APEX and EIC

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APEX workshop

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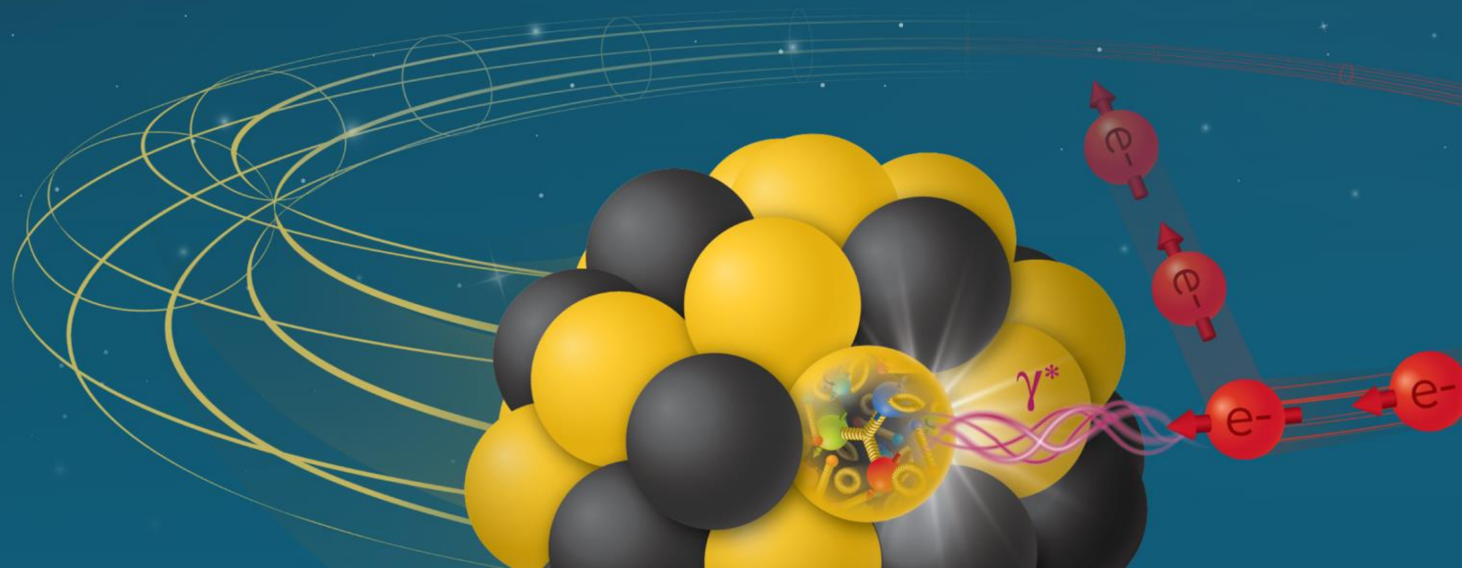
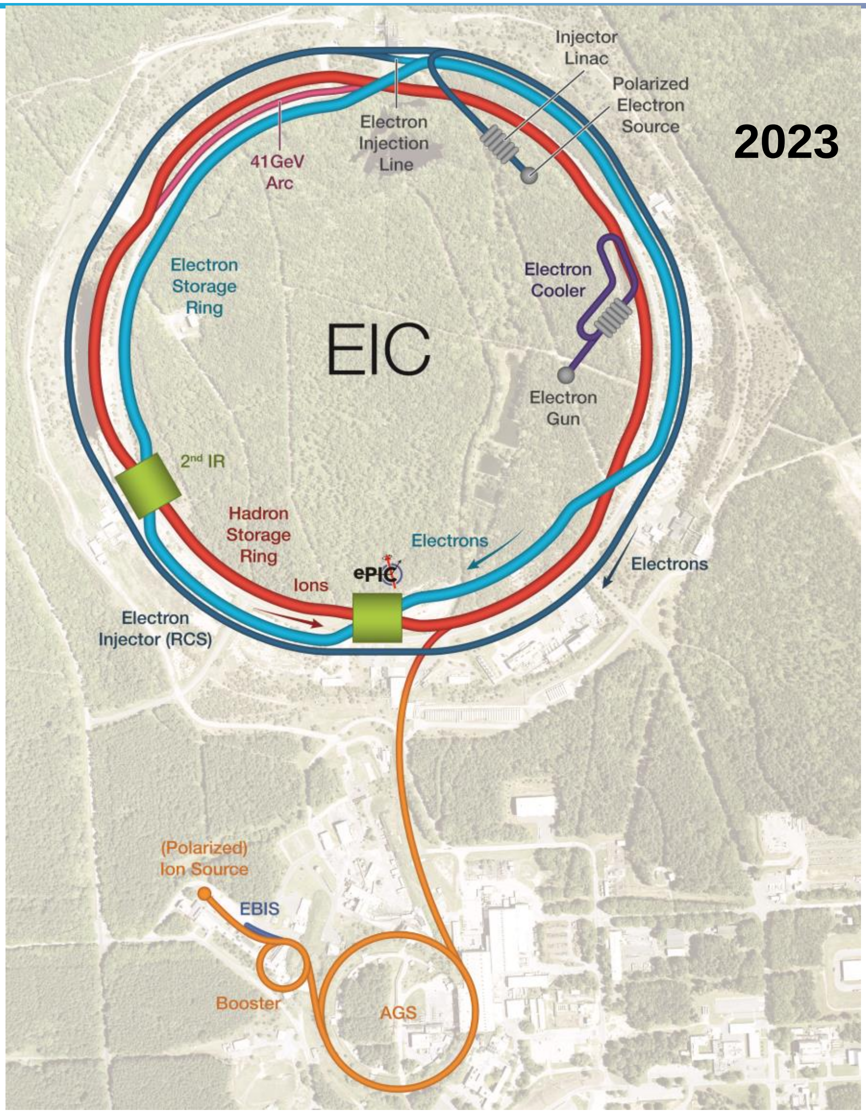
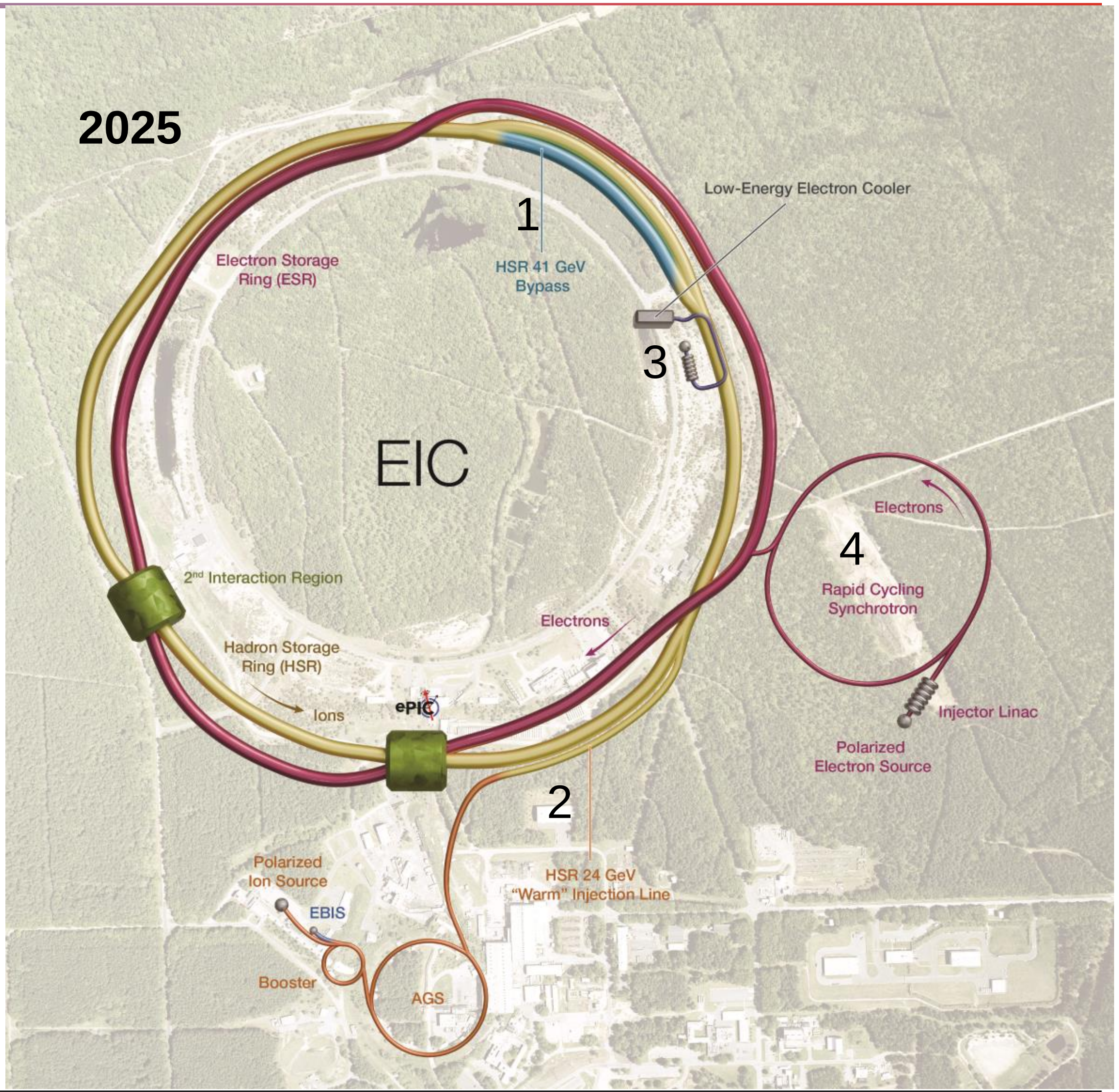
Electron-Ion Collider



EIC concept: Four Design Changes





Design Status and Progress

In 2024, the project made several key EIC design decisions. They will lead to formal Project Scope changes after the TCCB and the CCB processes.

1. Reuse the entire Yellow RHIC ring, delay the 41-GeV bypass (a Blue RHIC arc)
2. Implement a new room-temperature HSR injection line
3. Drop SHC, add LEC
4. Move RCS out of the collider tunnel
5. Delay the 28 nC/bunch and the 18 GeV capability implementation (ESR and RCS)
   - Initial capability: 7 nC/bunch and 10 GeV

These design decisions resolve uncertainties, challenges and risks to EIC performance, safety, and future operation and maintenance.

There is no change to the current preliminary KPPs and no change to the EIC cost objective.

Key accelerator physics concepts

- Flat hadron bunches (10:1 emittance ratio)
- Large crossing angle
- Beam-beam limits
- Spin preservation from source to collisions (protons and electrons)
- Swap-out electron injection (1 bunch/sec)
- Upgrade path: hadron cooling at collisions

Critical EIC Accelerator Technology Areas

- Hadron Beam Cooling
- Spin-transparent optics
  - High polarization for both beams from source to collisions
  - Swap-out injection for electron bunches (at 1 Hz) to maintain high polarization
- Crab cavities
  - Large-size, complex geometries;
  - Very tight phase and amplitude noise requirements
- IR magnets (large aperture, 2K SC magnets)

Accelerator Risks (all ranked as high)

1. RCS Integration in the tunnel – triggered
2. 400-MeV Linac does not meet requirements – triggered
3. SHC performance falls short of expectations – triggered
4. RCS Impedance too high
5. ESR Impedance too high
6. HSR Impedance too high
7. Direct-wound SC magnet failure
8. Collared SC magnet does not meet requirements
9. 197-MHz crab cavity does not meet requirements
10. Unforeseen severe events during commissioning

