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EIC Electron Injector Systems Overview

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We review the current plans for the EIC Electron Injector chain. This includes and overview of the accelerator chain necessary to deliver 5, 10 and 18 GeV polarized electrons to the Electron Storage Ring (ESR), the charge accumulation and polarized electron transport approach.

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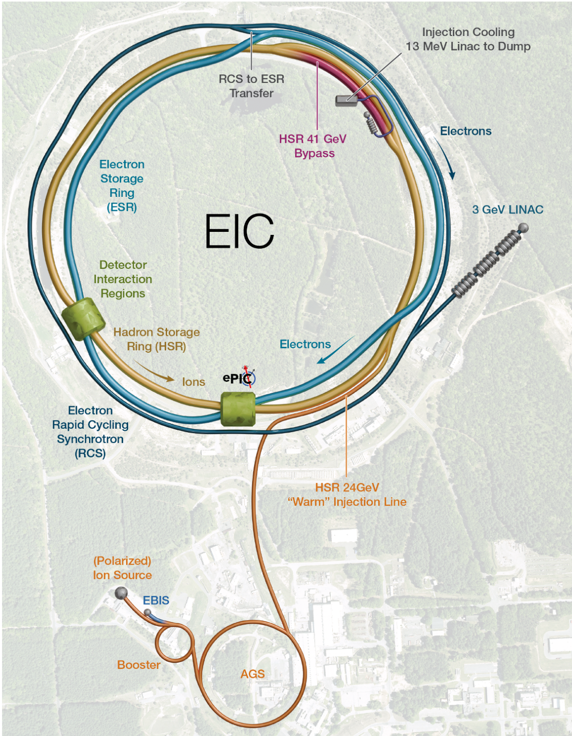

Figure 1: EIC layout

1. Introduction

The future Electron Ion Collider (EIC) is designed to collide polarized electrons with ions, from light protons, deuterons and Helium 3 to heavy Gold and Uranium ions at peak luminosities of 10^{33} to 10^{34} cm^{-2}sec^{-1} a factor of 100 to 1000 beyond that achieved by HERA collider. It will have a large range of center-of-mass energies from 29 to 140 GeV, a momentum acceptance for the detectors should be as high as $p_T = 200$ MeV/c and collide beams with a very flexible alternating polarization patterns in both rings.

The EIC is based on the existing Relativistic Heavy Ion Collider (RHIC), re-designing aspects of the RHIC yellow ring to become the EIC's Hadron Storage Ring (HSR) and making use of and upgrading the RHIC accelerator chain from the ion source to the AGS Booster and AGS machines. Currently RHIC's ion beam parameters are close to what is required for the EIC however it will require more bunches at three times higher beam current, with a lower vertical emittance and a peak energy of 20 GeV higher than RHIC at 275 GeV. Additionally there will be added a Strong Hadron Cooling system to maintain ion beam emittances during the EIC store.

The EIC will add to the Hadron ring a 5 to 18 GeV polarized electron Storage Ring (ESR) and its injector complex. To achieve an average polarization of 70% and meet the intensity requirements of the ESR, the Electron Injector System (EIS) will need to achieve the following capabilities:

- Accelerate electrons to 5,10 and 18 GeV with a polarization of 85%

- Deliver three 28n nC bunces at 5 and 10 GeV at a maximum rate of 0.66 Hz (every 1.5 secs) and two 11 nC at 18 GeV at a maximum rate 1 Hz.

The EIS consists of a pre-injector, a Rapid Cycling Synchrotron (RCS) and its transfer lines. It is planned that the EIC construction will be broken up into two phases. In phase I the peak energy of the electrons will be limited to 5 and 10 GeV and the beam will be limited to one 7 nC bunch per injection cycle with no charge accumulation. During Phase II the peak energy will be raised to 18 GeV and the beam current will be raised to 3 bunches with 28 nC per bunch delivered at 5 and 10 GeV with three bunches of 11 nC per bunch at 18 GeV. This will require charge accumulation in the RCS ring.

2. The Electron Pre-Injector System

The pre-injection will be located at IR4 of the RHIC complex and will be made up of a high voltage dc gun capable of achieving up to 11 nC of 90% polarized electrons [1]. However it will be initially operated at only 7.5 nC. The gun has reached peak voltages of 320 V with an average current of 67.5 μA. At the exit of the gun the electrons will be transported first through two Wien Filters each rotating the polarization by 45 degrees to place the beam polarization in the vertical direction. This will be followed by a 98 MHz, 591 MHz and 1300 MHz cavities interspersed with alternating solenoids to focus and bunch the beams. At the exit of this transport line the polarization will be measured using a Mott Polarimeter. The beam will then be transported through a 1.3 GHz SRF LINAC to reach 3 GeV. At the exit of this system the expected transverse emittance will be 6.1 nm-rad in both planes, the RMS bunch length should be 2.3 mm with an energy spread of 0.2%.

3. The Rapid Cycling Synchrotron

The beam from the LINAC will be injected into the RCS and accelerated to top energy in a lattice specially designed to avoid and minimize depolarizing spin resonances. This special lattice requires high tune and periodicity and special treatment of the arc connecting regions of the lattice. It also needs to be designed to have good off-momentum dynamic aperture (at least +/- 1.5% dp/p) to facilitate off-momentum charge injection and accumulation and a low average beta functions and low transition gamma to reduce the impact of collective effects.

The special RCS lattice design exploits the fact that strong spin resonances occur at $K = nP \pm Q_y$ for intrinsic spin resonances and $K = nP \pm [Q_y]$ where P is the lattice periodicity, n is an integer, Q_y is the vertical betatron tune and $[Q_y]$ is the ineger part of the vertical betatron tune. If we pick P and Q_y correctly we can avoid all the strong spin resonances in a given energy range. This is because in a dipole dominated ring the spin will precess at a rate of $G\gamma$ per turn where G is the anomalous g-factor and γ the standard relativistic Lorentz factor. In the case of the RCS's energy range from 3 to 18 GeV this ranges from $G\gamma = 6.8$ to 41. Thus picking a vertical tune above 50 and a periodicity above 96 we can avoid all the strong spin resonances in this energy range. This could be simply accomplished by building a ring using over 96 FODO cells with a vertical tune above 50. However the RCS should fit in the existing RHIC tunnel with a six-fold symmetry. It was discovered [2] that if one maintains a 360 degree phase advance across the insertion sections that the

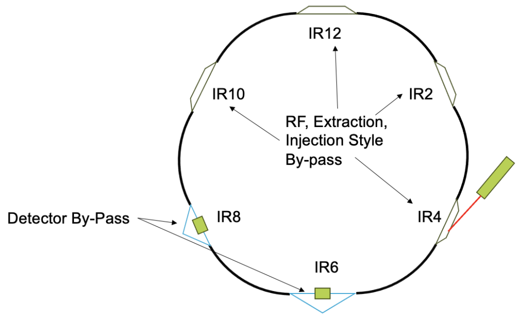

Figure 2: Electron Injector Schematic

Average Orbit RMS (mm)	Average Max Orbit (mm)	Polarization at 5 GeV (%)	Polarization at 10 GeV (%)	Polarization at 18 GeV (%)
0.273	1.26	99	99	98.7
0.436	2.02	99	99	97
0.553	2.53	99	99	95.3

Figure 3: Polarization Response to Closed Orbit Errors.

high super-periodicity can be recovered for the spin dynamics thus recovering a high polarization transmission.

The arc connecting regions for the future EIC have the additional complications that the RCS will need to have a trajectory which avoids the detector and other obstructions in the existing RHIC tunnel. However despite the complexity it was discovered that the appropriate optimization of the quadrupoles in the arc connecting regions high polarization transmission can be recovered using more sophisticated matching approaches [3] and brute force numerical optimization.

The current lattice can transport a polarized electron beam from 3 to 18 GeV with a vertical emittance as large as 1000 mm-mrad maintaining 96% polarization transmission through the intrinsic spin resonances. In reality the injected beam will be 36 mm-mrad normalized and will damp to much less than 1 mm-mrad by 18 GeV due to radiative effects. For such a lattice depolarization due to imperfection spin resonances is an issue since the strength of depolarization is proportional to vertical closed orbit errors. In the case of the current lattice we find that we can tolerate as high as 0.55 mm RMS vertical orbit distortion and still achieve 95% transmission to 18 GeV on average (see Table 3).

In the event that orbit smoothing does not achieve above 95% polarization transmission, orthogonal imperfection bumps can be constructed. These bumps target the real and imaginary part of the spin resonance.By building a corrector to the imperfection spin response matrix ($\vec{M}_S$) using DEPOL calculated imperfection resonances, one can calculate the necessary corrector strengths to achieve isolated and orthogonal bumps at any point during the ramp. Here we use

$$\vec{C} \cdot \vec{M}_S = \vec{\varepsilon}, \tag{1}$$

where $\vec{C}$ is a vector containing all the correctors, and $\vec{\varepsilon}$ is a vector containing all the real and imaginary parts of the imperfection spin resonances which are targeted. In our case it is 80 elements long, containing the real and imaginary imperfection resonances in the range $6 < a\gamma < 40$. By inverting this non-square matrix to a pseudoinverse matrix one can use it to construct an arbitrary set of imperfection bumps across the whole energy range. Using this approach we have constructed bumps representing arbitrary imperfection bumps in the imaginary and real plane for $a\gamma = 34$ to 40 with resonance strengths of ± 0.005. Everywhere else the imperfection strength is less than 10^{-5}. A value of 0.005 at 100 ms ramp rates represent a 10% spin kick. With imperfection bumps constructed in this fashion, there is no need to alter the corrector strengths over the acceleration cycle.

3.1 Injection and Charge accumulation approach

During phase I, no charge accumulation is necessary; single 7 nC bunches will be directly injected and accelerated in the RCS. However in phase II, three bunches of 28 nC each will need to be accumulated in the RCS. This will be built up from a train of three 7 nC bunches injected from the LINAC over 4 shots into the same three buckets using off-momentum injection. The three bunches will be separated by about 50 ns and the bunch train shots will occur every 200 msecs (5 Hz). The 200 msec pulse timing ensures that the injected bunches have time to damp to their equilibrium longitudinal emittance, creating room for the newly injected bunch.

4. Conclusion

The EIC electron injector system is progressing with the implementation of a 3 GeV SRF linac, and a new off-momentum charge accumulation approach. The RCS lattice has been optimized, successfully recovering good polarization performance while meeting operational demands. These advancements ensure the system's readiness for high-current polarized electron production and transport.

5. Acknowledgement

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