

Head-Tail Chromaticity measurement using 3D-BBQ revisited

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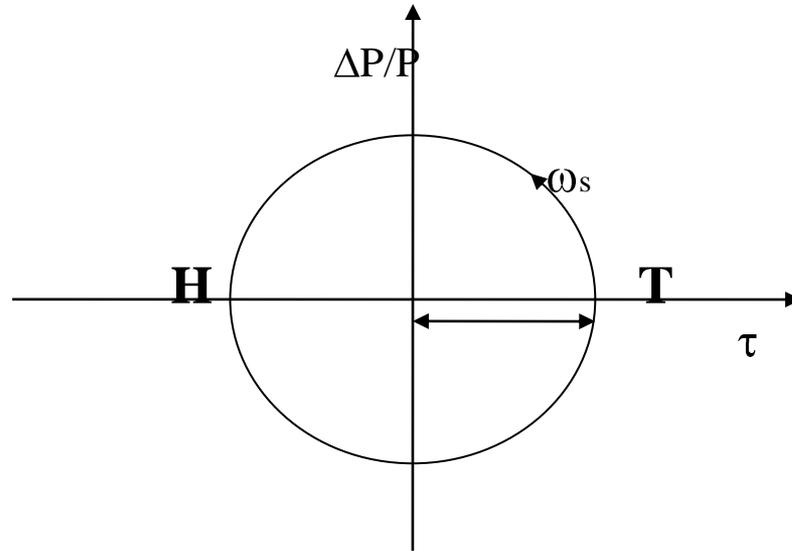
Based on several papers C.Y. Tan and I wrote together

1. Phys.Rev.ST Accel.Beams 14 (2011) 082802
2. Phys.Rev.ST Accel.Beams 11 (2008) 032802
3. Phys.Rev.ST Accel.Beams 11 (2008) 084401

Motivation

- We are interested in investigating non-destructive methods to measure chromaticity in RHIC
- In particular the head-tail phase difference approach using BBQ to detect head and tail phases.
- About 6 years back, C.Y.Tan, R. Jones and others at CERN considered the possibility of using the BBQ to sample the head and the tail to extract chromaticity via the head-tail phase shift.
- We considered both an isolated kick method and a continuous kick approach to piggy back on the pll tune measurements.
- We were unsure at the time if a continuous kick approach would yield usable phase information. However subsequent theoretical and experimental work using an AC dipoles and sampling via a scope showed that there was a clear phase shift which persists while the beam is continuously driven.
- However both the kicked and continuous excitation approach showed that there were problems with phase jitter related to the peak selection of the BBQ which made this an unreliable.
- I have a new idea which may resolve the issue of phase jitter by summing a carefully placed narrow pulse at the location in the bunch which we wish to sample.

Longitudinal Beam Dynamics



Longitudinal 'phase-space' Graph

$$\delta(s) = \frac{-2\pi q_s}{\eta C} r \sin(2\pi q_s s / C + \varphi)$$

$$z(s) = r \cos(2\pi q_s s / C + \varphi)$$

Chromaticity Measurement Using Head-Tail Phase Shift

In the presence of non-zero chromaticity the betatron frequency is perturbed by:

