Review of chromaticity measurement approaches using the head-tail phase shift method

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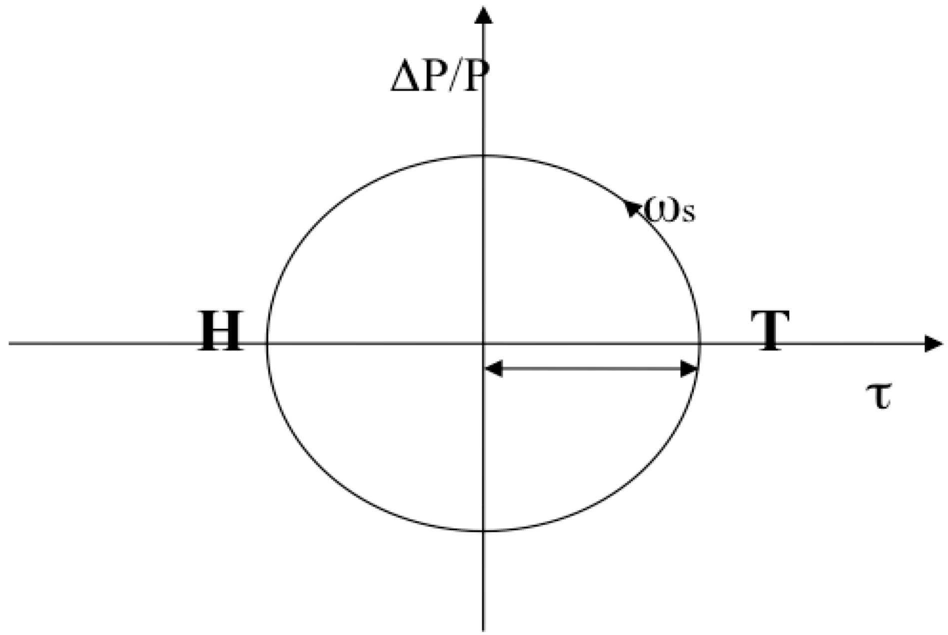
Overview

- Review the Head-Tail approach to measuring chromaticity
- Experimental Setup
- Results at Tevatron
- Simulations for RHIC lattice
- Experiments from RHIC lattice
  - Analysis
- Possible way forward
  - Impedance and 2^{nd} order Chrom effects.
- Other ideas and Failed Tests

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:

Head Tail Phase

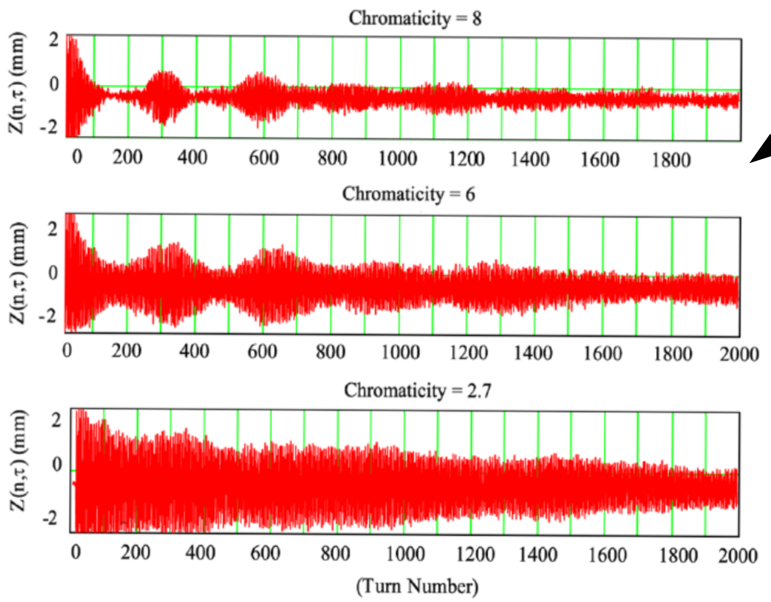
$$A \exp[\pm i(2\pi Q n + \frac{\xi \omega_0}{\eta} \tau (1 - \cos(2\pi q_s n)) + \frac{\delta \xi}{q_s} \sin(2\pi q_s n))]$$

Which when integrated over a Gaussian delta distribution gives[1]:

