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This note presents a beam-based method to check RHIC arc sextupole polarities using local horizontal orbit three-bumps at injection energy. We use 11 bumps in each arc, each covering two SFs (focusing sextupoles) and one SD (defocusing sextupole). If there are no wrong sextupole polarities, the tune shifts from bump to bump and the tune shift patterns from arc to arc should be similar. Wrong sextupole polarities can be easily identified from mismatched signs or amplitudes of tune shifts from bump to bump and/or from arc to arc. Tune shifts in both planes during this study were tracked with a high-resolution baseband tunemeter (BBQ) system. This method was successfully used to the sextupole polarity check in RHIC Blue and Yellow rings in the RHIC 2006 run.

1 Principle

1.1 General solution: sextupole based method

In the simple case where a single sextupole is covered by a local horizontal orbit bump, the horizontal and vertical tune shifts are:

$$\left\{ \begin{array}{lcl} \Delta Q_x & = & \frac{1}{4\pi}\beta_x(k_2 L)\Delta x_{co}, \\ \Delta Q_y & = & -\frac{1}{4\pi}\beta_y(k_2 L)\Delta x_{co} \end{array} \right. , \tag{1}$$

where $(\beta_x,\ \beta_y)$ are the horizontal and vertical beta functions at the sextupole, $(k_2 L)$ is the integrated sextupole strength, and x_{co} is the horizontal orbit change due to the bump. If x_{co} is positive in Eq. 1, the sign of $(k_2 L)$, or the sextupole polarity, is only decided by the signs of the tune shifts. For simplicity, in the following, we call a sextupole with positive polarity $k_2 > 0$ an SF sextupole, and call a sextupole with negative polarity $k_2 < 0$ an SD sextupole. The most general method is only useful when there is a single sextupole in the horizontal three-bump.

1.2 RHIC sextupole locations

Each ring of RHIC consists of six arcs and 144 sextupoles. Each arc has 11 periodic FODO cells. There are 12 SFs and 12 SDs in each arc. The phase advance per FODO cell is about 85° in each plane. There is one SF sextupole and one horizontal dipole corrector close to each arc focusing quadrupole, and one SD sextupole and one vertical dipole corrector close to each arc defocusing quadrupole in the regular arc FODO lattice. There are no horizontal dipole correctors close to defocusing quadrupoles, or vertical dipole correctors close to focusing quadrupoles. One defocusing SD sextupole in each arc is located outside of the standard FODO cell arc. 144 local three-bumps are required to cover all 144 sextupoles in each RHIC ring.

As shown in Fig. 1, it is not possible to create a horizontal orbit three-bump to only cover one sextupole in the RHIC arcs. These individual sextupole-based local horizontal three bumps always cover two to four sextupoles. The tune shifts are therefore different for these bumps even if the closed orbit bumps at the sextupoles are the same size. This complication makes it difficult to identify individual sextupole polarity problems by simply looking at the tune shift patterns during data acquisition.

1.3 Solution with multiple sextupoles per bump

Fig. 2 shows 13 three bumps constructed with horizontal correctors in the RHIC blue ring 6-7 o'clock arcs. Since each horizontal corrector is located near a FODO lattice beta max and SF sextupole, the center 11 horizontal three-bumps change the orbit significantly at one SF and two SD sextupoles, while the end two horizontal three-bumps change the orbit significantly at only one SD, or one SD and one SF sextupole. A single sextupole polarity reversal can then be found by an anomalous tune shift from two adjacent bumps; the magnitude and direction of the anomaly discriminates between SF or SD sextupole reversals. The end bumps are not in the periodic RHIC arc FODO lattice, so their setup is slightly different than the center 11 horizontal three-bumps.

We set the kicking strengths for the first dipole correctors of each bumps same. The strengths for the following other two dipole correctors are given by

$$\begin{cases} \dfrac{\theta_2}{\theta_1} & = & -\sqrt{\dfrac{\beta_1}{\beta_2}}\dfrac{\sin(\phi_3-\phi_1)}{\sin(\phi_3-\phi_2)} \\ \dfrac{\theta_3}{\theta_1} & = & -\sqrt{\dfrac{\beta_1}{\beta_3}}\dfrac{\sin(\phi_2-\phi_1)}{\sin(\phi_2-\phi_3)} \end{cases}, \tag{2}$$

where θ_i, $i = 1, 2, 3$, is the kicking strength for ith dipole corrector. β_i is the betatron amplitude function, and ϕ_i is the horizontal phase advance from the optics starting point.

Previous measurements of RHIC injection lattice optics indicate that injection arc optics are regular at the level of 5-10%. Closure of bumps constructed using the above equations with model beta function and tunes also confirm this regularity. With constant bump amplitude, tune shifts from each of the 11 center bumps should match, and should match comparable patterns produced in the other five arcs. Outliers immediately indicate isolated problem sextupoles. Systematic sextupole wiring errors can be found by comparing measurements to a model – tune shifts from all bumps are compared to a model that includes sextupole feed-down, and potential errors can be simulated by reversing or zeroing selected sextupoles until the modified model matches the measurements. These simulations are detailed in the next section.

There are some tips for identifying wrong sextupole polarities in the middle 11 arc FODO horizontal bumps:

- If there are no wrong sextupole polarities, the tune shifts from bump to bump and the tune shift patterns from arc to arc should be similar. Wrong sextupole polarities can be easily identified from mismatched signs or amplitudes of tune shifts from bump to bump and/or from arc to arc.
- If one SF sextupole has a wrong polarity, it will only affect the tune shifts of the bump which covers this SF sextupole since one SF is only covered once by one bump. If one SD sextupole has a wrong polarity, it will only affect the tune shifts of two adjacent bumps since one SD is only covered by two adjacent bumps.
- From the RHIC optics model, if there are no wrong sextupole polarities, horizontal and vertical tune shifts from each bump should be positive.
- If the horizontal tune shift from one bump is negative and the vertical tune shift from this bump is excessively negative, there is a possibility that the SF in this bump has a wrong polarity. The name of the suspicious SF can be easily identified since each bump only covers one SF.
- If the vertical tune shifts from two adjacent bumps are negative or close to zero and the horizontal tune shift from these bumps are excessively positive, there is a possibility that the SD covered by these two bumps has a wrong polarity.

