.r.t. the locked frequency.

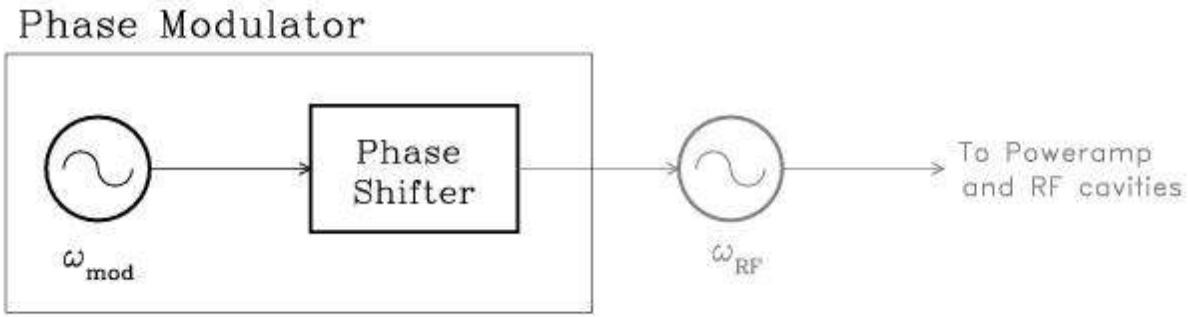
# Requirements

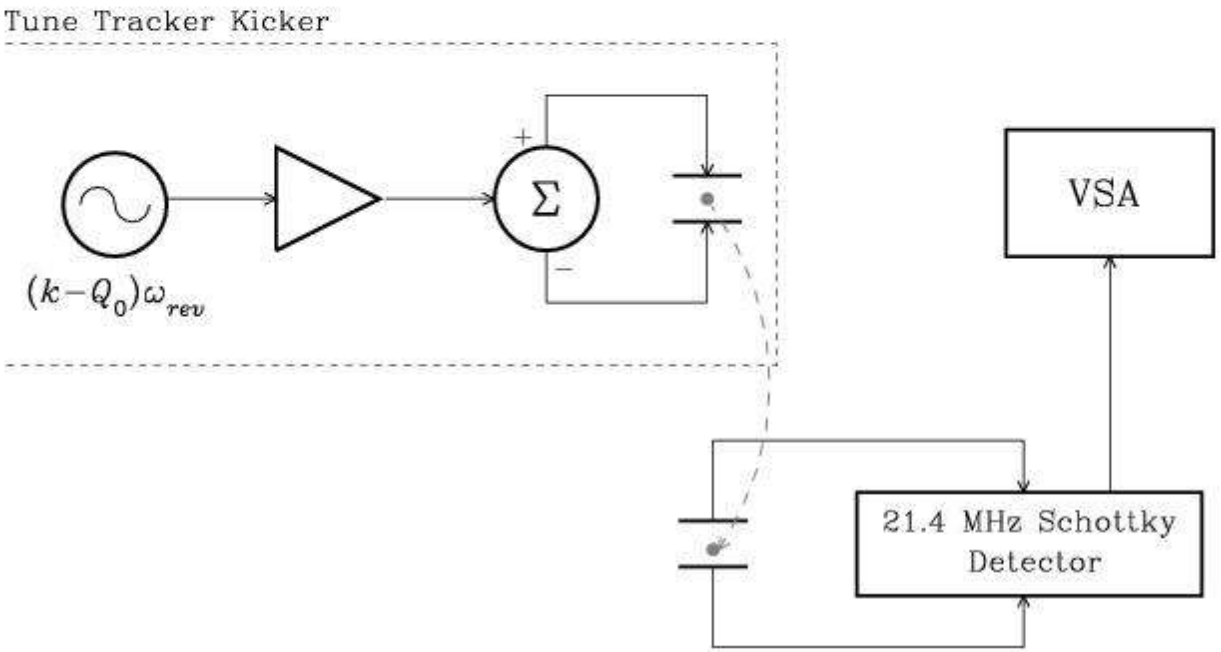
- Modulation frequency must be outside the closed loop bw of the TT. For Tevatron TT, closed loop bw is about 5Hz.
- Modulation frequency must less than ½ the synchrotron frequency to prevent emittance growth. For Tevatron at 150GeV approx 20Hz.
- $\Delta\phi_{\mathrm{mod}}$ is approx. 5 degrees or less to prevent beam loss and tune change < 0.0001. This corresponds to dp/p ~ 1e-5 if chromaticity is 5 to 20 in the Tev.

