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Collision optics in the RHIC 2 oclock interaction region

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1. Introduction

The RHIC nominal collision optics configuration as described in the RHIC Design [1] allows for β*=2m in all six interaction regions. Two interaction regions, IR6 and IR8 were designed to achieve further focusing to β*=1m. Smaller β at the interaction point means a higher maximum β in the final focus triplet, and consequently an increased effect of the IR triplet errors. For this reason the so-called "golden" triplet quadrupoles, that is the cold masses with the best (measured) field quality, were installed in IR6 and IR8. Furthermore a system of non-linear correctors is installed around IP6 and IP8, to allow compensation of non-linear effects from the IR quadrupoles.
During run 2001 IR8 was successfully operated at β*=1m, the further focusing delivering the predicted increase in luminosity. That led to consider the possibility of squeezing IR2, that hosts the Brahms and PP2PP experiments, also to β*=1m. This note considers the implications of this development for the machine performance. The layout in IR2 and equipment apertures are reviewed in Section 2, information about losses and backgrounds in the area from run 2001 are summarized is section 3. Section 3 concerns itself with the estimated effect from IR errors in IR2 due to the increased focusing, on the basis of beam data from run 2001. Conclusions and recommendations are drawn in Section 5.

2. Layout and aperture

Figure 1 shows the optics functions in IR2 for the Blue ring respectively for 2 m and 1m β* at the IP2 interaction point, and similarly Figure 2 for the Yellow ring.
2 o'clock is the home of much of RHIC instrumentation, installed in the warm sections between the Q3 and Q4 quadrupoles, both in the blue and yellow rings. As new instruments have been added for run 2003 (i.e. the electron detectors) and others have been moved, we systematically checked the apertures in the Q3-Q4 locations (where β's change significantly from the β*=2m to 1m optics). The figure of merit for RHIC has traditionally been to allow for 6 sigma of the beam distribution for a 40 π (end of store) transverse emittance.

