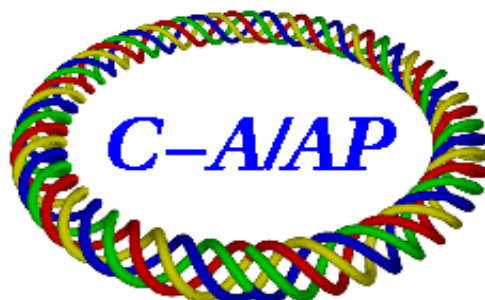


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This note presents a beam-based method to check RHIC arc sextupole polarities using local horizontal orbit three-bumps at injection energy. We use 11 bumps in each arc, each covering two SFs (focusing sextupoles) and one SD (defocusing sextupole). 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:

$$\begin{cases} \Delta Q_x &= \frac{1}{4\pi}\beta_x(k_2L)\Delta x_{co}, \\ \Delta Q_y &= -\frac{1}{4\pi}\beta_y(k_2L)\Delta x_{co} \end{cases}, \quad (1)$$

where (β_x, β_y) are the horizontal and vertical beta functions at the sextupole, (k_2L) 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_2L) , 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

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

where θ_i , $i = 1, 2, 3$, is the kicking strength for i th 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	B06-TH8	B06-TH10	B06-TH12	B06-SXF10	B06-SXD11	
2	B06-TH10	B06-TH12	B06-TH14	B06-SXD11	B06-SXF12	B06-SXD13
3	B06-TH12	B06-TH14	B06-TH16	B06-SXD13	B06-SXF14	B06-SXD15
4	B06-TH14	B06-TH16	B06-TH18	B06-SXD15	B06-SXF16	B06-SXD17
5	B06-TH16	B06-TH18	B06-TH20	B06-SXD17	B06-SXF18	B06-SXD19
6	B06-TH18	B06-TH20	B07-TH20	B06-SXD19	B06-SXF20	B07-SXD21
7	B06-TH20	B07-TH20	B07-TH18	B07-SXD21	B07-SXF20	B07-SXD19
8	B07-TH20	B07-TH18	B07-TH16	B07-SXD19	B07-SXF18	B07-SXD17
9	B07-TH18	B07-TH16	B07-TH14	B07-SXD17	B07-SXF16	B07-SXD15
10	B07-TH16	B07-TH14	B07-TH12	B07-SXD15	B07-SXF14	B07-SXD13
11	B07-TH14	B07-TH12	B07-TH10	B07-SXD13	B07-SXF12	B07-SXD11
12	B07-TH12	B07-TH10	B07-TH8	B07-SXF10	B07-SXD9	
13	B07-TH10	B07-TH8	B07-TH6	B07-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	B010-TH8	B010-TH10	B010-TH12	B010-SXF10	B010-SXD11	
28	B010-TH10	B010-TH12	B010-TH14	B010-SXD11	B010-SXF12	B010-SXD13
29	B010-TH12	B010-TH14	B010-TH16	B010-SXD13	B010-SXF14	B010-SXD15
30	B010-TH14	B010-TH16	B010-TH18	B010-SXD15	B010-SXF16	B010-SXD17
31	B010-TH16	B010-TH18	B010-TH20	B010-SXD17	B010-SXF18	B010-SXD19
32	B010-TH18	B010-TH20	B011-TH20	B010-SXD19	B010-SXF20	B011-SXD21
33	B010-TH20	B011-TH20	B011-TH18	B011-SXD21	B011-SXF20	B011-SXD19
34	B011-TH20	B011-TH18	B011-TH16	B011-SXD19	B011-SXF18	B011-SXD17
35	B011-TH18	B011-TH16	B011-TH14	B011-SXD17	B011-SXF16	B011-SXD15
36	B011-TH16	B011-TH14	B011-TH12	B011-SXD15	B011-SXF14	B011-SXD13
37	B011-TH14	B011-TH12	B011-TH10	B011-SXD13	B011-SXF12	B011-SXD11
38	B011-TH12	B011-TH10	B011-TH8	B011-SXD11	B011-SXF10	B011-SXD9
39	B011-TH10	B011-TH8	B011-TH6	B011-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

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	B02-TH8	B02-TH10	B02-TH12	B02-SXF10	B02-SXD11	
54	B02-TH10	B02-TH12	B02-TH14	B02-SXD11	B02-SXF12	B02-SXD13
55	B02-TH12	B02-TH14	B02-TH16	B02-SXD13	B02-SXF14	B02-SXD15
56	B02-TH14	B02-TH16	B02-TH18	B02-SXD15	B02-SXF16	B02-SXD17
57	B02-TH16	B02-TH18	B02-TH20	B02-SXD17	B02-SXF18	B02-SXD19
58	B02-TH18	B02-TH20	B03-TH20	B02-SXD19	B02-SXF20	B03-SXD21
59	B02-TH20	B03-TH20	B03-TH18	B03-SXD21	B03-SXF20	B03-SXD19
60	B03-TH20	B03-TH18	B03-TH16	B03-SXD19	B03-SXF18	B03-SXD17
61	B03-TH18	B03-TH16	B03-TH14	B03-SXD17	B03-SXF16	B03-SXD15
62	B03-TH16	B03-TH14	B03-TH12	B03-SXD15	B03-SXF14	B03-SXD13
63	B03-TH14	B03-TH12	B03-TH10	B03-SXD13	B03-SXF12	B03-SXD11
64	B03-TH12	B03-TH10	B03-TH8	B03-SXD11	B03-SXF10	B03-SXD9
65	B03-TH10	B03-TH8	B03-TH6	B03-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	Y05-TH8	Y05-TH10	Y05-TH12	Y05-SXF10	Y05-SXD11	
2	Y05-TH10	Y05-TH12	Y05-TH14	Y05-SXD11	Y05-SXF12	Y05-SXD13
3	Y05-TH12	Y05-TH14	Y05-TH16	Y05-SXD13	Y05-SXF14	Y05-SXD15
4	Y05-TH14	Y05-TH16	Y05-TH18	Y05-SXD15	Y05-SXF16	Y05-SXD17
5	Y05-TH16	Y05-TH18	Y05-TH20	Y05-SXD17	Y05-SXF18	Y05-SXD19
6	Y05-TH18	Y05-TH20	Y04-TH20	Y05-SXD19	Y05-SXF20	Y05-SXD21
7	Y05-TH20	Y04-TH20	Y04-TH18	Y05-SXD21	Y04-SXF20	Y04-SXD19
8	Y04-TH20	Y04-TH18	Y04-TH16	Y04-SXD19	Y04-SXF18	Y04-SXD17
9	Y04-TH18	Y04-TH16	Y04-TH14	Y04-SXD17	Y04-SXF16	Y04-SXD15
10	Y04-TH16	Y04-TH14	Y04-TH12	Y04-SXD15	Y04-SXF14	Y04-SXD13
11	Y04-TH14	Y04-TH12	Y04-TH10	Y04-SXD13	Y04-SXF12	Y04-SXD11
12	Y04-TH12	Y04-TH10	Y04-TH8	Y04-SXD11	Y04-SXF10	Y04-SXD9
13	Y04-TH10	Y04-TH8	Y04-TH6	Y04-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	Y01-TH8	Y01-TH10	Y01-TH12	Y01-SXF10	Y01-SXD11	