# Limitations

- If only using VSA to demodulate, can only get magnitude of chromaticity. Cannot get sign without adding more hardware. Coming real soon now ...
- Will not work at transition because $\eta = 0$.
  - Not a problem at Tevatron or LHC.
- Longitudinal dampers which work on coupled bunch mode zero will damp this.
  - Should not be a problem at the Tevatron because current dampers do not work on mode 0.

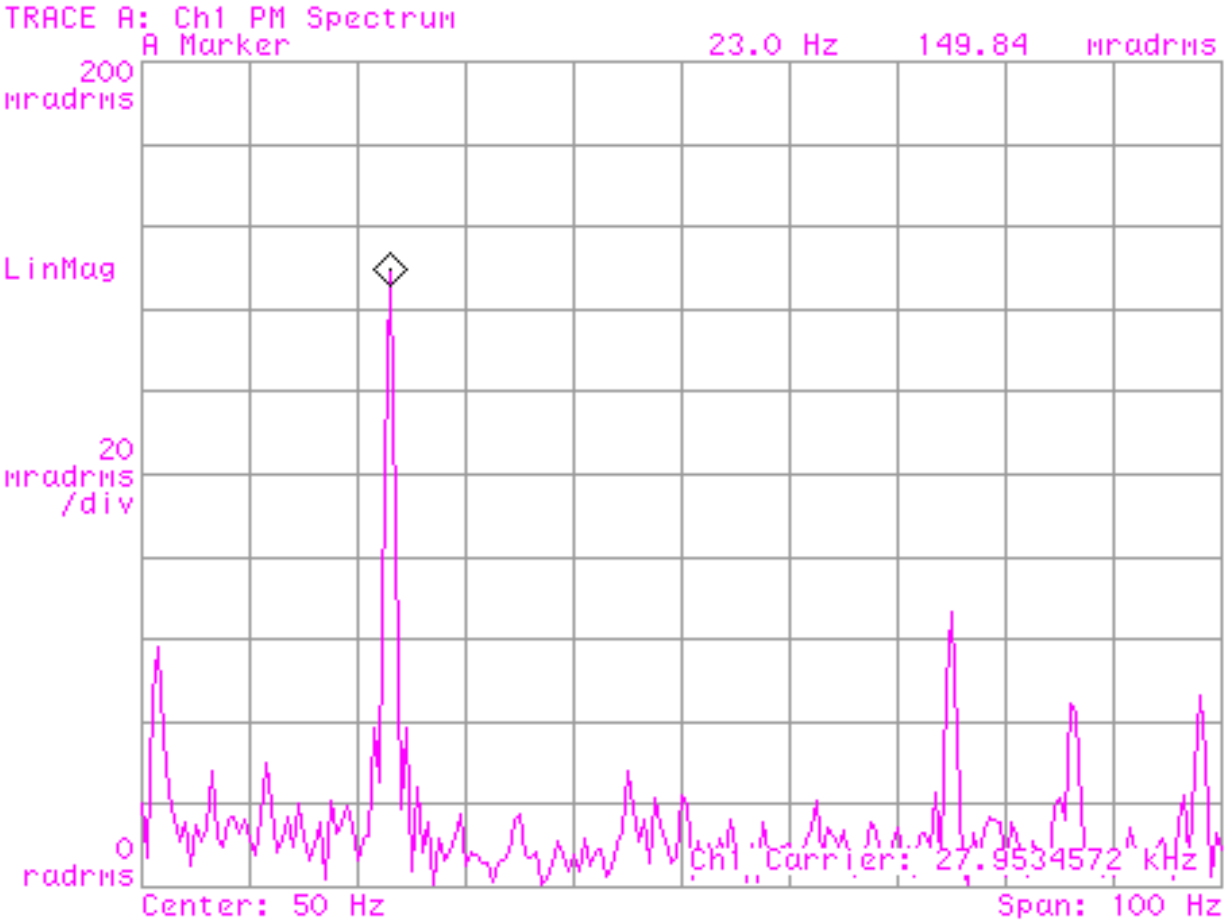
# Set up


Phase Modulator
Phase Shifter
$\omega_{mod}$
$\omega_{RF}$
To Poweramp and RF cavities