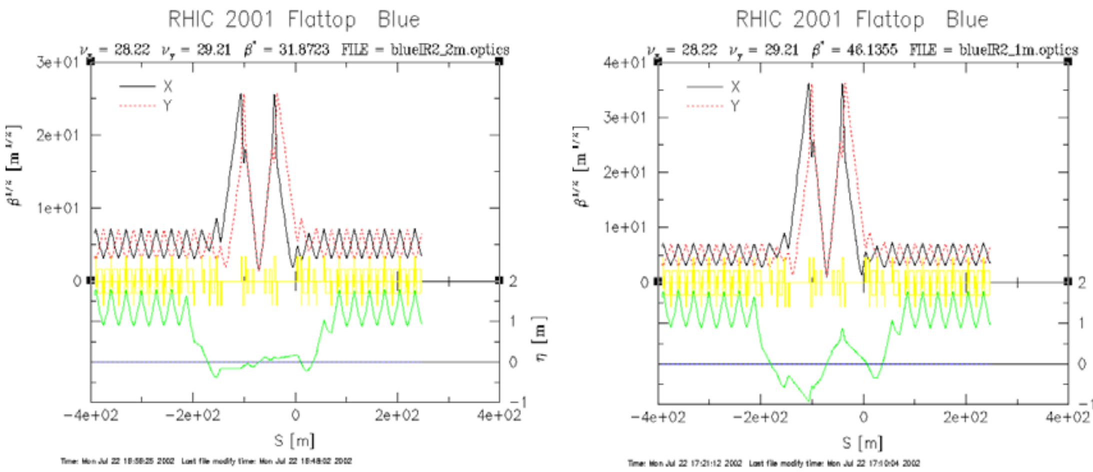


Figure 1. Optics function in IR2, Blue ring, for β*=2m and 1m

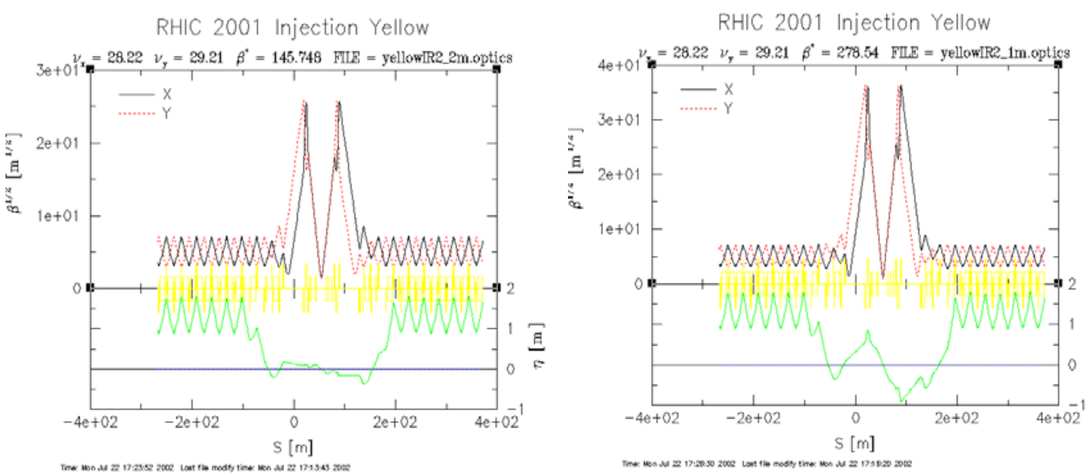


Figure 2. Optics function in IR2, Yellow ring, for β*=2m and 1m

Figure 3 describes the layout and aperture of relevant equipment in IP2, including the schematics of the interaction region geometry. For every sector (BI1, YO1 on the 1 o'clock side, and BO2, YI2 on the 2 o'clock side) one can find a list of the installed equipment with its location (distance from IP in meters), and aperture (in cm). The values of the beta functions at the beginning and end of the Q3-Q4 warm straight section for the 1m β* optics are also included for completeness. We calculated at every instrument position the sigma of the beam distribution (in mm) and compared with the available aperture. For some instruments close to Q3 end, where the betas increase rapidly with the 1m β* optics (for instance the movable BPM's and the transverse dampers), the aperture does not fulfill the criterion of having 6 sigma (at 40 π mm mrad emittance) clearance.

Distance from IP		aperture
IPM-H	70.74	7x3cm
Cooling PU	69.22	
ED+SL	65.55	
RomPot	59.54	
RomPot	56.66	
IPM-V	54.45	3x7cm
PLL kicker	52.62	6cm
CarbWire	51.94	7cm
ED+SL	46.04	
LumiMon	42.50	7cm
4 Striplines	41.09	6cm
BPM	39.46	5.6cm

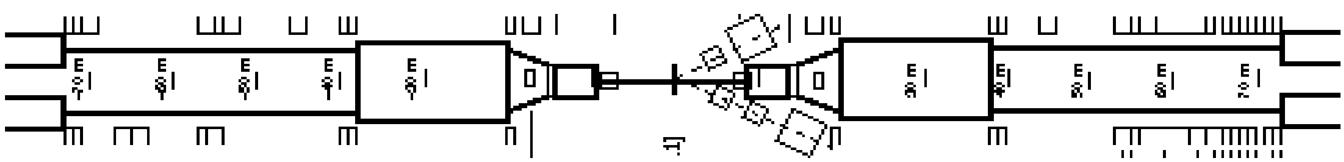
YO1

	2m	1m
βx(40m)	205	411
βy(40m)	588	1167
βx(70m)	8	6
βy(70m)	59	93

BO2

	2m	1m
βx(40m)	204	409
βy(40m)	588	1165
βx(70m)	7	5
βy(70m)	63	101

Distance from IP		aperture
IPM-H	70.83	7x3cmV
Schottky	69.13	3.4cm
DCCT	68.38	3.4cm
WCM	67.63	3.4cm
ButtonBPM	66.88	3.4cm
RomPot	59.54	
RomPot	56.66	
IPM-V	54.45	3x7cm
CarbWire	52.95	7cm
PLL Kicker	52.28	6cm
ED+SL	46.02	
Lumi Mon	42.50	7cm
4 Striplines	41.09	6cm
BPM	39.46	5.6cm
		(5 x 8.4 mm)



Distance from IP		aperture	beam sigma (40π)
MovBPM	40.93	5.6cm	8.4 x 5mm
PLL kicker	43.03	6cm	
ED(2)+SL	45.29		
MCP+SL	45.64		
TransDamp	52.16	3.5cm	5.6 x 2.4mm
TransDamp	54.16	3.5cm	
ED+SL	61.40		

