EXPERIENCE WITH IBS-SUPPRESSION LATTICE IN RHIC *

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Abstract

An intra-beam scattering (IBS) is the limiting factor of the luminosity lifetime for RHIC operating with heavy ions. In order to suppress the IBS we designed and implemented new lattice with higher betatron tunes. This lattice had been developed during last three years and had been used for gold ions in yellow ring of the RHIC during d-Au part of the RHIC Run-8. The use of this lattice allowed both significant increases in the luminosity lifetime and the luminosity levels via reduction of beta-stars in the IPs. In this paper we report on the development, the tests and the performance of IBS-suppression lattice in RHIC, including the resulting increases in the peak and the average luminosity. We also report on our plans for future steps with the IBS suppression.

INTRODUCTION

Relativistic Heavy Ion Collider (RHIC) at BNL comprises of two 3.8 km superconducting storage rings – called Yellow and Blue – which cross each other in six interaction points (IPs) and is very versatile [1].

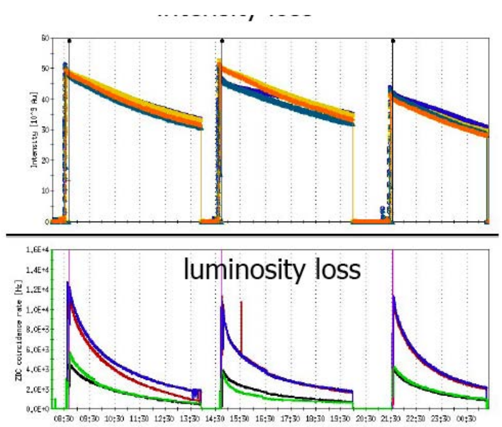

Figure 1: Typical evolution of the RHIC Au beam intensities in Yellow and Blue rins (top) and luminosity in four detectors (bottom) in Run 4.

It operates with beams of 250 GeV polarized protons, 100 GeV/u deuterons (D), heavy, fully stripped ions from Cu to Au [2] with energy of 100 GeV per nucleon. One of most unusual modes colliding deuteron and gold ions was utilized during the D-Au Run-8 this year [3].

Luminosity lifetime in RHIC heavy ion collisions is strongly affected by transverse emittance growth and can be as short as a couple of hours. Short luminosity lifetime affects both the integrated luminosity as well as the reliability of the system. As shown in Fig. 1, there are losses in the beams intensities caused by the longitudinal IBS, and additional (and most significant) reduction of the luminosity from transverse IBS. Overall loss of integrated luminosity from transverse emittance growth can be as high as a factor of two.

Collider-Accelerator Department (C-AD) has been developing both remedies and active methods of contra-acting longitudinal and transverse IBS, ranging from electron [4] and stochastic cooling [5] to modification of RHIC lattice.

In contrast of two cooling methods, the later methods is least expensive and is least intrusive. This paper is dedicated to the development, test and use of new RHIC lattice with suppressed transverse IBS. For shortness we call them "IBS-suppression lattices". The use of this lattice during D-Au Run 8 in Yellow ring operated with Au ions [3] proved to be very effective. The IBS-suppression lattice provided additional positive effects, not all of which were anticipated when the IBS-suppression for RHIC was first suggested in 2004 [6]:

– possibility to reduce β^* from 1.2 m to 0.8, i.e. 50% luminosity increase;
– lower orbit compaction factor and shorter vertex distribution;
– 15% larger area of the RF bucket, which also made vertex luminosity higher;
– a significant reduction of the electron cloud effects in the IPs caused by the use of lattices with different transition energies (γ_t) in Blue and Yellow rings.

One of the most pleasant effects of the IBS-suppression lattice was that they naturally prefer lower β^* in the IP compared with the standard RHIC lattice.

In this paper we present the idea of IBS-suppression lattice, briefly describe history of its development during dedicated accelerator experiments and first results of using it for D-Au run-8.

IDEA OF IBS-SUPPRESSION LATTICE

The idea of IBS-suppression lattice for RHIC is based a well-know formula connecting transverse and longitudinal IBS diffusion coefficients [7]:

$$\frac{d\varepsilon_x}{ds} = H(s)\cdot\frac{d\delta_E^{\,2}}{ds};\qquad H(s) = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$$

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which is valid for high energy accelerators ($\gamma >> \gamma_t$). Thus, reduction of the H-function provides the possibility of reducing (suppressing) transverse IBS. This method is well known and well understood in developing of low emittance light sources, but was not utilized in the RHIC design [8].

