RHIC BBA Measurement, Analysis & Related Issues

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BBA Measurements During APEX 5/30/2012

(25 in Blue, 21 in Yellow, Incomplete list)

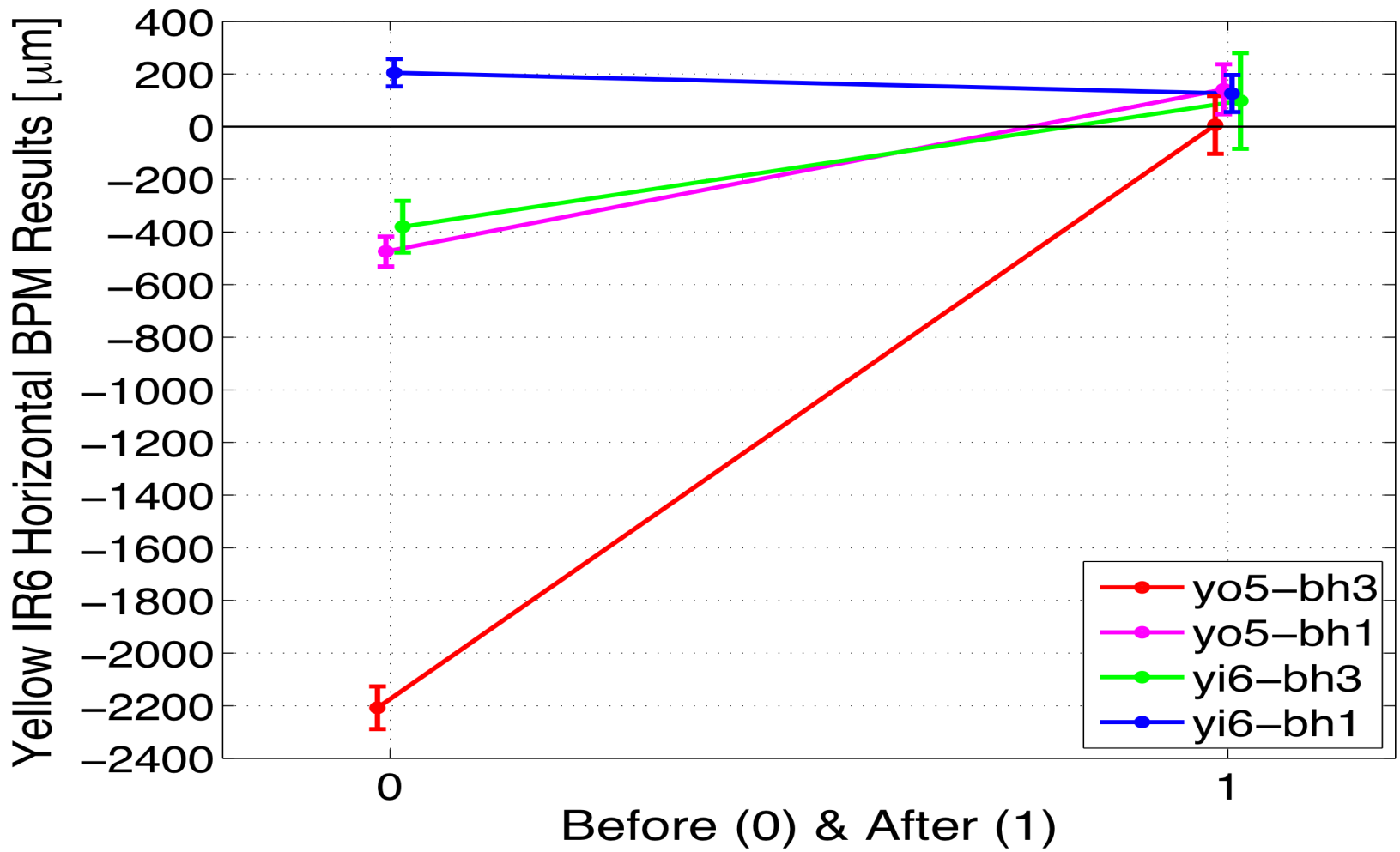
BPM	QUAD	DATE & TIME	Result [mm]	Adjusted Result	Error [µm]
bi5-bh3	bi5-qf3	5/30/2012 12:42:49	0.081	-1.232	140
bi5-bv3	bi5-qf3	5/30/2012 12:47:07	-0.165	0.689	92
bo7-bh3	bo7-qd3	5/30/2012 12:50:40	0.505	-0.231	133
bo7-bv1	bo7-qd1	5/30/2012 13:00:11	-0.483	0.250	96
bo7-bv3	bo7-qd3	5/30/2012 12:53:41	-0.328	0.858	132
bo7-bh1	bo7-qd1	5/30/2012 12:57:23	0.176	0.673	139
bi8-bh1	bi8-qf1	5/30/2012 13:03:16	0.177	1.292	158
bi8-bv1	bi8-qf1	5/30/2012 13:06:11	-0.143	0.385	575
bi8-bh3	bi8-qf3	5/30/2012 13:09:57	0.254	-0.540	126
bi8-bv3	bi8-qf3	5/30/2012 13:13:15	-0.076	1.271	133
bi9-bh3	bi9-qf3	5/30/2012 13:16:08	-1.616	-1.691	330
bi9-bv3	bi9-qf3	5/30/2012 13:19:07	-0.500	1.095	339
bi9-bh1	bi9-qf1	5/30/2012 13:22:26	0.201	-0.193	151
bi9-bv1	bi9-qf1	5/30/2012 13:25:21	0.102	0.286	217

BPM	QUAD	DATE & TIME	Result [mm]	Adjusted Result	Error [µm]
bo10-bh1	bo10-qd1	5/30/2012 13:28:12	0.472	1.144	245
bo10-bv1	bo10-qd1	5/30/2012 13:31:10	-0.930	-0.697	122
bo10-bh3	bo10-qd3	5/30/2012 13:34:37	0.504	0.208	57
bo10-bv3	bo10-qd3	5/30/2012 13:37:29	0.169	0.935	64
bo11-bh3	bo11-qd3	5/30/2012 13:40:53	-0.061	-0.185	146
bo11-bv3	bo11-qd3	5/30/2012 13:44:06	-0.808	0.667	72
bo11-bh1	bo11-qd1	5/30/2012 13:47:11	0.339	0.232	132
bo11-bv1	bo11-qd1	5/30/2012 13:50:21	-0.231	0.046	122
bi12-bh1	bi12-qf1	5/30/2012 13:53:15	0.018	0.244	276
bi12-bv1	bi12-qf1	5/30/2012 13:56:13	-0.201	-0.091	70
bi12-bh3	bi12-qf3	5/30/2012 13:59:07	-0.113	-0.986	138
yo8-bh1	yo8-qd1	5/30/2012 13:26:34	0.384	0.853	366
yo8-bv1	yo8-qd1	5/30/2012 13:29:52	-0.663	0.012	158

...

