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Luminosity scaling of electron gold collisions in the RHIC rings

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1 Introduction

In principle it is possible to collide heavy ions with positrons in RHIC, with the positrons circulating in one of the two existing rings. In this scenario a fundamental constraint is placed on the luminosity performance by the synchrotron radiation heat load incurred at cryogenic temperatures. Alternatively, an additional purpose built ring in the RHIC tunnel could circulate positrons or (more likely) electrons. Such a room temperature ring would be much less constrained by cooling system requirements. This note calculates the approximate scaling of the achievable luminosity, *either* constraining the synchrotron radiation power to an upper bound of 1 Watt per meter of dipole bend, *or* with no such constraint.

It is implicitly assumed that

- the heavy ions are gold
- bunches naturally hold about 10^{11} charges, so $N_{Au} = 10^9$, and $N_e \leq 10^{11}$
- the nominal number of bunches in each ring is $b = 120$
- both beams are round, with the same rms collision beam size σ^*
- the smallest collision beam size occurs when $\beta_0^* = 1.0$ meter for a gold energy of $\gamma_0 = 100$ with a 95% (6π) normalized emittance of $\epsilon = 12\pi$ microns.

Many issues are ignored for the sake of brevity. These include

- injector availability
- beam-beam effects
- geometrical difficulties - DX (crossing magnet) acceptance, et cetera
- the potential need to limit the discrepancy between γ_e and γ_{Au}

2 Unconstrained luminosity

The luminosity for electron gold collisions is

$$L = \frac{fbN_e N_{Au}}{4\pi\sigma^{*2}} \tag{1}$$

where the revolution frequency $f = 78$ kHz in RHIC. At the highest gold energy the collision beam size is

$$\sigma_0^* = \sqrt{\frac{\epsilon\beta_0^*}{6\pi\gamma_0}} = 141 \;\; [\mu\text{m}] \tag{2}$$

Holding the maximum beam size in the triplet constant, the collision beam size scales like $1/\gamma_{Au}$

$$\sigma^* = 141 \left(\frac{100}{\gamma_{Au}}\right) \;\; [\mu\text{m}] \tag{3}$$

Thus the unconstrained luminosity, with $bN_e = 1.2 \times 10^{13}$ stored electrons, is

$$L = 3.7 \times 10^{29} \left(\frac{\gamma_{Au}}{100}\right)^2 \;\; [\text{cm}^{-2}\text{s}^{-1}] \tag{4}$$

This is an order of magnitude calculation only!

3 Luminosity constrained by radiant power

The synchrotron power radiated per meter of RHIC dipole is

$$P = bN_e \frac{fC_g E_e^4}{2\pi\rho^2} \tag{5}$$

where E_e is the positron energy (in GeV), $\rho = 243.8$ m is the dipole bending radius, and $C_g = 8.846 \times 10^{-5}$ m GeV^{-3} is a universal constant. Putting this together gives

$$P = 355 \left(\frac{bN_e}{1.2 \times 10^{13}}\right) \left(\frac{E_e}{10}\right)^4 \;\; [\text{Wm}^{-1}] \tag{6}$$

This shows that it is necessary to reduce bN_e (the total number of positrons stored) in order to limit the cryogenic heat load in the positron energy range of interest. The maximum heat load is approximately $P_c = 1$ W m^{-1}, so that the luminosity constrained by radiant power is

$$L = 1.0 \times 10^{27} \left(\frac{P_c}{1}\right) \left(\frac{10}{E_e}\right)^4 \left(\frac{\gamma_{Au}}{100}\right)^2 \;\; [\text{cm}^{-2}\text{s}^{-1}] \tag{7}$$

This, too, is an order of magnitude calculation only!

4 Conclusions

The need to limit the cryogenic heat load from synchrotron radiation to about 1 Watt per meter places a strict constraint on the number of positrons that can be stored in a RHIC ring. This in turn limits the attainable luminosity to about 10^{27} cm^{-2}s^{-1} for 10 GeV positrons in collision with full energy gold ions.

A third ring in the RHIC tunnel at room temperature, with water cooling, could dissipate head loads larger than 1 kilowatt per meter. This would completely remove the constraint on the number of positrons (or electrons) that could be stored, at the expense and complexity of having to build an additional ring.