Tune Tracker Kicker
$(k-Q_0)\omega_{rev}$
+
−
Σ
VSA
21.4 MHz Schottky Detector

# Demodulated Signal

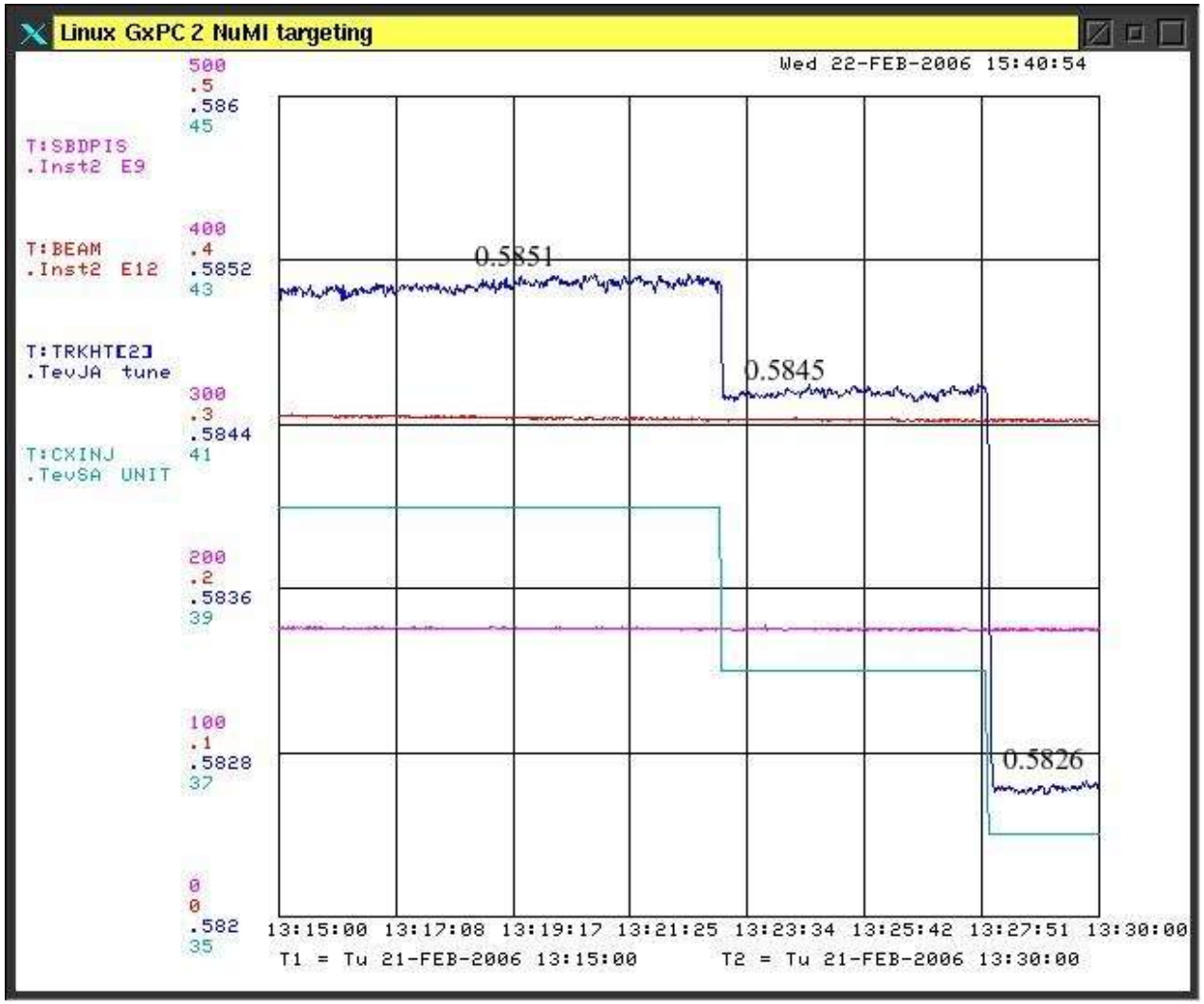
Date: 01-14-06 Time: 03:17 AM




Mod freq = 23Hz

$\Delta\phi_{mod}$ = 10 deg.