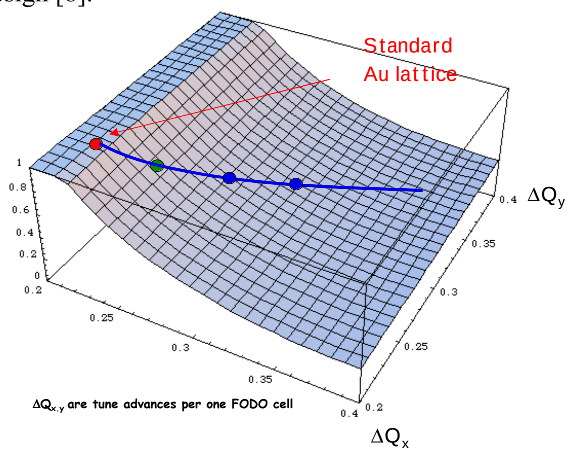

Figure 2: Reduction of the transverse IBS diffusion in RHIC depending of the tune advances per cell. Red dot corresponds to the original RHIC lattice tune advances (82 degrees per cell) used in RHIC from Run-1 till Run-7.

RHIC lattice comprises 6 IP regions, where H-function is very low [8] and six arcs with a regular FODO lattice. Dominant contribution into the transverse IBS diffusion originates in the arcs, which make it simple to describe the idea of the IBS-suppression lattice – increase the tune advance in RHIC arc's cells to the level allowed by existing RHIC power supplies, its super-conducting quadrupoles and its elaborate current distribution system [8].

Fig. 2 shows relative reduction of the transverse IBS diffusion as a function of the tune advances per arc cell. Quite naturally, the <H>-function falls rapidly with grows of horizontal tune advance per cell, ΔQ_h, and depends only slowly on the vertical tune advance per cell, ΔQ_v (there is the growth of the <H> when ΔQ_h approaches 0.5, which is of interest and also out of reach for RHIC – hence, it is not shown here). What is the most remarkable in this picture that designed RHIC tune advance has 3 times higher transverse IBS diffusion compared with the minimum possible value at ~140^o per cell.

In addition to a simple analytical model, we used code well-benchmarked BETACOOL code [9] for exact simulation of the IBS process. One of the comparison between BETACOOL prediction and the measurements is shown in Fig. 3.

Practically the range of the useful and reachable tune advances per cell is determined by existing feeding system for RHIC superconducting magnets, which has multiple inter-connections and current limits imposed by feeders and by power supplies. It is also limited by necessity of dispersion compression from the arcs to the IP and matching in all six IPs with desirable β^*.

At injection (10 GeV/u for Au ions), RHIC uses β^*~10 m in all IPs. During acceleration, β^* in two IPs (IP6 and IP8, where RHIC two remaining detectors are located) is squeezed to about 1 m, while remaining ~ 5-10 in the other IPs. There are additional constrains imposed by various RHIC system, such as diagnostics, which are extend beyond this paper.

Naturally, because of stronger focusing in the arcs, the IBS suppression lattice prefers lower β^* in the IP. It makes it easier to β^* to 1 m and below, bit it is slightly more complicated to increase β^* to about 10 m at injection. Thus, in initial trials we were using β^*=3m for injection and later, for operational lattice, increased it to β^*=5 m or above.

Experimental IBS lattice development started in 2004 and was tested during dedicated accelerator physics experiments as a part of Cu-Cu Run-5 in 2005 and Au-Au Run-7 in 2007. The first IBS-suppression lattice we had been testing had 92^o horizontal phase advance. We expected 30% decrease of the IBS diffusion, i.e. ~ 40% increase in the luminosity lifetime. This step, even not so dramatic, was considered to be sufficient to prove that concept is correct and that by changing settings existing RHIC power supplies, RICH performance can significantly be improved. It was and it is the first step to the next IBS suppression lattices with phase advances of 100^o and 110^o [10]. These lattices will provide for 2-fold reduction of the transverse IBS compared with the designed RHIC lattice.

A number of people expressed their scepticism if IBS lattice can be operational at all?, if there is enough sextupole strength?, if dynamic aperture would collapse?, etc. It took three years and number of trail and errors attempts to prove that this scepticism unsubstantiated.

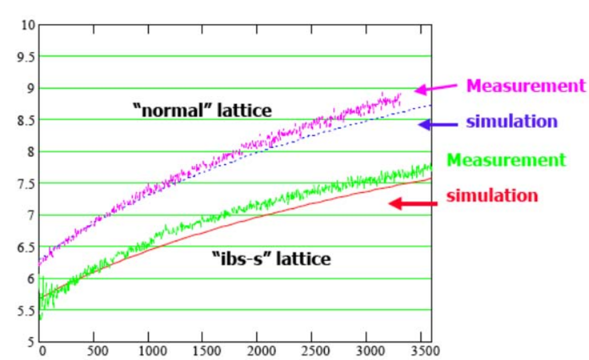

Figure 3 Comparison of emittance growth measurements and simulations with 100 GeV/u Au ion in RHIC rings for standard (82 degrees per cell) and IBS-suppressed (92 degrees per cell) lattices. Vertical axis: normalized horizontal emittance (mm mrad); horizontal axis: time in seconds.