YI2

	2m	1m
βx(40m)	587	1162
βy(40m)	205	411
βx(70m)	63	101
βy(70m)	7	5

BI1

	2m	1m
βx(40m)	586	1162
βy(40m)	205	411
βx(70m)	95	162
βy(70m)	4	3

Distance from IP		aperture
MovBPM	40.94	5.6cm
PLL kicker	43.05	6cm
ED+SL	49.30	
TransDamp	52.16	3.5cm
TransDamp	54.16	3.5cm
ButtonBPM	66.88	3.4cm
WCM	67.63	3.4cm
DCCT	68.38	3.4cm
Schottky	69.13	3.4cm
Cooling Kick	70.63	

Figure 3. Layout and aperture of relevant equipment in IR2 (Blue and Yellow rings)

3. Losses and backgrounds

Loss patterns in the IR's are plotted in the following Figures 4, 5 and 6.

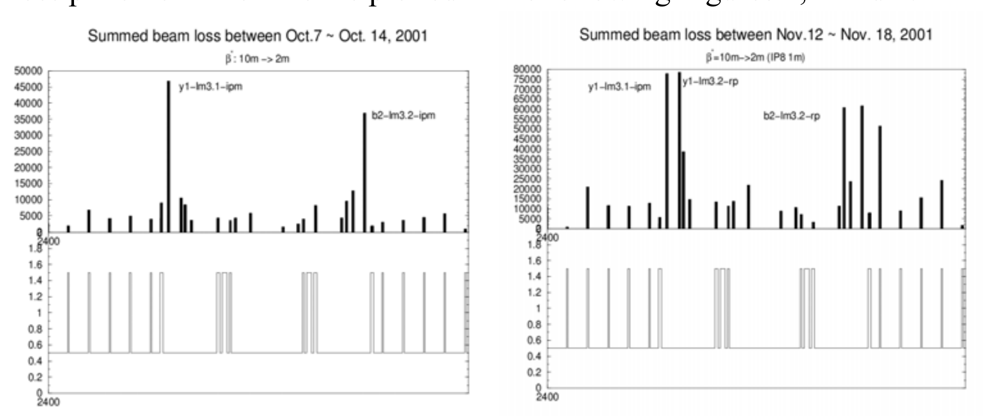


Figure 4. Integrated losses (1 week) at 2 o'clock for β*=2m in all IR's (left) and for β*=1m in IP8 (right).

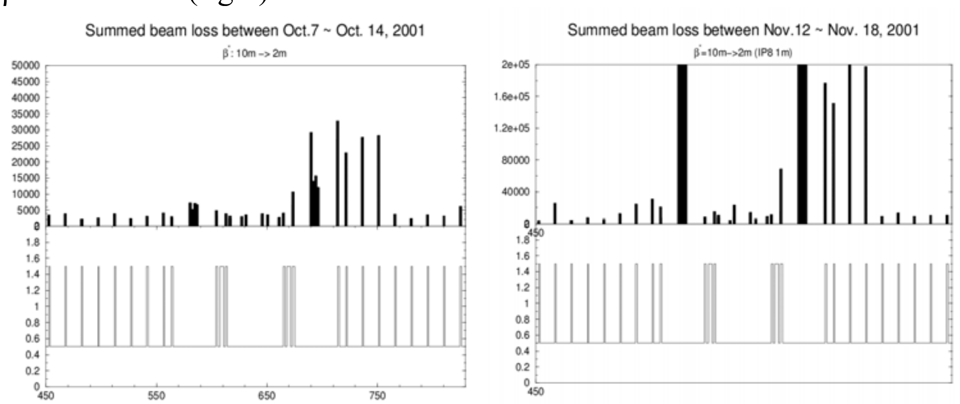


Figure 5: Integrated losses (1 week) at 8 o'clock for β*=2m in all IR's (left) and for β*=1m in IP8 (right).