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

Experimental Set-up

Nice long coherence times in Tevatron



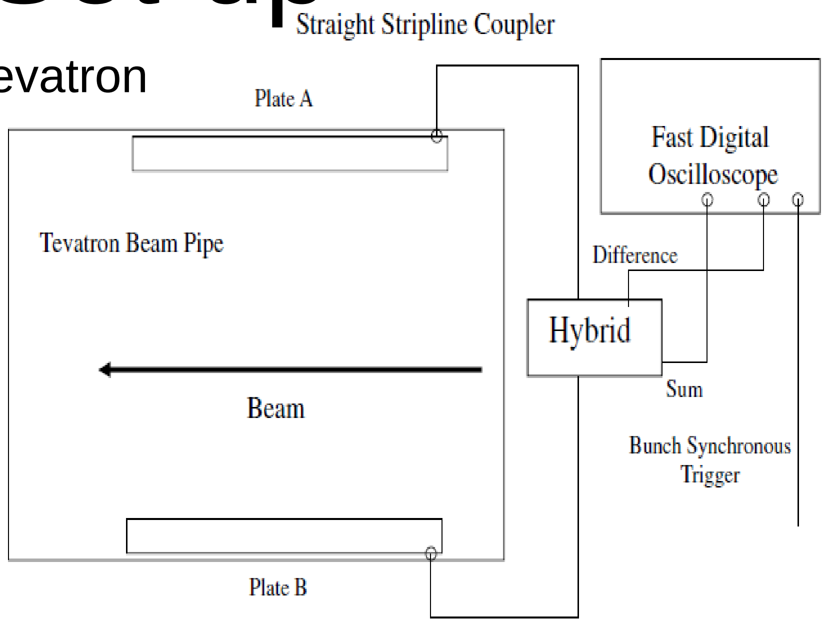


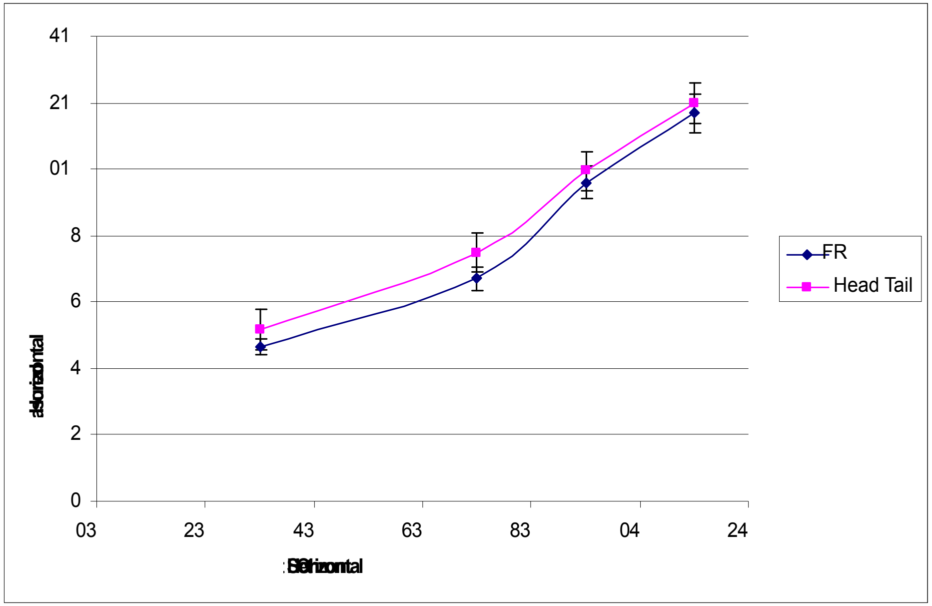
FIG. 1. Experimental setup.

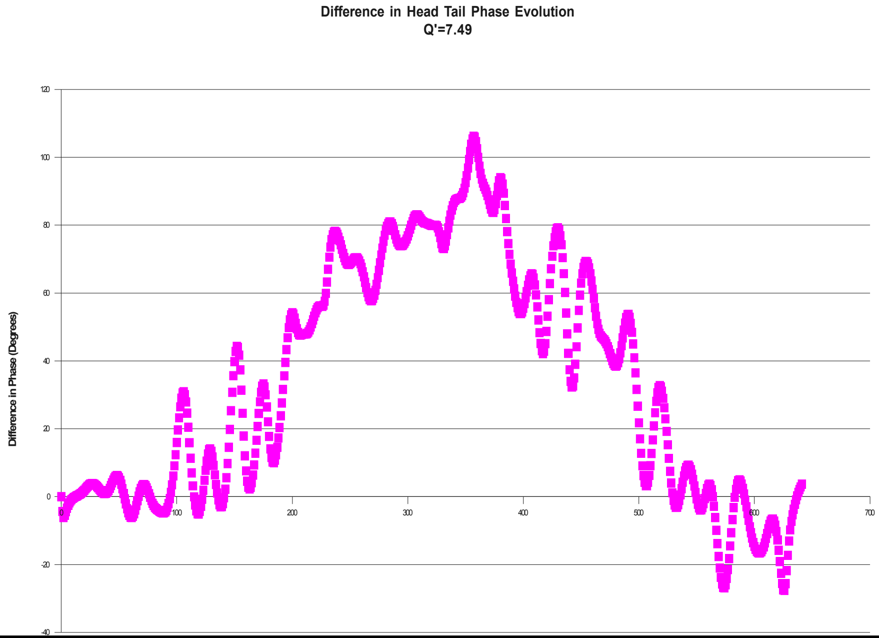
This idea was first proposed and tested at CERN by R. Jones and others but never used operationally, since it was destructive and it was challenging to make it reliable.