Developing new ramp in RHIC was initially very cumbersome, and progress during Run-5 (2005) was marginal – the main problems were related to the tune swings during the ramp and corresponding beam losses and quench-link protection events. Following run with polarized protons could not be used for IBS-lattice development.

Progress with tune and coupling feed-back dramatically speed-up development of the rumps with IBS suppression lattice, and in Spring of 2007 we had succeeded with the program and directly measured effect of the IBS lattice on transverse emittance growth. Selected data from these tests, shown in Figs. 3 and 4, prove our expectation that transverse IBS diffusion was reduced by 30%.

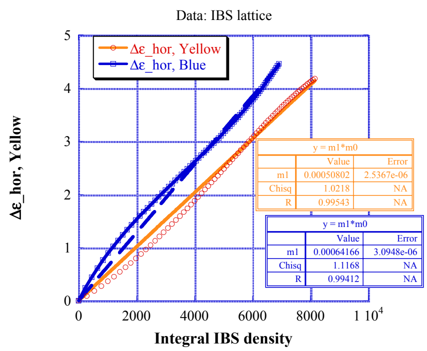

Figure 4: Results of measured emittance growth for 100 GeV/u Au ion beams in Vertical axis: normalized horizontal emittance (mm mrad); horizontal axis is integrated IBS density (see below).

Measurements, shown in Fig. 4, we done during a dedicated accelerator experiment by the end of the Run-7. We did used both rings with six bunches in each ring with various intensities and emittances for comparative studies. Blue ring was operated with standard 82^{o} RHIC lattice, and in Yellow ring was operated with IBS suppression 92^{o} lattice. As shown in [7], the IBS diffusion scales as:

$$D_{IBS//} = \frac{N r_c^{\,2} c}{2^5 \pi \gamma^3 \varepsilon_x^{\,3/2} \sigma_s} \left\langle \frac{f(\chi_m)}{\beta_y v} \right\rangle$$

This is why we are using integrated IBS density:

$$IBS\ \ Integral\ (t) = \int_o^t \frac{N(t')dt'}{\sigma_z \sqrt{\varepsilon_h \varepsilon_v (\varepsilon_h + \varepsilon_v)}}$$

(where $N(t')$ is the bunch $\varepsilon_h, \varepsilon_v$ are horizontal and vertical emittance and σ_z) as horizontal axis in Fig.4. It allows us to compare various bunches in RHIC and to compare two rings properly.

We started d-Au run using IBS-suppression lattice dAu80 (Fig. 5) for Yellow ring operating with the gold ions. The lattice turned out to be very robust and required modest efforts for its development. One positive side effect of this lattice was the fact that deuterons and Au ions were passing through transition at different time during the ramp, and this significantly reduce electron cloud effect in the IP, where both beams going through the same vacuum chamber. As we discussed above, this IBS suppression lattice that reduced the transverse growth of the gold-ion beam by 30%. Furthermore, this lattice also ensured not only better transition crossing but also better rebucketing, resulting in 10-15% more gold ions in the central RF bucket.

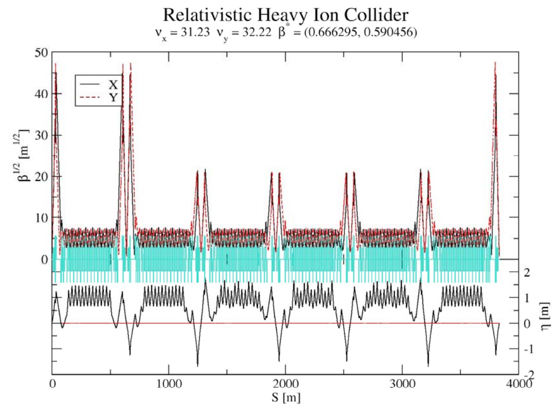

Figure 5: Lattice functions for dAu80 IBS-suppression lattice used in Yellow ring for d-Au Run-8 in 2007/2008.

Furthermore, reduced IBS rate for gold ions, allowed us to reduce β* from 1.2 m to 0.8 m in Yellow ring (followed by similar squeeze for deuterons, which have very low IBS diffusion) in two steps: dAu81 and dAu82 lattices correspondently. This modifications further raised luminosity by 25-50%.

CONCLUSSION

Idea of IBS-suppression lattice for RHIC was developed as a part of dedicated accelerator experiments at RHIC. Positive experience with this lattice during D-Au Run-8 in 2007/2008 and significant enhancements of the integrated luminosity removed any remaining scepticism and opposition for the use of these lattices. Furthermore, plans for next Au-Au in RHIC are based on the use of two dedicated IBS-suppression lattices in Yellow and Blue rings with different transition energies.

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