# REVIEW OF CHROMATICITY MEASUREMENT APPROACHES USING HEAD-TAIL PHASE SHIFT METHOD AT RHIC *

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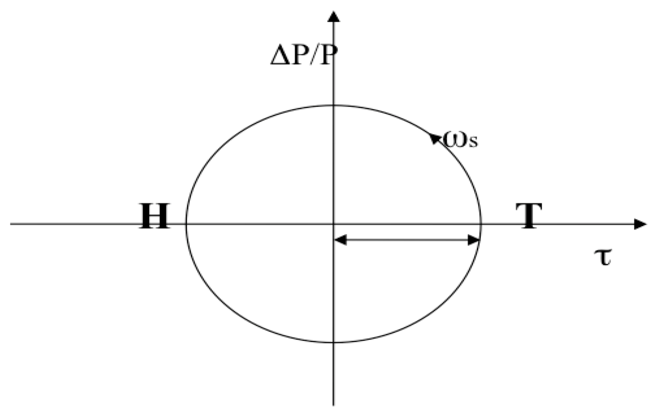
*Abstract*

We review tests of the head-tail phase shift method using various approaches at BNL's RHIC. Both the standard and some more exotic approaches to measure the phase differential between the head and tail of a bunched beam has been attempted at RHIC. The standard kick beam and measured phase evolution of the head and tail of a given bunch has been tried at RHIC. Additionally a more exotic approach to measure the head versus tail phase difference has been tried. In this approach we used a BBQ pickup and kicker with the input stripline signal to the BBQ mixed with a nano second pulse timed to the head and tail of the bunch. In this way we hoped to force the BBQ to sample the head or tail of the bunch depending on the pulse timing. We report on the results and challenges which each approach presented.

## 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:

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

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

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

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

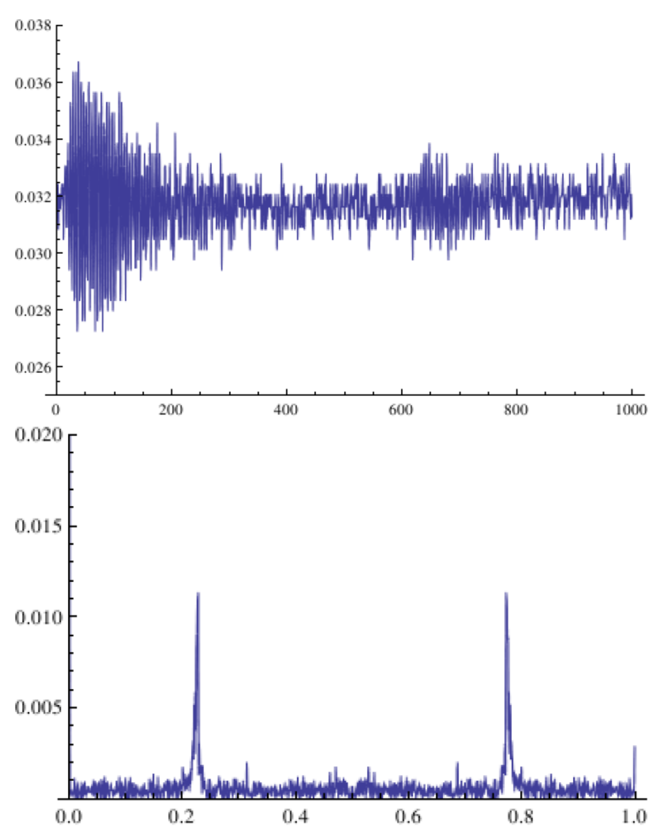


Figure 1: Vertical turn-by-turn difference signal (top) and FFT (bottom)

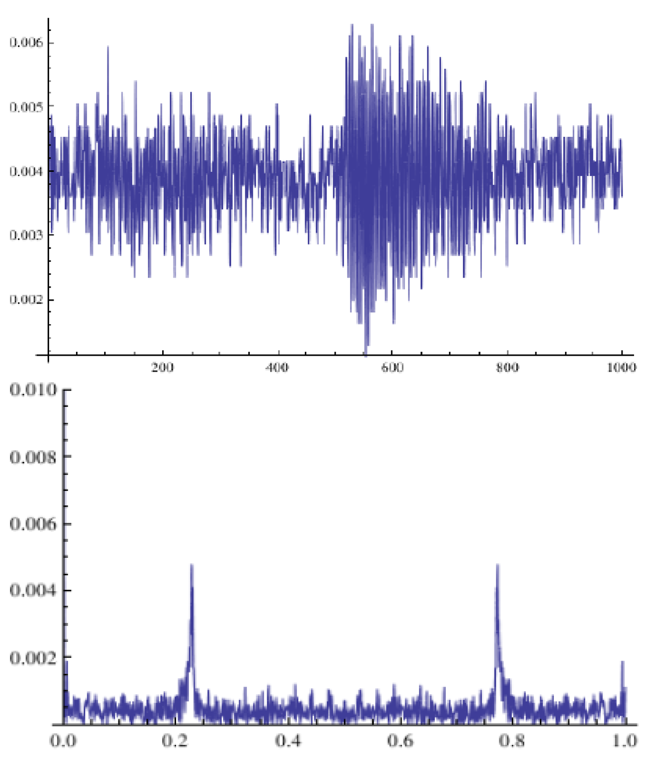


Figure 2: Horizontal turn-by-turn difference signal (top) and FFT (bottom)