Later It was developed for use in the Tevatron by myself with help of E. Lorman. The performance in the Tevatron was more reliable since we had less net Landau damping at the time and thus longer coherence times for each kick (before use of Octupoles).

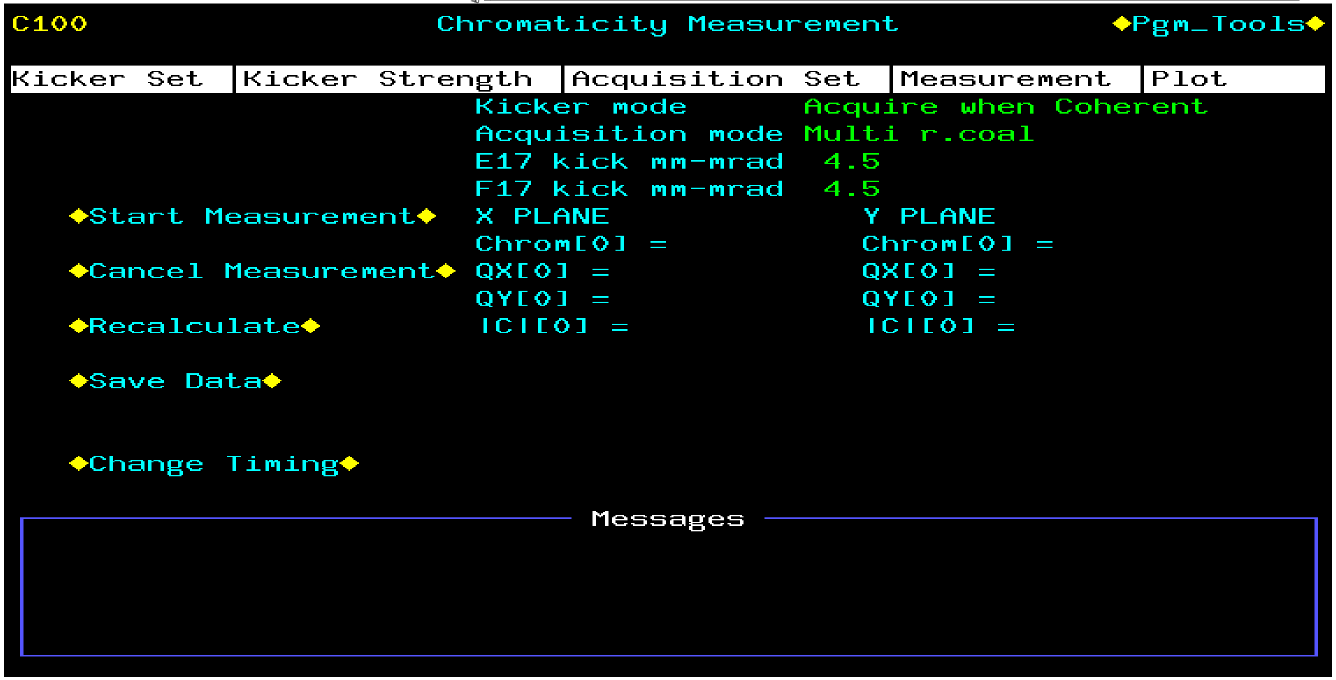
I know there was some work also done here at RHIC but I haven't seen any published papers on this yet. Between 2013-2015 we repeated these experiments.

Tevatron Results





Results good enough for a dedicated application used during shot setup. (never got It to work for uncoalesced bunches due to dancing bunches issues).