28	Y01-TH10	Y01-TH12	Y01-TH14	Y01-SXD11	Y01-SXF12	Y01-SXD13
29	Y01-TH12	Y01-TH14	Y01-TH16	Y01-SXD13	Y01-SXF14	Y01-SXD15
30	Y01-TH14	Y01-TH16	Y01-TH18	Y01-SXD15	Y01-SXF16	Y01-SXD17
31	Y01-TH16	Y01-TH18	Y01-TH20	Y01-SXD17	Y01-SXF18	Y01-SXD19
32	Y01-TH18	Y01-TH20	Y012-TH20	Y01-SXD19	Y01-SXF20	Y01-SXD21
33	Y01-TH20	Y012-TH20	Y012-TH18	Y01-SXD21	Y012-SXF20	Y012-SXD19
34	Y012-TH20	Y012-TH18	Y012-TH16	Y012-SXD19	Y012-SXF18	Y012-SXD17
35	Y012-TH18	Y012-TH16	Y012-TH14	Y012-SXD17	Y012-SXF16	Y012-SXD15
36	Y012-TH16	Y012-TH14	Y012-TH12	Y012-SXD15	Y012-SXF14	Y012-SXD13
37	Y012-TH14	Y012-TH12	Y012-TH10	Y012-SXD13	Y012-SXF12	Y012-SXD11
38	Y012-TH12	Y012-TH10	Y012-TH8	Y012-SXD11	Y012-SXF10	Y012-SXD9
39	Y012-TH10	Y012-TH8	Y012-TH6	Y012-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	Y09-TH8	Y09-TH10	Y09-TH12	Y09-SXF10	Y09-SXD11	
54	Y09-TH10	Y09-TH12	Y09-TH14	Y09-SXD11	Y09-SXF12	Y09-SXD13
55	Y09-TH12	Y09-TH14	Y09-TH16	Y09-SXD13	Y09-SXF14	Y09-SXD15
56	Y09-TH14	Y09-TH16	Y09-TH18	Y09-SXD15	Y09-SXF16	Y09-SXD17
57	Y09-TH16	Y09-TH18	Y09-TH20	Y09-SXD17	Y09-SXF18	Y09-SXD19
58	Y09-TH18	Y09-TH20	Y08-TH20	Y09-SXD19	Y09-SXF20	Y09-SXD21
59	Y09-TH20	Y08-TH20	Y08-TH18	Y09-SXD21	Y08-SXF20	Y08-SXD19
60	Y08-TH20	Y08-TH18	Y08-TH16	Y08-SXD19	Y08-SXF18	Y08-SXD17
61	Y08-TH18	Y08-TH16	Y08-TH14	Y08-SXD17	Y08-SXF16	Y08-SXD15
62	Y08-TH16	Y08-TH14	Y08-TH12	Y08-SXD15	Y08-SXF14	Y08-SXD13
63	Y08-TH14	Y08-TH12	Y08-TH10	Y08-SXD13	Y08-SXF12	Y08-SXD11
64	Y08-TH12	Y08-TH10	Y08-TH8	Y08-SXD11	Y08-SXF10	Y08-SXD9
65	Y08-TH10	Y08-TH8	Y08-TH6	Y08-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.

