QUEST FOR A NEW WORKING POINT IN RHIC*

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Abstract

The beam-beam interaction is a limiting factor in RHIC's performance, particularly in proton operation. Changing the working point is a strategy to alleviate the beam-beam effect and improve the performance of the machine. Experiments at injection energy and simulations have been performed for a set of working points to determine the best candidates.

INTRODUCTION AND TECHNIQUES

RHIC consists of two rings that provide head-on collisions at up to four interaction points for a wide range of particle species. The magnetic rigidity is about 81 T·m at injection and up to 832 T·m at store. The candidates for a new working point that would improve RHIC's performance were taken from other hadron colliders and accommodated for collisions of positively charged particles. Table 1 shows the initial list of candidates, the limiting resonances and the suitability to host polarized proton beams. This suitability was evaluated by the examination of the polarization plots from [1]. Those working points that would not provide an optimum polarization were rejected. The last two working points of the table were tested and used during the 2004 RHIC polarized proton run. Testing new working points at top energy represents a very expensive investment since it requires setting up an energy ramp, which can take days of dedicated operation. Instead we studied the beam-beam effects for different working points at injection energy, since the beam-beam parameter does not depend on the energy or the beta functions at the IPs:

$$\xi_{x,y} = \frac{N r_0}{4\pi\epsilon_N} , \tag{1}$$

where N is the number of particles per bunch, r_0 is the classical radius of the particle and ϵ_N is the rms normalized emittance. The beam-beam is not the only limiting factor at store. The magnetic non-linearities present in the interaction regions considerably reduce the dynamic aperture of the lattice [2]. The dynamic aperture was estimated for these different working points by tracking particles for 10^6 turns with the code SixTrack [3]. This code also has the capability of simulating the beam-beam interaction in the weak-strong approximation. In the following we discuss experiments performed with gold ions at injection energy, predictions from simulations and the experience at the new working points obtained during the 2004 polarized proton run.

Table 1: Working point candidates taken from hadron colliders and accommodated for collisions of equally charged particles.

Ring	Qx	Qy	Resonances	Spin
RHIC design	0.19	0.18	5,6,11	OK
RHIC oper.	0.235	0.225	4,9	OK
HERA-p	0.292	0.298	7,10	No
LHC	0.31	0.32	3,10	OK
Tevatron	0.578	0.59	2,7,10,11	No
ISR	0.955	0.93	10,11	OK
SPS collider	0.69	0.685	3,10	OK
RHICpp_04	0.735	0.73	4,7,11	OK

EXPERIMENTS & SIMULATIONS

Experiments to assess beam-beam effects at injection were performed with gold ions during the 2004 gold operation. Each beam consisted of 56 bunches with about 0.7×10^9 Au^{+79} ions per bunch. The beam decay rate was measured with and without collisions by fitting the wall current monitor intensity curve at the different tunes. Collisions were set at two interaction points (STAR and PHENIX). During these experiments tune scans were carried out in the blue ring. The measured ion decay rates are shown in Fig. 1 for RHIC operation, RHIC design and SPS plus RHICpp_04 working points. By comparing the black (no collisions) and the red (with collisions) dots of these plots it is observed how the beam-beam interaction drives particular resonances. For instance, the strong effect of the seventh order resonance in the SPS plus RHICpp_04 tune scan is striking. These scans are most useful for locating tunes where the beam-beam effect is the least troublesome. The RHIC design working point has the longest beam lifetime and the widest window of stability, followed by RHICpp_04 and RHIC operation working points. SPS tunes have the worst performance due to the strong third order resonance driven by the sextupolar fields of the superconducting dipoles of RHIC. These sextupolar fields get weaker as energy increases, and therefore this working point is still considered for store.

For predictions at store a model containing the non-linearities of the magnets in the interaction regions was constructed [2]. The beam-beam interaction is also considered in the weak-strong approximation for the four inter-

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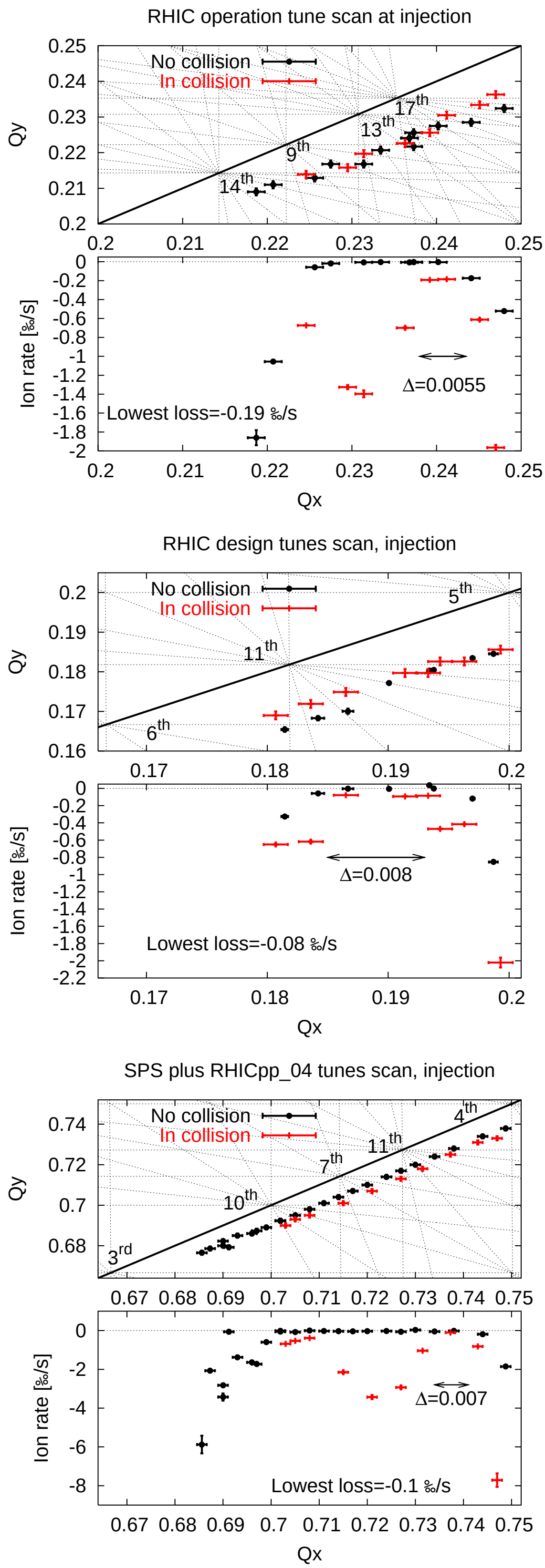

Figure 1: Tune scans for RHIC operation, RHIC design and SPS plus RHICpp_04 working points (from top to bottom). The upper part of the plots shows the location in the tune diagram and the bottom part of the plots shows the ion loss rate in units of part per mill per second.

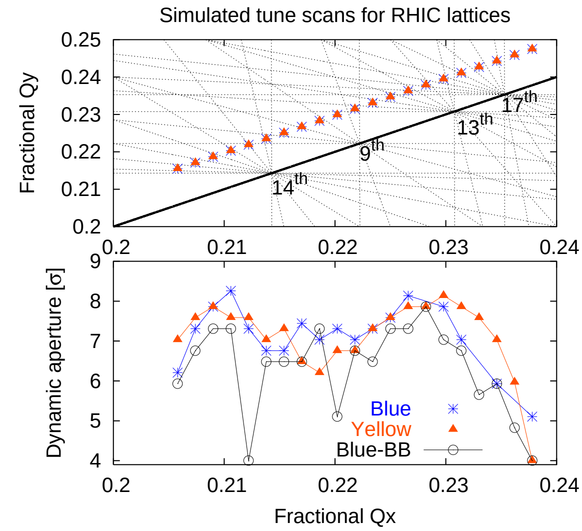

Figure 2: 10^6 turn dynamic aperture around RHIC operation working point for the Blue and Yellow lattices and Blue including beam-beam.