2014 APEX tests in RHIC.

Simulation Results:

Figure 3: Horizontal turn-by-turn in Tevatron at injection

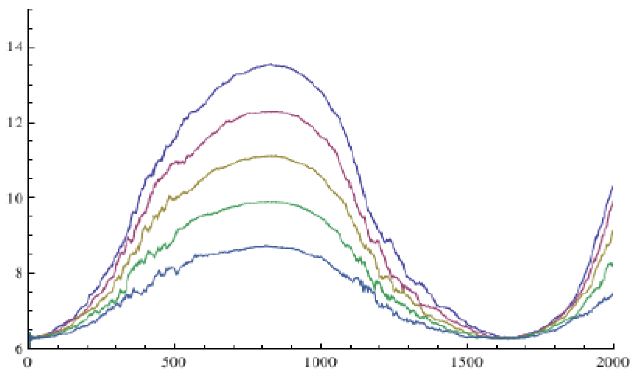


Figure 4: Simulation of head-tail phase shift with a single RF frequency. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

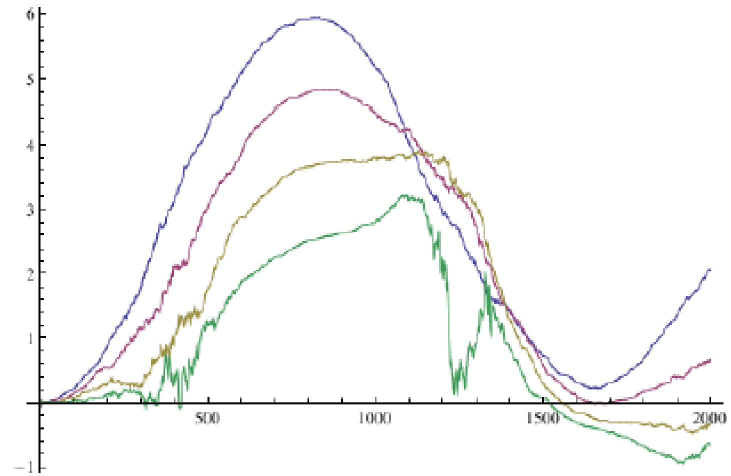
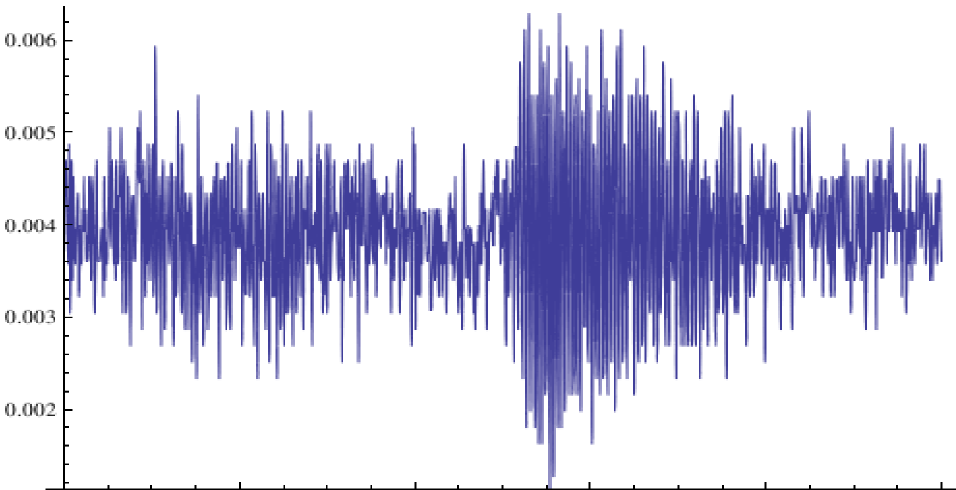


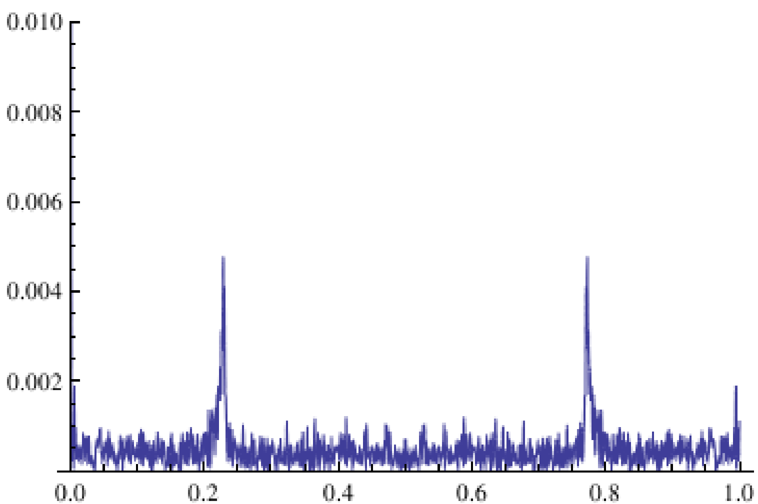
Figure 5: Simulation of head-tail phase shift with two RF frequencies. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

