BNL-102119-2014-TECH

RHIC/AP/8;BNL-102119-2013-IR

High Luminosity p-p Operation at RHIC

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August 1993

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USDOE Office of Science (SC)

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RHIC/AP/8
August 13, 1993
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With possible interest in b-physics at RHIC it is timely to attempt to assess a reasonable goal for luminosity with p-p collisions which does not involve major modifications to the present machine design. This is obviously not a "day one" scenario but rather an assessment of what the achievable luminosity could be after several years of operation. In the first section I'll pick some beam parameters and then see how these numbers impact the present machine design.

Beam Parameters

Some of the beam parameters are relatively straightforward. Decreasing the bunch spacing to be less than 110ns while theoretically possible involves significant equipment modifications and is therefore outside the spirit of this report. I will assume 114 bunches. The interaction point β^* is taken to be 1m. Lower β^* values, while possible from a dynamic aperture standpoint, demand significant changes to the power supplies and the lattice matching trim quadrupoles run beyond the short sample limit at close to this value. In terms of bunch density; the nominal RHIC specifications call for a bunch intensity of 10^{11} ppb with a transverse emittance of 20π (95% normalized, mm-mrad) and a longitudinal area of 0.3 eV-s. Increasing the bunch intensity is obviously possible since the AGS was operating at 2×10^{12} ppb during the last fixed target run. However since both the transverse and longitudinal emittance are deliberately blown up during AGS fixed target operation there are no suitable measurements of beam emittances associated with this high intensity AGS mode. There are also no beam parameters available for "low intensity" AGS operation such as required for this exercise. It would appear that bunch intensities in the range of 2.5 - 3×10^{11} ppb, transverse emittances of 15 - 20π, and longitudinal emittances of ~0.5 eV-s, are consistent with AGS bunch *densities* obtained during recent fixed target operation [1]. If all else fails then injection line collimation of higher intensity bunches could be used to produce beam of these parameters. The next (94) AGS run with the gamma-t jump and upgraded RF system should be able to provide a good indication of whether this parameter set is achievable without collimation.

The nominal beam parameters are therefore:-

Intensity	$2.5 - 3 \times 10^{11}$
Transverse emittance	$15 - 20\pi$
Longitudinal emittance	~ 0.5 eV-s
Number of bunches	114
Beta Star	1m
Beam Energy	250 Gev

A beam such as this would produce an instantaneous luminosity of ~ 5×10^{32} cm^{-2} s^{-1}. The beam-beam tune shift in this regime is ~ 0.01/X-ing and thus lifetime considerations probably indicates that only two IP's could have collisions in this mode. The average number of interactions per collision is given by:

$$\langle n \rangle = \frac{\sigma_{inel} L}{N_b f_0}$$

taking the total inelastic cross-section to be 20 mb, $L = 5 \times 10^{32}$, $N_b = 114$, and $f_0 = 80$ kHz then the average number of interactions per crossing is 1.1, a reasonable rate.

Impact on RHIC

The increase of total circulating current is factor of 5-6 greater than the nominal RHIC design thus there are issues related to beam stability and beam power which must be considered.

The nominal beam dump design has approximately a factor of 4 safety margin with respect to the fracture limit on the steel absorber and an order of magnitude with respect to quenching the downstream quadrupole Q4 from particles escaping from the sides of the dump absorber. Adding an additional 80 cm of graphite to the dump is sufficient to regain the safety margin with respect to the steel [2]. A factor of 2 margin on Q4 quench threshold is probably insufficient and some shielding would be needed on the front face of the quad. Neither of these issues is fundamental.

The increased beam current will result in additional power dissipated in the bore tube of the cryogenic magnets. At 3×10^{11} ppb, 114 bunches, and an rms bunch length of 40 cm then each dipole will receive an additional ~2-3 W of heat input into the bore tube. The total increased refrigerator load at 4.5K is therefore ~1kW which is well within the present safety margin of ~10kW. The temperature increase from recooler to recooler is estimated [3] to be ~60mK which again does not pose a problem.

The beam induced cavity detuning on the 26 MHz accelerating RF system will be increased to ~ 66 kHz; still less than the frequency swing due to velocity changes for the heavy ions. Beam loading induced voltage problems during transition are not applicable for protons.

Longitudinal coupled bunch modes driven by the 26 MHz accelerating system for modes 31 and 44 would appear the biggest issue for longitudinal stability. Assume a factor of 10 reduction from HOM damping then the growth rate in the absence of Landau damping for these modes is $\sim 10^{-1}$ s at these intensities which is equal to the specifications on the longitudinal damper i.e. it runs flat out. This aspect would require a further look if high luminosity became desirable. Coupled bunch modes driven by the storage system should not be an issue.

The longitudinal microwave stability threshold at flattop was estimated for the nominal RHIC proton parameters to be Z/n ~ 2 ohms [4]. The impedance threshold is related to the momentum spread and the instantaneous current by:

$$\frac{Z}{n} \propto \left[\frac{\left(\frac{\Delta p}{p}\right)^2}{I_0} \right]$$

Increasing the bunch current by a factor of 2.5 -> 3 is ameliorated somewhat by increasing the longitudinal emittance from 0.3 -> 0.5 eV-s, and can also be helped by increasing the cavity voltage from 300 kV to 600 kV. Under these conditions the stability threshold is reduced to 1.3 -> 1.5 ohms. The present estimate for the RHIC broadband impedance is ~ 1.0 ohm with the shielded bore tube bellows. Bunch intensities in the 2.5 - 3×10^{11} range thus appear to be about the maximum we can contemplate unless we can increase the longitudinal emittance which can be rebucketed. Rebucketing defines the maximum longitudinal emittance of 0.5 eV-s.

Transverse stability requirements are given by the low frequency resistive wall and transverse microwave effects (transverse mode coupling). The resistive wall growth time is ~8 ms at injection [5] which is within the range of the transverse damper specified at 400W. Transverse microwave effects appear to be Landau damped [6]

Conclusions

At this time it appears that a maximum p-p luminosity of 5×10^{32} is a realistic goal for RHIC. At this intensity collisions at only 2 out of the 6 IR's are possible due to the beam-beam tune shift. Individual bunch intensities and total beam power are close to both stability and operational limits and thus a luminosity of this magnitude is a reasonably natural fall-out from the machine design and not the result of any single feature. A measurement of the beam parameters in the AGS in this intensity regime is desirable.

References

[1] Bill Weng

[2] Alan Stevens

[3] Don Brown

[4] RF Conceptual design report

[5] Mike Blaskiewicz

[6] Workshop on RHIC Performance Pg. 381