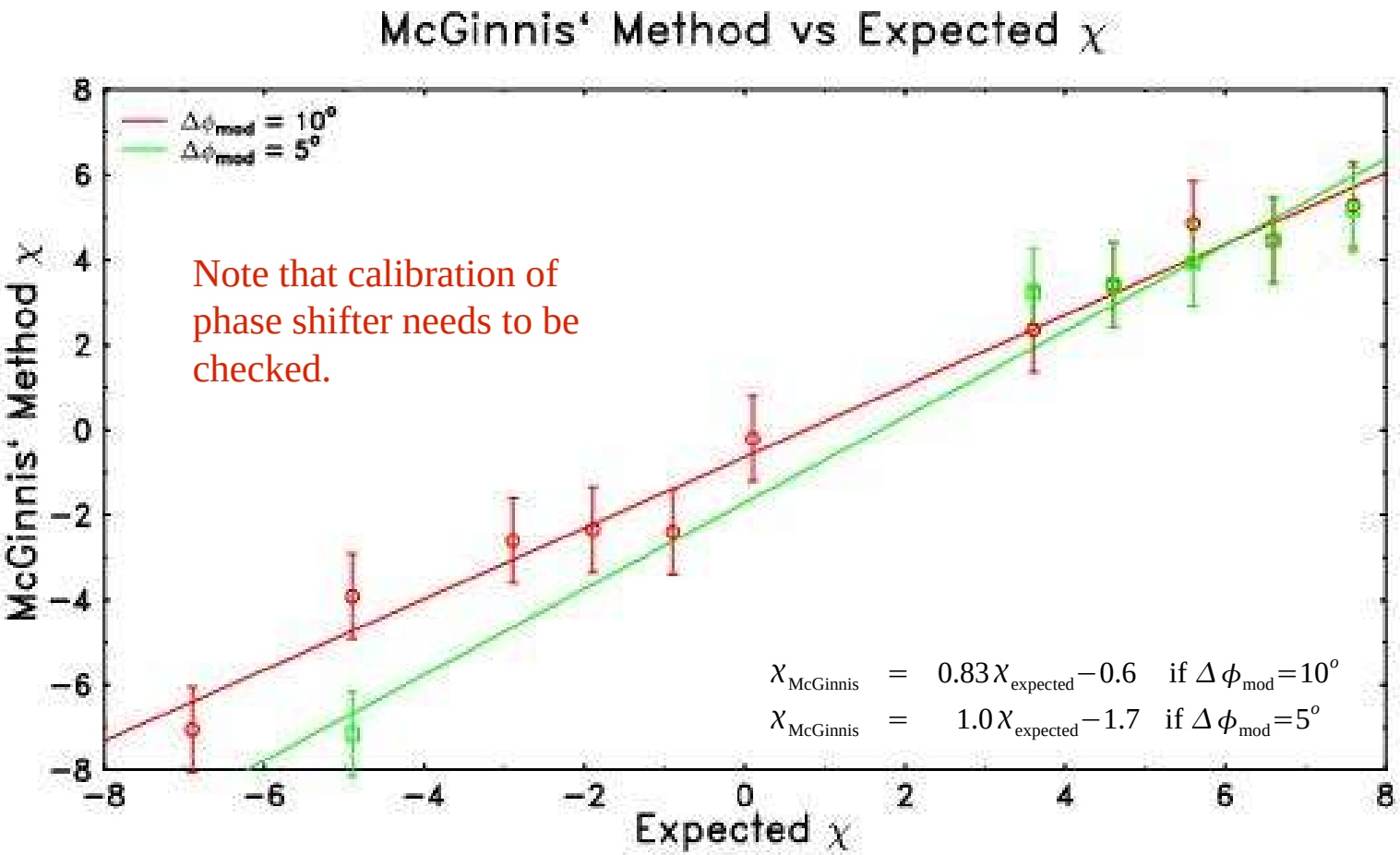
# Tracking with Phase Modulation ON




No beam loss during modulation of $\Delta\phi_{mod} = 5$ deg.