1.4 Numerical simulations

Numerical simulations were carried out to verify the above corrector based method. Based on the Blue ring injection optics, we set the kicking strengths of first horizontal dipole correctors to be $\theta_1 = 2.0 \times 10^{-4}$rad.

Fig. 3 shows the horizontal and vertical tune shifts without any wrong sextupole polarities for the 13*2 bumps in the first two arcs. The tune shifts from the middle 11 bumps repeat very well among each other, and the tune shift pattern is clearly the same between the first and second arcs.

Fig. 4 shows the tune shifts from these bumps when an SF sextupole in the first arc and an SD sextupole in the second arc have reversed polarity in the model. With the above sign and amplitude rules for the tune shifts, it is quite straightforward to pick out the sextupoles with incorrect polarities from the tune shift data.

2 Beam experiment in RHIC

2.1 Bump Setup

Tab. 1 lists the correctors, bumps, and covered sextupoles for all 78 bumps (6*13) in the RHIC Blue ring.

```
No.       -------correctors---------   ----covered sextupoles---------

1          BO6-TH8   BO6-TH10  BO6-TH12     BO6-SXF10 BO6-SXD11
2          BO6-TH10  BO6-TH12  BO6-TH14     BO6-SXD11 BO6-SXF12 BO6-SXD13
3          BO6-TH12  BO6-TH14  BO6-TH16     BO6-SXD13 BO6-SXF14 BO6-SXD15
4          BO6-TH14  BO6-TH16  BO6-TH18     BO6-SXD15 BO6-SXF16 BO6-SXD17
5          BO6-TH16  BO6-TH18  BO6-TH20     BO6-SXD17 BO6-SXF18 BO6-SXD19
6          BO6-TH18  BO6-TH20  BO7-TH20     BO6-SXD19 BO6-SXF20 BO7-SXD21
7          BO6-TH20  BO7-TH20  BO7-TH18     BO7-SXD21 BO7-SXF20 BO7-SXD19
8          BO7-TH20  BO7-TH18  BO7-TH16     BO7-SXD19 BO7-SXF18 BO7-SXD17
9          BO7-TH18  BO7-TH16  BO7-TH14     BO7-SXD17 BO7-SXF16 BO7-SXD15
10         BO7-TH16  BO7-TH14  BO7-TH12     BO7-SXD15 BO7-SXF14 BO7-SXD13
11         BO7-TH14  BO7-TH12  BO7-TH10     BO7-SXD13 BO7-SXF12 BO7-SXD11
12         BO7-TH12  BO7-TH10  BO7-TH8      BO7-SXF10 BO7-SXD9
13         BO7-TH10  BO7-TH8   BO7-TH6      BO7-SXD9

14         BI8-TH7   BI8-TH9   BI8-TH11     BI8-SXF9 BI8-SXD10
15         BI8-TH9   BI8-TH11  BI8-TH13     BI8-SXD10 BI8-SXF11 BI8-SXD12
16         BI8-TH11  BI8-TH13  BI8-TH15     BI8-SXD12 BI8-SXF13 BI8-SXD14
17         BI8-TH13  BI8-TH15  BI8-TH17     BI8-SXD14 BI8-SXF15 BI8-SXD16
18         BI8-TH15  BI8-TH17  BI8-TH19     BI8-SXD16 BI8-SXF17 BI8-SXD18