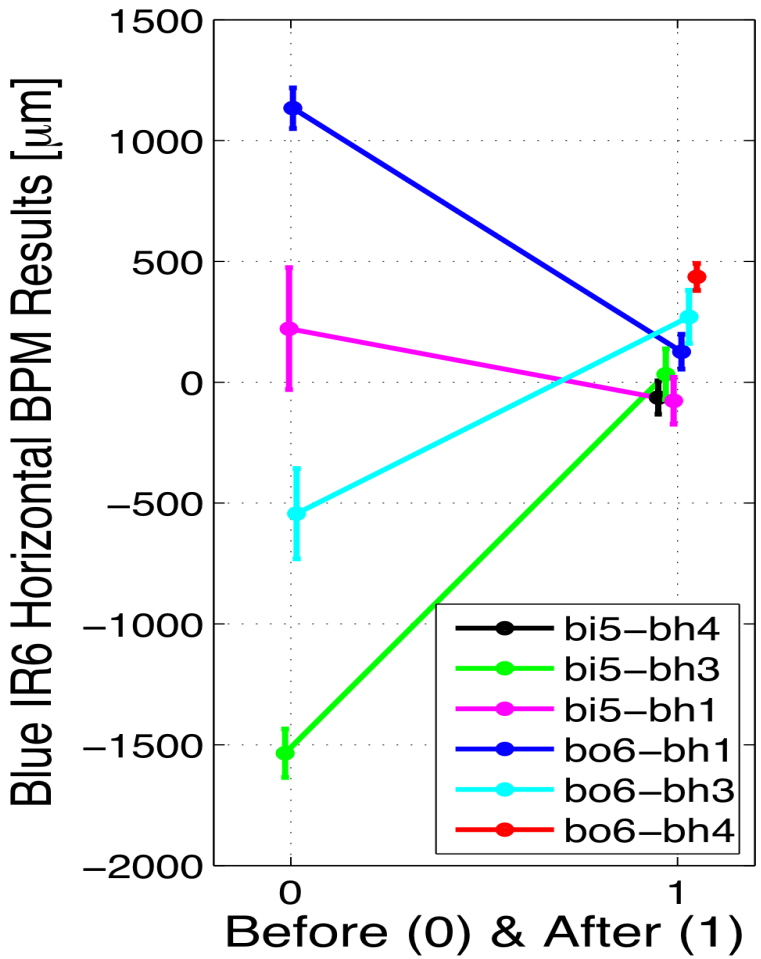
Results from the BBA Analysis

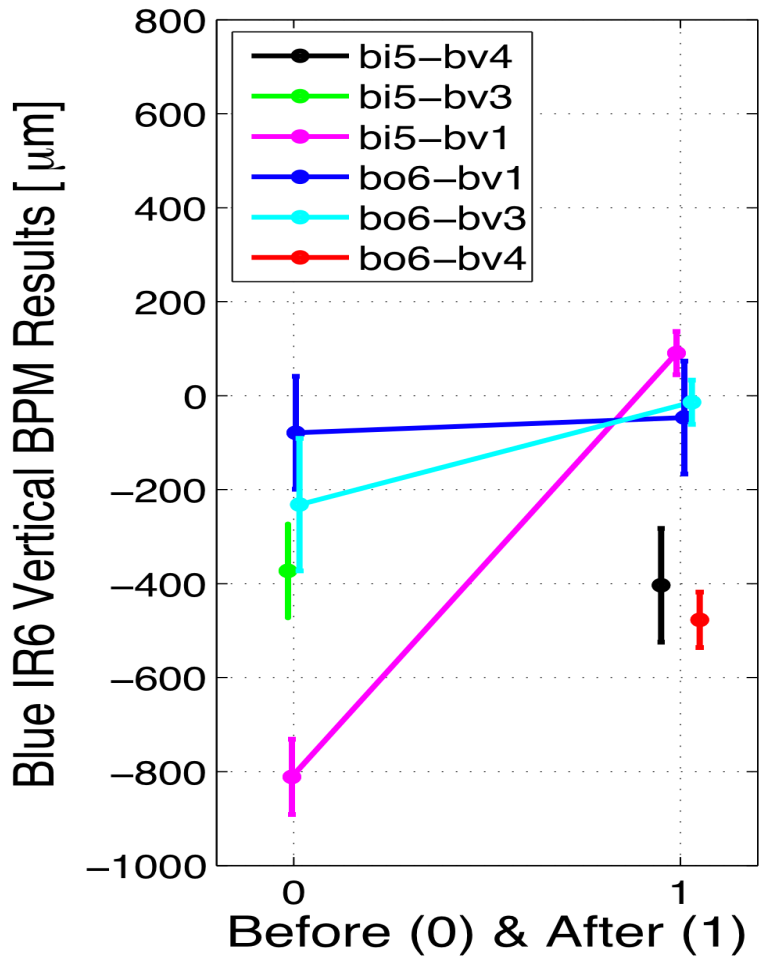
Yellow IR 6, measured 5/2/2012, installed 5/7/2012, re-measured 5/16/2012



Results from the BBA Analysis

Blue IR6 BPM results (APEX 5/2/2012, bi5-bv3 not working)





BBA Measurement Status (at Q1 & Q3)

During RHIC run12

	bh1	bv1	bh3	bv3		bh1	bv1	bh3	bv3
bi1-					yo1-	5/30/12	5/30/12	5/30/12	5/30/12
bo2-					yi2-	5/30/12	5/30/12	5/30/12	
bo3-					yi3-			5/30/12	
bi4-					yo4-				
bi5-	5/2/12	5/2/12	5/30/12	5/30/12	yo5-	5/16/12	5/16/12	5/16/12	5/16/12
bo6-	5/2/12	5/2/12	5/2/12	5/2/12	yi6-	5/16/12	5/16/12	5/16/12	5/16/12
bo7-	5/30/12	5/30/12	5/30/12	5/30/12	yi7-	5/16/12	5/16/12	5/16/12	5/16/12
bi8-	5/30/12	5/30/12	5/30/12	5/30/12	yo8-	5/30/12	5/30/12	5/17/12	5/17/12
bi9-	5/30/12	5/30/12	5/30/12	5/30/12	yo9-	5/17/12	5/30/12	5/30/12	5/30/12
bo10-	5/30/12	5/30/12	5/30/12	5/30/12	yi10-	5/17/12	5/30/12	5/17/12	5/30/12
bo11-	5/30/12	5/30/12	5/30/12	5/30/12	yi11-	5/17/12	5/30/12	5/30/12	5/30/12
bi12-	5/30/12	5/30/12	5/30/12		yo12-	5/30/12	5/30/12	5/17/12	5/30/12

Summary

1. There are 48 BPMs (Q1 &Q3) in each ring.
2. Measured 31 in Blue, 40 in Yellow
3. Complete all measurement in IR6 and IR8 in both rings
4. Confirmed some of them. Results are generally good.
5. Needs 3 hours in both rings (to get a complete set of data for the next year and to confirm the few very large offsets).

Goal of this BBA Session

1. Verify the BBA results from the previous measurements (last APEX and/or last two years);
2. Obtain BBA measurements on other BPMs;
3. Test a possibly more thorough BBA measurement procedure and compare the results to that of previous BBA measurement. The procedure is to do BBA systematically on all the measurable quad/BPM in IR one-by-one from upstream to downstream: (a) Starting BBA measurement from Q4trim/BPM4 pair upstream of IP; (b) use 3 correctors to put the beam through the center of Q4trim found through step (a); (c) move on to BBA measurement on Q3/BPM3 and Q1/BPM1; (d) move the beam to the center of Q1 before moving on to the Q1/BPM1 on the other side of IP…
4. Test possible strategy for beam alignment (optimum beam path) through IR (Q4-Q3-Q2-Q1-Q1-Q2-Q3-Q4) by iteration through the following steps: (a) BBA measurements in the section (6 BPMs, horizontal and vertical) and find the correction to BPMs; (b) include the BPM corrections into a target orbit; c) apply orbit feedback to move the beam as close to the targeted orbit as possible. Then repeat (a) to (c) to see if the result converges.