Tune moved when chrom knob changed. (Checked that tune change not synch. freq or 23 Hz. However, I need to be sure)

# Results for Tevatron

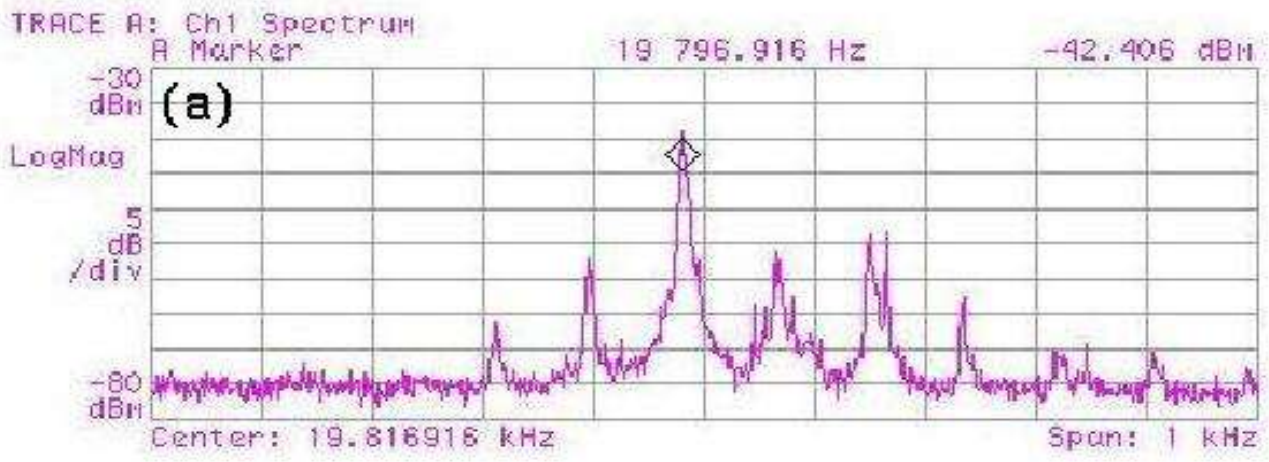


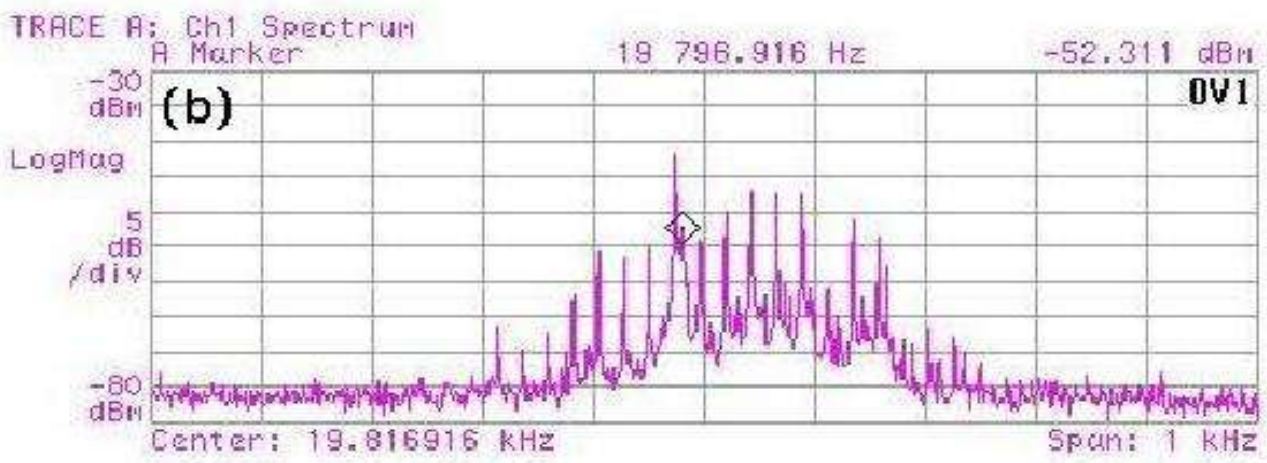

Note that calibration of phase shifter needs to be checked.

$$\chi_{\text{McGinnis}} = 0.83\,\chi_{\text{expected}} - 0.6 \quad \text{if } \Delta\phi_{\text{mod}} = 10^o$$

$$\chi_{\text{McGinnis}} = 1.0\,\chi_{\text{expected}} - 1.7 \quad \text{if } \Delta\phi_{\text{mod}} = 5^o$$

# Using 3D-BBQ




TT still at 21.4MHz and locked.