19         BI8-TH17  BI8-TH19  BI9-TH21     BI8-SXD18 BI8-SXF19 BI8-SXD20
20         BI8-TH19  BI9-TH21  BI9-TH19     BI8-SXD20 BI9-SXF21 BI9-SXD20
21         BI9-TH21  BI9-TH19  BI9-TH17     BI9-SXD20 BI9-SXF19 BI9-SXD18
22         BI9-TH19  BI9-TH17  BI9-TH15     BI9-SXD18 BI9-SXF17 BI9-SXD16
23         BI9-TH17  BI9-TH15  BI9-TH13     BI9-SXD16 BI9-SXF15 BI9-SXD14
24         BI9-TH15  BI9-TH13  BI9-TH11     BI9-SXD14 BI9-SXF13 BI9-SXD12
25         BI9-TH13  BI9-TH11  BI9-TH9      BI9-SXD12 BI9-SXF11 BI9-SXD10
26         BI9-TH11  BI9-TH9   BI9-TH7      BI9-SXD10

27         BO10-TH8   BO10-TH10  BO10-TH12  BO10-SXF10 BO10-SXD11
28         BO10-TH10  BO10-TH12  BO10-TH14  BO10-SXD11 BO10-SXF12 BO10-SXD13
29         BO10-TH12  BO10-TH14  BO10-TH16  BO10-SXD13 BO10-SXF14 BO10-SXD15
30         BO10-TH14  BO10-TH16  BO10-TH18  BO10-SXD15 BO10-SXF16 BO10-SXD17
31         BO10-TH16  BO10-TH18  BO10-TH20  BO10-SXD17 BO10-SXF18 BO10-SXD19
32         BO10-TH18  BO10-TH20  BO11-TH20  BO10-SXD19 BO10-SXF20 BO11-SXD21
33         BO10-TH20  BO11-TH20  BO11-TH18  BO11-SXD21 BO11-SXF20 BO11-SXD19
34         BO11-TH20  BO11-TH18  BO11-TH16  BO11-SXD19 BO11-SXF18 BO11-SXD17
35         BO11-TH18  BO11-TH16  BO11-TH14  BO11-SXD17 BO11-SXF16 BO11-SXD15
36         BO11-TH16  BO11-TH14  BO11-TH12  BO11-SXD15 BO11-SXF14 BO11-SXD13
37         BO11-TH14  BO11-TH12  BO11-TH10  BO11-SXD13 BO11-SXF12 BO11-SXD11
38         BO11-TH12  BO11-TH10  BO11-TH8   BO11-SXD11 BO11-SXF10 BO11-SXD9
39         BO11-TH10  BO11-TH8   BO11-TH6   BO11-SXD9

40         BI12-TH7   BI12-TH9   BI12-TH11  BI12-SXF9 BI12-SXD10
41         BI12-TH9   BI12-TH11  BI12-TH13  BI12-SXD10 BI12-SXF11 BI12-SXD12
42         BI12-TH11  BI12-TH13  BI12-TH15  BI12-SXD12 BI12-SXF13 BI12-SXD14
43         BI12-TH13  BI12-TH15  BI12-TH17  BI12-SXD14 BI12-SXF15 BI12-SXD16
44         BI12-TH15  BI12-TH17  BI12-TH19  BI12-SXD16 BI12-SXF17 BI12-SXD18
45         BI12-TH17  BI12-TH19  BI1-TH21   BI12-SXD18 BI12-SXF19 BI12-SXD20
46         BI12-TH19  BI1-TH21   BI1-TH19   BI12-SXD20 BI1-SXF21 BI1-SXD20
47         BI1-TH21   BI1-TH19   BI1-TH17   BI1-SXD20 BI1-SXF19 BI1-SXD18
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48	BI1-TH19	BI1-TH17	BI1-TH15	BI1-SXD18	BI1-SXF17	BI1-SXD16
49	BI1-TH17	BI1-TH15	BI1-TH13	BI1-SXD16	BI1-SXF15	BI1-SXD14
50	BI1-TH15	BI1-TH13	BI1-TH11	BI1-SXD14	BI1-SXF13	BI1-SXD12
51	BI1-TH13	BI1-TH11	BI1-TH9	BI1-SXD12	BI1-SXF11	BI1-SXD10
52	BI1-TH11	BI1-TH9	BI1-TH7	BI1-SXD10		
53	BO2-TH8	BO2-TH10	BO2-TH12	BO2-SXF10	BO2-SXD11	
54	BO2-TH10	BO2-TH12	BO2-TH14	BO2-SXD11	BO2-SXF12	BO2-SXD13
55	BO2-TH12	BO2-TH14	BO2-TH16	BO2-SXD13	BO2-SXF14	BO2-SXD15
56	BO2-TH14	BO2-TH16	BO2-TH18	BO2-SXD15	BO2-SXF16	BO2-SXD17
57	BO2-TH16	BO2-TH18	BO2-TH20	BO2-SXD17	BO2-SXF18	BO2-SXD19
58	BO2-TH18	BO2-TH20	BO3-TH20	BO2-SXD19	BO2-SXF20	BO3-SXD21
59	BO2-TH20	BO3-TH20	BO3-TH18	BO3-SXD21	BO3-SXF20	BO3-SXD19
60	BO3-TH20	BO3-TH18	BO3-TH16	BO3-SXD19	BO3-SXF18	BO3-SXD17
61	BO3-TH18	BO3-TH16	BO3-TH14	BO3-SXD17	BO3-SXF16	BO3-SXD15
62	BO3-TH16	BO3-TH14	BO3-TH12	BO3-SXD15	BO3-SXF14	BO3-SXD13
63	BO3-TH14	BO3-TH12	BO3-TH10	BO3-SXD13	BO3-SXF12	BO3-SXD11
64	BO3-TH12	BO3-TH10	BO3-TH8	BO3-SXD11	BO3-SXF10	BO3-SXD9
65	BO3-TH10	BO3-TH8	BO3-TH6	BO3-SXD9		
66	BI4-TH7	BI4-TH9	BI4-TH11	BI4-SXF9	BI4-SXD10	
67	BI4-TH9	BI4-TH11	BI4-TH13	BI4-SXD10	BI4-SXF11	BI4-SXD12
68	BI4-TH11	BI4-TH13	BI4-TH15	BI4-SXD12	BI4-SXF13	BI4-SXD14
69	BI4-TH13	BI4-TH15	BI4-TH17	BI4-SXD14	BI4-SXF15	BI4-SXD16
70	BI4-TH15	BI4-TH17	BI4-TH19	BI4-SXD16	BI4-SXF17	BI4-SXD18
71	BI4-TH17	BI4-TH19	BI5-TH21	BI4-SXD18	BI4-SXF19	BI4-SXD20
72	BI4-TH19	BI5-TH21	BI5-TH19	BI4-SXD20	BI5-SXF21	BI5-SXD20
73	BI5-TH21	BI5-TH19	BI5-TH17	BI5-SXD20	BI5-SXF19	BI5-SXD18
74	BI5-TH19	BI5-TH17	BI5-TH15	BI5-SXD18	BI5-SXF17	BI5-SXD16
75	BI5-TH17	BI5-TH15	BI5-TH13	BI5-SXD16	BI5-SXF15	BI5-SXD14
76	BI5-TH15	BI5-TH13	BI5-TH11	BI5-SXD14	BI5-SXF13	BI5-SXD12
77	BI5-TH13	BI5-TH11	BI5-TH9	BI5-SXD12	BI5-SXF11	BI5-SXD10
78	BI5-TH11	BI5-TH9	BI5-TH7	BI5-SXD10		

Tab. 2 lists -the correctors, bumps, and covered sextupoles for all 78 bumps (6*13) in -the RHIC Yellow ring.

No.	-------correctors---------			----covered sextupoles---------		
1	YO5-TH8	YO5-TH10	YO5-TH12	YO5-SXF10	YO5-SXD11	
2	YO5-TH10	YO5-TH12	YO5-TH14	YO5-SXD11	YO5-SXF12	YO5-SXD13
3	YO5-TH12	YO5-TH14	YO5-TH16	YO5-SXD13	YO5-SXF14	YO5-SXD15
4	YO5-TH14	YO5-TH16	YO5-TH18	YO5-SXD15	YO5-SXF16	YO5-SXD17
5	YO5-TH16	YO5-TH18	YO5-TH20	YO5-SXD17	YO5-SXF18	YO5-SXD19
6	YO5-TH18	YO5-TH20	YO4-TH20	YO5-SXD19	YO5-SXF20	YO5-SXD21
7	YO5-TH20	YO4-TH20	YO4-TH18	YO5-SXD21	YO4-SXF20	YO4-SXD19
8	YO4-TH20	YO4-TH18	YO4-TH16	YO4-SXD19	YO4-SXF18	YO4-SXD17
9	YO4-TH18	YO4-TH16	YO4-TH14	YO4-SXD17	YO4-SXF16	YO4-SXD15
10	YO4-TH16	YO4-TH14	YO4-TH12	YO4-SXD15	YO4-SXF14	YO4-SXD13
11	YO4-TH14	YO4-TH12	YO4-TH10	YO4-SXD13	YO4-SXF12	YO4-SXD11
