# SMALL GAP MAGNETS AND VACUUM CHAMBERS FOR eRHIC*

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*Abstract*

eRHIC[1][2][3], a future high luminosity electron-ion collider at Brookhaven National Laboratory (BNL), will add polarized electrons to the list of colliding species in RHIC. A 10-30 GeV electron energy recovery linac (ERL) will require up to six passes around the RHIC 3.8 km circumference. We are developing and testing small (5 mm) gap dipole and quadrupole magnets and vacuum chambers for cost-effective eRHIC passes [4]. We are also studying the sensitivity of eRHIC pass optics to magnet and alignment errors in such a small magnet structure. We present the magnetic and mechanical designs of the small gap eRHIC components and prototyping test progress.

## INTRODUCTION

There has been a growing interest in the physics community in building a high energy, high luminosity polarized electron-ion collider to study the fundamental structures of nucleons and nuclei and details of QCD theory governing the interactions in nuclear matter. eRHIC will generate 3-10 GeV high intensity electron beams. The design of eRHIC based on an ERL opens a way to high luminosities of more than $10^{33}$ $cm^{-2}s^{-1}$.

In the ERL-based eRHIC design, the electron accelerator includes a superconducting ERL and several re-circulating passes to accelerate the electrons to 10 GeV with possible extension to higher energies (Fig. 1). The development of small gap magnets (dipoles and quadrupoles) and a common vacuum chamber (Fig. 2) compatible with a multi-pass ERL has a high potential for a cost effective solution for eRHIC by using the existing RHIC tunnel for four of its five return loops In other solutions (such as the ring-ring option), the synchrotron radiation will be too strong and energy consumption will be prohibitive. Use of an ERL for eRHIC provides an electron beam with very small emittance and size. It permits design of loop magnets with very small gaps (a few millimeters) and install with a single vacuum chamber (Fig. 2).

## MAGNETS

A C-shaped dipole magnet with limited extent towards a common vacuum chamber should provide the field quality necessary for beam stability and beam quality. By applying 640 A current per pole, we expect to create a 3160 Gauss uniform dipole field. The allowed multipole components are all at or below the 3E-4 level at a radius of R=2 mm . Fig. 3 shows a flux plot by using Opera [5].

A 47 cm long dipole prototype has been built and is ready for testing. The C-shaped core was made of 1006

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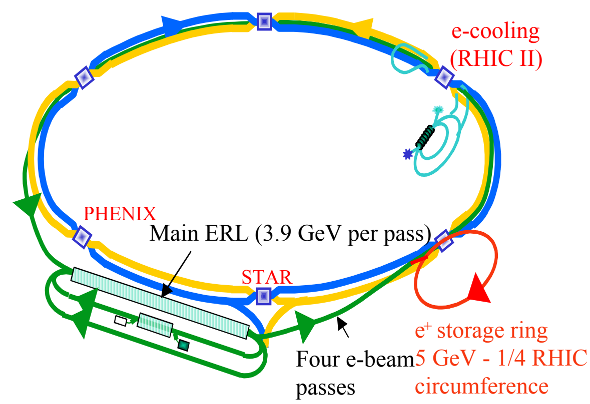


Figure 1: Layout of the high energy, high luminosity eRHIC based on a 5-pass SRF ERL.

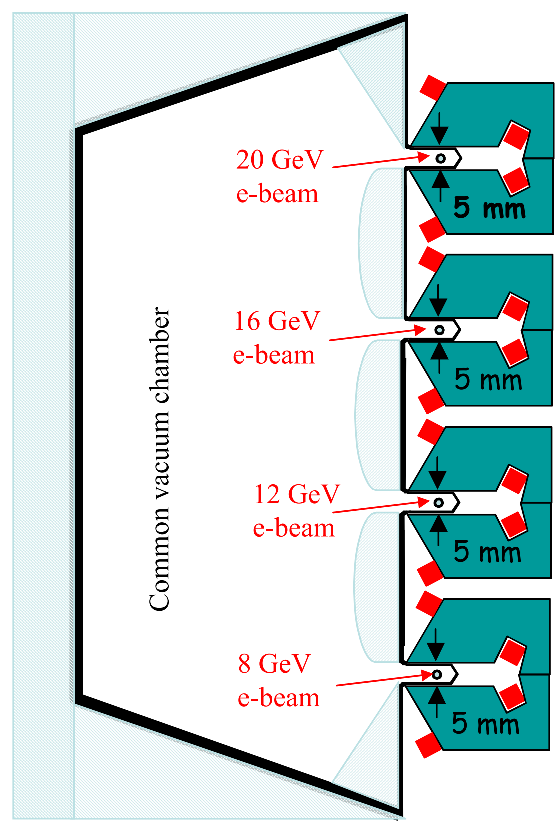


Figure 2: Sketches of common vacuum chamber with 4 layers of magnets.

steel and was manufactured by using EDM in the BNL Central Shops Division. Natural air-cooled conductors should be able to sustain the ohmic heat due to the relatively low current density (2.5A/mm$^2$). Fig. 4 shows some photos of the prototype dipole.