Procedure of this BBA Session

The BBA results in ROUND 0:

(a) Install the offsets based on the best results from previous BBA sessions.
(b) Use liveFeedback to send the orbit at all BPMs in IR6 to zero mm (or, as close as Feedback could make it) before starting Round 1.

For each measurement in ROUND 1:

(a) Took a BBA measurement on the 1st quad upstream of IR;
(b) installed the offset into the BPM;
(c) run liveFeedback for ~10 seconds to re-zero beam on those BPMs using the newly installed orbPositionOffsetS value;
(d) On the next BPM downstream, repeat steps (a) to (c).

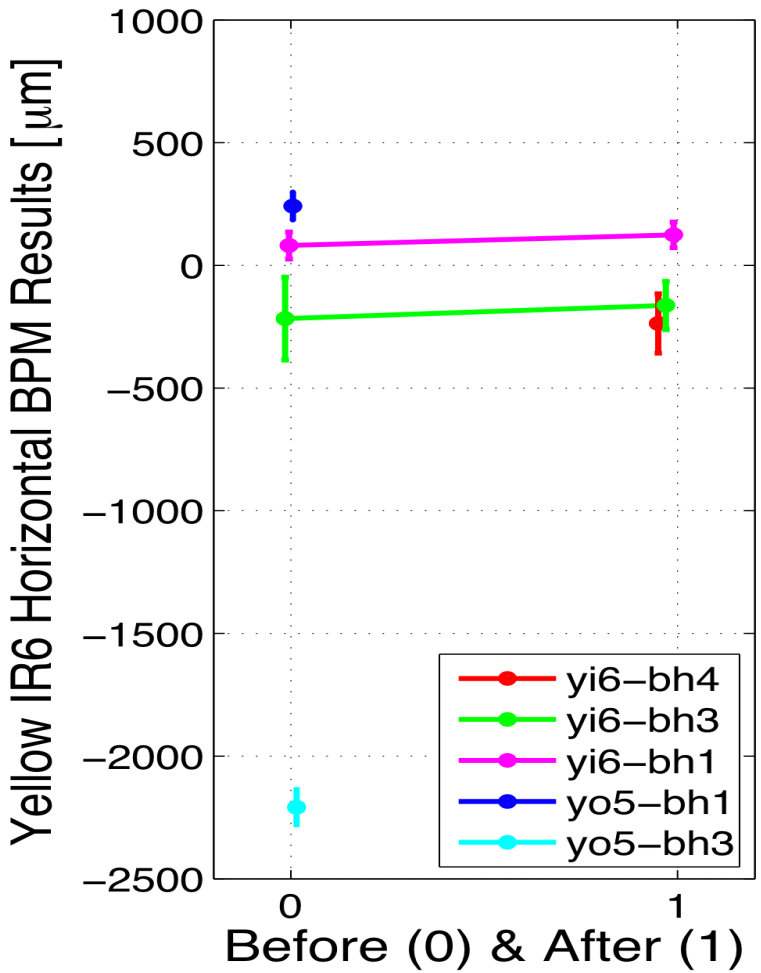
Results from the BBA Analysis

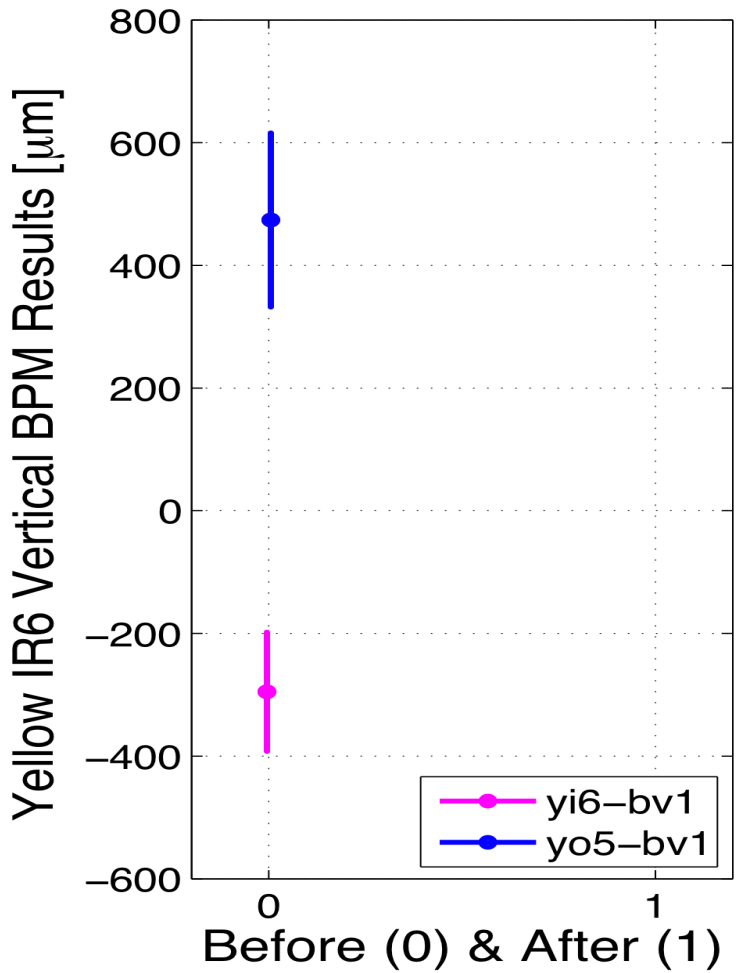
Complete list of the BBA measurements during APEX 5/2/2012

BPM	QUAD	DATE and TIME	Res. [mm]	Err [μm]
bi5-bh4	bi5-tq4	5/2/2012 10:12:07	-0.0306	65
bi5-bh4	bi5-tq4	5/2/2012 10:37:48	-0.0632	69
bi5-bh3	bi5-qf3	5/2/2012 10:42:44	0.0331	105
yi6-bh4	yi6-tq4	5/2/2012 10:52:29	-0.2369	121
yi6-bh3	yi6-qf3	5/2/2012 10:58:24	-0.1636	98
yi6-bh1	yi6-qf1	5/2/2012 11:03:53	0.1242	52
bi5-bh1	bi5-qf1	5/2/2012 11:04:18	-0.0765	97
bo6-bh1	bo6-qd1	5/2/2012 11:14:33	0.1264	72
bo6-bh3	bo6-qd3	5/2/2012 11:19:48	0.2704	110
bo6-bh4	bo6-tq4	5/2/2012 11:25:09	0.436	56
bi5-bv4	bi5-tq4	5/2/2012 11:30:23	-0.4035	121
bi5-bv1	bi5-qf1	5/2/2012 11:42:34	0.0905	46
bo6-bv1	bo6-qd1	5/2/2012 11:48:26	-0.0466	120
bo6-bv3	bo6-qd3	5/2/2012 11:53:23	-0.0139	47
bo6-bv4	bo6-tq4	5/2/2012 11:57:59	-0.477	59

Results from the BBA Analysis

Yellow IR6 BPM results (APEX 5/2/2012, three measurements)





Results from the BBA Analysis

BPM yo5-bh3 (10 sets of measurements in 2 years)

