REDUCTION OF β*AND INCREASE OF LUMINOSITY AT RHIC

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Abstract

The reduction of β* beyond the 1m design value at RHIC has been consistently achieved over the last 6 years of RHIC operations, resulting in an increase of luminosity for different running modes and species. During the recent 2007-08 deuteron-gold run the reduction to 0.70 from the design 1m achieved a 30% increase in delivered luminosity. The key ingredients allowing the reduction have been the capability of efficiently developing ramps with tune and coupling feedback, orbit corrections on the ramp, and collimation, to minimize beam losses in the final focus triplets, the main aperture limitations for the collision optics. We will describe the operational strategy used to reduce the β*, at first squeezing the beam at store, to test feasibility, followed by the operationally preferred option of squeezing the beam during acceleration, and the resulting luminosity increase. We will conclude with future plans for the beta squeeze.

INTRODUCTION

RHIC has been in operation for 9 years. The design value is β*=1m in the high luminosity interaction points (IR6 and IR8, hosting the STAR and PHENIX detectors respectively). Since 2004 (Run-4) a consistent effort has been undertaken in the framework of the APEX program (a regularly scheduled period of 12h /week devoted to beam studies aimed at machine improvements) to the lowering of β* in high energy RHIC operations, with the following goals:

- Direct increase of machine luminosity
- Preparation for dynamical β* reduction on the store, to take full advantage of future smaller transverse emittance, once the planned transverse stochastic cooling system is operational (2011).

After a brief history of the β* developments, we will describe the operational methodology used to develop ramps with lower β* with particular emphasis on critical issues and systems. Then we will present as an example results for RHIC Run-8. We will conclude with an overview of plans for the present RHIC run (Run-9) and for the planned RHIC luminosity upgrade.

CHRONOLOGY

Table 1 summarizes the history of β* used in high-energy RHIC operations and in beam studies. After the early runs we started operations with the design β*=1m. In parallel, studies established the feasibility of lower β* and that resulted in ensuing physics running with lower β* .

Table 1. Summary of β* in Operations and APEX Studies

Run	Species	Energy (GeV/u)	β*(m) operations	β*(m) APEX
Run-1	Au - Au	65.2	3	
Run-2	Au - Au	100	1	
Run-3	d - Au	100	2	
	P - P	100	1	
Run-4	Au - Au	100	1	0.85
	P - P	100	1	
Run-5	Cu - Cu	100	0.85	
	P - P	100	1	
Run-6	P - P	100	1	
Run-7	Au - Au	100	0.8	0.65
Run-8	d - Au	100	1→0.7	0.7
	P - P	100	1	0.65
Run-9	P - P	250	0.7	*0.5*
	P - P	100	0.7	*0.5*

Development of lower β* started in Run-4 with Au-Au when we squeezed to β* =0.85m at store, by using β* knobs constructed with the online model. After the energy ramp, where β* is squeezed from 10m at injection to the design 1m at store, we ramped the IR quadrupoles at store to β*=0.85m over a few minutes, and eventually established the viability of the configuration with a 56x56 bunch physics store. In the following ion run, Run-5 Cu-Cu, we ran operations with β*=0.85. The viability of the squeeze at store was confirmed during Run-7 with Au-Au when we reduced β* during studies from 0.8 to 0.65m. In the d-Au Run-8, started with β*=1m in operations, we reduced β* in studies to 0.7m on the ramp for both rings and ran in this configuration for the reminder of the run, with a net 30% increase in luminosity. We also established the feasibility at store of a lower β* =0.65m with polarized protons at 100 GeV. For this year run (Run-9) we have been successfully running with a nominal β* in of 0.7m both in 250 and 100 GeV operations. More detailed results on Run-8 and plans for Run-9 will follow.

METHODOLOGY

Procedure

The established procedure for β* squeezing during acceleration includes preparation before beam, ramp development, store tuning and test of physics operations with a physics store.

Before beam, the optics model matching to lower β* in IP6 and IP8 is turned into a ramp with ramp application software (RampEditor, RampManager, that distributes settings to the PS WFG's). The ramp, typically 300 s, is first tested without beam to make sure power supply limits are not exceeded, and to tune the quench protection system.

Ramp development

Ramp development follows with a limited number of bunches (6 or 12 per ring) and nominal bunch intensity. Care is taken to avoid sources of emittance growth to minimize losses in the aperture limiting triplets during the $\beta*$ squeeze. The ramps are done with tune and coupling feedback, especially critical to control the strong coupling during the squeeze. Orbits need correction to 0.2-0.3mm rms on the squeeze, chromaticity needs tuning to avoid emittance blow-up due to transverse instability.

Store set-up

Once the beams get to store, typically after 3-4 tuning ramps, we tune for lifetime at store, working further on orbit, tunes, coupling, and chromaticity. We then steer for collisions and compare collision rates with the baseline $\beta*$ configuration, and test collimation. Optics measurements follows, dispersion and optics measurements with AC dipole [1], to measure the effective $\beta*$. Measured $\beta*$ are typically in within 10-15% from nominal, and $\beta*$ is also verified with Vernier scans in operation.

Test of physics ramp and store

Once operations with 6-12 bunches are established we test the viability of the new configuration with a physics store (56 to 109 bunches per ring at the nominal bunch intensity), for ramp transmission, collimation, and determination of experimental backgrounds. If all checks out we can use the lower $\beta*$ in operations. We then readjust non-linear corrections for the new configuration, namely non-linear chromaticity corrections[2] and local IR correction [3], that reduce the normal and skew sextupole effects on the tune with amplitude from the IR triplets.

Critical Systems

In order to allow for faster ramp development the tune and coupling feedback system has been critical both during operations ramp development and during beam studies. Continuous tune and coupling measurements are acquired with the BBQ (broad band Q tracker) [4] and a feedback system is implemented to keep tunes constant on the ramp and to minimize coupling. Once a ramp with tune/coupling feedback has successfully brought the beams to store, the correction settings on quadrupoles and skew quadrupoles are 'replayed', i.e. fed back to the quadrupole and skew quadrupole ramp settings so that for operations ramps we are not depending on having the feedback system active. This has been the default operations set-up for RHIC.

Orbit control, especially during the $\beta*$, is essential, and automatic orbit corrections are implemented both on the ramp and at store every ½ h.

RESULTS: RUN-8

Run-8 consisted of two operation modes, deuteron-gold collisions at 100 GeV/u followed by polarized protons at 100 GeV. In both configurations we started with initial $\beta*$ =1m.

$\beta*$ with Deuteron-gold (d-Au)

We first reduced $\beta*$ in the yellow ring (Au), where we ran a lattice with higher phase advance per arc cell to minimize intra beam scattering effects. After 2 attempts, the 3rd ramp with tune feedback brought the beam to store with good transmission (Figure 1 and 2.)

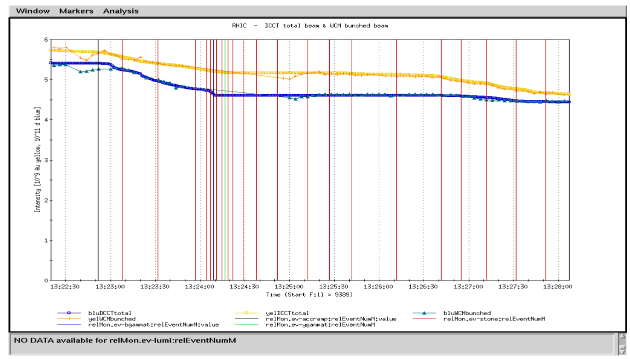

Figure 1. First successful ramp with $\beta*$=0.7m in yellow.

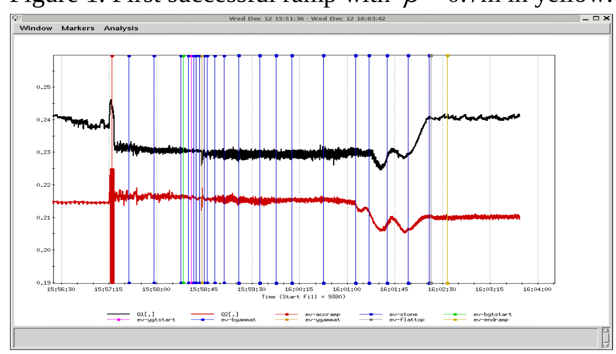

Figure 2. Tunes on the ramp, feedback and interpolation of tunes on the last part of the ramp.

A 56x56 physics ramp allowed us to establish that indeed the normalized collision rates ratios between the baseline (yellow at 1m) and the one with squeezed optics (yellow at 0.70m) yielded the expected 15% luminosity increase.

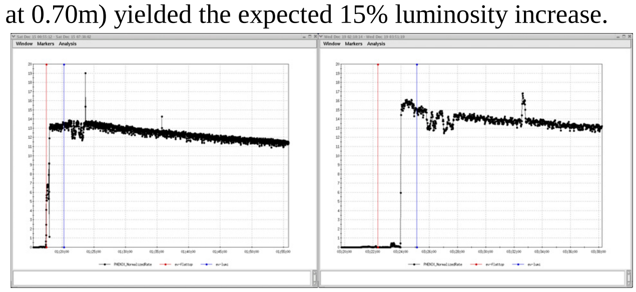

Figure 3. Comparison of normalized (for total intensity) collision rates for 1m $\beta*$ (left) and 0.70m (right) in the expected 15% ratio.

Once we established the feasibility of operations with yellow at $\beta*$=0.7m, we repeated the development for the blue ring, running deuterons, following again the procedure already described. The squeeze in the blue ring yielded also the expected ratio in normalized collision rates. (see Figure 4)

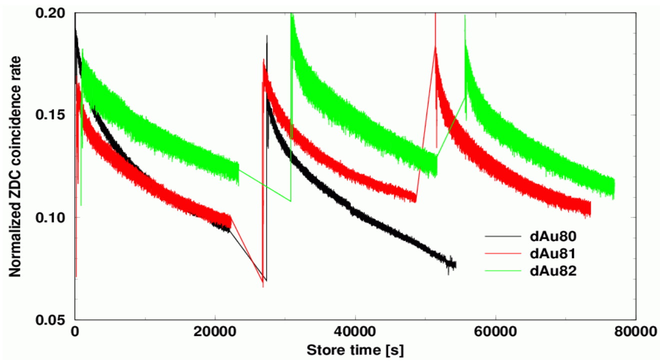

Figure 4. Comparison of normalized ZDC collision rates for the original configuration (dAu80, β*=1m in blue and yellow), for the yellow squeeze (dAu81, β*=1m in blue and β*=0.7m in yellow) and for both rings (dAu82) at β*=0.70m.

The entire development took an integrated beam time of ~24h, over a few days. We ran the reminder of the d-Au run with β*=0.7m in both rings, gaining ~30% in integrated luminosity for the run.

β* with Polarized Proton Collisions (P-P)

Given the good outcome with ion operations we devoted study time during Run-8 P-P operations to test for the first time a lower β* with P-P. It took a total of 5h of ramp development and 1.5 h of store tuning to demonstrate collisions and collimations with β*=0.65m in both rings. The timeline of the study is summarized in Figure 5.

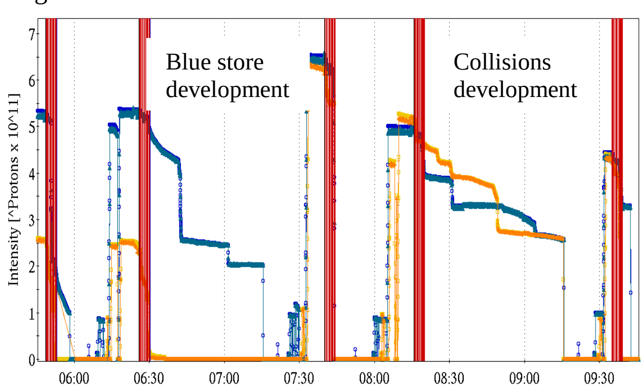

Figure 5. Summary of ramp and store beam study for the 0.65m optics during P-P Run-8.

Although we decided not to run operations in Run-8 with the squeezed optics, since the focus of the run was on polarization development and uptime for delivered luminosity, the study established that there were no show stoppers to operate with β*=0.65m at 100 GeV, that is aperture-wise equivalent to 0.4m at 250 GeV P-P. Ramp efficiency was ~95%, non-linear corrections worked, as well as collimation. In Run-9 we have been running this year with nominal β*=0.7m in operations at both 250 GeV and 100 GeV.

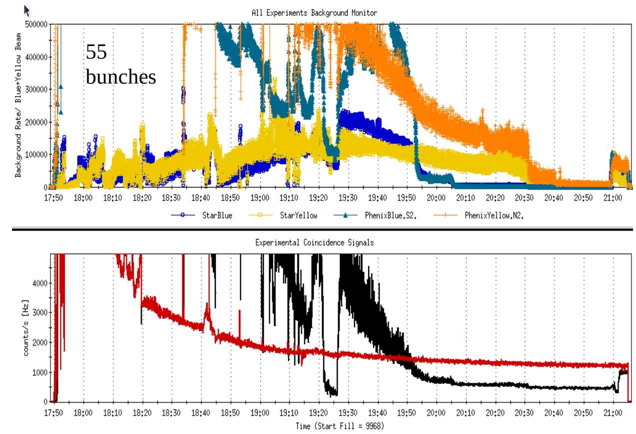

Figure 6. Collimation and collision steering during the test of 0.65m optics in P-P with a 56 bunches physics store.

FUTURE PLANS

The immediate plan for Run-9 is to test feasibility of the β*=0.5m configuration with 250 GeV P-P (already started) and with 100 GeV.

β*=0.5m and possibly lower are part of the overall luminosity upgrade plan for RHIC[5]. A critical part that can open the possibility of lower β* is the planned development of transverse stochastic cooling. When this is operational, dynamic β* squeeze on the ramp is a possibility to maximize luminosity returns from lower transverse emittances. To go below 0.5m it will be necessary to upgrade a limited number of interaction region power supplies (Q4 and Q5 trims, and Q89). Significantly lower β* configurations would be possible only with an upgrade of the triplet quadrupoles.

CONCLUSIONS

Reduction of β* at the IP6 and IP8 interaction point has been a successful and inexpensive way to increase RHIC luminosity over the last 5 years of RHIC operations at high energy. The plan is to further develop this capability for RHIC in the framework of the planned luminosity upgrade plan.

ACKNOWLEDGEMENTS

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