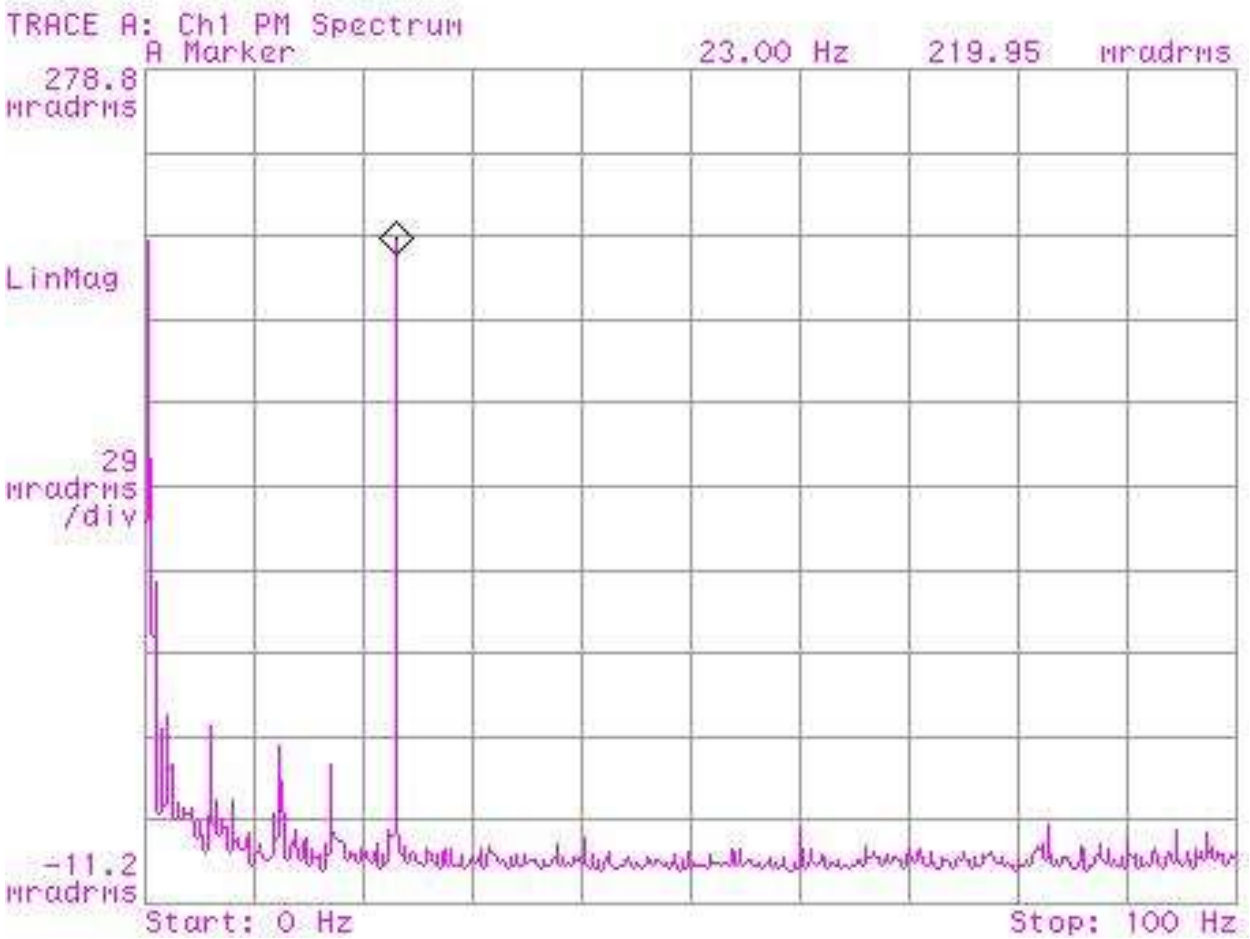
(a) phase mod off.

(b) phase mod on.

$\Delta\phi_{mod}$ = 40 deg.