BBA measurement run-time data file names	center [μm]	error [μm]
yo5-bh3_log_Wed_Mar__3_08:55:10_2010	-1996	377
yo5-bh3_log_Tue_Mar__9_23:21:13_2010	-2081	408
yo5-bh3_logQ1_Wed_Mar_21_19:03:46_2012	-2208	81
yo5-bh3_logQ1_Sun_Apr_22_09:50:07_2012	-2150	118
yo5-bh3_logQ1_Sun_Apr_22_09:56:57_2012	-1997	119
yo5-bh3_logQ1_Sun_Apr_22_10:00:26_2012	-2265	173
yo5-bh3_logQ1_Sun_Apr_22_10:04:24_2012	-1863	197
yo5-bh3_logQ1_Sun_Apr_22_11:56:37_2012	-2152	91
yo5-bh3_logQ1_Sun_Apr_22_12:01:54_2012	-2211	207
yo5-bh3_logQ1_Sun_Apr_22_12:06:47_2012	-2316	149
Average	-2124	192
Standard deviation	140	114

Conclusion

1. BBA on RHIC produce reliable results now.

2. There are some room for improvement
   (a) Systematic measurement
   (b) Iteration through measure-align-measure-align

3. Accuracy limitation: ~0.1 mm
   (a) Quads physical misalignment relative to each other
   (b) Limited correctors
   (c) repeatability under same machine settings

Results from the BBA Analysis

from 1Hz BPM reading of all BPMs in all arcs

	3/21/12		3/3/10		3/9/10		3/27/11	
BPM	Offset	Error	Offset	Error	Offset	Error	Offset	Error
	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)	(μm)
yo5-bh1	242	57	220	180	135	229	-125	240
			318	225			-206	230
yo5-bh3	-2208	81	-1996	377	-1866	264		
yi6-bh1	81	55	200	484	350	304		
yi7-bh1	-240	93	-269	74	-264	385		
yo8-bh1	268	123	-137	74	-268	875		
yo8-bh3	652	68	457	116	416	251		

Principle of BBA measurement

If the closed orbit of beam relative to the magnet center of the ith quadrupole located at s_i is $x(s_i)$, deflection angle is:

$$\theta_i = k_i L_i x(s_i)$$

Changing the quad strength k_i by Δk_i or change $x(s_i)$ by $\Delta x(s_i)$ gives additional deflection angle $\Delta\theta_i$.
The transverse orbit displacement at position s due to deflection θ_i is:

$$\Delta x(s) = \frac{\sqrt{\beta(s)}}{2\sin(\pi\nu)} \sum_{i=1}^{N} \theta_i \sqrt{\beta(s_i)}\ \cos(|\phi(s) - \phi(s_i)| - \pi\nu)$$

The objective of BBA is to measure the beam offset $x(s_i)$ by steering the beam and minimizing the measured orbit shift associated with changing the quad strength. Then $x(s_i)$ is used to zero the reading of the BPM near by the quadrupole.

Using $\Delta k_i = 2 \times 10^{-3}$ m^{-2} to avoid large optics, tune, and beam lifetime changes. This is 1.7–2.5% of a typical IR quadrupole strength at RHIC injection.

Why is BBA Measurement Difficult in RHIC

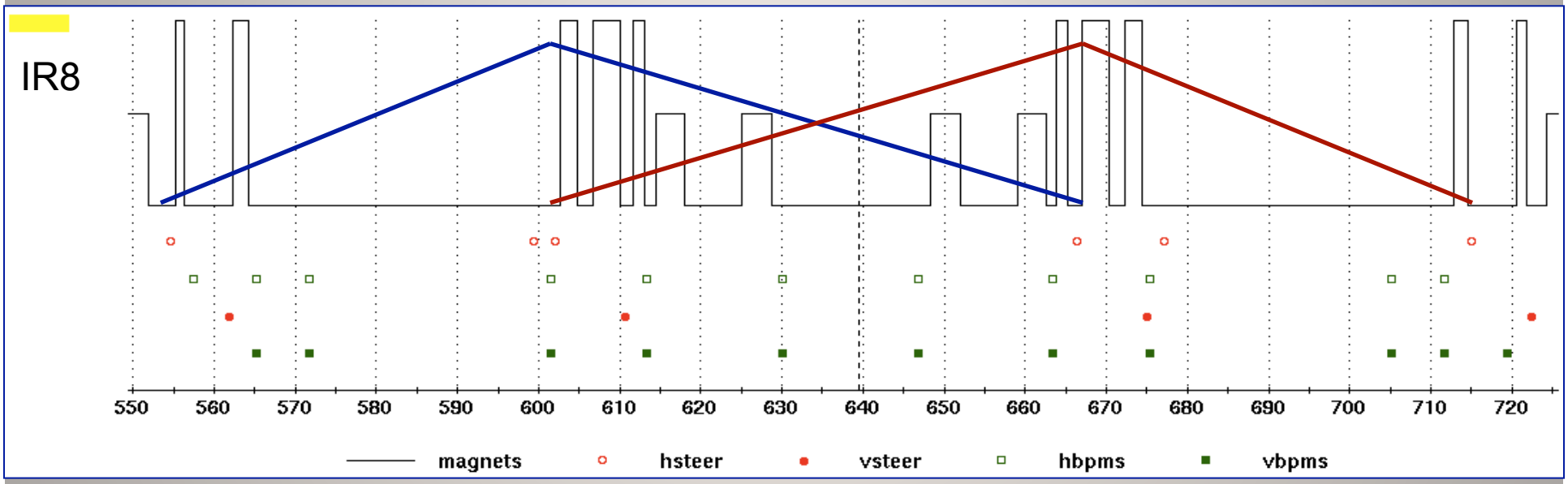
Why is BBA Measurement Difficult in RHIC:

1. Limited dipole correctors. In each 3-corrector bump there are 6-7 quads, 2 DXs, 2 D0s
2. Can't decouple the effects of Q1, Q2, Q3 and they are equally strong
3. Unknown magnet alignment errors
4. Unknown beam positions and angles at the first corrector (beam angle at triplet)
5. Very large ring. When all the BPMs in all arcs are used, some BPMs contribute to noise ore than to signal.
6. Signal/Noise ratio is low.

Possible Solutions:

1. Try to treat the triplet as one unit. Minimize total deflection anglein the section
2. Minimize the frequency of quadrupole change. (Procedure with 1-Q-Move)
3. Chose subgroup (or single) of BPMs
4. Step-by-step (faster easier procedure, using of 1kHz BPM signals)