- I used a similar set-up as was done in the Tevatron connecting the button BPM scope to the yellow stripline.
- I used the Artus turn-by-turn kicker to excite the beam and acquired data in the vertical and horizontal planes.
- We performed 18 measurements at Store Energy with the Au beam scanning through different chromaticity settings.

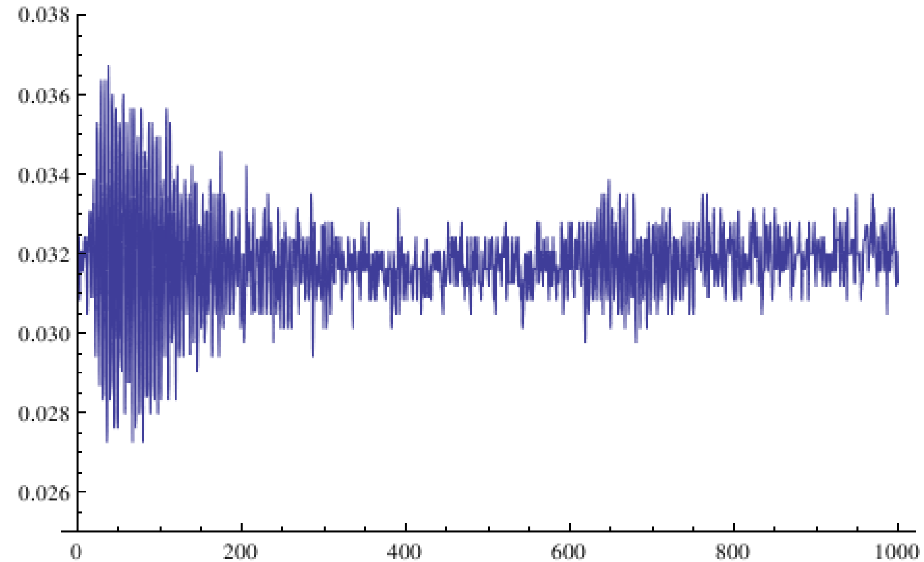
Actual Results

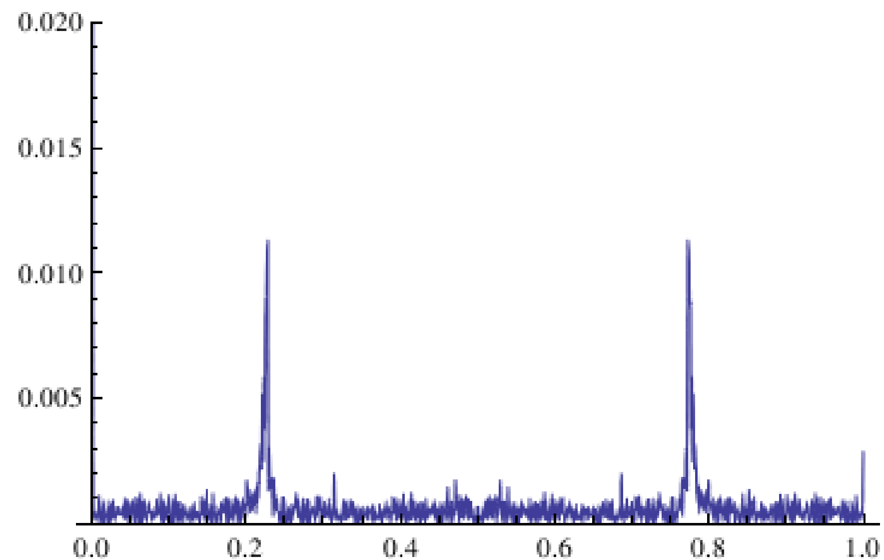
Horizontal difference signal





Vertical difference Signal





Analysis of Results

- Obviously dechorence time much faster than in Tevatron. Dies before a full Synchrotron period → Similar to the SPS
- Extracting clean phase signal very challenging
- Phase signal very noisy, cleaned it up a bit by looking at many longitudinal slices and fitting the slope.