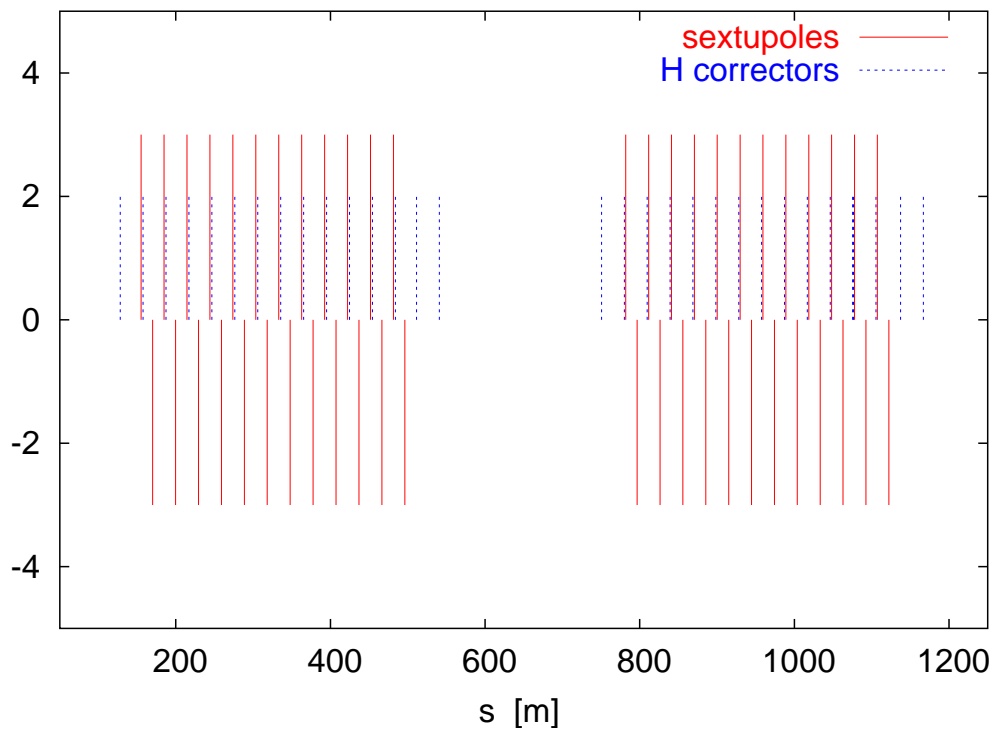


Figure 1: Sextupoles and horizontal correctors in the first two RHIC Blue ring arcs.

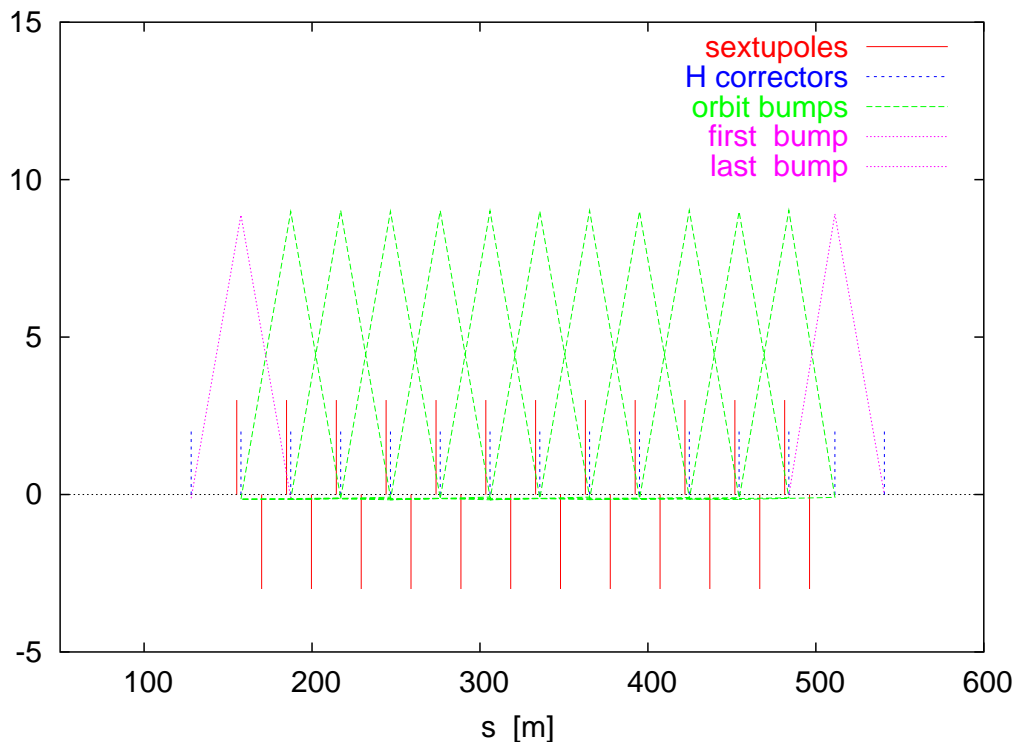


Figure 2: Proposed corrector based bumps in the first arc.