Three-corrector-bumps in BBA Measurements



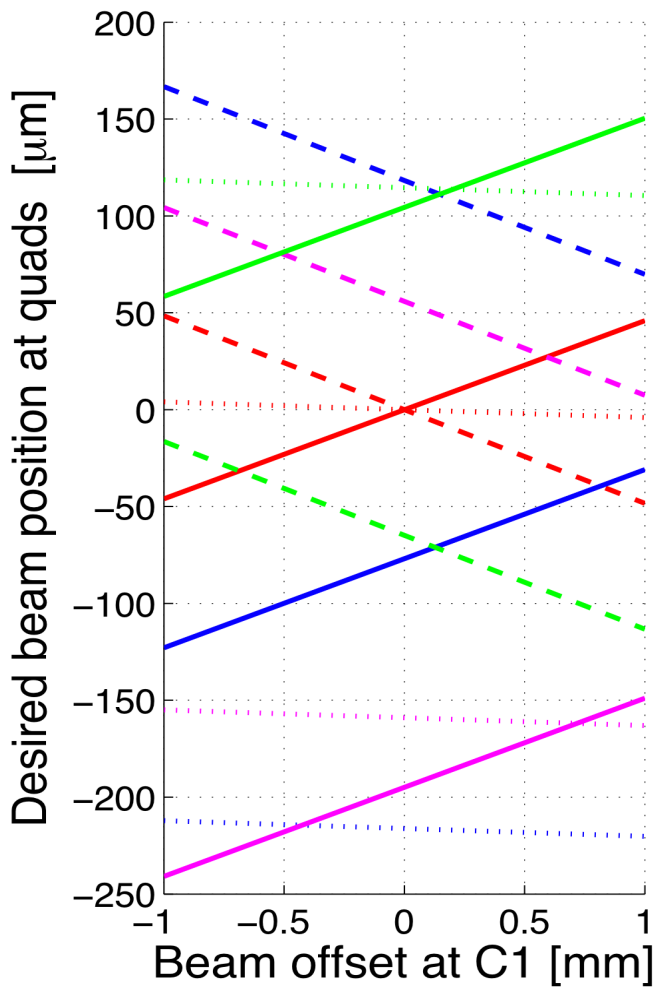
Quad Settings During BBA Measurements

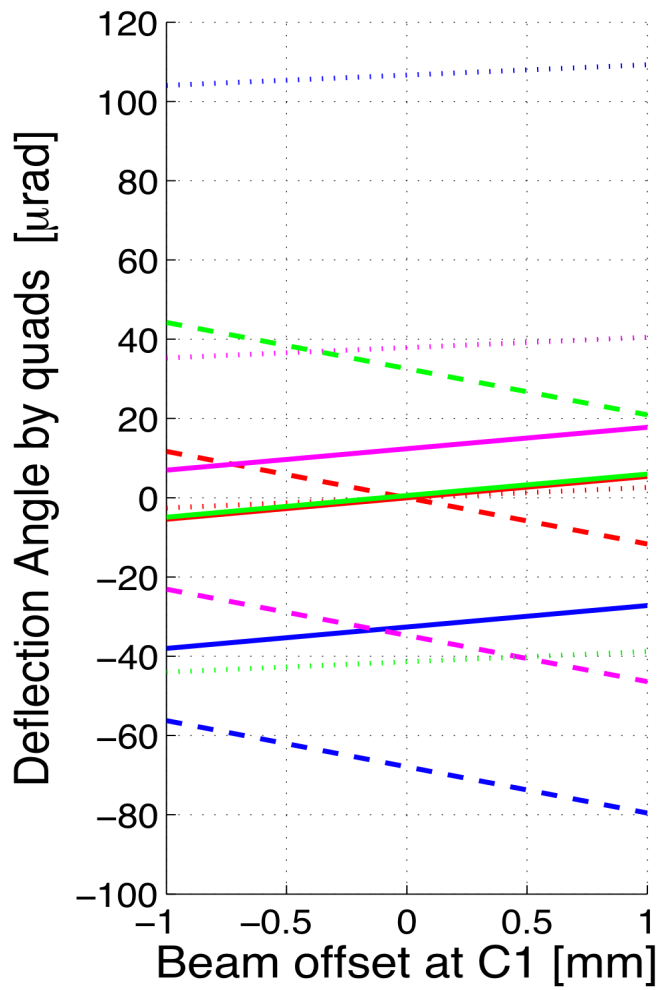
pp12b-v2 at injection

Magnet Names	Length [m]	k [m-2]	kL [m-1]
Q1	1.44	0.0818	0.1178
Q2	3.4	-0.1887	-0.6416
Q3	2.1	0.1148	0.2411
tQ4	0.75	0.0378	0.0284
Q4	1.83	-0.1637	-0.2996
tQ5	0.75	0.0135	0.0101
tQ6	0.75	-0.0134	-0.01
Q7	0.95	0.0834	0.0792
Q8	1.13	-0.091	-0.1028
Q9	1.13	0.0891	0.1007

Effects of unknown position & angle at C1

bi8 triplet with a range of assumed misalignments in Q1, Q2 & Q3





XQ1 = 0.0
XQ2 = 0.0
XQ3 = 0.0

XQ1 = 200 μm
XQ2 = -50 μm
XQ3 = 400 μm

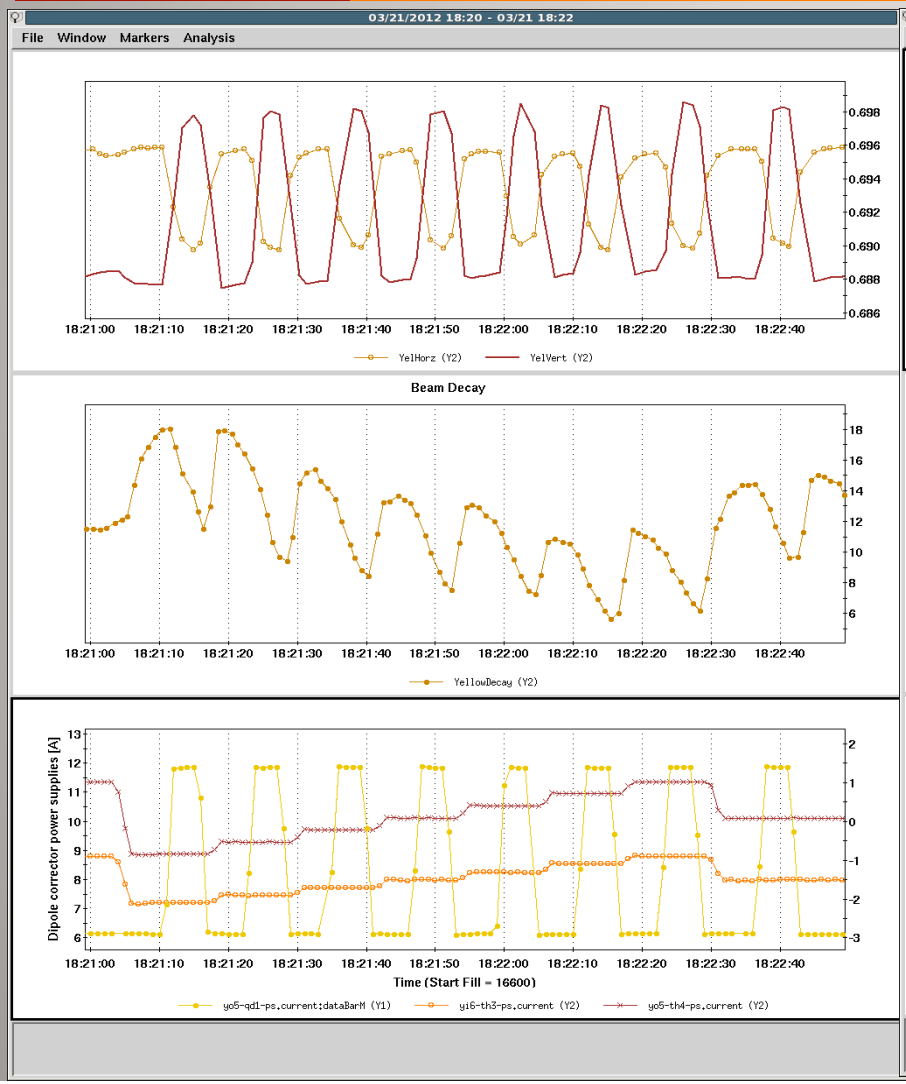
XQ1 = -300 μm
XQ2 = -100 μm
XQ3 = 200 μm