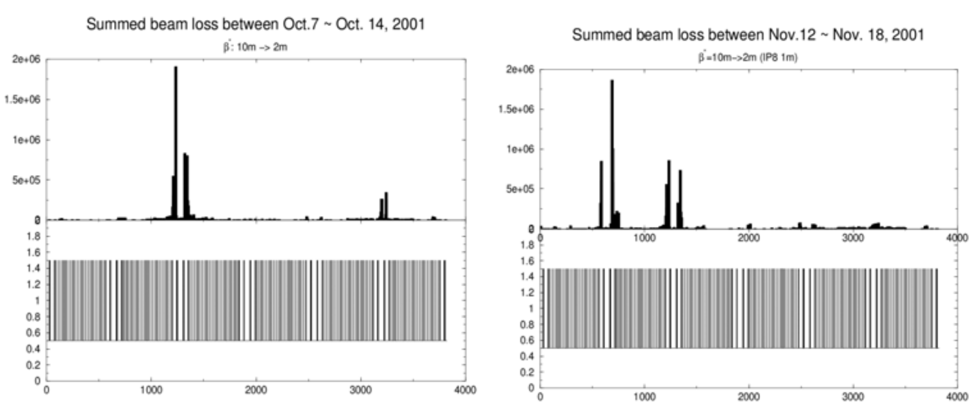


Figure 6. Integrated losses (1 week) around the ring for β*=2m in all IR's (left) and for β*=1m in IP8 (right).

Figure 4 compares integrated losses in IR2 in 2 different weeks, the left side in the collision optics configuration with all IR's at β*=2m, the right side the same but with IP8 further squeezed to β*=1m. Losses are concentrated in the Q3-Q4 warm regions. Figure 5 presents the same information for IP8, comparing integrated losses before and after the beta squeeze to 1m. Figure 6 shows integrated losses on the same optics configurations for the whole ring. It is clear that squeezing from 2m to 1m in at the interaction point greatly increases the losses in the Q3-Q4 warm spaces, that become larger than the losses at the abort dump, the machine traditionally limiting aperture.

In fact during run 2001 we struggled already with losses and background in IR2. For example during the proton run (with a fixed β*=3m optics in all IR's), losses on the ramp were systematically concentrated in the abort region and at IR2, as seen in Figure 7.

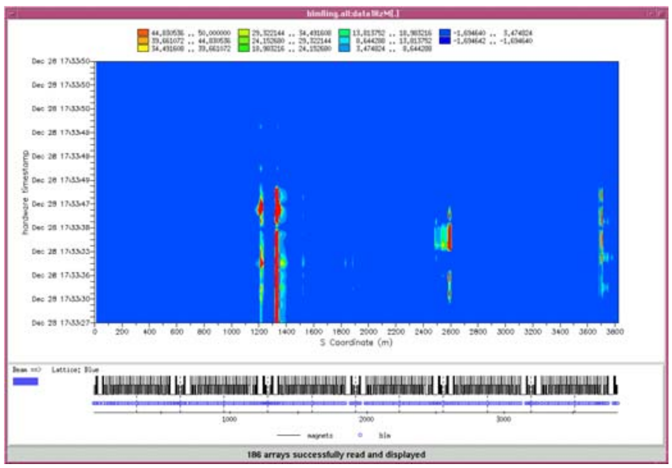


Figure 7. Typical losses on the ramp during the proton run.

We also had to fight spurious coincidences at Brahms at injection caused by background. Figure 8 records spurious event rates at Brahms at the MHz level. To get the rates down to KHz level (right hand side of Figure 8) a **8mm** horizontal bump was applied at 2600m in Yellow (YI2), centered about 45m after IP2, and left there for the rest of the run.

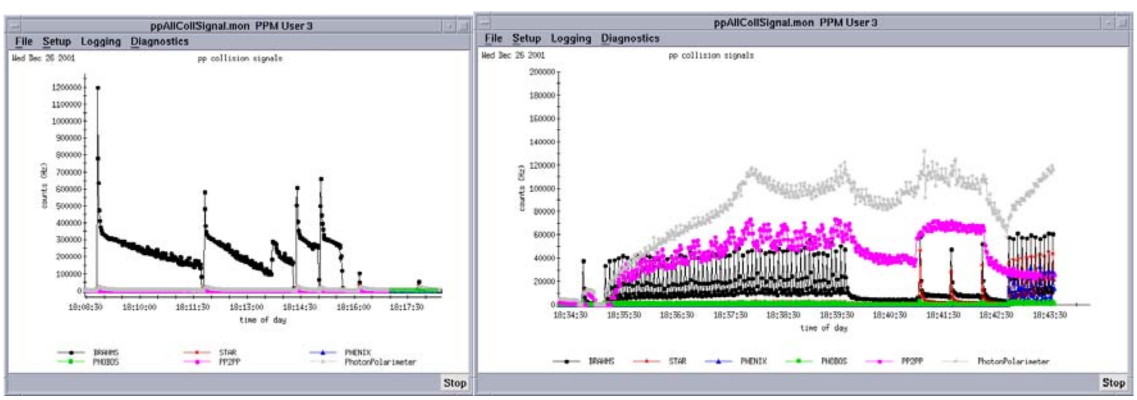


Figure 8. Comparison of Brahms experimental rates before (left) and after the setting of a bump at 2600m to reduce background.

4. Effects of IR errors

The maximum β in the β*=1m collision optics is doubled to ~1300 m as compared to the maximum of ~650m for the β*=2m optics. That increases the effect of the nonlinear magnet IR errors. The measured tune shift with amplitude of the orbit closed bump in the IR2 triplets (with β*=2m) is compared to the one in IR8 in Section 4.2, after the IR skew quadrupole errors measured in IR2 is briefly reviewed in Section 4.1.

4.1 Skew quadrupole IR errors

The IR skew quadrupole errors were measured with beam in the run 2001 and skew quadrupole corrector settings based on those measurements were put into the rings in the last run [3]. After the run the magnetic field at several triplets including ones from IR2 have been measured to check the quadrupole roll values. The IR skew quadrupole corrector settings used at the last run compare very well with the settings calculated assuming the measured roll errors, as can be seen in Figure 7. The largest difference is at Yellow 1o'clock triplet that should be measured again with the beam next run. More detailed information about the roll of individual triplet cold masses are reported in Figure 8.

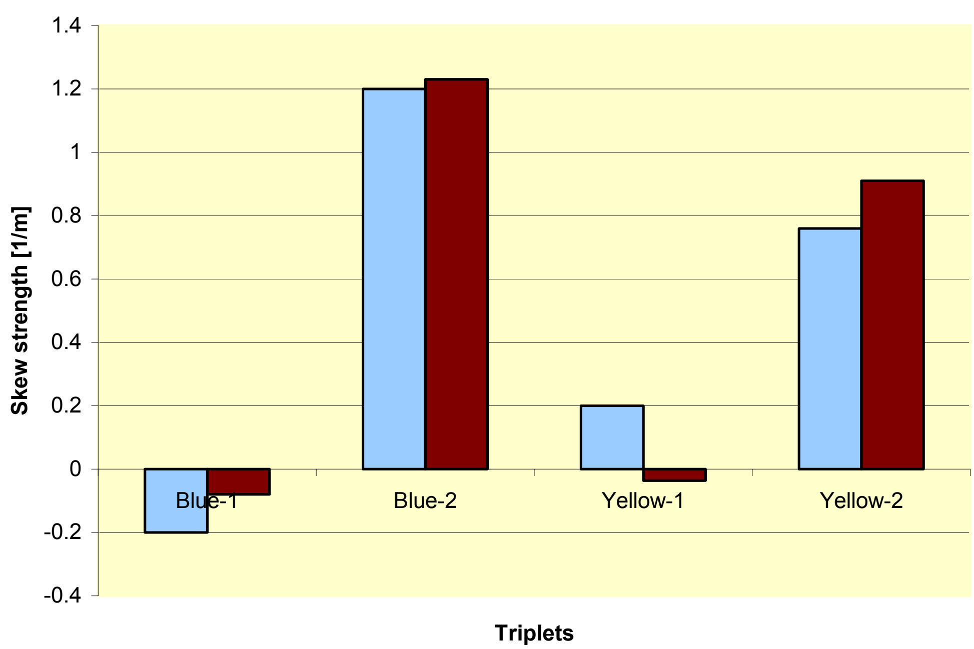


Figure 7: IR2 skew corrector strengths as measured with beam (light-blue) and as calculated using quad roll measurement data (dark-red)[4].