$$\omega_{\beta}(\delta) = \omega_{\beta 0} + \omega_0 \xi \delta$$

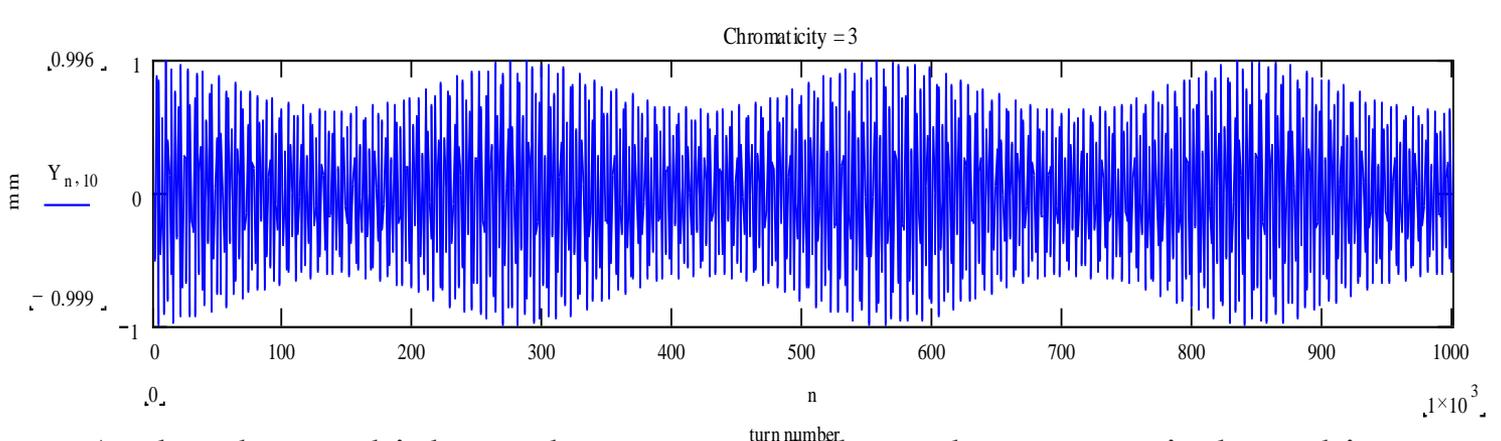
the equation of motion per particle becomes:

$$A \exp\left[\pm i(2\pi Qn + \frac{\xi \omega_0}{\eta} \tau (1 - \cos(2\pi q_s n)) + \frac{\delta \xi}{q_s} \sin(2\pi q_s n)) \right]$$

Which when integrated over a gaussian δ distribution gives[1]:

$$X(\xi, \tau, n) = e^{-\frac{\omega_0^2 \xi^2 \sigma_{\tau}^2}{2\eta^2} \sin^2(2\pi q_s n)} \sin \left[2\pi Qn + \frac{\omega_0 \xi}{\eta} \tau (1 - \cos(2\pi q_s n)) \right]$$

The result of this simple model predicts a beam envelope which recovers every half synchrotron period.

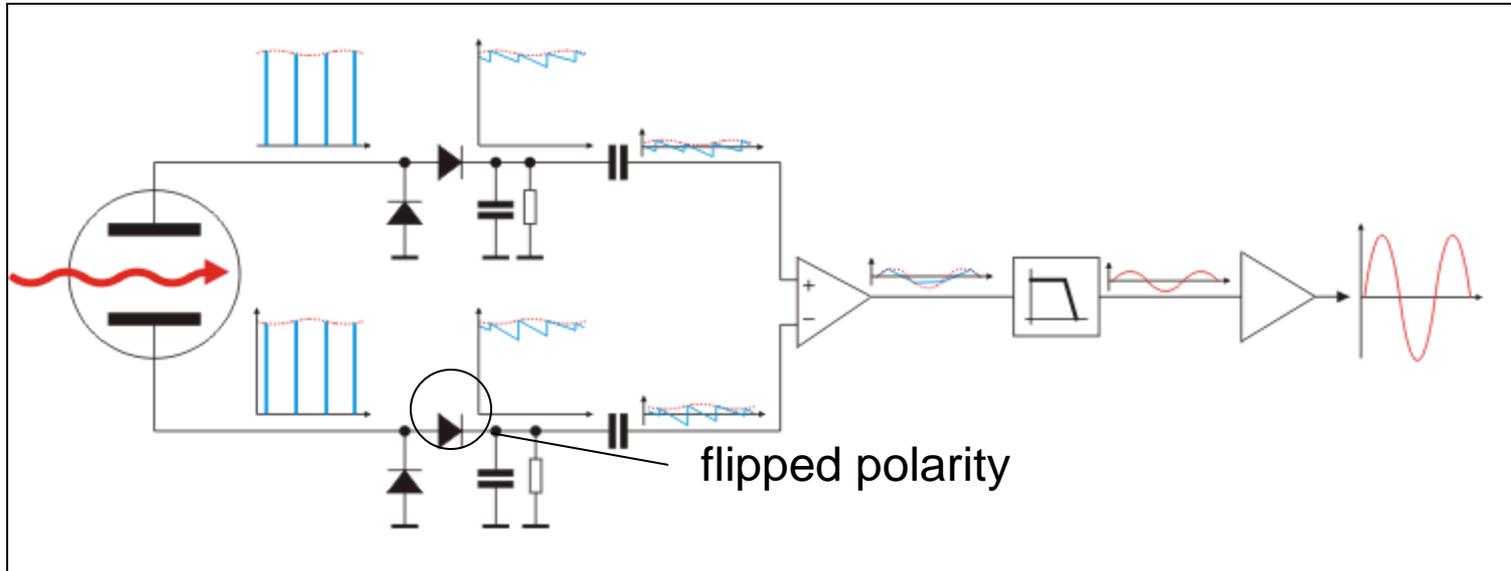


And a phase which recovers every full synchrotron period reaching a maximum phase difference every half synchrotron period. Thus from the phase difference between two locations in a bunch the chromaticity can be calculated using:

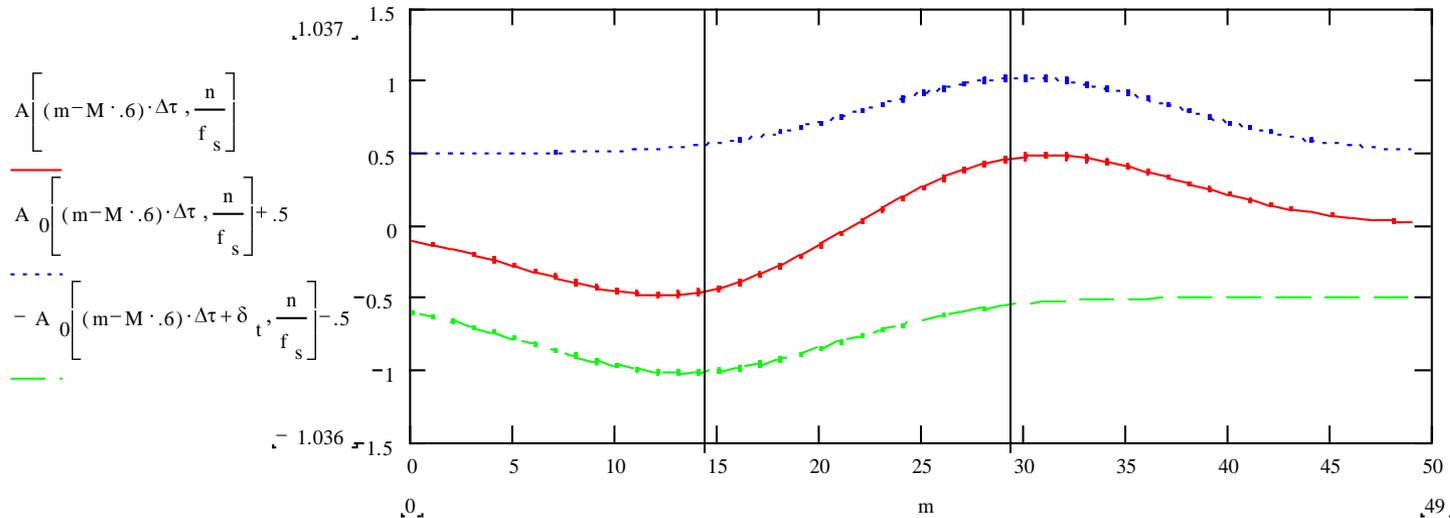
$$\xi = -\eta \frac{\Delta\Psi}{\omega_o \Delta\tau (\cos(2\pi n q_s) - 1)}$$

After a lot of work one can show in the case of continuously driven for zero emittance we get the same thing only a factor of 2 replaces the (cos() - 1) term:

Set-up



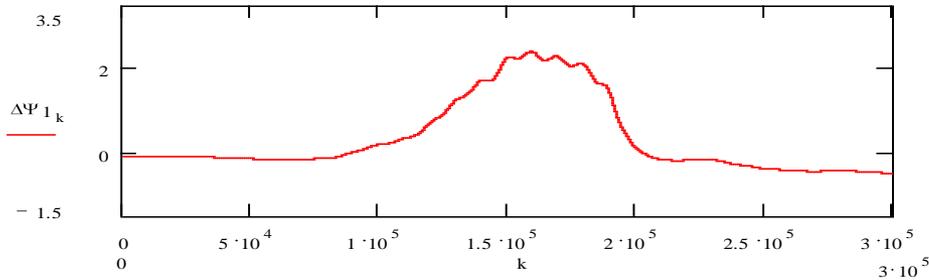
In the original experiment at the Tevatron and then later at the SPS we attached the BBQ to the stripline or BPM with one of the diodes flipped to sample the negative peak. The output of the BBQ was then sampled by a fast digital oscilloscope at 25MHz



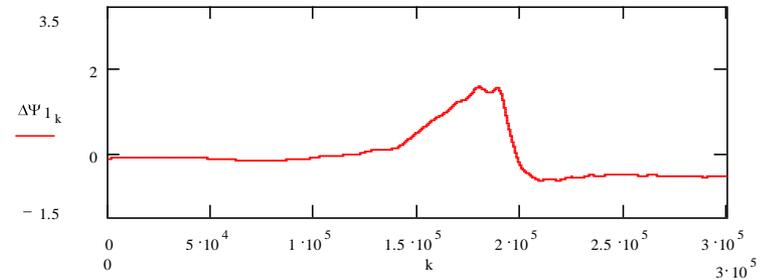
The BBQ peak detects. Because of the over-lap in the doublet positive and negative peak detector should effectively sample different parts of the bunch. However the peak location in the bunch may experience some jitter which should be correlated with: closed orbit offset, kick amplitude and rms bunch length.

$$A_0 \left[\tau, t \right] := 0.5 \cdot \left[\Sigma \left[\tau, t \right] \cdot \left[\frac{\left| X_{\beta} \left[\tau, t \right] + X_0 \right|}{27} + 1 \right] \right]$$

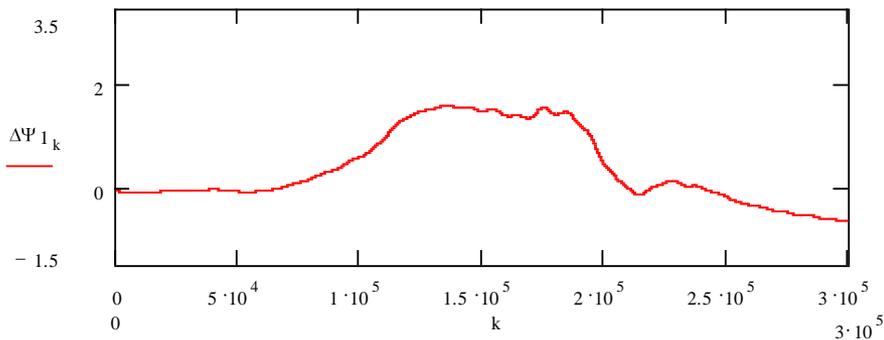
Some results for the kicked method in the Tevatron



BBQ Chromaticity = 5.04 units Traditional Head-Tail = 5.2



Peak chromaticity 4.4 units occurs ~ 60 turns later than it should. Traditional Head-Tail = 4.29



BBQ Chromaticity = 3.66 units Traditional Head-Tail 5.86

At the SPS the results of continuous excitation also showed phase shift. However it was not consistent.

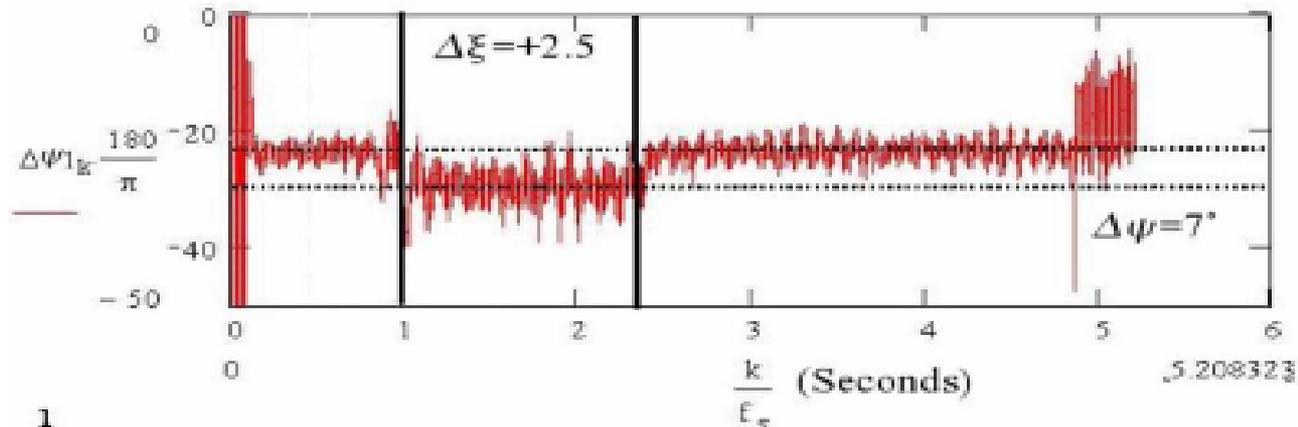


FIG. 1: Shown here is the phase difference between the head and tail with continuous kicks. The head-tail phase changed when the chromaticity was increased by 2.5 units. This data was collected by the authors and the CERN beam instrumentation group during the SPS machine studies period on 29 Sep 2006.

Careful studies at the Tevatron using an AC dipole and scope showed definitely that there is a phase shift correlated with Chromaticity.

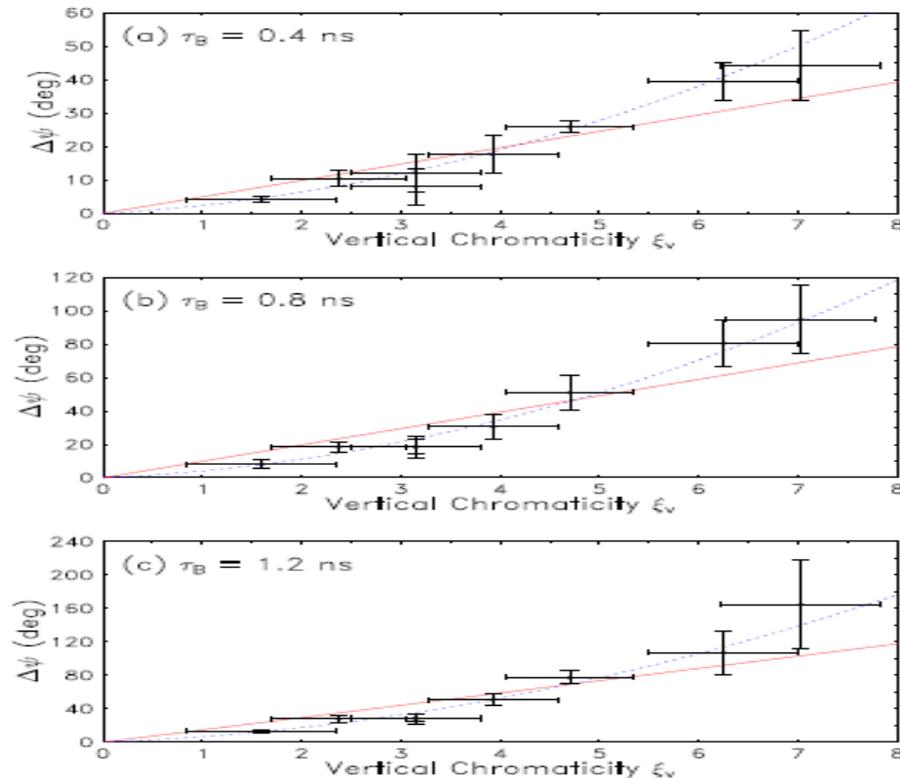
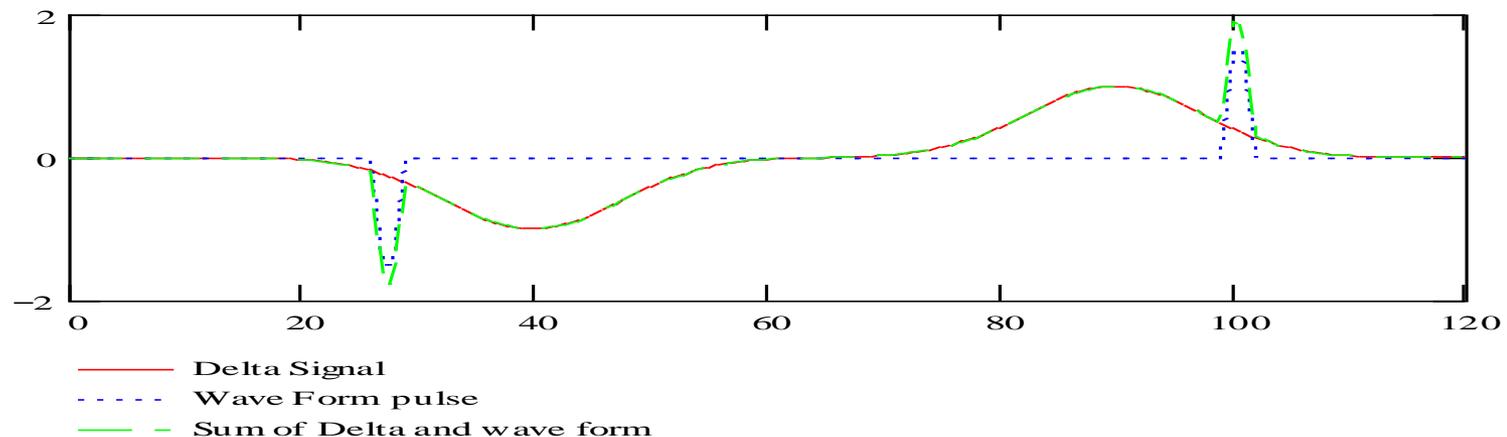


