A STRAIGHT SECTION DESIGN IN RHIC TO ALLOW HEAVY ION ELECTRON COOLING*

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Abstract

The Relativistic Heavy Ion Collider (RHIC) has been continuously producing exciting results. One of the major luminosity limitations of the present collider is the intra beam scattering. A path towards the higher luminosities requires cooling of the heavy ion beams. Two projects in parallel electron and stochastic cooling are progressing very well. To allow interaction between electrons and the RHIC beams it is necessary to redesign one of the existing interaction regions in RHIC to allow for the longer straight section with fixed and large values of the betatron functions. We present a new design of the interaction region for the electron cooling in RHIC.

INRODUCTION

RHIC has exceeded designed beam intensities and luminosity requirements during first few years of operation. Unfortunately, as predicted, intrabeam scattering presents a major limitation for luminosity enhancement during heavy ion collisions. The luminosity upgrade requires electron and stochastic cooling to suppress the intrabeam scattering. The average luminosity of the Au^{79+} on Au^{79+} collisions, should reach $\sim 70 \cdot 10^{26}$ cm^{-2}s^{-1} from presently achieved $5 * 10^{26}$ cm^{-2}s^{-1}, while the peak luminosity will be $90 \cdot 10^{26}$ cm^{-2}s^{-1} from $15 \cdot 10^{26}$ cm^{-2}s^{-1}, already achieved. Electron cooling of RHIC will be the to use bunched electron beam [1]. The electron bunches of the similar size as the heavy ion bunches will be traveling together with the ion bunches with the same speed within the new interaction region of RHIC. A betatron function of $\beta^* \sim 400$ m is required from the present optimization of electron cooling parameters.

RHIC present lattice design and constraints

The RHIC is made of two identical superconducting *"blue"* and *"yellow"* rings with equal lengths and parallel to each other as they intersect each other at six interaction regions (IR). The lattice functions have sixth fold symmetry at injection energy, while at collisions each interaction region is adjusted to the beta β^* functions at the interaction points (IP) of the experiments, accordingly. The lattice functions of each ring are anti-symmetric from one side of the IP to the other. The focusing quadrupole is in the middle within a triplet on one side while there are two of them surrounding the defocusing quadrupoles on the other side of the IP. An example of the present RHIC lattice at on of the large experiments is presented in Fig. 1.

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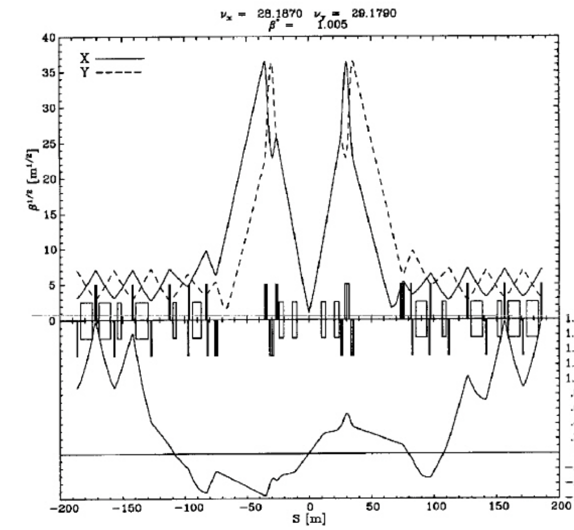

Fig. 1: Betatron functions (β_x full and β_y dashed) at one anti-symmetric interaction region. The dispersion function is presented bellow with zero value at the IP.

One of the interaction regions (IR 2 o'clock) without experiments has been selected for the electron cooling. Two kinds of magnets (*"D0"* and *"DX")* bend the beams opposite ways and bring them into a collision downstream of the high focusing triplet quadrupoles. The dispersion matching and zero dispersion at the IP are provided by the missing dipoles scheme within the standard *"FODO"* cells. The IP dipoles are presented in Fig. 2.

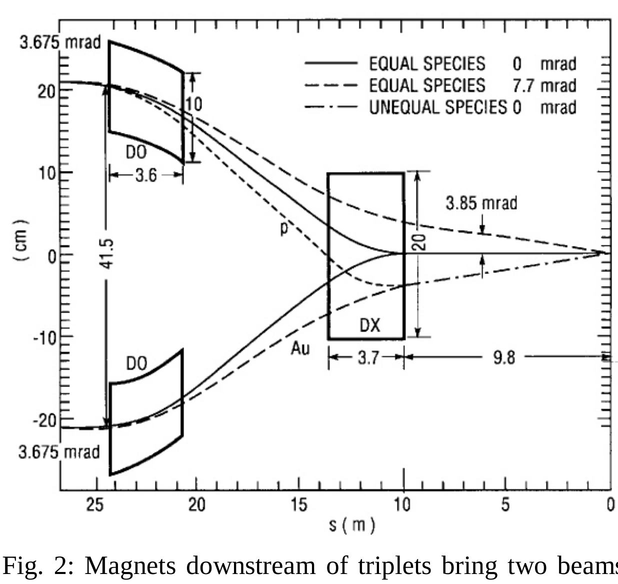

Fig. 2: Magnets downstream of triplets bring two beams into a collision. There is 9.8 meters from the dipole to the IP.

The last *"D5"* dipoles after the end of the arcs direct the beams towards the *"D0"* magnets. This geometrical constraint for the new electron cooling IR design is presented schematically in Fig. 3.

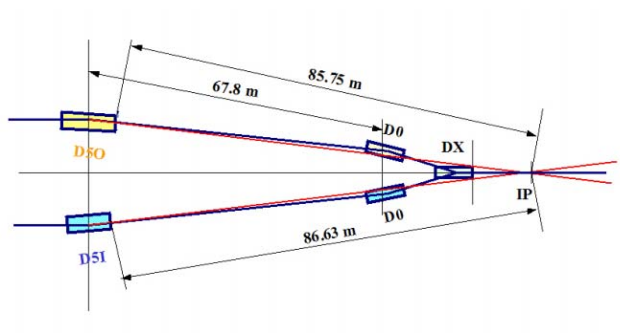

Fig. 3: Present (blue) geometrical constraint with the *"D0"* and *"DX"* magnets and future (red) beam lines without magnets.

Tuning limitations due to power supply system

The arc quadrupoles in each ring are connected to the same quadrupole bus. The bus crosses at each defocusing quad. An additional "shunt" power supply is added to the current in opposite direction allowing a distinction between the focusing from defocusing currents. The quadrupoles in the interaction region (counted from one in the triplets to ten towards the arcs) have limited capabilities for tuning. In addition to few additional parallel shunt power supplies there are few interaction region quadrupoles *"trim quadrupoles"* to improve tuning range. The tuning quadrupoles are *Q4T*, *Q5T*, *and Q6T*, they replaced the 75 cm superconducting sextupoles with maximum gradient of G_t*~28.3 T/m* and nominal operating current of 100 A. The regular superconducting quadrupoles have gradients *~60 T/m*, although they are capable of running up to *G~95 T/m*. These tuning limitations exist due to cost optimization and dramatic reduction in the number of power supplies. Additional limitation on tuning comes from the number of superconducting leads from the power supplies to the magnets and their power limitation. The present shunt power supplies limitations are best presented in Fig. 4.

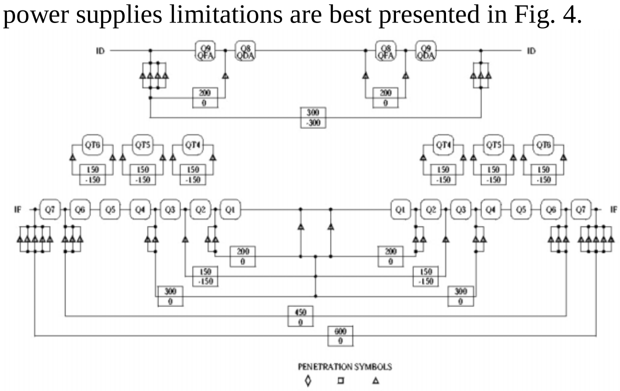

Fig. 4: Interaction power supply system for one of the interaction regions with penetrations presented.