12	YO4-TH12	YO4-TH10	YO4-TH8	YO4-SXD11	YO4-SXF10	YO4-SXD9
13	YO4-TH10	YO4-TH8	YO4-TH6	YO4-SXD9		
14	YI3-TH7	YI3-TH9	YI3-TH11	YI3-SXF9	YI3-SXD10	
15	YI3-TH9	YI3-TH11	YI3-TH13	YI3-SXD10	YI3-SXF11	YI3-SXD12
16	YI3-TH11	YI3-TH13	YI3-TH15	YI3-SXD12	YI3-SXF13	YI3-SXD14
17	YI3-TH13	YI3-TH15	YI3-TH17	YI3-SXD14	YI3-SXF15	YI3-SXD16
18	YI3-TH15	YI3-TH17	YI3-TH19	YI3-SXD16	YI3-SXF17	YI3-SXD18

19	YI3-TH17	YI3-TH19	YI3-TH21	YI3-SXD18 YI3-SXF19 YI3-SXD20
20	YI3-TH19	YI3-TH21	YI2-TH19	YI3-SXD20 YI3-SXF21 YI2-SXD20
21	YI3-TH21	YI2-TH19	YI2-TH17	YI2-SXD20 YI2-SXF19 YI2-SXD18
22	YI2-TH19	YI2-TH17	YI2-TH15	YI2-SXD18 YI2-SXF17 YI2-SXD16
23	YI2-TH17	YI2-TH15	YI2-TH13	YI2-SXD16 YI2-SXF15 YI2-SXD14
24	YI2-TH15	YI2-TH13	YI2-TH11	YI2-SXD14 YI2-SXF13 YI2-SXD12
25	YI2-TH13	YI2-TH11	YI2-TH9	YI2-SXD12 YI2-SXF11 YI2-SXD10
26	YI2-TH11	YI2-TH9	YI2-TH7	YI2-SXD10

27	YO1-TH8	YO1-TH10	YO1-TH12	YO1-SXF10 YO1-SXD11
28	YO1-TH10	YO1-TH12	YO1-TH14	YO1-SXD11 YO1-SXF12 YO1-SXD13
29	YO1-TH12	YO1-TH14	YO1-TH16	YO1-SXD13 YO1-SXF14 YO1-SXD15
30	YO1-TH14	YO1-TH16	YO1-TH18	YO1-SXD15 YO1-SXF16 YO1-SXD17
31	YO1-TH16	YO1-TH18	YO1-TH20	YO1-SXD17 YO1-SXF18 YO1-SXD19
32	YO1-TH18	YO1-TH20	YO12-TH20	YO1-SXD19 YO1-SXF20 YO1-SXD21
33	YO1-TH20	YO12-TH20	YO12-TH18	YO1-SXD21 YO12-SXF20 YO12-SXD19
34	YO12-TH20	YO12-TH18	YO12-TH16	YO12-SXD19 YO12-SXF18 YO12-SXD17
35	YO12-TH18	YO12-TH16	YO12-TH14	YO12-SXD17 YO12-SXF16 YO12-SXD15
36	YO12-TH16	YO12-TH14	YO12-TH12	YO12-SXD15 YO12-SXF14 YO12-SXD13
37	YO12-TH14	YO12-TH12	YO12-TH10	YO12-SXD13 YO12-SXF12 YO12-SXD11
38	YO12-TH12	YO12-TH10	YO12-TH8	YO12-SXD11 YO12-SXF10 YO12-SXD9
39	YO12-TH10	YO12-TH8	YO12-TH6	YO12-SXD9

40	YI11-TH7	YI11-TH9	YI11-TH11	YI11-SXF9 YI11-SXD10
41	YI11-TH9	YI11-TH11	YI11-TH13	YI11-SXD10 YI11-SXF11 YI11-SXD12
42	YI11-TH11	YI11-TH13	YI11-TH15	YI11-SXD12 YI11-SXF13 YI11-SXD14
43	YI11-TH13	YI11-TH15	YI11-TH17	YI11-SXD14 YI11-SXF15 YI11-SXD16
44	YI11-TH15	YI11-TH17	YI11-TH19	YI11-SXD16 YI11-SXF17 YI11-SXD18
45	YI11-TH17	YI11-TH19	YI11-TH21	YI11-SXD18 YI11-SXF19 YI11-SXD20
46	YI11-TH19	YI11-TH21	YI10-TH19	YI11-SXD20 YI11-SXF21 YI10-SXD20
47	YI11-TH21	YI10-TH19	YI10-TH17	YI10-SXD20 YI10-SXF19 YI10-SXD18
48	YI10-TH19	YI10-TH17	YI10-TH15	YI10-SXD18 YI10-SXF17 YI10-SXD16
49	YI10-TH17	YI10-TH15	YI10-TH13	YI10-SXD16 YI10-SXF15 YI10-SXD14
50	YI10-TH15	YI10-TH13	YI10-TH11	YI10-SXD14 YI10-SXF13 YI10-SXD12
51	YI10-TH13	YI10-TH11	YI10-TH9	YI10-SXD12 YI10-SXF11 YI10-SXD10