FIG. 7: These plots show the data analysed for $\tau_B = 0.4$ ns, 0.8 ns and 1.2 ns. The red line is calculated from Eq. (39) and the blue dotted line is a quadratic fit of the data using coefficients from Table II.

The experiment showed that there was a quadratic term not accounted for in the theory. Latter work has more recently indicated that this is probably due to mixing of 2nd order Chromaticity and Impedance. In any case it is probably linear enough for a feedback system to work and in worst case can be accounted for empirically. However the issue of phase jitter remains.

Proposed Solution

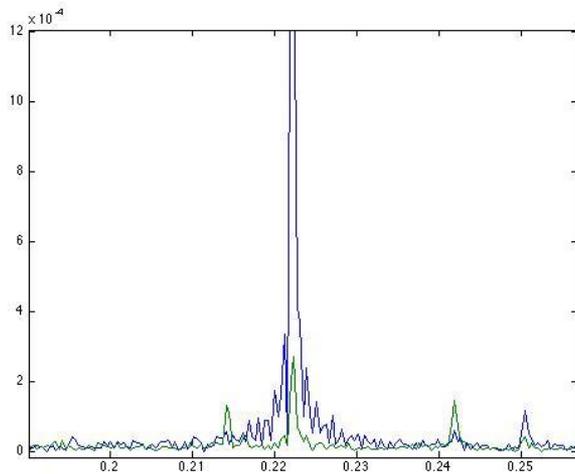
- To control the sampled position of the BBQ in the bunch, we propose summing a controlled square pulse of ≤ 0.5 nsecs to force the BBQ to select only the local peak and thus betatron oscillations at the location of the pulse. In this case we can also now separate the pulse from the reflected pulse by appropriate summing and delays. Using the positive pulse for head sampling and the negative for tail:



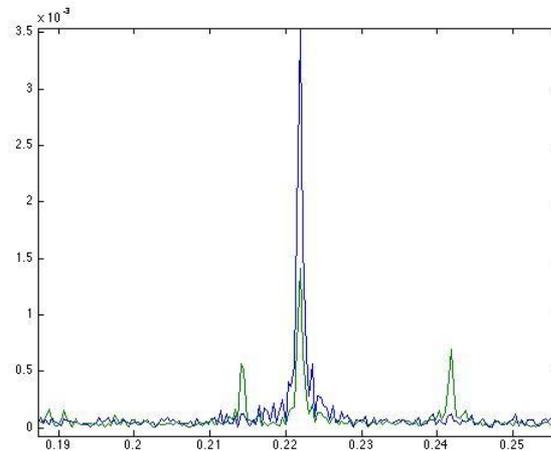
Results from Experiment So Far

- Had trouble with first pulse generator getting timing right.
- Kevin Smith loaned us his 500 MHz generator made 1 nsec pulses
- However square pulse produced a lot of noise in the BBQ circuit for some reason
 - Couldn't see any tune when all bunches summed pulse signal
 - Could see something when 1-16 bunches summed in
 - Noise appeared correlated with cable lengths..I think we still need to solve some reflection issues
 - We have some results at Injection with one bunch

FFT at injection single bunch from pulse delayed by 8 nsecs from each other

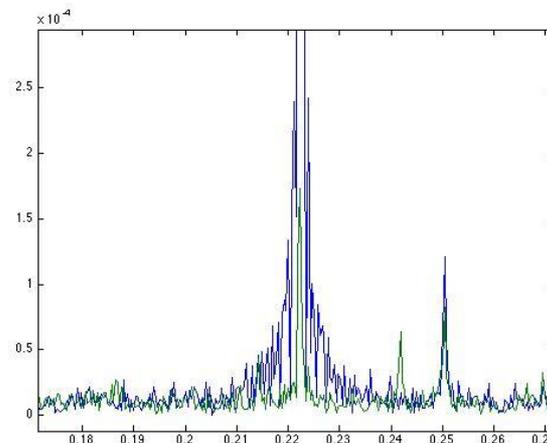


1 nsec width with 0.4 Volts

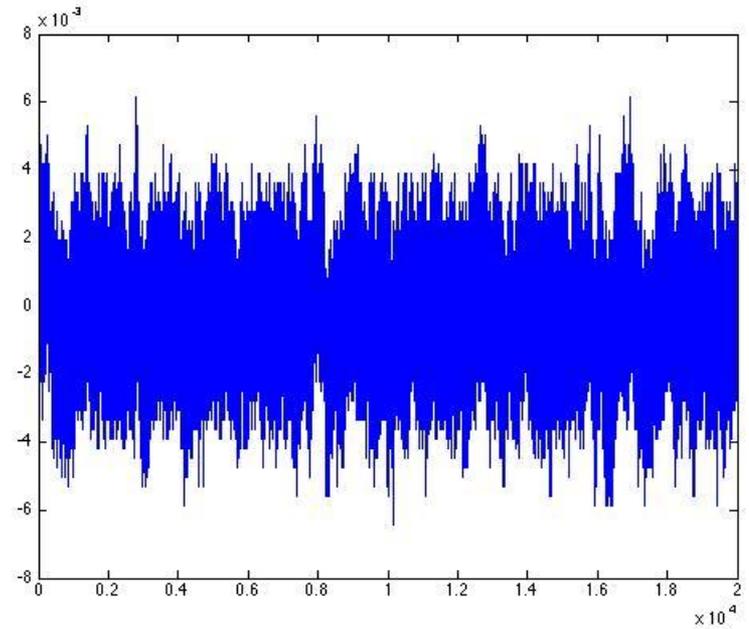
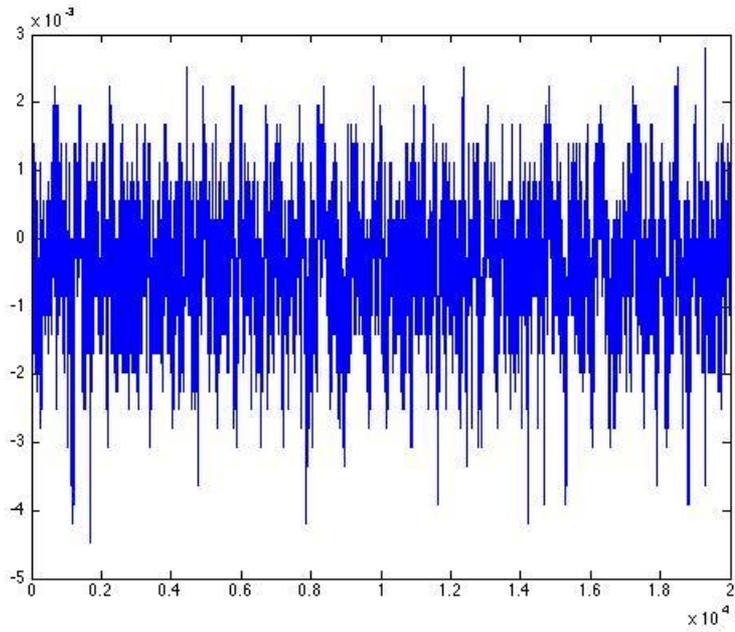