The electron cooling interaction region design

The geometrical constraint for the new interaction region is schematically presented in Fig. 3. The path lengths of the two beams in RHIC have to be equal to each other, as they have to collide at the different interaction regions. Many options to keep the beam path conserved and allow future electron ion collider interaction region, have been explored. It would be possible to remove crossing at two of the IR's and flipping the polarities of dipole magnets in the arcs as presented in Fig. 5.

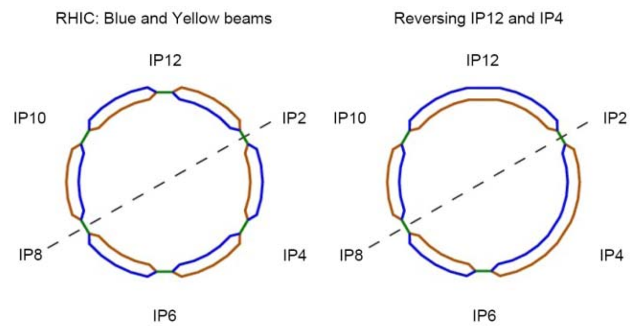

Fig. 5: Other possible solutions: Two new interaction regions in RHIC for e-RHIC and electron cooling.

An interaction region without the bending elements *"DX"* and *"D0"* was selected due to relatively large expenses required to flip the polarities of the superconducting dipoles in the arcs. The geometrical part of the electron cooling interaction region solution has already been presented in Fig. 3. The beam will traveling from the last dipole labeled as *"D5"* (dipole *"D5I"* belongs to the ring closer to the center –"inside" ring, while the dipole *"D5O"* belongs to the ring further of the RHIC center – the "outside" ring). The two *"D5"* dipoles will have small changes in the bending angles: The *"D5O"* magnet will bend for 3.68% more while the *"D5I"-4.63 %* less, schematically presented in Fig. 3.

Constraints and requests for lattice functions

The electron cooling requires:

- The length of the magnet free straight section needs to be at least ~80 meters long.
- The betatron functions along the straight should be β^*_x and β^*_y ~ 400 m with zero slopes α_x and α_x ~0.
- The dispersion function and its slope D_x' and D_x should be equal to zero.

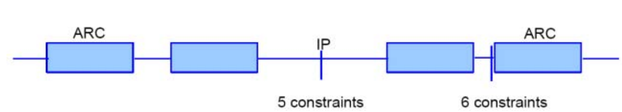

Fig. 6: Betatron function constraints in the IR design.

At the same time the betatron functions and dispersion function have to be matched to the lattice upstream of the dipole *"D5":*

- Six constraints: β_x, β_y, α_x, α_y, and the slope and the dispersion function D_x' and D_x on one side of the interaction region, and to the lattice functions at the downstream side of the *"D5"* at the opposite side.

The relatively large values of the horizontal and vertical amplitude functions, β_x and β_y, are provided by two symmetric triplets on opposite sides of the IP. The new position of the triplet magnets should be as close as possible to the *"D5"*magnets to give a long magnet free straight section. Because the large value of the β^* ~400 m is required, a distance from the minimum of the amplitude functions from β_{D5}, close to D5 to the triplet has to be a least 24 m. This comes from the parabolic dependence of the betatron functions with respect to the distance: $\beta(s) = \beta_{D5} + s^2/\beta_{D5}$.