The roll misalignment in IR2 are large both in the Blue and the Yellow rings and some of the skew quadrupole correctors nested in the IR2 triplet necessary to compensate for the roll, are already close to their maximum current. A precise local compensation of the quadrupole rolls is necessary to avoid readjusting the correctors during the β* squeeze.
IR triplet gradient errors produce optical function distortions around the rings and restrict the precision of the collision steering bumps. These errors are in the process of being analyzed and IR2 needs to be compared with the other interaction regions.

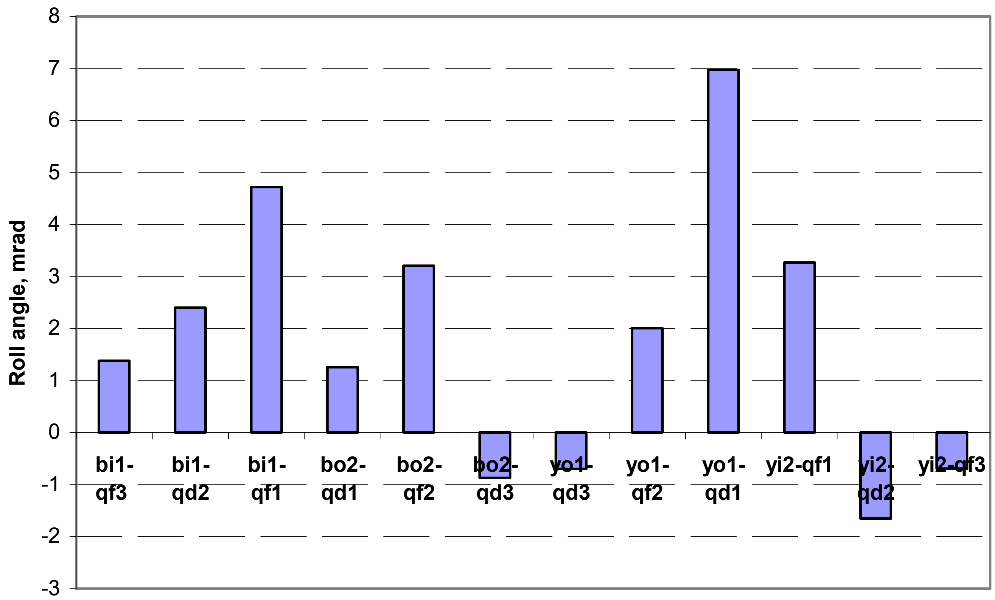


Figure 8: Measured field roll angles in IR2 triplets (from magnet field measurements)[5].

4.2 Nonlinear IR errors

The IR2 nonlinear effect have been measured with the IR bump technique, that consist on creating a local closed bump at the IR triplet, and continuously measuring the tune variation as a function of the bump amplitude. The technique and the results obtained as a basis for IR correction during run 2001 are summarized in [2], to which we refer for more details. The IR2 bump data for β*=2 m are here compared to β*=2 m data in IR8, for which we also have β*=1 m data. That allows a rough estimate of the effect of IR2 errors in b*=1m optics.
A complete set of bump data in IR2 were taken November 19 2001 and the conditions are summarized in Table 1.

<u>Ramp21_1006173521</u>			
• BI1	vertical	+10/-3mm	8:34am
• BO2	horizontal	+/- 5mm	8:43am
• BO2	vertical	+/- 5 mm	8:51am
• BO7	horizontal	+/- 5mm	8:59am
• BO7	vertical	+/- 5mm	9:30am
• BI1	horizontal	+/- 5mm	8:09am
• YO1	horizontal	+/- 5mm	9:40am
<u>Ramp21_1006207162</u>			
• YI2	horizontal	+/- 5mm	17:19pm
• YO1	vertical	+/- 5mm	17:46pm
• YI2	vertical	+/- 5mm	17:51pm

Table 1. IR bump data inventory for IR2 (β*=2m)

Figure 9 shows the power supply currents, used to create and monitor the bump and the corresponding Schottky tune measurements during the bump sweep (0 to +5mm, then –5mm and back to 0) that typically is 2-3 minutes.