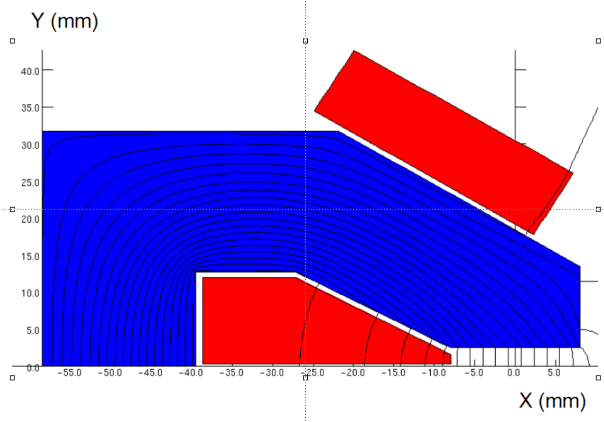


Figure 3: Dipole flux plot.

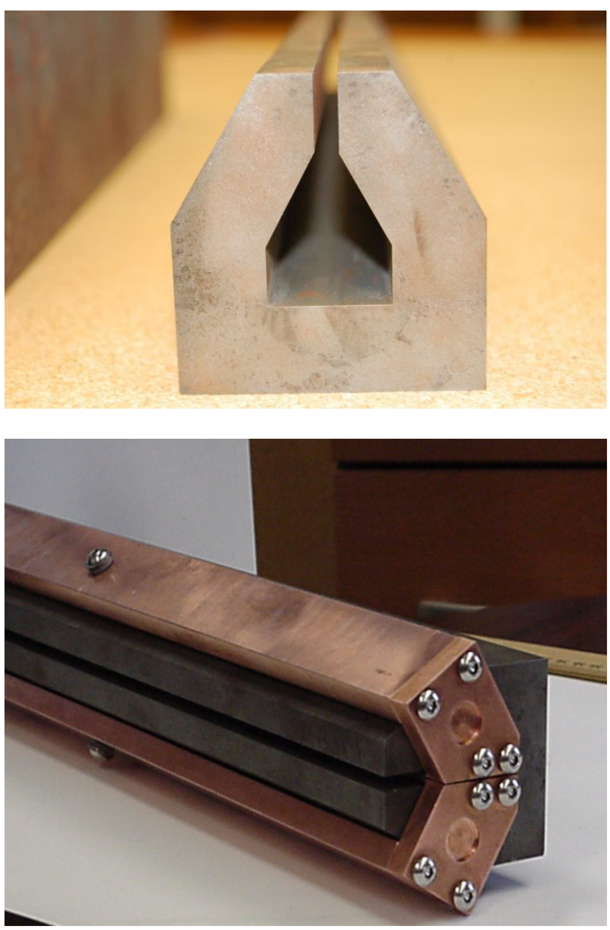

Figure 4: Dipole Prototype: photographs of the 47-cm long dipole core with 5 mm magnetic gap (top) and the same dipole equipped with copper coils ready for magnetic measurements (bottom).

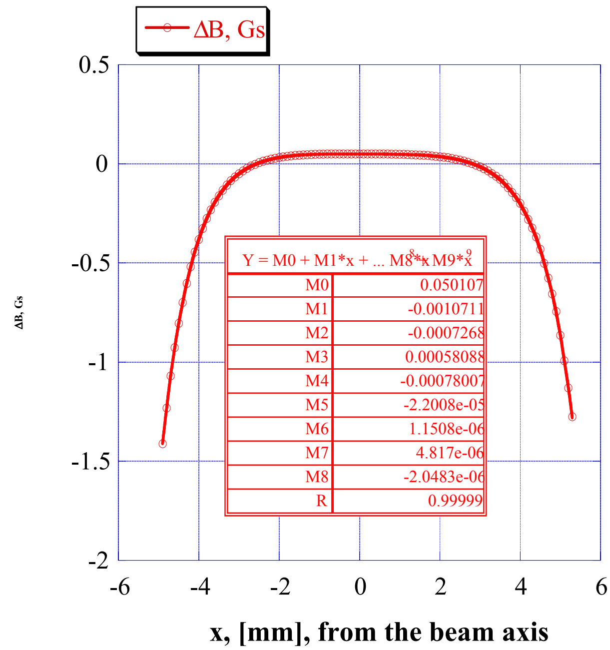


Figure 5: Non-linear component of the dipole magnet field in the vicinity of the beam axis.

We estimate that the horizontal magnet aperture required for normal operation of eRHIC is +/- 2 mm. The quality of the designed dipole filed has ΔB/B of +/- 10$^{-5}$ within this aperture and satisfies our requirements of has ΔB/B of +/- 10$^{-4}$ within aperture of +/- 4 mm. We do not expect any serious problem coming from the nonlinearities of the dipole field in eRHIC.