2 nsec width with 0.7 Volts

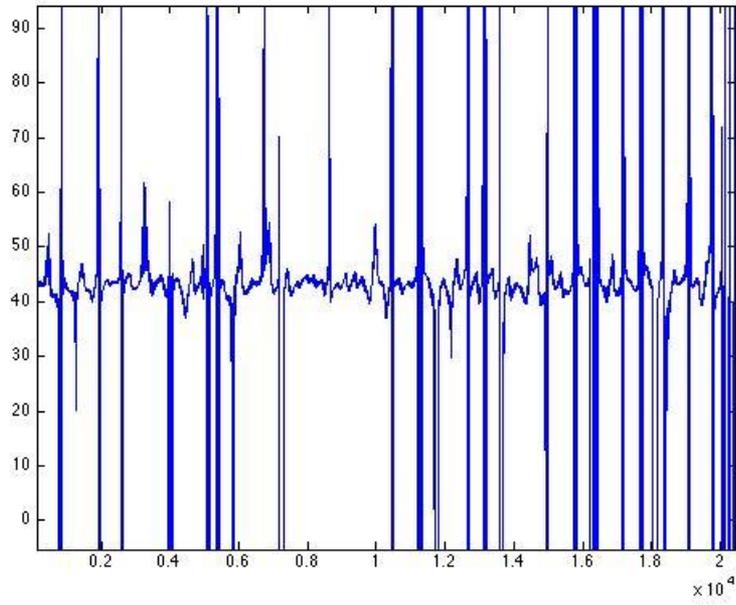
1 nsec width with 0.2 Volts



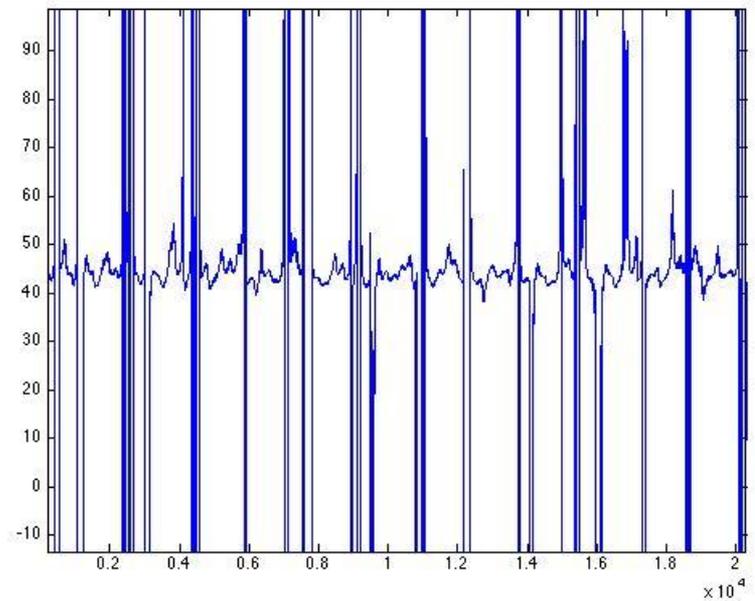
Delay length causes noise difference



Head Tail Phase difference



1 nsec pulse at 0.2 Volts



1 nsec pulse at 0.4 Volts

Plans for APEX 13

- Test Gaussian pulse signal to see if noise is reduced
- Need several hours during which chroms are changed so that I can take phase data and see if there is a correlation between measured phase difference and chroms.