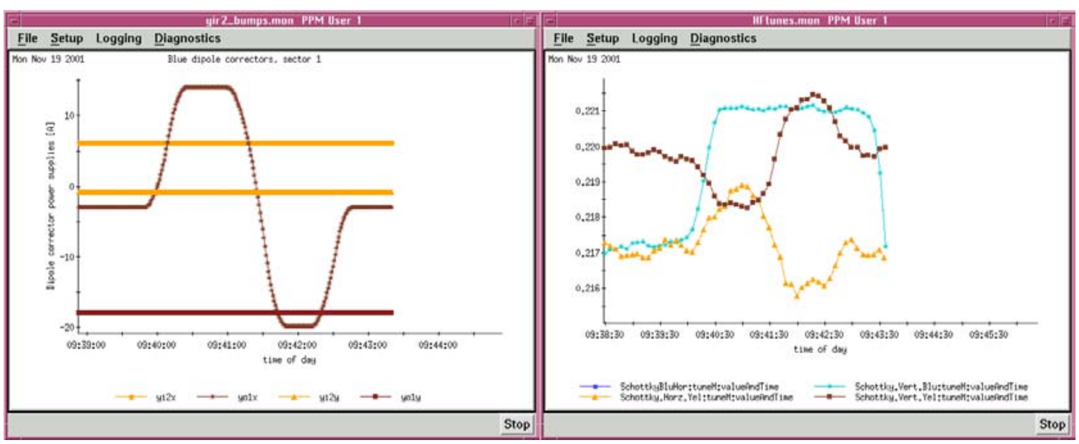


Figure 9. Example of horizontal bump in YI1 and corresponding Schottky tunes measurements in the Yellow ring (yellow trace is horizontal, brown is vertical)

Tune measurements were taken at the same time with the PLL (see in Figure 10 measurements for the same bump as in Figure 9). PLL and Schottky data were systematically cross checked during the data analysis to minimize the possibility of measurement errors.

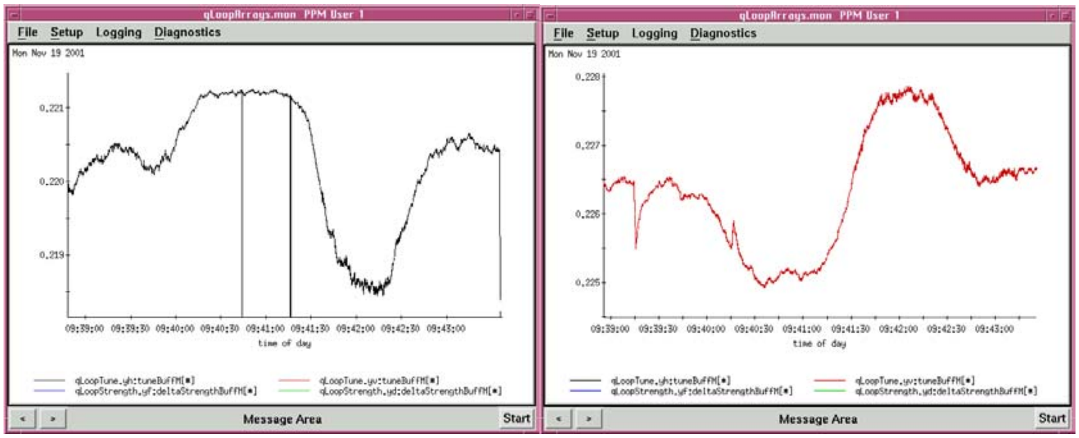


Figure 10. PLL tune measurement during the horizontal bump in YI1.

Table 2 summarizes the tune vs. bump amplitude data in IR2. For every IR 2 triplet, horizontal and vertical tune shifts are determined at the extreme of the bump (positive +5 mm and negative –5 mm), and for horizontal and vertical bumps. The general procedure for analysis of IR data is to record and fit every curve to a polynomial and so determine the value of the field multipolar errors. Unfortunately, a Logger failure at the time we tool data in IR2 prevented this analysis, and limits us in this case to look only at tune shifts at the maximum bump amplitude. All other IR data were properly logged.