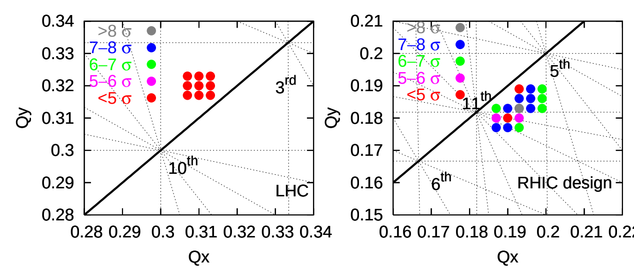

Figure 3: 10^6 turn dynamic aperture around LHC and RHIC design working points.

action points of RHIC. A beam-beam parameter of $\xi_{x,y} = 0.0012$ is used in all the simulations. The minimum dynamic aperture (DA) is defined here as the lowest transverse amplitude that originates unstable motion for five transverse phase-space angles within 10^6 turns. In Figs. 2-4 the dynamic apertures for tune scans around RHIC operation, LHC, RHIC design and SPS plus RHICpp_04 working points are shown. The beam σ corresponds to a normalized emittance of $2.5\ \mu m$. LHC tunes give the worst performance and RHIC design, SPS and RHICpp_04 tunes have dynamic apertures slightly above 8 sigma. The maximum DA for RHIC operation tunes is slightly below 8 sigma. SPS tunes might be the best candidates having the widest window of stability of the DA peak at about Qx=0.69.

THE PROTON RUN

With these data it is not straightforward to predict the best tunes at store. SPS tunes represent the preferred candidate from simulation, but injection at these tunes is not possible without correcting the third order resonance. RHIC design tunes have the least beam-beam effect at injection but the small space between the sixth and fifth order resonances would make setting up the energy ramp a difficult task. The decision was made to use the RHICpp_04 tunes

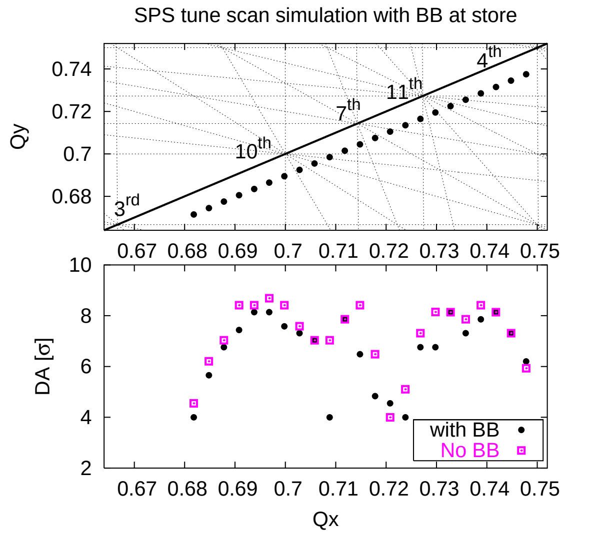

Figure 4: 10^6 turn dynamic aperture around SPS and RHICpp_04 working points.