52	YI10-TH11	YI10-TH9	YI10-TH7	YI10-SXD10

53	YO9-TH8	YO9-TH10	YO9-TH12	YO9-SXF10 YO9-SXD11
54	YO9-TH10	YO9-TH12	YO9-TH14	YO9-SXD11 YO9-SXF12 YO9-SXD13
55	YO9-TH12	YO9-TH14	YO9-TH16	YO9-SXD13 YO9-SXF14 YO9-SXD15
56	YO9-TH14	YO9-TH16	YO9-TH18	YO9-SXD15 YO9-SXF16 YO9-SXD17
57	YO9-TH16	YO9-TH18	YO9-TH20	YO9-SXD17 YO9-SXF18 YO9-SXD19
58	YO9-TH18	YO9-TH20	YO8-TH20	YO9-SXD19 YO9-SXF20 YO9-SXD21
59	YO9-TH20	YO8-TH20	YO8-TH18	YO9-SXD21 YO8-SXF20 YO8-SXD19
60	YO8-TH20	YO8-TH18	YO8-TH16	YO8-SXD19 YO8-SXF18 YO8-SXD17
61	YO8-TH18	YO8-TH16	YO8-TH14	YO8-SXD17 YO8-SXF16 YO8-SXD15
62	YO8-TH16	YO8-TH14	YO8-TH12	YO8-SXD15 YO8-SXF14 YO8-SXD13
63	YO8-TH14	YO8-TH12	YO8-TH10	YO8-SXD13 YO8-SXF12 YO8-SXD11
64	YO8-TH12	YO8-TH10	YO8-TH8	YO8-SXD11 YO8-SXF10 YO8-SXD9
65	YO8-TH10	YO8-TH8	YO8-TH6	YO8-SXD9

66	YI7-TH7	YI7-TH9	YI7-TH11	YI7-SXF9 YI7-SXD10
67	YI7-TH9	YI7-TH11	YI7-TH13	YI7-SXD10 YI7-SXF11 YI7-SXD12
68	YI7-TH11	YI7-TH13	YI7-TH15	YI7-SXD12 YI7-SXF13 YI7-SXD14
69	YI7-TH13	YI7-TH15	YI7-TH17	YI7-SXD14 YI7-SXF15 YI7-SXD16
70	YI7-TH15	YI7-TH17	YI7-TH19	YI7-SXD16 YI7-SXF17 YI7-SXD18
71	YI7-TH17	YI7-TH19	YI7-TH21	YI7-SXD18 YI7-SXF19 YI7-SXD20

72	YI7-TH19	YI7-TH21	YI6-TH19	YI7-SXD20	YI7-SXF21	YI6-SXD20
73	YI7-TH21	YI6-TH19	YI6-TH17	YI6-SXD20	YI6-SXF19	YI6-SXD18
74	YI6-TH19	YI6-TH17	YI6-TH15	YI6-SXD18	YI6-SXF17	YI6-SXD16
75	YI6-TH17	YI6-TH15	YI6-TH13	YI6-SXD16	YI6-SXF15	YI6-SXD14
76	YI6-TH15	YI6-TH13	YI6-TH11	YI6-SXD14	YI6-SXF13	YI6-SXD12
77	YI6-TH13	YI6-TH11	YI6-TH9	YI6-SXD12	YI6-SXF11	YI6-SXD10
78	YI6-TH11	YI6-TH9	YI6-TH7	YI6-SXD10		

These tables can be used to set up scripts to iterate through all the bumps, as described in the next section. They can also be used to correlate bump anomalies and possible miswired sextupoles during offline and online data analysis.

2.2 Beam Experiment and Results

In RHIC run_06, the above method was used to check all chromaticity sextupole polarities in RHIC during the APEX beam study period of March 22, 2006, starting at 14:50. The machine ramp and stone were pp30::injection. The rings were decoupled at injection, and the tunes were separated to avoid coupling interference in tune measurements. Scripts were written to adjust consecutive three-bumps with +5 mm amplitudes through the arcs in each ring while monitoring and logging the tunes with the BBQ tunemeter system and orbits in all BPMs. Each bump took 25–30 seconds; the total data acquisition time for both rings was under two hours. The blue ring was scanned first, and then the yellow ring. The scripts record timestamps for each bump, and these records were later used to correlate bumps to logged BBQ tunemeter stripchart data.