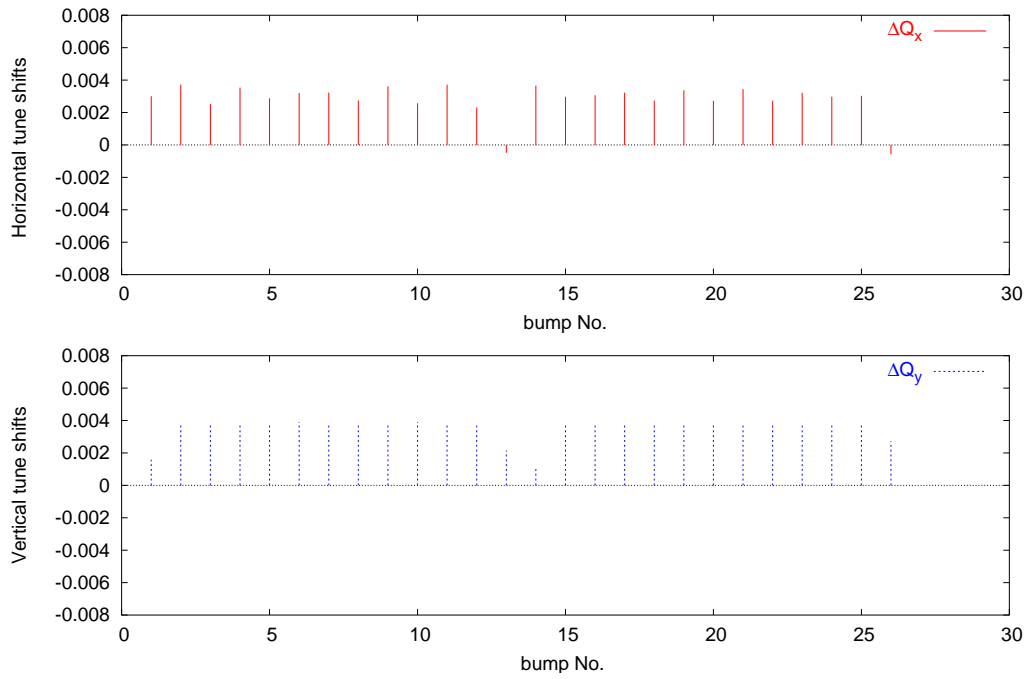


Figure 3: With no wrong sextupole polarities: simulated tune shifts for the bumps in the first two Blue ring arcs

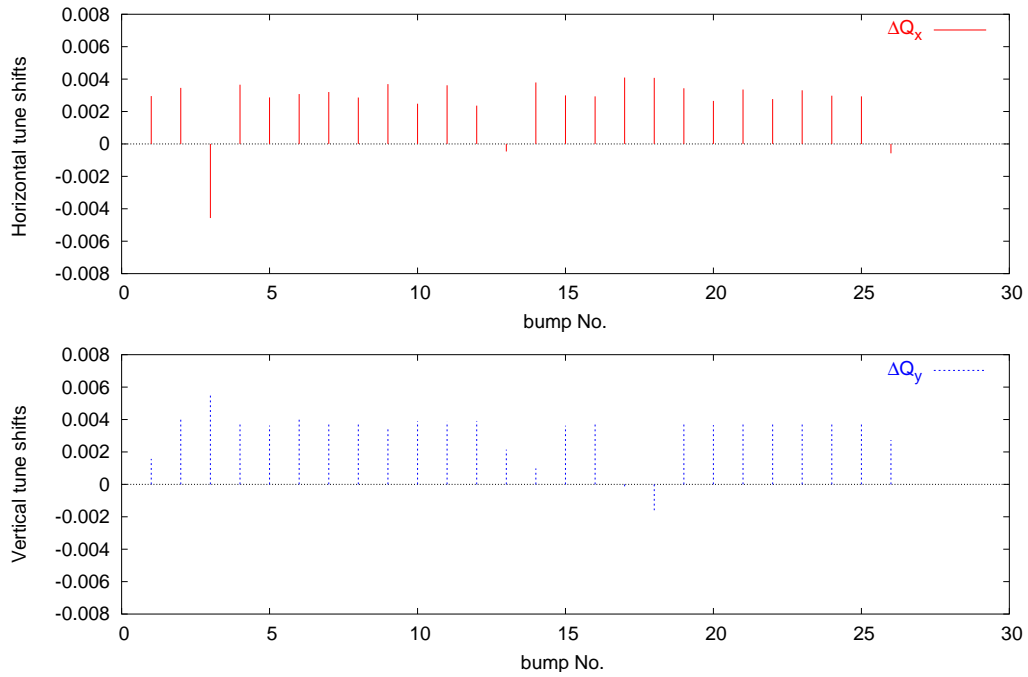


Figure 4: With two reversed sextupole polarities: simulated tune shifts for the bumps in the first two Blue ring arcs.

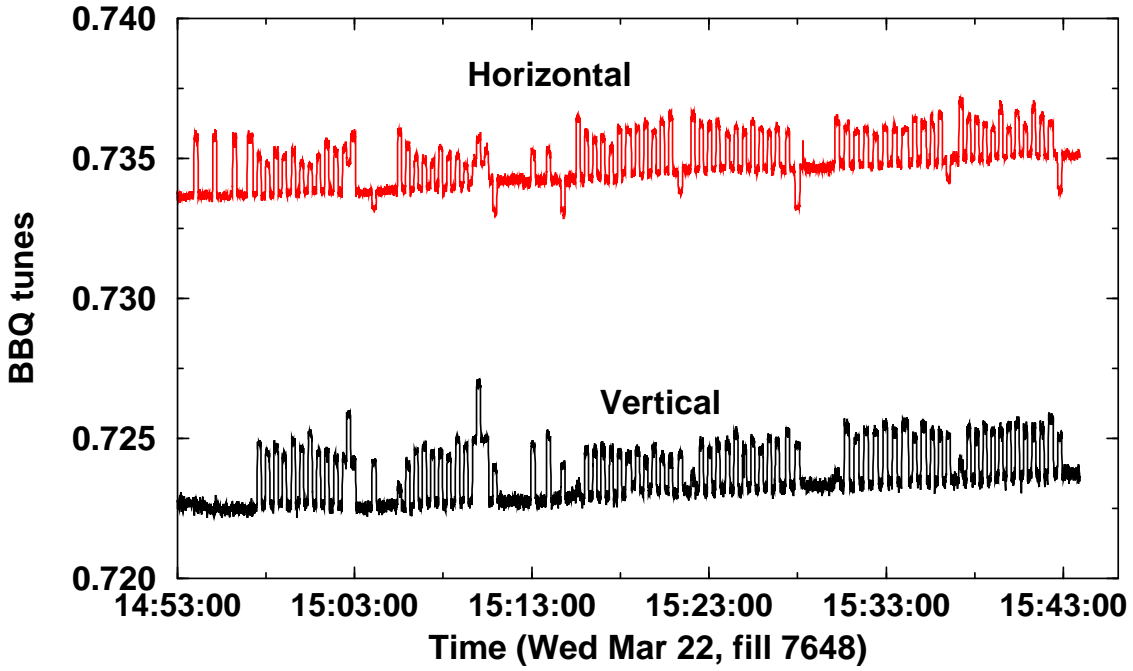


Figure 5: Blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. Anomalies at 15:02 and 15:09 are the result of bumps not being removed, and are not due to miswired sextupoles.