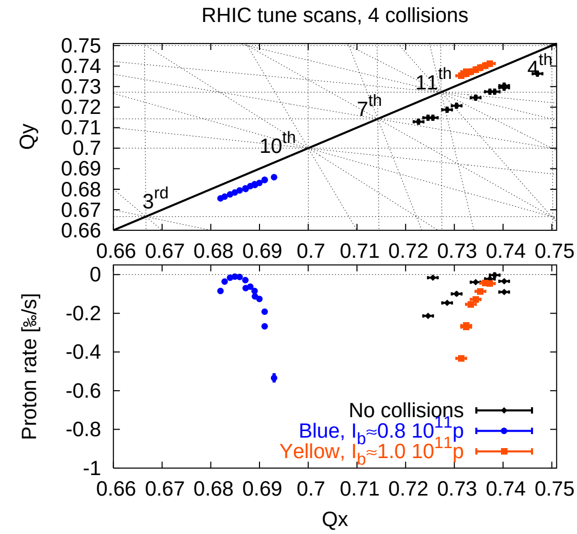

Figure 6: Experience with SPS and RHICpp_04 working points during RHIC 2004 polarized proton operation.

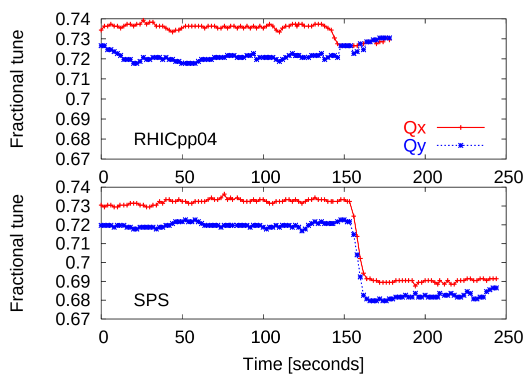

Figure 5: Tunes along the energy ramp for the two working points used in the 2004 RHIC polarized proton run.

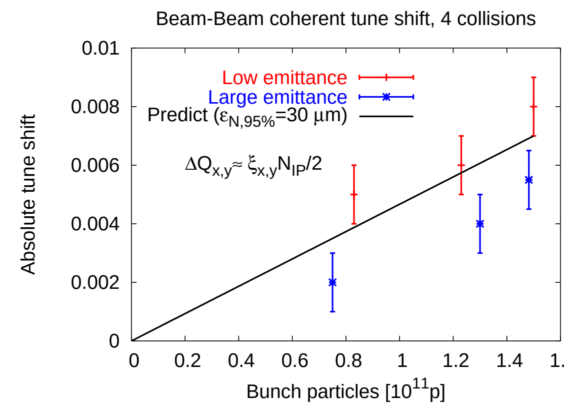

Figure 7: Absolute coherent beam-beam tune shifts measured during RHIC 2004 polarized proton operation.

for the 2004 proton run. In addition, the SPS working point was also studied at store since the proximity of these two working points allowed the corresponding tune variation at top energy. Going from RHICpp_04 tune to SPS tunes involves crossing the seventh and the tenth order resonances. This was done after the last strong spin resonance (slightly below 100 GeV) and before the beta functions at two interaction regions are squeezed to 1 m. The tune swing was implemented without beam loss as shown in Fig. 5. Tune scans were performed at store for the two working points with and without collisions, as shown in Fig. 6. These studies show a slightly better performance of SPS tunes from the point of view of beam lifetime. SPS tunes also proved to have an improved polarization transmission efficiency and an improved polarization lifetime.

The luminosity was pushed to the maximum during the proton run by increasing the bunch intensity and reducing the bunch emittance; this also implies an increase in the beam-beam parameter. We cannot directly measure the beam-beam parameter, instead we measured the coherent beam-beam tune shift by subtracting the tunes before and after collisions were established. This tune shift, $\Delta Q_{x,y}$, is approximately half of the beam-beam parameter $\xi_{x,y}$ and the number of interactions N_{IP}. Measurements are shown in Fig. 7. The maximum tune shift of $\Delta Q_{x,y} = 0.008$ corresponds to a beam-beam parameter of approximately $\xi_{x,y} \approx 0.004$. This was associated with a peak luminosity close to 10^{31} cm^{-2}s^{-1}. With only two collisions the beam-beam parameter was also pushed up to $\xi_{x,y} \approx 0.007$.

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