NS-FFAG FOR ELECTRON-ION COLLIDER IN RHIC (ERHIC)*

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Abstract

A future electron ion collider "QCD test facility" is designed in the present Relativistic Heavy Ion Collider (eRHIC) tunnel. Electron acceleration and de-acceleration is preformed with energy recovery linac with multiple passes. We report on a combination of a multi-pass linac with the Non-Scaling Fixed Field Alternating Gradient (NS-FFAG) arcs. A single NS-FFAG arc allows electrons to pass, in the first stage of eRHIC, through the same structure with an energy range between 1.28 and 10 GeV. The NS-FFAG is placed in the existing RHIC tunnel. The 100 MeV injector bring the polarized electrons to the 0.9 GeV superconducting linac. After three passes through the linac 2.8 GeV electrons enter NS-FFAG arc and after 8 passes reach the energy of 10 GeV. After collisions the beam is brought back by the NS-FFAG, decelerated to the initial energy and directed to the dump.

INTRODUCTION

The eRHIC, future "QCD factory", will provide collisions between polarized electrons and: polarized protons in an energy range of 100-250 (325) GeV; light ions (d, Si, Cu); heavy ions 50-200 (130) GeV/u; and, polarized He^3 215 GeV/u. Electrons will circulate in the present RHIC tunnel as shown in Figure 1.

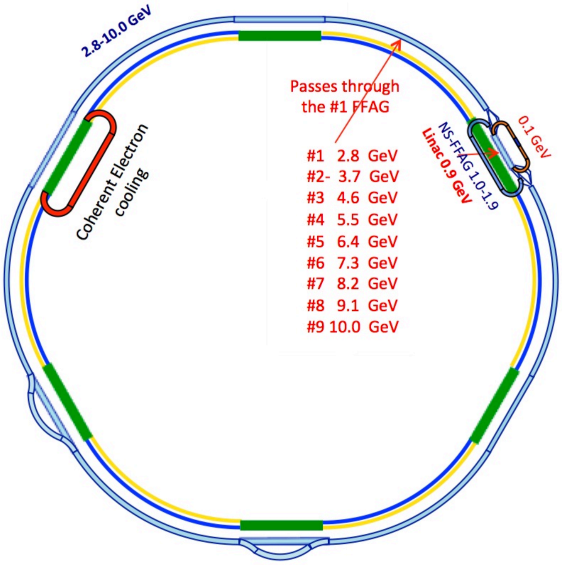

Figure1: Schematic layout of the electron NS-FFAG in the RHIC tunnel – blue and yellow superconducting ion rings are shown, as well as the position of the coherent electron cooling.

The Energy Recovery Linac (ERL) is proposed due to the beam-beam tune shift limitation in the ring-ring case for achieving higher luminosities and due to ability to recover the energy of ~1 GW with a dump energy equal to the injection energy. To reduce the cost and number of elements in the tunnel, a single NS-FFAG ring is proposed with an energy acceptance between 2.8-10 GeV for the first stage of eRHIC.

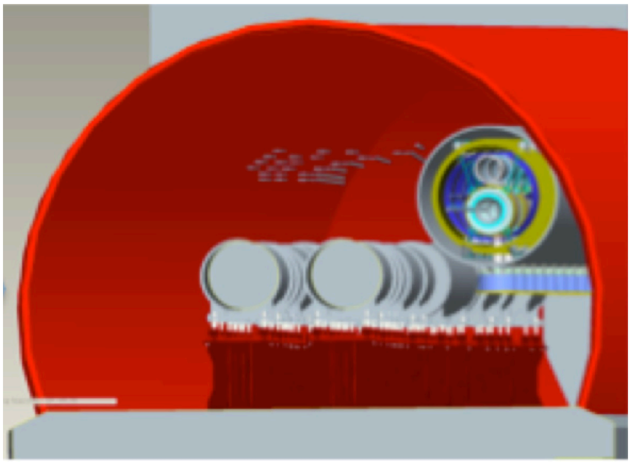

Figure 2: Two RHIC rings with electron linac on the right side above.