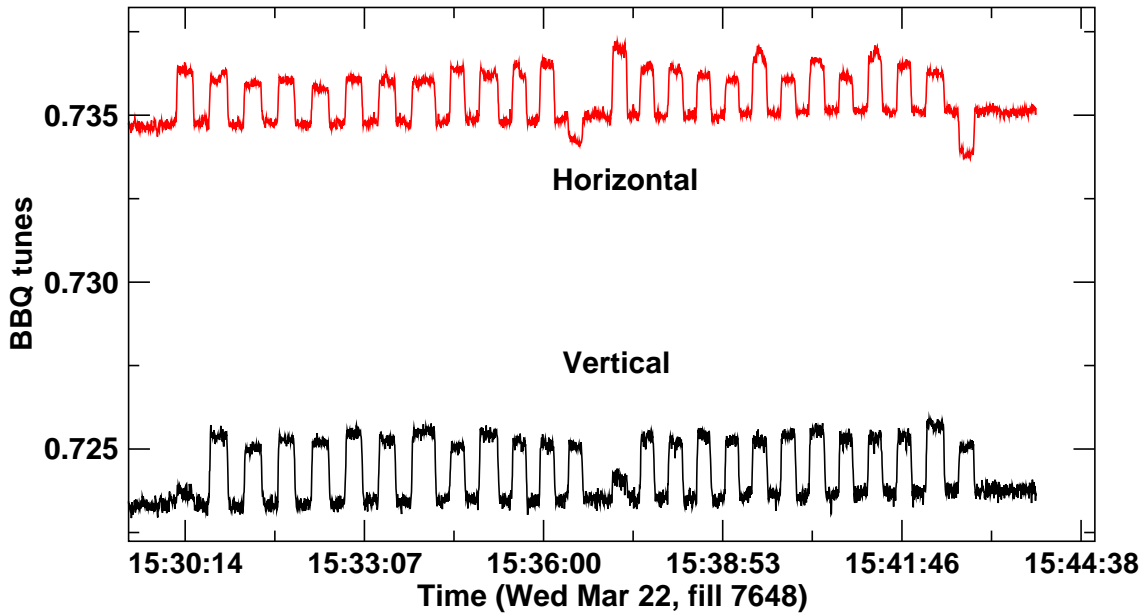


Figure 6: A zoom of the blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 6/7, and 8/9 o'clock, showing detailed bump configurations for correctly wired chromaticity sextupoles.

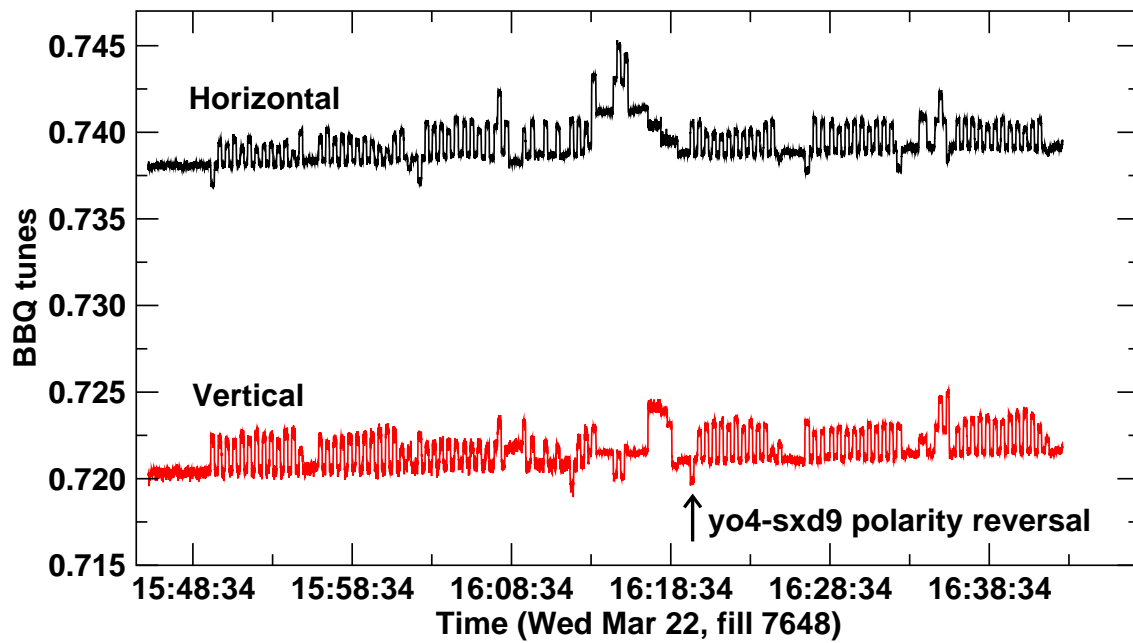


Figure 7: Yellow BBQ tunemeter data acquired for scans of yellow ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. The bump at 16:19 indicates a polarity reversal of chromaticity sextupole yo4-sxd9.