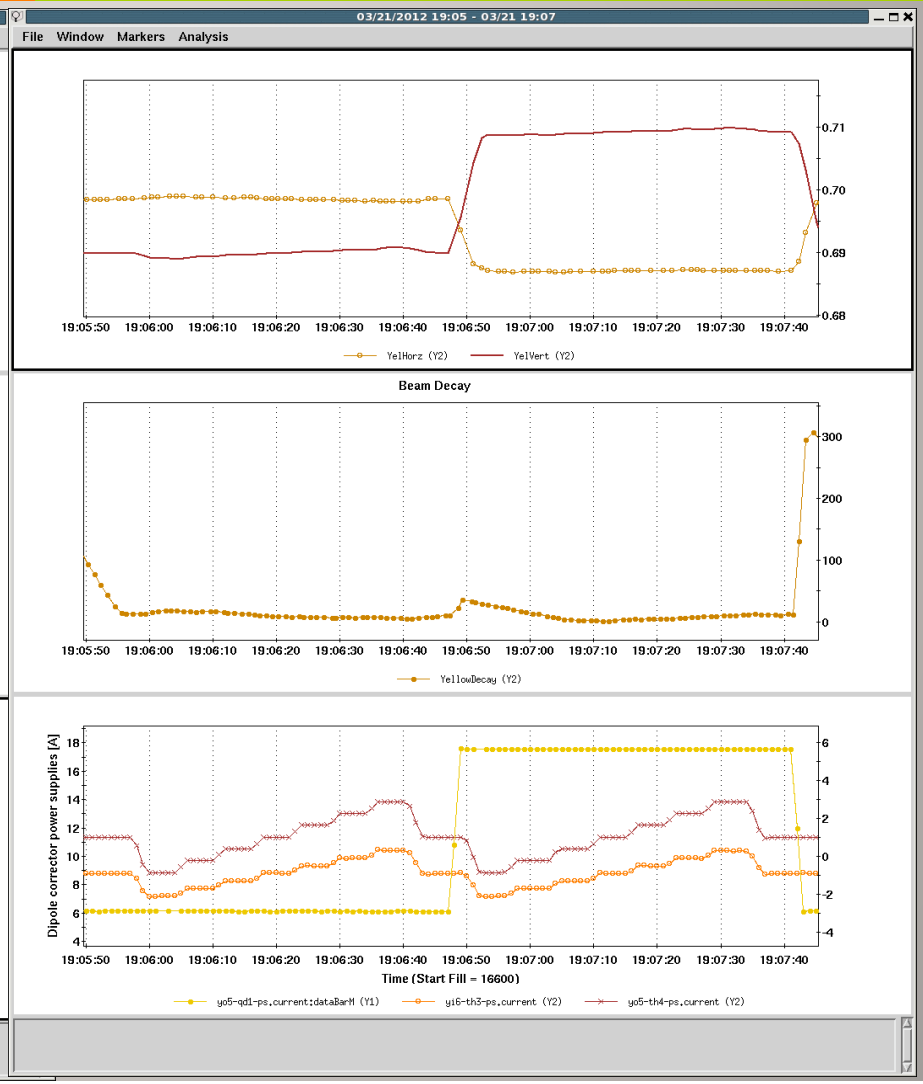
XQ1 = 100 μm
XQ2 = 50 μm
XQ3 = -200 μm

$|\theta_{C1}| < 20$ μrad
$|\theta_{Q1}| < 40$ μrad
$|\theta_{Q2}| < 110$ μrad
$|\theta_{Q3}| < 80$ μrad

BBA Measurements (03/21/2012)

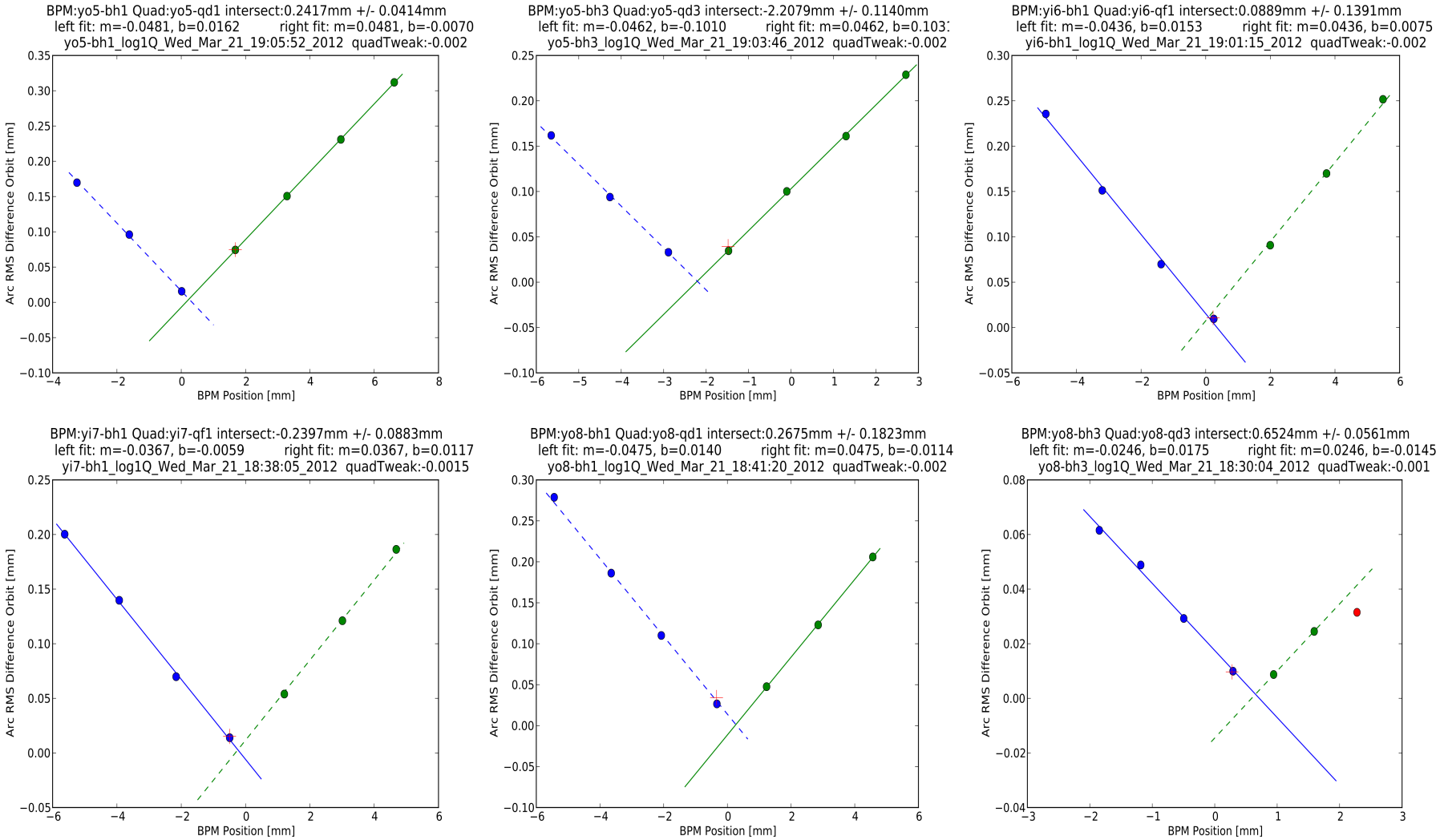
traditional procedure vs. 1-Q-move procedure





BBA Analysis of Beam Experiment (03/21/2012)

from 1Hz (all arc) BPM reading



What we have learned from BBA measurement

1. Possible to develop nonconventional procedure to improve the accuracy/speed

   When the machine is reasonably stable BBA measurement can be performed by taking baselines (without changing the quad) for all beam-offset locations, then change quad once and take the measurement at the same set of offset locations. (It allows us to manipulate the offset in a nonconventional fashion in order to improve the accuracy/speed.)