### *Quadrupole Magnets*

To eliminate unwanted multipole components (especially sextupole), we designed a modified "Collins type" [6] quadrupole magnet (Fig. 6), in which dipole and sextupole components are not allowed by symmetry. The vertical gap (5 mm) between two half parts will be connected by using an aluminum 6061 plate. From the simulation, we expect that a gradient above 20 T/m can be achieved without problems. Since the electron beam size will be quite small (on the order of a few micrometers), we define the good field region as an aperture with 1 mm radius. The largest unwanted higher order (12-pole) component is 2E-4 level within this region.

Further engineering design is in process, which includes (1) optimization of the conductor cross-section; (2) choosing the best structure design to minimize the tolerances due to assembly; (3) maximizing the height of the entire magnet to achieve even larger field gradient; (4) possible improvements on the design based on the beam dynamics tolerance studies.

The quadrupole prototype will be finalized and fabricated by the third quarter of 2009.

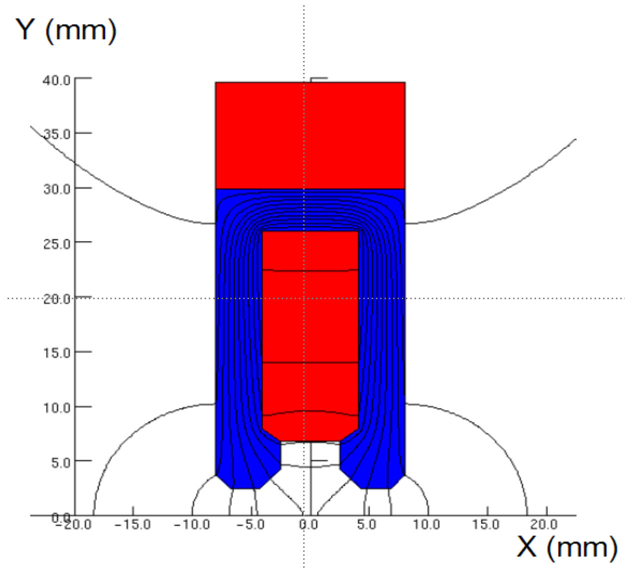

Figure 6: Quadrupole flux plot.

### *Vacuum Chamber*

Common vacuum chamber design and construction is indeed a challenge in this project. The horizontal width of the "saw-tooth", or the distance between the beam center and the edge of magnet, will directly affect the vacuum quality due to conductance, and therefore beam losses as a result of multiple scattering. At present, this beam center to edge distance is 8 mm. Stress and stiffness finite element numerical analysis (ANSYS [7]) of the thin wall (0.03") aluminum vacuum chamber under 1 atmospheric pressure has been completed. The stresses and the deviation of the walls are predicted to be at an acceptable level. The currently pursued construction method is extruded aluminum with finish machining operations on the exterior of the chamber.

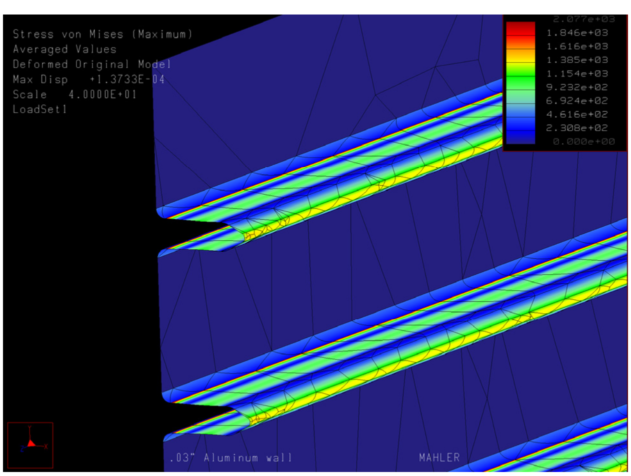

Figure 7: Stress and displacement analysis of aluminum prototype of eRHIC vacuum chamber. The maximum displacement of the vacuum chamber in the gap is 3.5 micrometers.

## FIELD MEASUREMENTS

Magnetic field measurement on the dipole prototype is under preparation. We plan to use Group 3 Hall probe mounted on a 3-axis translation stage to map the field. The 5 mm gap barely allows the probes along with its holder to fit in the gap. It will be possible to do both longitudinal and radial scans using this system.

The same measurement system may be used for the quadrupoles to carry out radial scans in the midplane of the magnet at many axial locations. This would provide measurements of both the quadrupole field strength and higher order harmonics.

## OPTICS SIMULATIONS AND TOLERANCE STUDIES

Optics simulations have been studied since October 2008. Based upon the future measurements on dipole and quadrupole prototype magnets, simulation will include more realistic field errors and possible estimated alignment errors in the loop lattice. Emittance growth and beam losses will be better understood, which will benefit to the future eRHIC overall design.

## REFERENCES

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