Non-Scaling FFAG

Revival of the Fixed Field Alternating Gradient (FFAG) accelerators previously developed in fifties [1,2,3] is very evident. They have very large momentum acceptance with beam accelerated under a constant magnetic field. The scaling FFAG have been mostly built in Japan: started with a the proof of principle (POP) proton accelerator at KEK, the 150 MeV proton accelerator (presently at the Kyushu University), 150 MeV accelerator at Osaka University, and many electron scaling FFAG's built for different applications. Although the scaling FFAG's have an advantage of the fixed magnetic field the synchrotrons are dominant accelerators in spite of magnetic field variation with energy. This is mostly due to significantly smaller aperture requirements. Large aperture magnets accommodate for the large orbit offsets. The aperture size is significantly reduced with the Non-Scaling FFAG's (NS-FFAG) [4]. The maximum of the orbit offsets are $-18.6\,\mathrm{mm}<\Delta x<0$ in the example presented. The NS-FFAG has fixed magnetic fields designed for the reference momentum. The maximum electron energy of 10 GeV, in the first stage of eRHIC, is selected for the reference energy with circular beam orbit. This is to reduce the synchrotron radiation, as the radius of the curvature is r=318 m.

NS-FFAG 2.8-10 GEV

The electron ring follows the shape of the RHIC tunnel and six arcs have 132 identical NS-FFAG cells. Each cell

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is made of three combined function magnets: the central 1.25 m long is a defocusing magnet with a gradient of G_D=-17.9 T/m and dipole field of B_D=0.1T, while the two surrounding, 0.5m long, are focusing magnets with a gradient of G_F=23.7 T/m and dipole field of B_F=0.1 T. Properties of a NS-FFAG cell are shown in Figure 3.

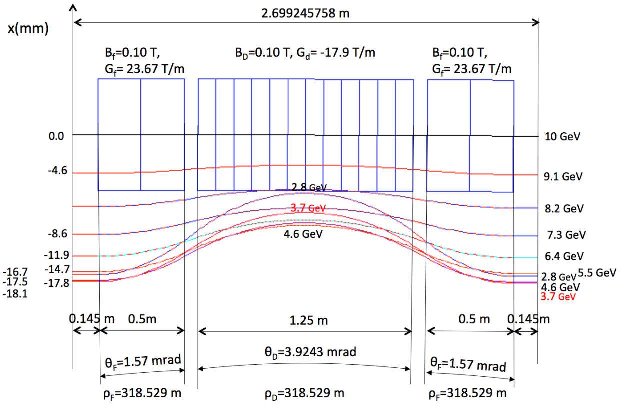


Figure 3: Basic NS-FFAG cell properties.

The tune dependence on energy is shown in Figure 4.

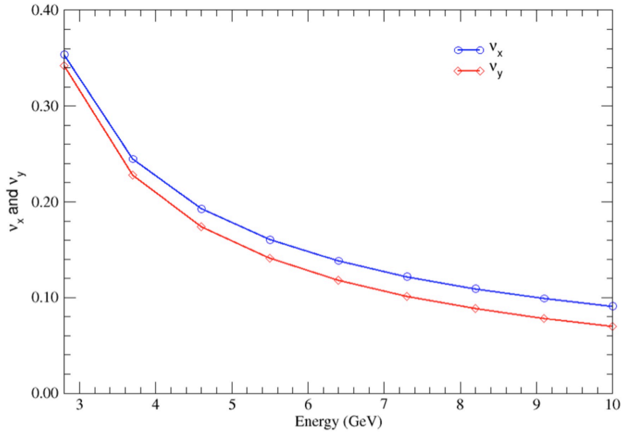


Figure 4: Betatron tunes dependence on energy.

The path length in NS-FFAG has a parabolic function with respect to the beam energy range with a minimum corresponding to the momentum compaction or transition energy equal to zero. A relation ship between bending angles Ratio=θ_F/θ_D of the two magnets defines the shape of the parabola as shown in Figure 5. The ratio of Ratio=θ_F/θ_D =0.4 was selected to allows for almost symmetric dependence in the time of flight with respect to the medium energy of E=6.4 GeV and the largest bending radius to reduce the synchrotron radiation.

A connection of the NS-FFAG to the linac is presented in Figure 6. The spreaders on one side of the linac and combiners on the other side allow at the same time adjustment of the time of flight for each energy so the bunches arrive at linac at the top of the linac RF wave or if they are decelerated to the bottom of it.