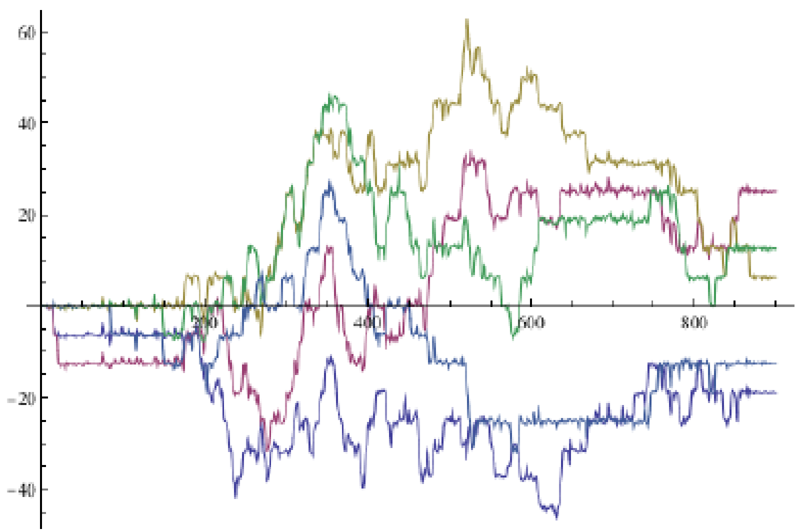


Figure 6: The Phase shift between different head-tail bunch slices plotted against turn number (x axis) as actually measured at RHIC

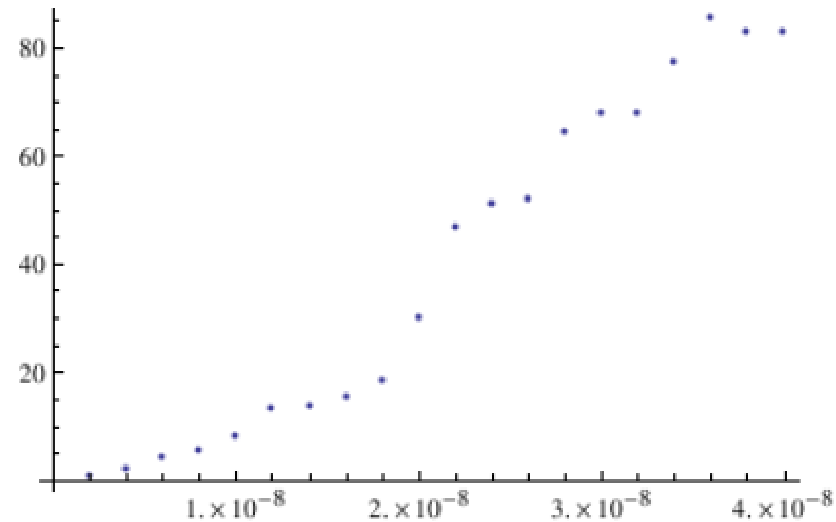
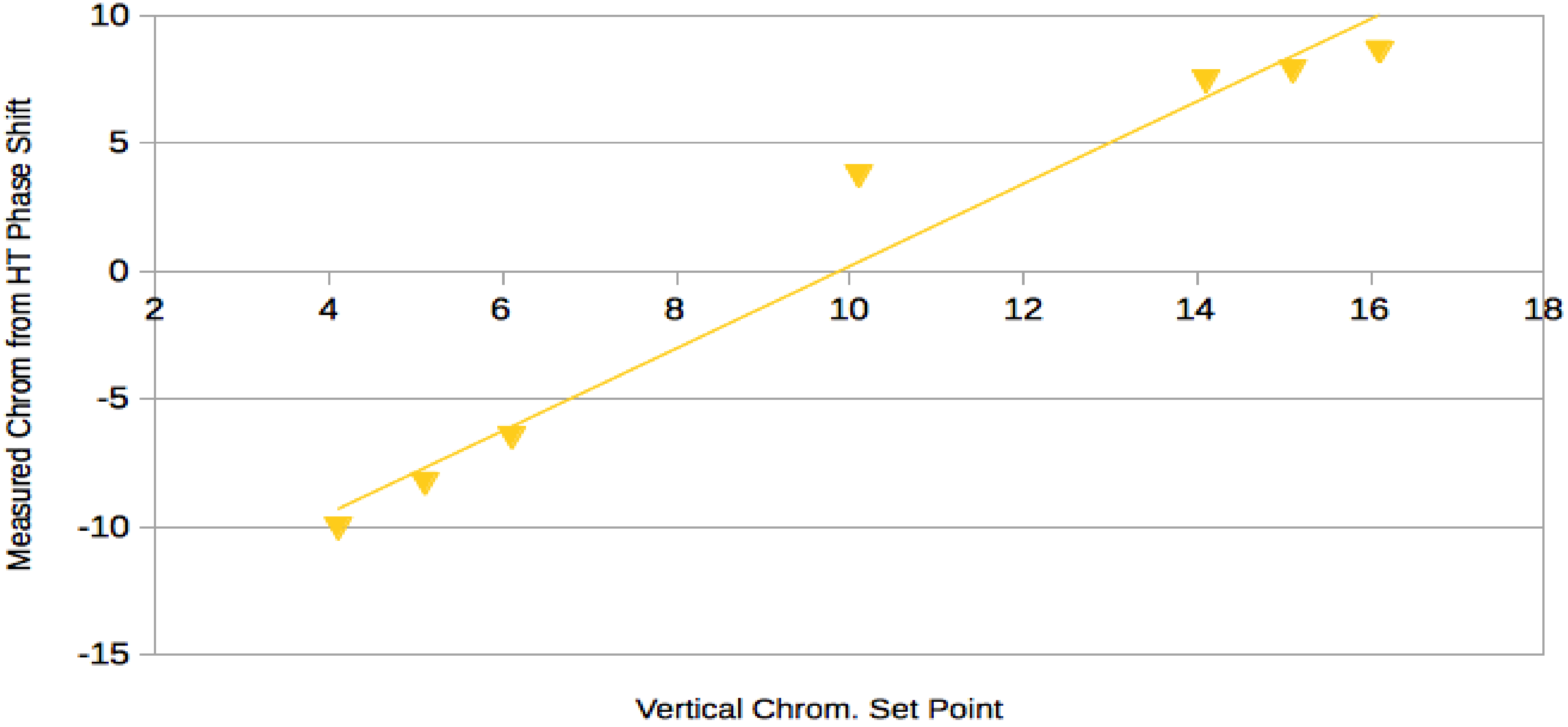


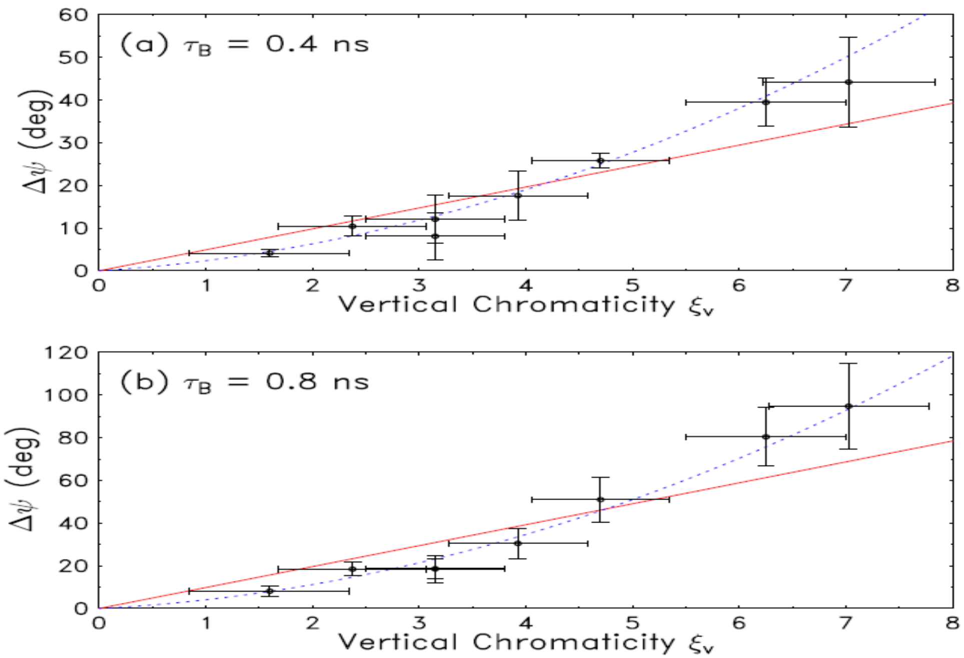
Figure 7: Plot of average Head-Tail phase difference for various $\Delta\tau$. From the slope one should be able to deduce chromaticity.

Chromaticity setting versus Phase Shift evaluated value



Possible Way forward

- Using driven oscillations via AC dipole or kicker
- Tested already several years ago in Tevatron by C.Y. Tan and myself
  - Results showed there exists a linear regime which could be used to extract chroms but susceptible to impedance effects
- Still needs to be tested in RHIC



Things to Worry about: Linear Chromaticity Shifting

- Effect of impedance and higher order chromaticity on the measurement of linear chromaticity

  V. H. Ranjbar and C. Y. Tan Phys. Rev. ST Accel. Beams 14, 082802 (2011)

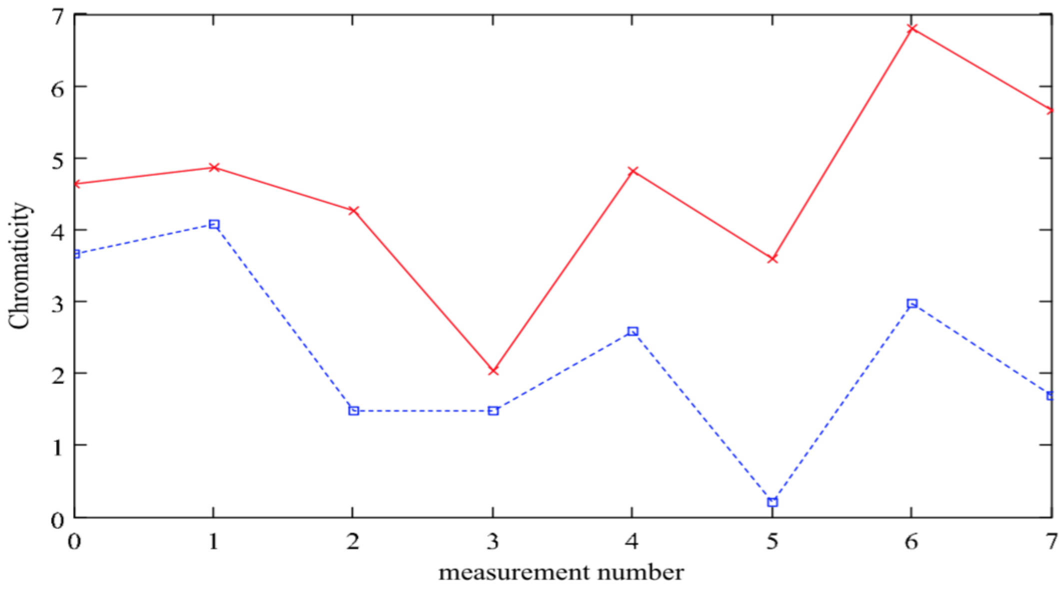
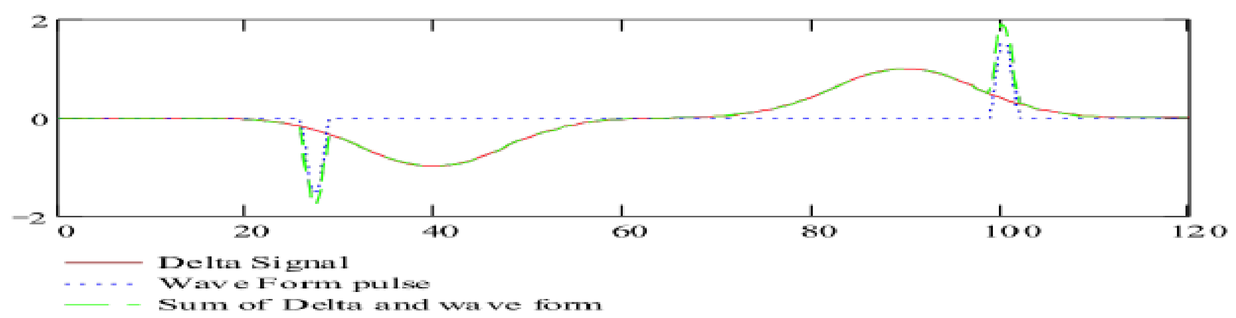


FIG. 4. Measurements made on several occasions since 2005, showing a consistent difference between coalesced and uncoalesced proton chromaticity measurements.

Other ideas Failures: Pluse Mixing Tests

- Based on old idea of using BBQ to detect head and tail signal
- Problem: BBQ is a peak detector so position longitudinal location in bunch not fixed and jitters.
- Solution: Mix artifical pulse to force BBQ to pick desired longitudinal location in bunch.



I couldn't get it to work. When added pulse signal became too noisey to extract tune

Other ideas : in process

- Using BBQ data (i.e. phase and amplitude), longitudinal emittance, intensity, Energy, RF parameters.
  - Train Machine learning to extract chromaticity or other beam parameters.