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

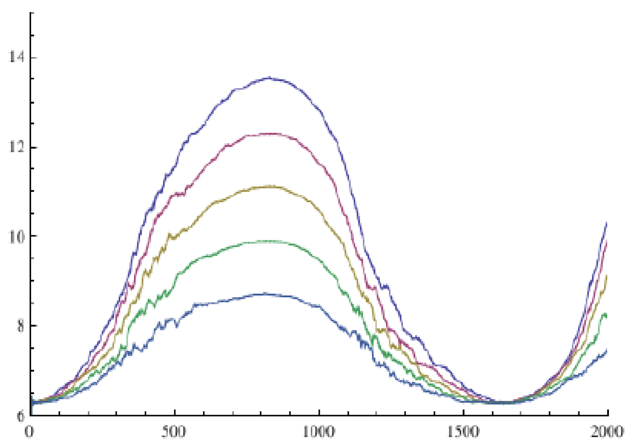


Figure 4: Simulation of head-tail phase shift with a single RF frequency. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

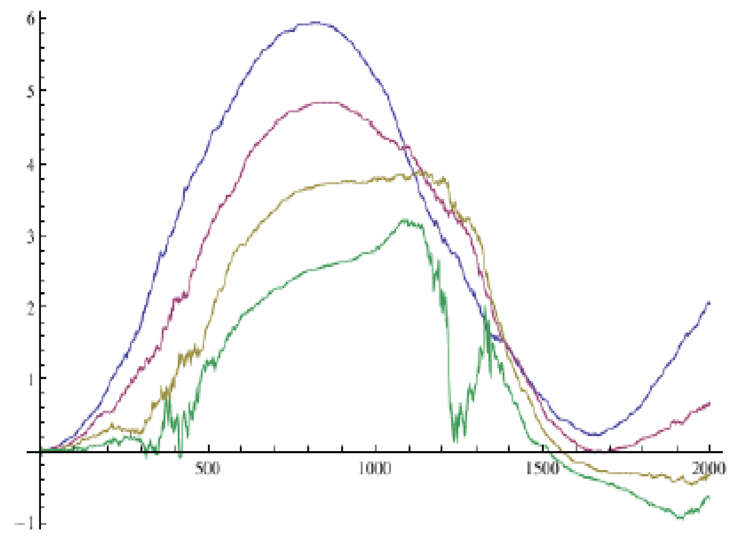


Figure 5: Simulation of head-tail phase shift with two RF frequencies. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

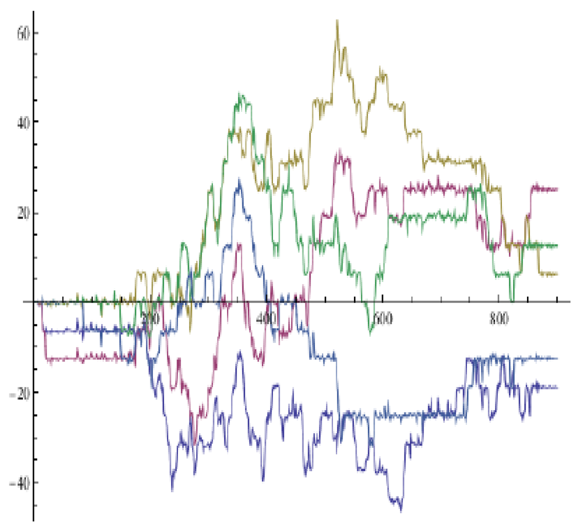


Figure 6: The Phase shift between different head-tail bunch slices plotted against turn number (x axis) as actually measured at RHIC

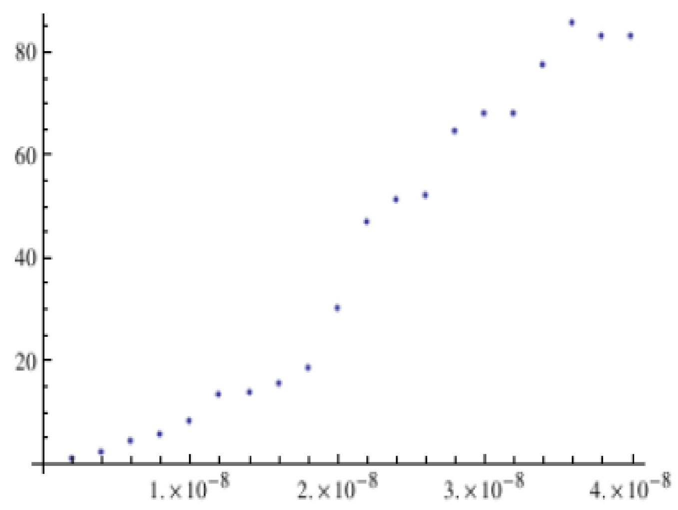


Figure 7: Plot of average Head-Tail phase difference for various $\Delta\tau$. From the slope one should be able to deduce chromaticity.