2. A step towards streamline measurement: knowledge on measurement parameters

   A careful choice of beam-offset range and the amount of quad strength change in a given lattice can improve measurement accuracy without much sacrifice of beam lost. It was found the best beam-offset range is [-4.0 4.0]mm with quad strength change of -0.002 on Q1 or Q2 at injection.

3. A step towards automatic analysis: data requirement for reliable analysis

   Needs minimum 9 measurement points (4 on positive side and 4 on the negative side) to have confidence of good measurement since a line obtained from fitting 2 or 3 measurement points appears to be unreliable.

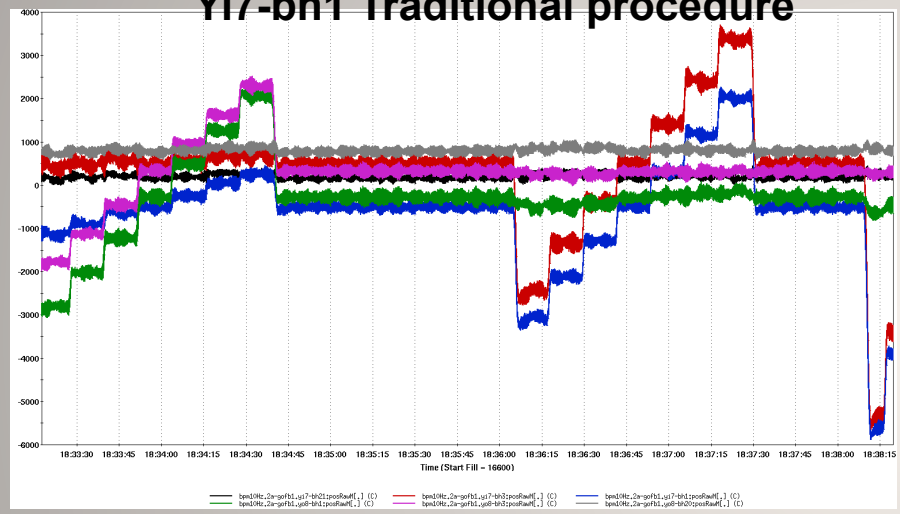
4. Knowledge on measurement accuracy vs. 1Hz BPM reading settle time

   The 3 seconds waiting time for the 1Hz BPM reading appears to be adequate. But the first/last measurement point (after a big step from/to the original setting) is bad in some of the measurements. The solution could be a 4-5 seconds waiting for the first and the last step.

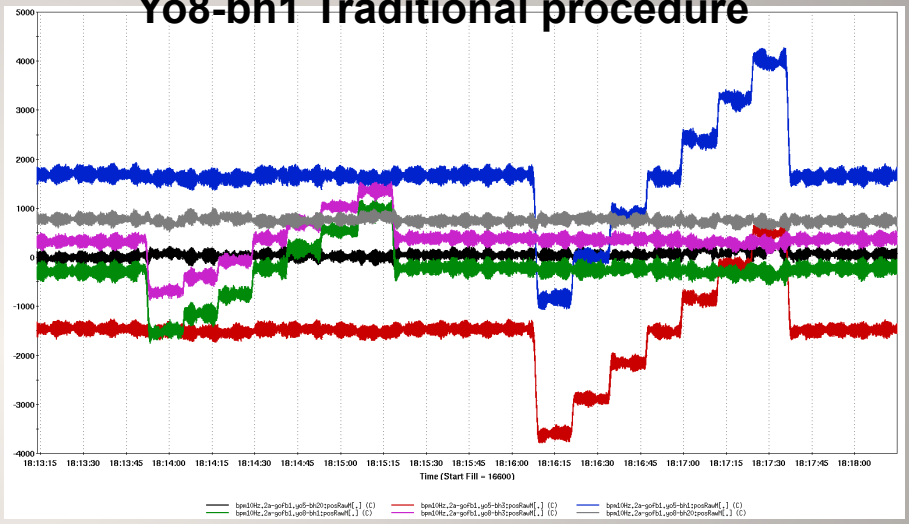
Beam Experiment (03/21/2012)

1kHz signals on BPM 1kHz signals on BPM in yi7 & yo8 during yi7-bh1 & yo8-bh1 measurement