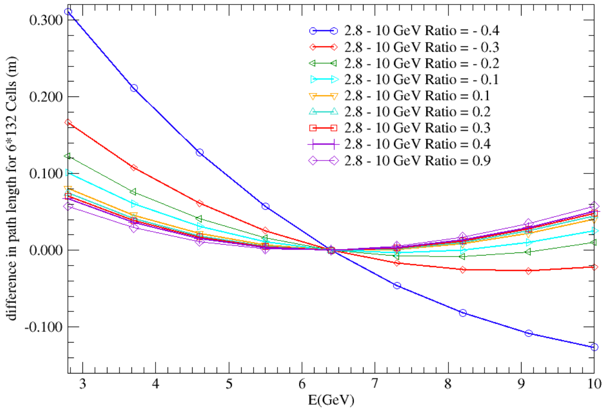


Figure 6: The six arcs time of flight dependence on the ratio between to angles of bending of the two magnets.

The maximum orbit offset dependence on the ratio between the two magnets is presented in Figure 7.

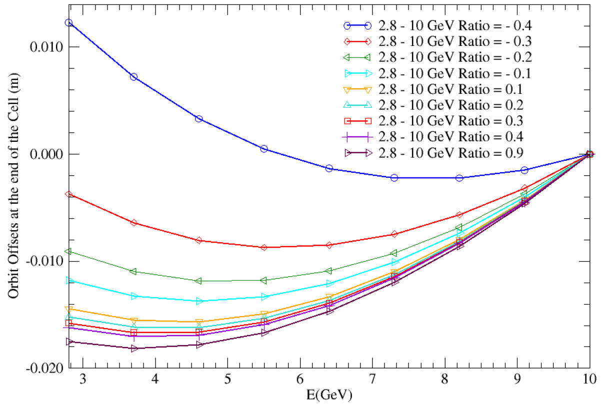


Figure 7: Maximum of the orbit offsets dependence on energy for different ratios of the bending angles θ_F/θ_D.

2.8-10 GeV Magnet Design

The defocusing combined function magnet made of combination between the permanent magnet SmCo is shown in Figure 8.

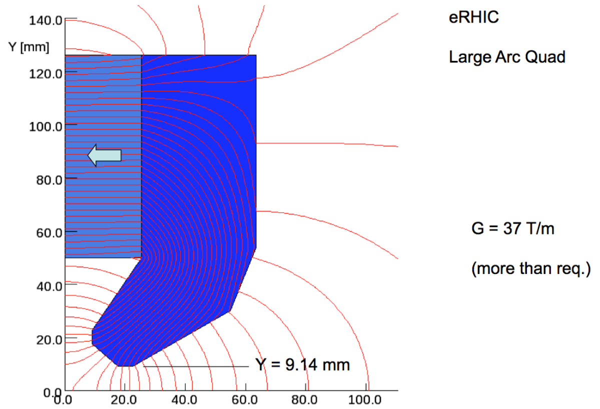


Figure 8: Defocusing combined function magnet.

A magnet design for the focusing combined function magnet is shown in Figure 9.

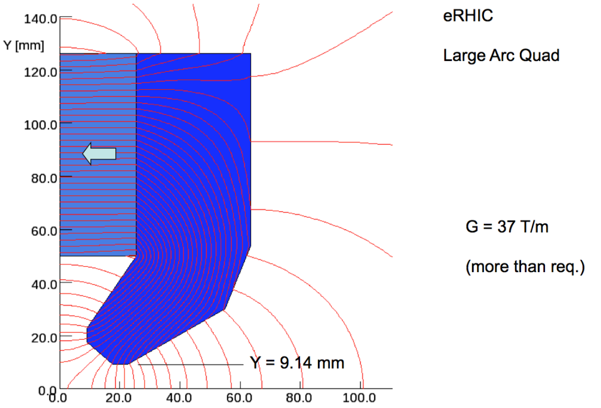
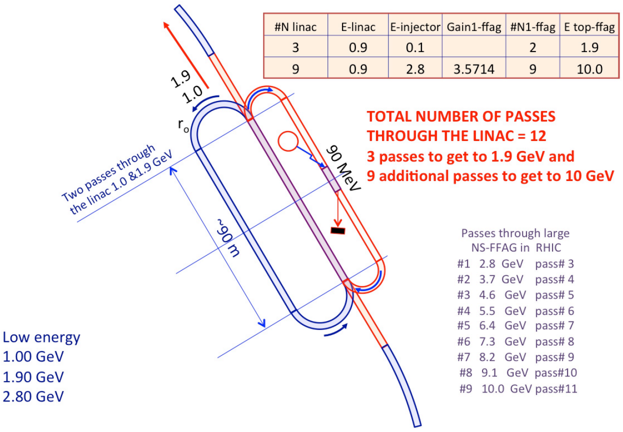


Figure 9: Focusing combined function magnet.

1-1.9 GEV NS-FFAG

The area around interaction region at 4 o'clock is selected for placement of the linac, injector and the NS-FFAG racetrack for two passes of electron beam with energy of 1 and 1.9 GeV. The 90 MeV injector receives electrons with energy of 10 MeV from the polarized electron source as schematically shown in Figure 10.



#N linac	E-linac	E-injector	Gain1-ffag	#N1-ffag	E top-ffag
3	0.9	0.1		2	1.9
9	0.9	2.8	3.5714	9	10.0

TOTAL NUMBER OF PASSES THROUGH THE LINAC = 12
3 passes to get to 1.9 GeV and
9 additional passes to get to 10 GeV

Figure 10: Schematic presentation of the linac with the injector, polarized electron source, and small NS-FFAG.

The new civil construction will be necessary for the small NS-FFAG ring as shown in Figure 11.

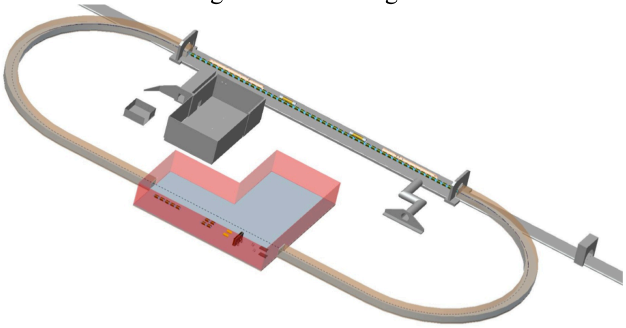


Figure 11: Linac and small NS-FFAG layout.

The basic NS-FFAG cell for the two passes with energies of 1 and 1.9 GeV is shown in Figure 12.

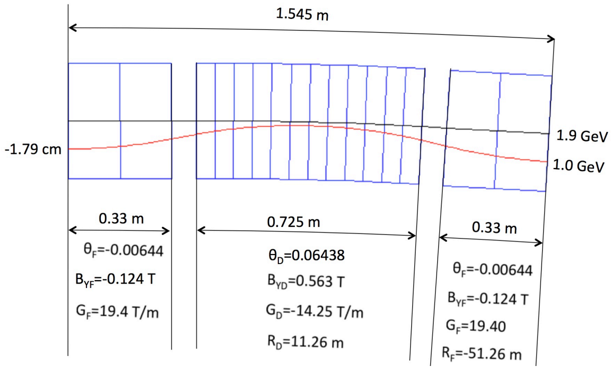


Figure 12: The NS-FFAG cell with two passes and 30 m radius of a curvature.

ORBIT CORRECTION

A random misalignment of the magnets, with a Gaussian distribution with maximum errors of 50, 100, and 150 μm, was implemented. Orbit for all energies were recorded and corrected with two correctors per cell.

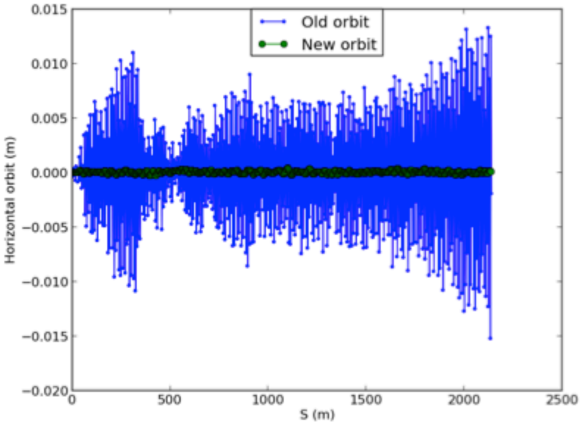


Figure 13: Correction of the orbit due to misalignment.

SUMMARY

A new approach of the NS-FFAG electron lattice design for the ERL eRHIC project is being studied. Two 2.8-10 GeV and 1-1.9 GeV NS-FFAG's lattices are designed and studied. Magnet design and beam dynamics studies are in progress.

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