Fig. 5 shows BBQ tunemeter data acquired during the scan of the blue ring. This data includes tests of the bumps, and proceeds in groups from arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. There are two anomalies at 15:02 and 15:09 — these are the result of bumps that were not removed before the next bump was applied, and are not due to miswired sextupoles. Comparison of data in this figure to simulation indicates that all chromaticity sextupoles in the RHIC blue ring are wired correctly. A zoom of this data showing the details of tune response in correctly wired chromaticity sextupoles is shown in Fig. 6.

Fig. 7 shows BBQ tunemeter data acquired during the scan of the yellow ring. This data also includes tests of the bumps, and proceeds in groups from arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. This data is significantly harder to interpret from 16:08 to 16:18, when control system problems interfered with the three-bump script operation. This data was removed, and remaining yellow measurements were manually compared to the script logs and simulations. This comparison indicated that one sextupole, yo4-sxd9, had a reversed polarity. Once understood, this is fairly easy to see in data in Fig. 7 at 16:19:33, where the vertical tune clearly moves in the wrong direction. The wiring for this sextupole was corrected on April 4, 2006, and the correct polarity was confirmed with this method on April 12.

Both BBQ measurements show base tunes that gradually increase with time. This tune shift is about 0.002 up in both planes over about one hour, inconsistent with tune drift from persistent currents. This is likely due to some sort of systematic drift in the BBQ data, or feed-down effects of slow orbit drifts.

During the beam study, horizontal orbit motion due to in the arcs was also noted when bumps were applied. For constant frequency, the momentum shift due to a fractional closed orbit length change $\Delta C/C$ is $\delta = \gamma_T^2\ \Delta C/C$. Observed orbit motion outside of the bump in regular arcs of RHIC was 0.5 mm, corresponding to a fractional energy change of $\delta = 2.5 \times 10^{-4}$ and a fractional closed orbit length change of $\Delta C/C = 5 \times 10^{-6}$. This is completely consistent with the +5 mm horizontal bumps used along three-bumps that have 30 m between correctors in the RHIC arcs. The horizontal orbit motion from this effect in other chromaticity sextupoles is 10% of the bump size; this effect can be neglected when determining sextupole polarities, but should be included for measurement of optics from this data.

3 Conclusions

We have presented a beam-based method to check RHIC chromaticity sextupole polarities using local horizontal orbit three-bumps. This method was successfully used to check all sextupoles in RHIC in March, 2006. All blue chromaticity sextupoles had correct polarities verified; in the yellow ring, a single sextupole, yo4-sxd9, was found to be reversed. The wiring for this sextupole was corrected on April 4 2006, and the corrected polarity was confirmed during another beam study on April 12 2006.

4 Acknowledgements

We thank Johan Bengtsson, and Rama Calaga for help with the data acquisition during the beam experiment, and C-AD operations for their support.

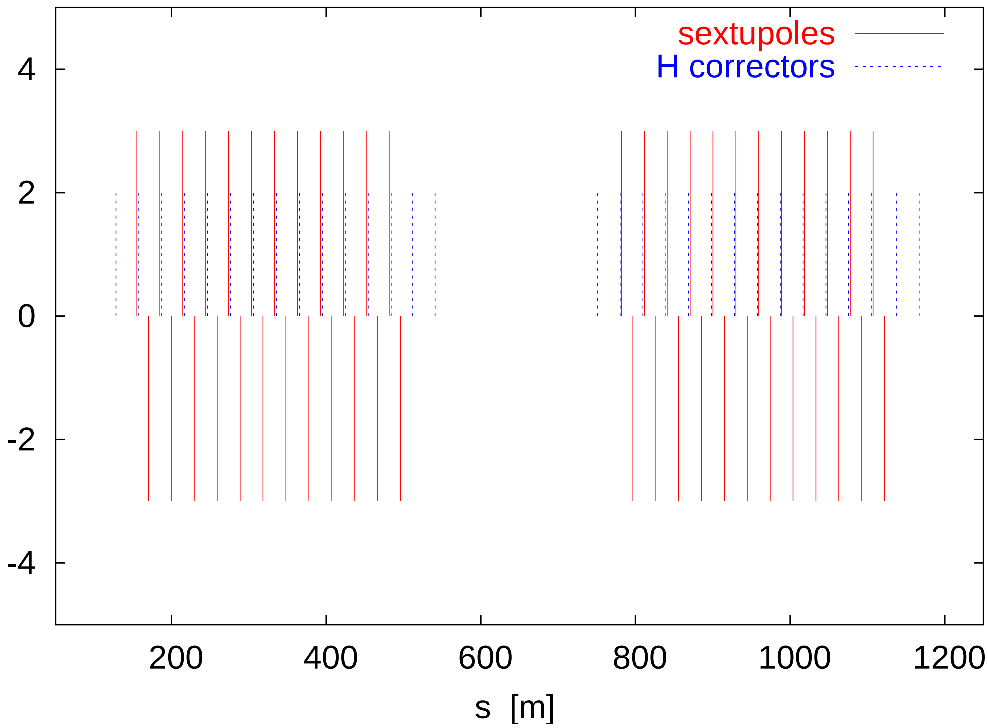

Figure 1: Sextupoles and horizontal correctors in the first two RHIC Blue ring arcs.

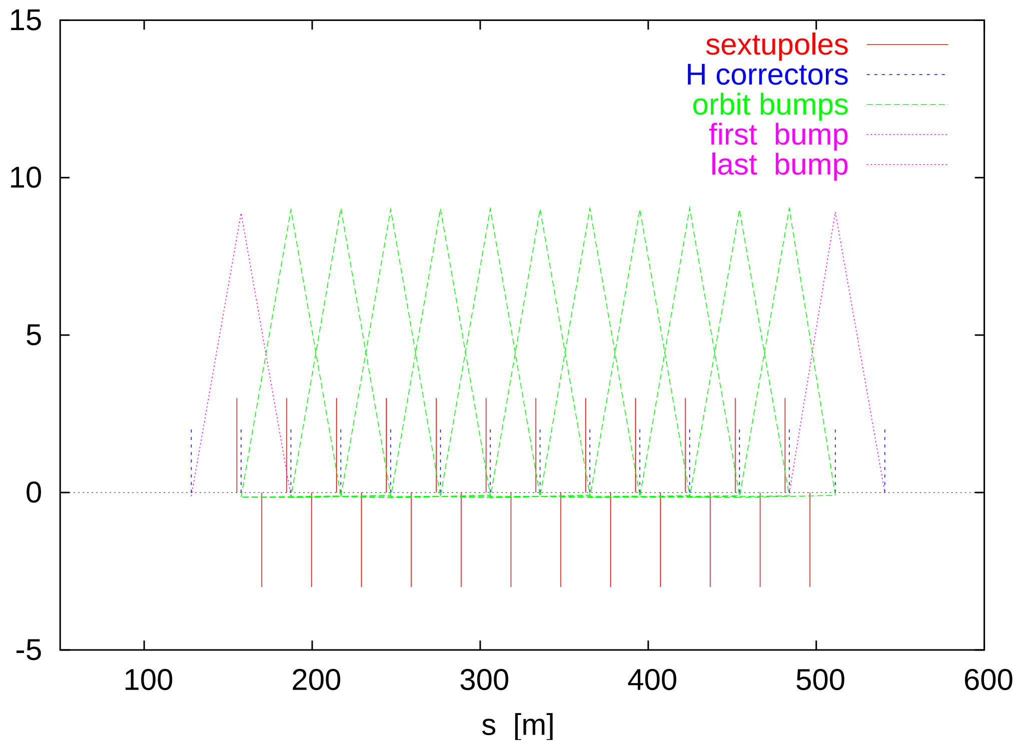

Figure 2: Proposed corrector based bumps in the first arc.

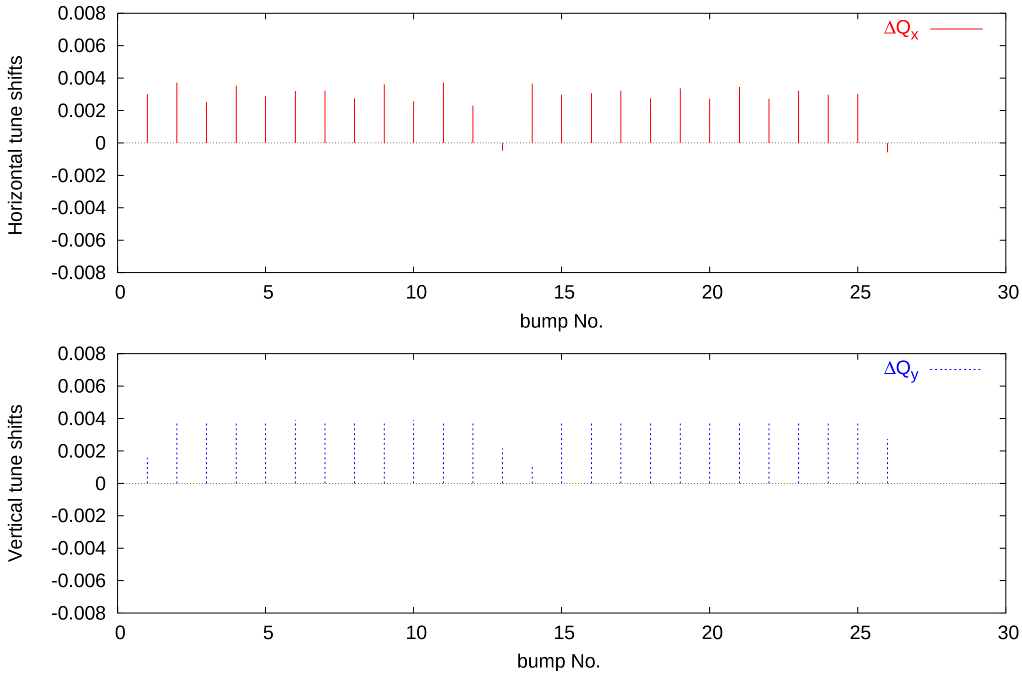

Figure 3: With no wrong sextupole polarities: simulated tune shifts for the bumps in the first two Blue ring arcs

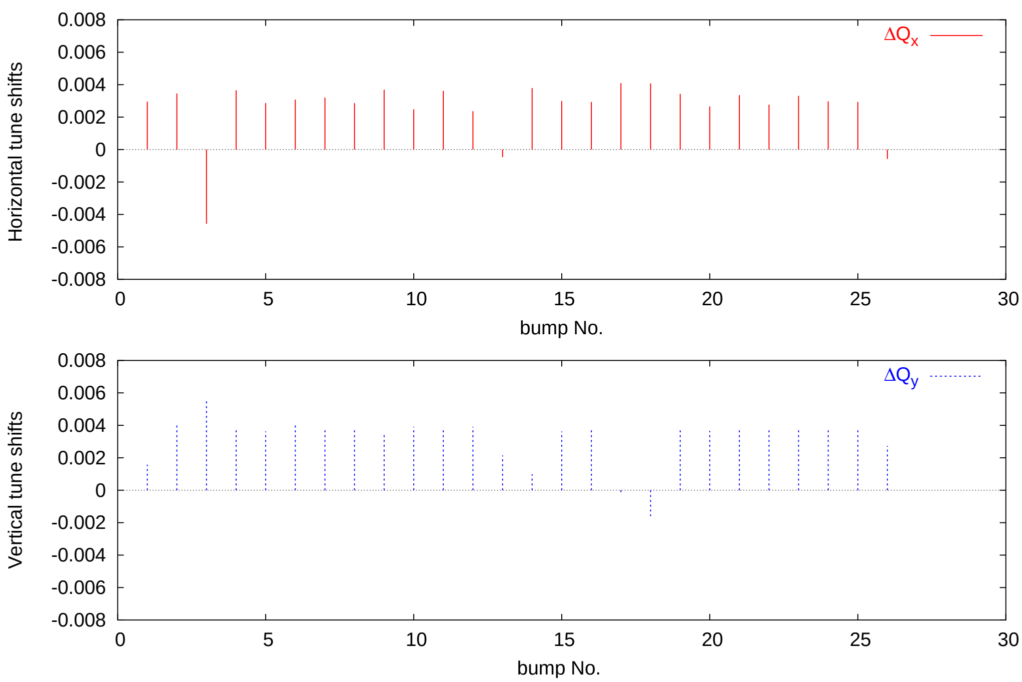

Figure 4: With two reversed sextupole polarities: simulated tune shifts for the bumps in the first two Blue ring arcs.

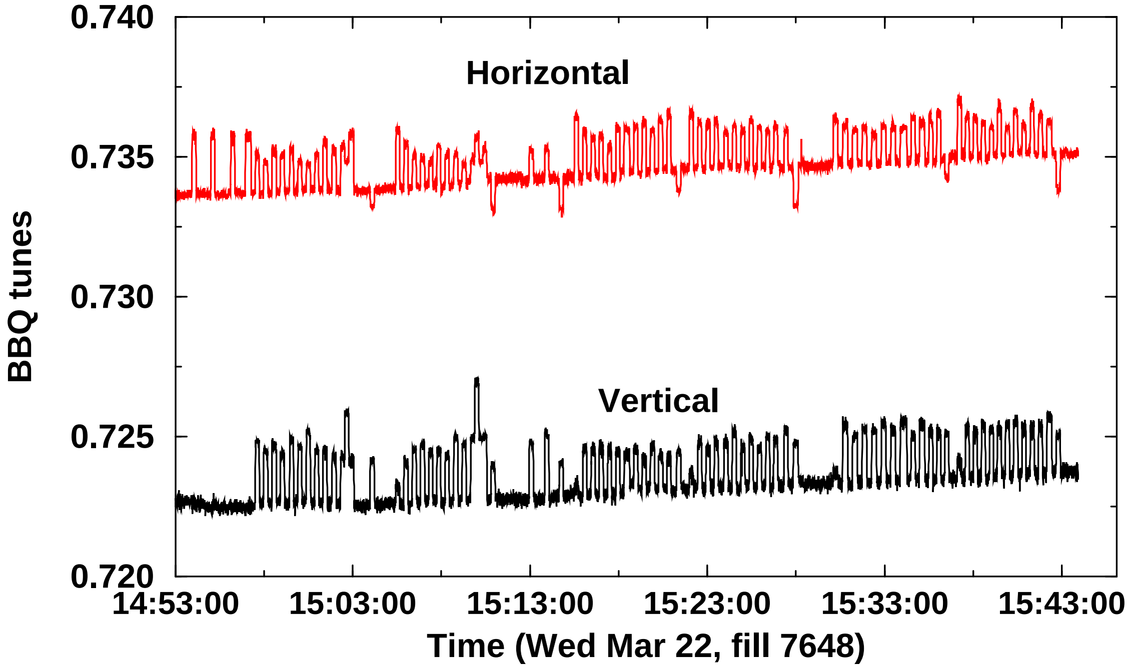

Figure 5: Blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. Anomalies at 15:02 and 15:09 are the result of bumps not being removed, and are not due to miswired sextupoles.

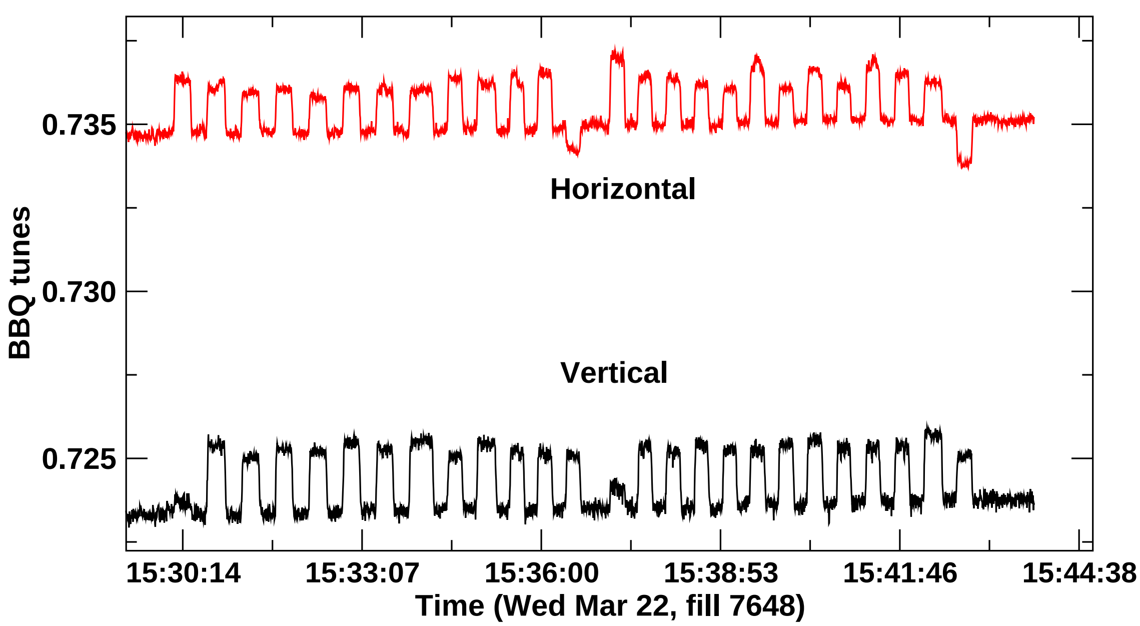

Figure 6: A zoom of the blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 6/7, and 8/9 o'clock, showing detailed bump configurations for correctly wired chromaticity sextupoles.

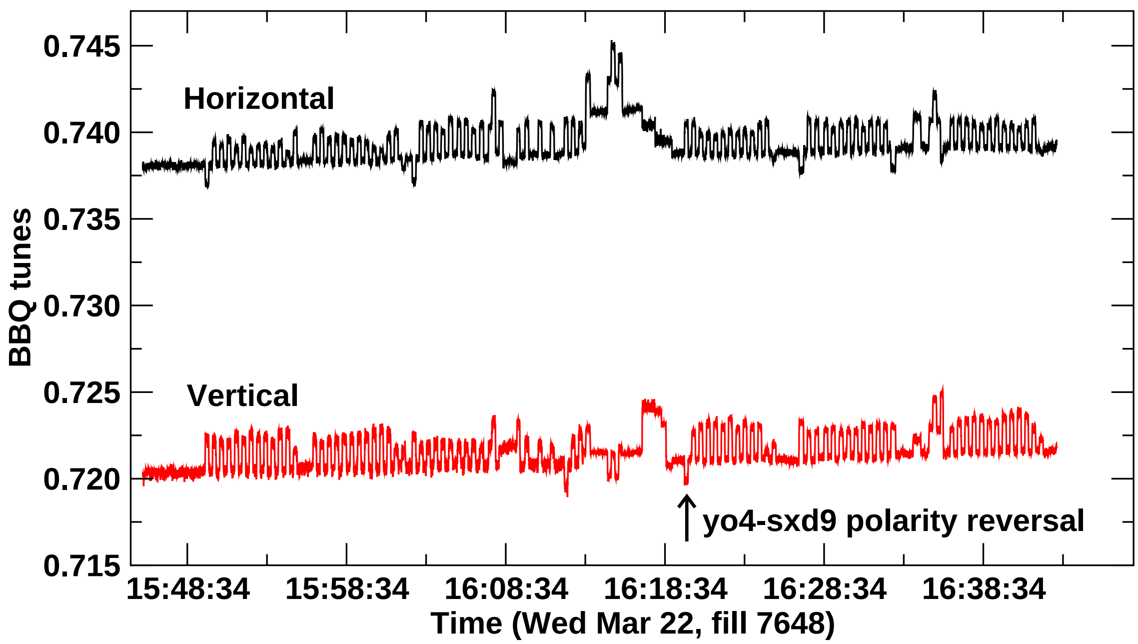

Figure 7: Yellow BBQ tunemeter data acquired for scans of yellow ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. The bump at 16:19 indicates a polarity reversal of chromaticity sextupole yo4-sxd9.