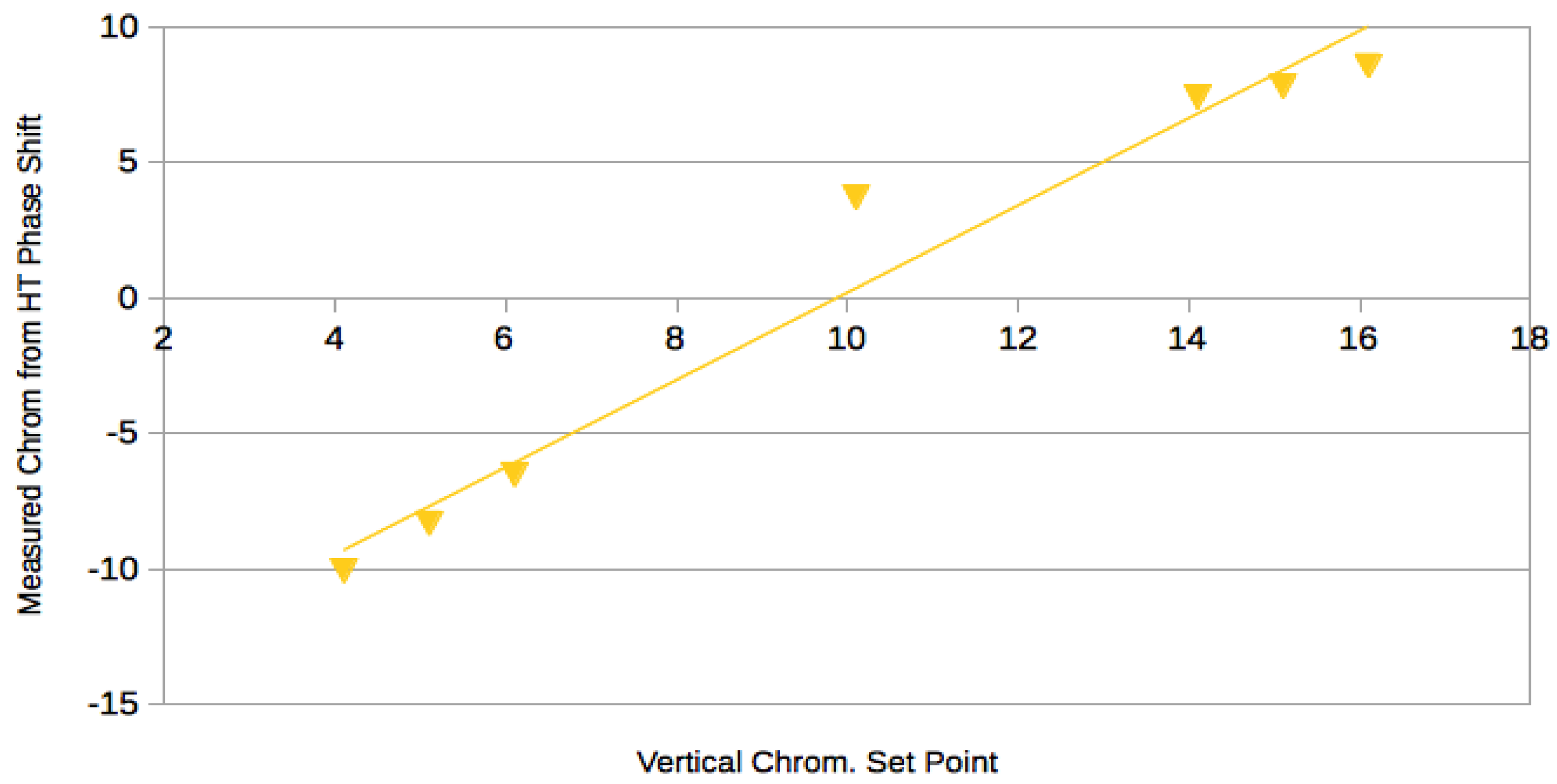



Figure 8: Head-Tail measurement of Chromaticity in vertical plane versus Chromaticity set points for RHIC at 100 GeV.

*PULSE MIXING TESTS*

To control the sampled position of the BBQ in the bunch, we proposed 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 separate the pulse from the reflected pulse by appropriate summing and delays as was done in the standard setup at the Tevatron. Using the positive pulse for head sampling and the negative for tail. A schematic of the pulse summing method is shown in Fig. (9).

Tests at RHIC in 2012-2014 showed that when the pulse was summed, this generated a large amount of noise in the signal which appeared to swamp any observed effect. Later a more gaussian like pulse was tried but it too generated a large noise effect in the BBQ electronics.

## 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: