BNL-102240-2014-TECH

RHIC/AP/134;BNL-102240-2013-IR

Protons on Gold at Identical Rigidities

S. Peggs

September 1997

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

RHIC/AP/134
September 1997

Protons on gold at identical rigidities

S. Peggs

1 Motivation

The nominal operational scenario for proton on gold collisions in RHIC has both beams circulating with same Lorentz β, in order to trivially ensure that beams moving down the center of the magnets have synchronized collisions. This leads to two different rigidities $B\rho$, since

$$B\rho \ [\mathrm{T\,m}] \ = \ 3.3356 \, \frac{AM_0}{Z} \, \beta\gamma \tag{1}$$

where M_0 is the mass per nucleon in GeV/c^2. Using $(Z, A, M_0) = (1, 1, .93827)$ for protons, and $(79, 197, .93113)$ for gold ions, then

$$(B\rho)_p \ = \ 3.1297 \, \beta\gamma \tag{2}$$

$$(B\rho)_{Au} \ = \ 7.7450 \, \beta\gamma \tag{3}$$

The operating parameters of Table 1 apply in the case of equal speed proton and gold bunches at top energy,

Unfortunately, the two beams must pass through a common DX magnet on either side of each interaction point before being split into separate rings. Since protons are bent much more strongly than gold ions, the DX magnet must be translated sideways in order to avoid beam scraping. It is cumbersome and time consuming to move these magnets, when going between collisions with identical species and collisions with protons on gold.

In principle it is possible to avoid moving DX magnets by colliding protons on gold at the same (maximum) rigidity. Synchronous collisions are guaranteed, in this scenario, simply by locking the RF frequencies of the two rings. This forces the ideal closed orbit in each ring systematically inward or outward, so that the total closed orbit circumference is adjusted appropriately. These closed orbit shifts may or may not be tolerable in practice. This paper evaluates their size, and makes preliminary comments on their practicality.

2 Equal rigidities

When protons and gold ions both circulate at the same maximum rigidity, the proton parameters of Table 2 apply. Comparison of Tables 1 and 2 shows that

Quantity	units	value
Gold rigidity $(B\rho)_{Au}$	[Tm]	839.5
Proton rigidity $(B\rho)_p$	[Tm]	339.24
$\beta\gamma$		108.391
$1-\beta$		4.3×10^{-5}

Table 1: Operating parameters for equal speed protons and gold ions.

Quantity	units	value
Proton rigidity $(B\rho)_p$	[Tm]	839.5
$\beta\gamma$		268.234
$1-\beta$		0.7×10^{-5}

Table 2: Proton parameters when protons also have the maximum rigidity.

protons go faster than gold ions by $\Delta\beta = \beta_p - \beta_{Au} = 3.6 \times 10^{-5}$. This difference is accommodated, for example, by setting the common RF frequency so that the revolution frequency f_{rev} of the gold ring is increased from its nominal value by the same amount that the proton ring frequency is decreased. This is accomplished at the cost of changing the synchronous momentum by $\Delta p/p$, where

$$\frac{\Delta f_{rev}}{f_{rev}} = \eta_{slip} \frac{\Delta p}{p} \quad (4)$$

$$= \pm \frac{\Delta\beta}{2} \quad (5)$$

The slip factor η_{slip} is essentially the same for both rings, given by

$$\eta_{slip} = \frac{1}{\gamma_T^2} - \frac{1}{\gamma^2} \approx \frac{1}{\gamma_T^2} \quad (6)$$

where $\gamma_T = 22.89$ is the transition gamma of RHIC. Thus, the synchronous momentum shift is

$$\frac{\Delta p}{p} \approx \pm \frac{\Delta\beta}{2} \gamma_T^2 = \pm 9.4 \times 10^{-3} \quad (7)$$

where the positive sign applies to the proton ring. Since the maximum dispersion is $\widehat{\eta} = 1.9$ meters, the closed orbit is systematically shifted by as much as

$$\Delta X_{extreme} \;\approx\; \pm\,\widehat{\eta}\,\frac{\Delta\beta}{2}\,\gamma_T^2 \;=\; \pm\,18\ \text{[mm]} \tag{8}$$

even before random orbit errors are added.

3 Summary and Conclusions

When protons and gold ions collide synchronously at the same maximum rigidity, systematic orbit displacements as large as 18 mm are required in both rings. Although this maximum displacement is an uncomfortably large fraction of the 40 mm coil radius of the arc magnets, acceptable beam storage performance may be possible.

In the absence of real operating experience, it is not possible to predict with confidence that RHIC will operate acceptably well in this mode. However, it is possible that Machine Studies with a single beam in 1999 will provide the confidence to seriously contemplate equal rigidity synchronous collisions of protons on gold.

Even if 18 mm closed orbit displacements turn out to be impractical, it may still be possible to avoid moving DX magnets by adopting a compromise scenario, part way between equal speed and equal rigidity extremes. Also, some advantage may be gained by removing the implicit assumption that the beams collide head-on (although with a common mode crossing angle).