# BBQ Phase Demodulated

Date: 03-25-04 Time: 05:25 AM



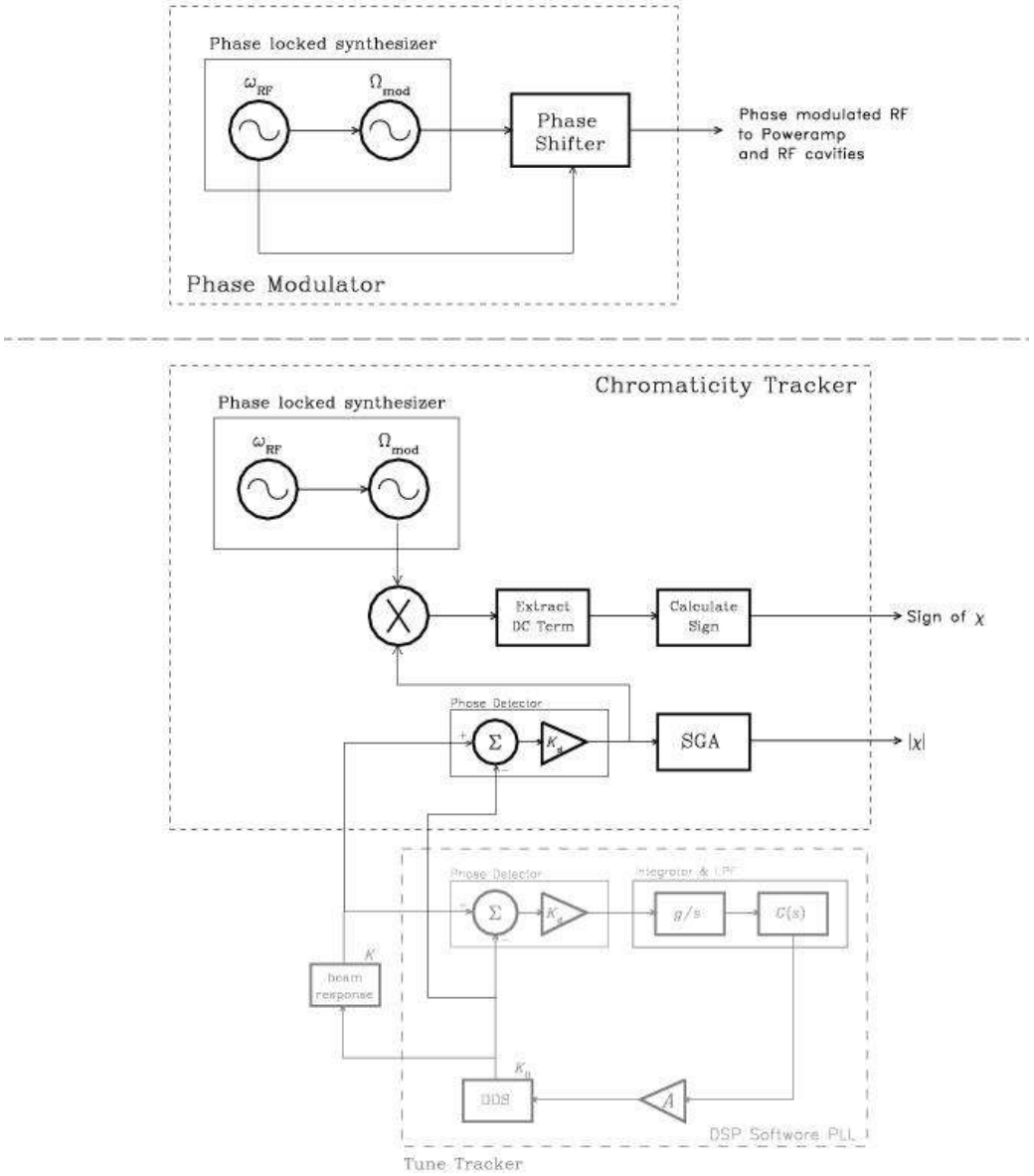

$\Delta\phi_{\text{mod}} = 5\text{deg.}$

# Chrom Measured using BBQ

**Table 2. Chromaticity Measured with 3D-BBQ**

| $\chi_{expected}$ | $\chi_{McGinnis}$ |
|---|---|
| 8* | 11 |
| 6 | 7 |
| 4 | 4 |

# Planned Implementation (Phase II)



# Conclusion

- TT is now routinely used for stores.
  - People are using it in a “feedforward” sense to tune the Tevatron between stores.
  - Quite robust and not much attention needed for it to work.
- Future plan is to work on chromaticity tracking.
  - Preliminary work shows that the McGinnis method is promising. However, I need to prove that it will work up the ramp and thru the squeeze.
  - Note that LHC synchrotron frequency is 64 Hz at injection (450GeV) and 23Hz at flattop (7TeV). TT for CT must have closed loop bw of ~5Hz if McGinnis method is used.

# Acknowledgements


- The Tevatron group for supporting this project.
- US-LARP
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