The RHIC design uses the "missing dipoles" scheme, within a few *"FODO"* cells, to provide the zero dispersion at the IP. The two removed *"D0"* and *"DX"* dipoles do not influence the dispersion function as their angles are almost equal but opposite sign, the betatron functions do not differ too much, and the phase difference is very small.

The quadrupoles strengths, as presented in Fig. 7, are adjusted to provide zero dispersion at the end of the *"D5"*magnets and correct slopes α_x and α_y to allow rise of the amplitude functions β_x and β_y to the triplets.

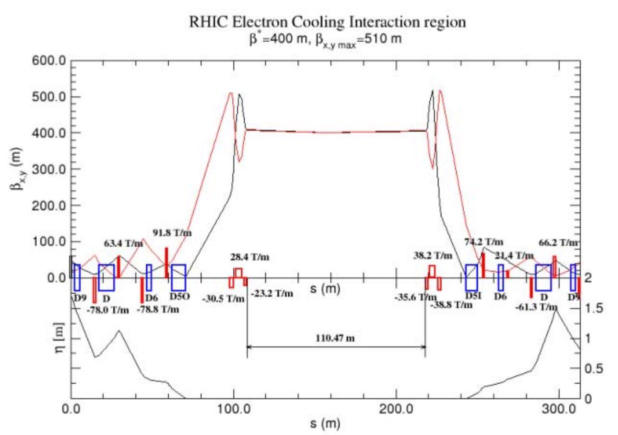

Fig. 7: The symmetric triplet solution for the electron cooling interaction region. Available length is 110 meters for electron ion interactions with β^*=400m. Dispersion is presented in the lower part of the chart.

The presented solution does fulfill all conditions set by the electron cooling requirements. Unfortunately due to limitations in tuning capabilities in RHIC a few quadrupoles have gradients settings outside of the available range in currents, but within achievable gradients. The triplets at both sides provide relatively "flat" dependence of the amplitude functions through the interaction region.

The three-dimensional sketch of the electron cooling interaction region together with the electron recovery linac, is presented in Fig. 8. Two beam lines connecting *"D5"*magnets from one side of the IP to the other, need to be vertical separated for about ~10 cm. This requires two small dipoles on each side. They will produce vertical dispersion of D_y=10 cm between the triplets but keeping the vertical dispersion to zero at the rest of the RHIC rings. The electron beam with energy of 54 MeV will be reused from one ring to the other before returning to the energy recovery linac. The dog bone beam line is necessary for electrons to allow entrance to the common beam pipes and change the direction of motion for the other ring.

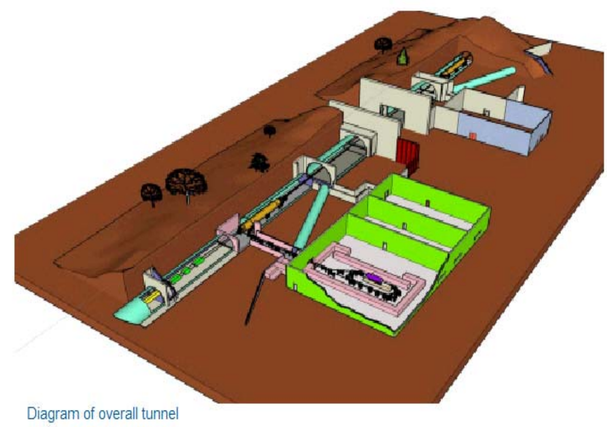

Fig.8: A three-dimensional sketch of the electron cooling interaction region.

CONCLUSIONS

A design of the interaction region for the electron cooling is presented. A solution was found under very stringent constraints. Limitation of the RHIC magnet and power supplies system does not provide wide range of adjustments. Large changes from the RHIC design lattice are difficult to achieve. Before the final dessision for the new interaction region design is made, other solutions, where available length of the free area and zero dispersion could be compromised, should be revisited.

REFERENCES

[1] Ilan Ben-Zvi, " The ERL High Energy Cooler for RHIC", this conference Invited Oral, TUZBPA01.