TRIPLET	β* [m]	Bump [mm]	ΔQH +5mm	ΔQH -5mm	ΔQV +5mm	ΔQV -5mm
BI1	2	H 5 -5 V 5 -5	**+0.0023** **+0.001**	**-0.001** **-0.0015**	*0.00* *+0.0011*	*+0.001* *+0.000*
BO2	2	H 5 -5 V 5 -5	-0.0006 +0.0007	0.0005 -0.001	**+0.001** -0.0005	**-0.0011** +0.0005
YO1	2	H 5 -5 V 5 -5	**+0.001** **-0.0015**	**-0.0012** +0.0007	**-0.0015** **+0.0012**	**+0.0014** -0.0009
YI2	2	H 5 -5 V 5 -5	*+0.0002* **-0.001**	*-0.0002* **+0.0012**	-0.0003 +0.0011	+0.0004 -0.0007

Table 2. Tune shifts with bump amplitude in IR2 with b*=2m collision optics. The bump amplitude is 5mm everywhere.

TRIPLET	β* [m]	Bump [mm]	ΔQH +amplitude	ΔQH -amplitude	ΔQV +5mm	ΔQV -5mm
BO7	**1**	H 5 -5 V 5 -5	-0.0015 -0.0013	+0.002 +0.001	-0.0006 +0.0004	+0.0008 0.000
BO7	**2**	H 15 9 -8 -15 V 15 -15	-0.0022 -0.0009 -0.0029	+0.0024 +0.004 + 0.002	+0.001 0.000 +0.0007	-0.0012 –0.0019 -0.001
YI7	**1**	H 5 -5 V 5 -5	+0.0012 +0.0028	-0.001 -0.003	-0.0025 -0.003	+0.0045 +0.004
YI7	**2**	H 15 -15 V	+0.0024	*0.0005*	-0.002	+0.002

Table 3. Tune shifts vs. bump amplitude at IP8. Comparison of values for b*=2m and 1m collision optics (bump amplitude not always 5 mm).

The tune shifts at IR2 with β*=2m are comparable or larger than the tune shifts in IR8 with β*=2m. In the analysis of the latter, one has to pay attention to the fact the data were taken for amplitudes larger than 5mm (from 8 up 15mm), as listed in Table 3. The IR8 data were taken at a different time and the emphasis in these measurements was to build up the largest bump compatible with machine stability and no losses. The IR8 data for β*=1m correspond to 5mm amplitude bumps. In IR8, when going from β* 2m to 1m, the non-linear tune shifts increase, possibly one of the causes for the lifetime problem that emerged in the yellow ring, and that was not cured by working point optimization.

5. Conclusions and plans for run 2003.

In summary, analysis of the IR2 layout and of beam data from run 2001 leads to the following conclusions, for the β*=1m collision optics:

- The aperture in some of the equipment in the warm space close to Q3 is marginal, if we adopt as a figure of merit 6 sigma clearance for 40 π mm mrad transverse emittance
- IR2 is a loss area already with β*=2m optics
- Roll errors in the IR2 triplets are large
- The non-linear effects are larger in IR2 than in IR8, for the same optics.

These effects do not seem compelling enough to prevent running IR2 at β*=1m in the future but to allow this machine development it may be necessary to increase the current limit on the skew quadrupole correction circuits, and to install at least the low order non-linear corrector power supplies. Powering up sextupole, skew sextupole and octupole corrector circuits in both rings requires at least 12 extra 50 A power supplies.

The plan for run 2003 is to use the non-linear correctors in IR8 (and possibly in IR6 if it is run at β^*=1m). To achieve that we need:

- An application to ease and speed-up the setting of local IR correctors with IR bumps
- The offline model to cross check and compare beam data with simulations

Work is in progress to have this working for the run 2003.

6. References

[1] RHIC Design Manual (http://www.agsrhichome.bnl.gov/NT-share/rhicdm/)
[2] F. Pilat, P. Cameron, V. Ptitsyn, J-P. Koutchouk, "Linear and nonlinear corrections in the RHIC interaction regions", WEPLE042, EPAC 2002, Paris. (http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/WEPLE042.pdf)
[3] F. Pilat, M.Bai, J. Beebe-Wang, J. Cardona, W. Fischer, V. Ptitsyn, "Coupling measurement and correction during RHIC run 2001 and development for 2003", C-A/AP/77 Note, 2002. (http://www.agsrhichome.bnl.gov/AP/ap_notes/ap_note_77.pdf)
[4] Corrector strength calculation done by J.Cardona.
[5] Magnet field measurements from A.Jain.

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