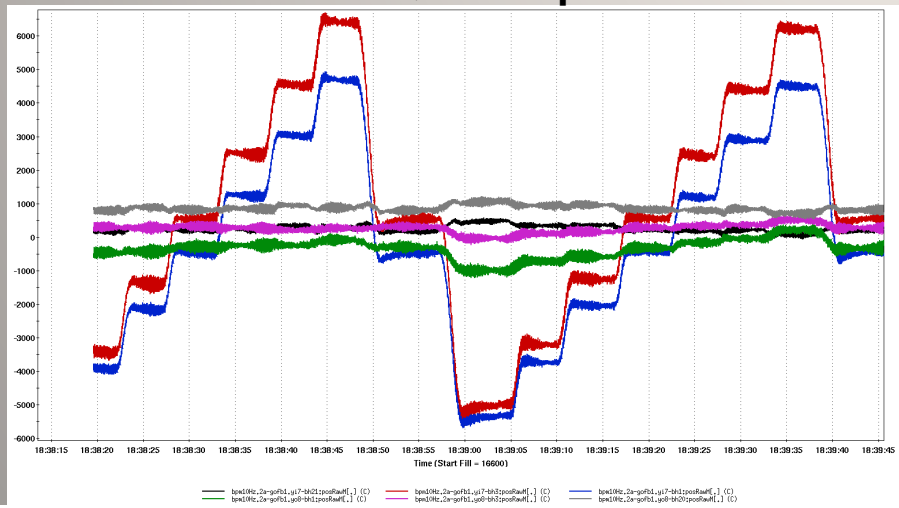
Yi7-bh1 Traditional procedure



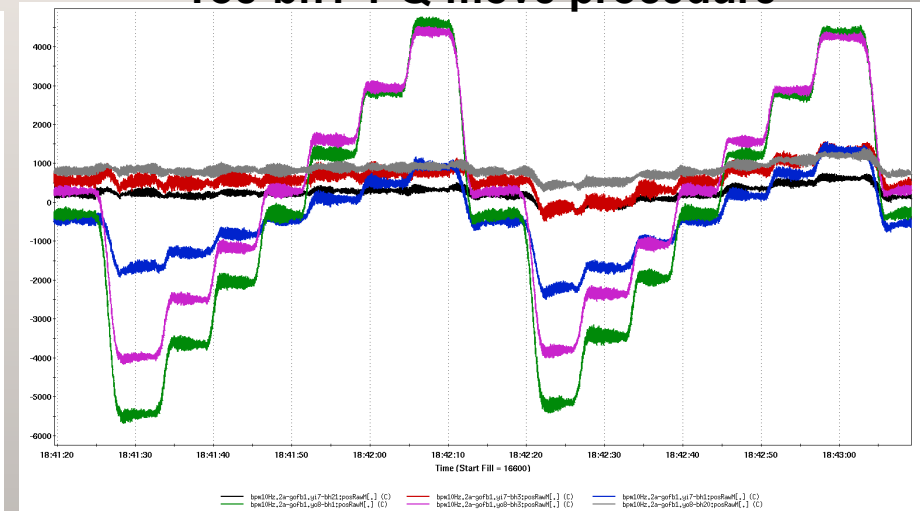
Yo8-bh1 Traditional procedure

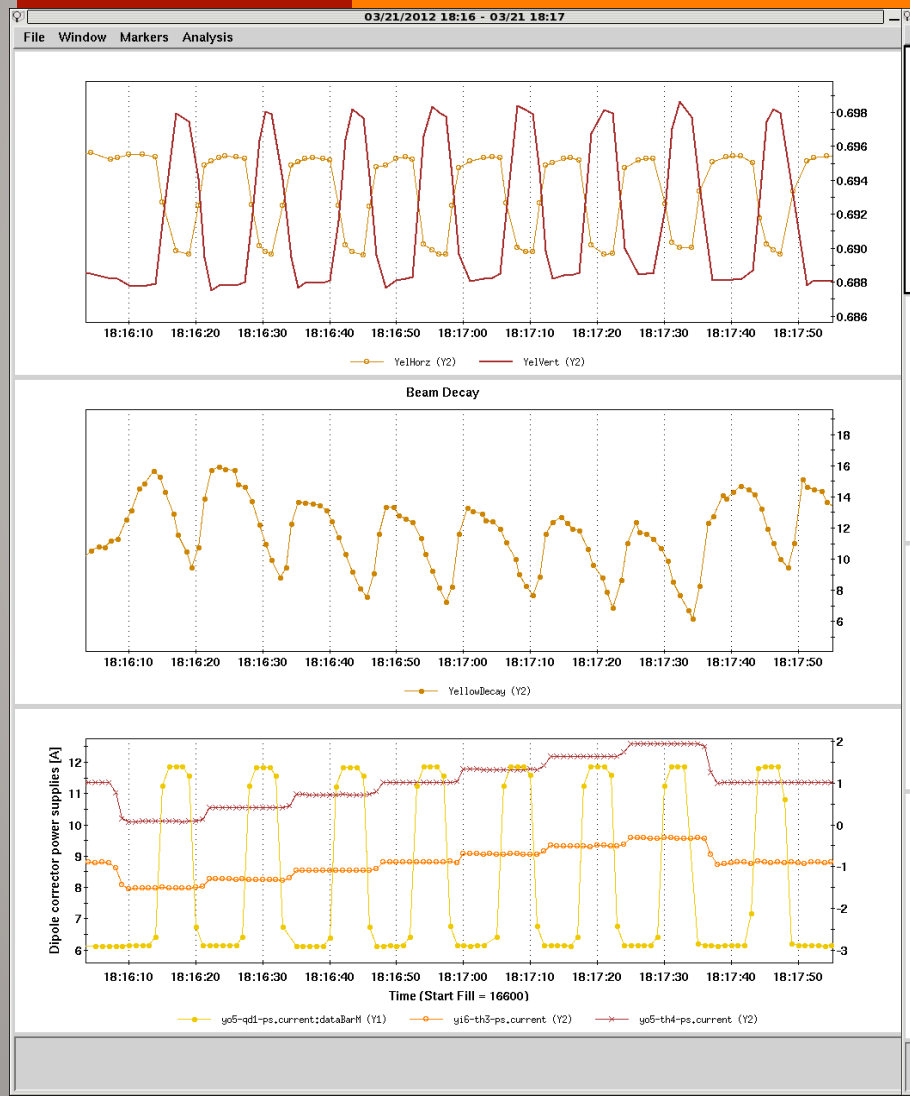
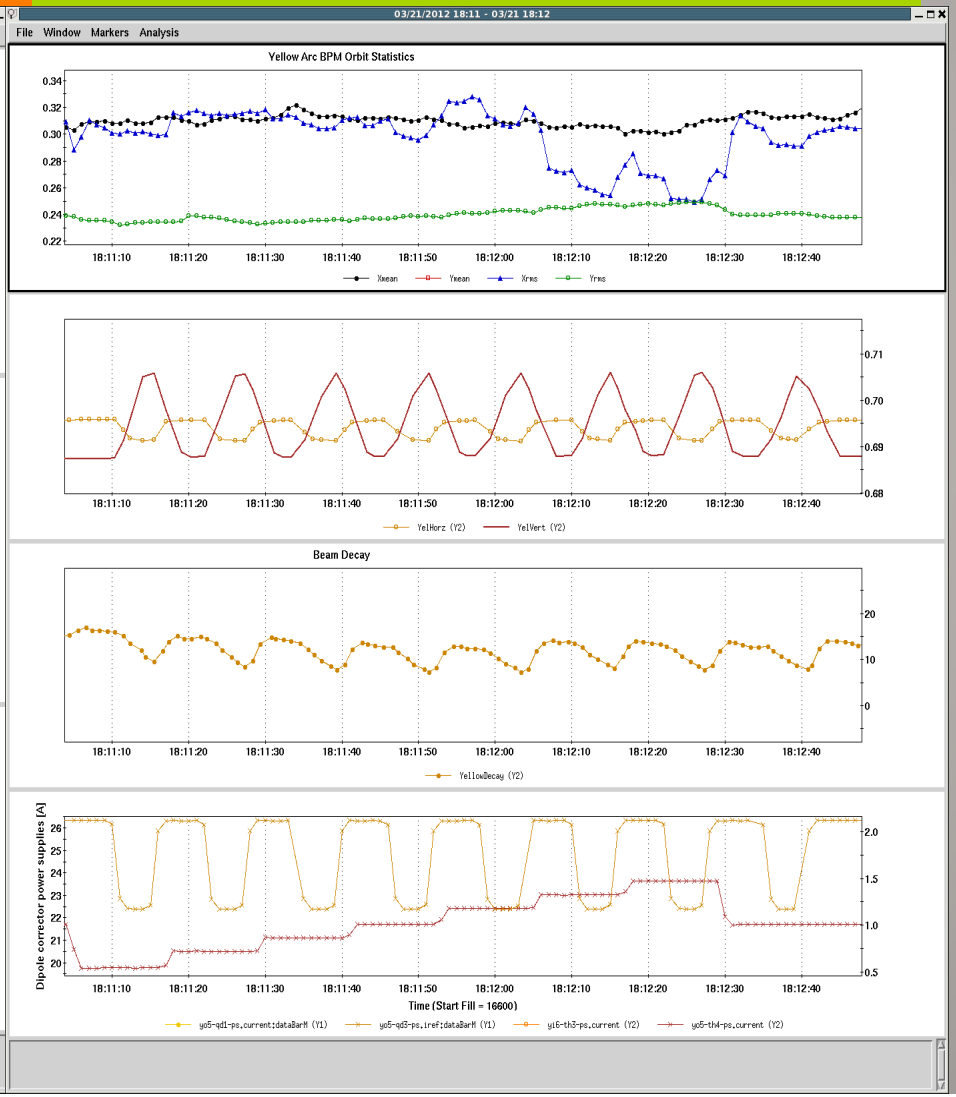


Yi7-bh1 1-Q-move procedure



Yo8-bh1 1-Q-move procedure



BBA Measurements (03/21/2012)

during two measurements on BPM yo5-bh1