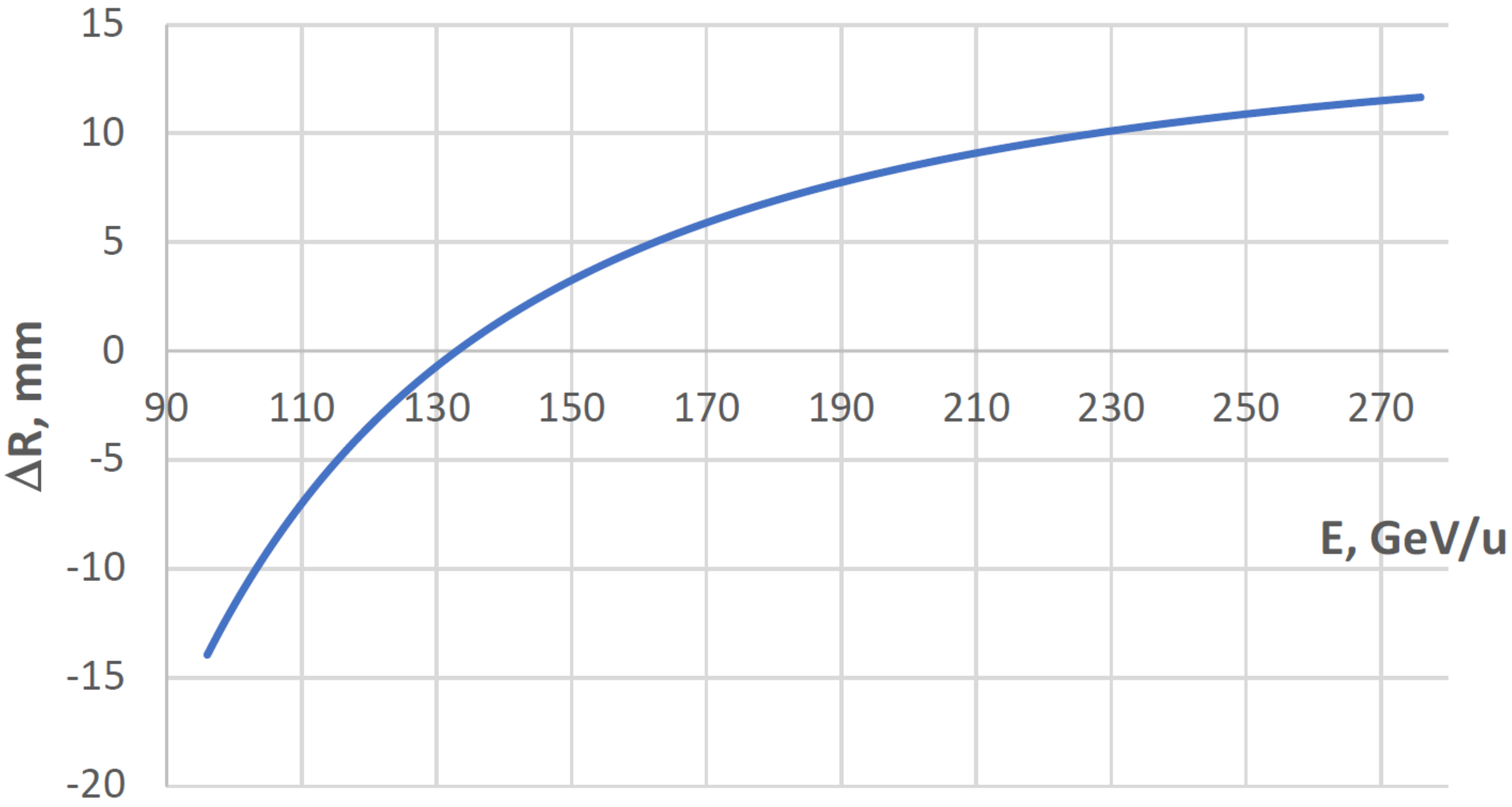
From RHIC to HSR

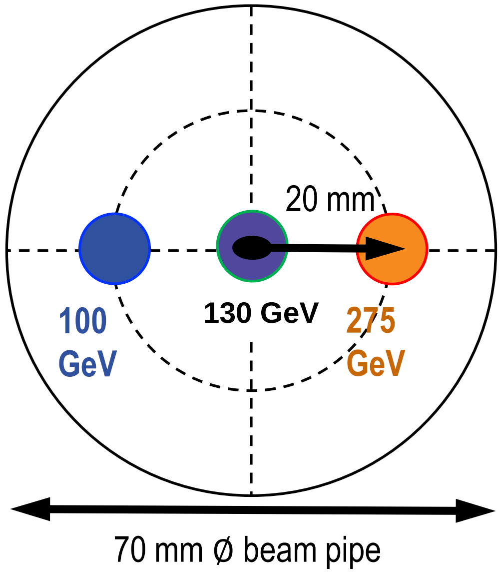
Tripled beam current, shorter bunch length, shorter bunch distance, ‘flat’ beams with small vertical emittance

- EIC Hadron Storage Ring (HSR) to be composed of existing arcs of the Yellow RHIC ring (remove unused magnets)
- Insert sleeves coated with copper and amorphous carbon into superconducting magnet beam pipes to improve conductivity and reduce secondary electron yield (-> electron cloud)
- Add new RF cavities
- Add hadron cooling to create ‘flat’ bunches
- Add crab cavities, new IR SC magnets
- Add a collimation system

CD3A -- Actively Cooled Beam Screen Material procurement

Beam Energy and Average Orbit Radius in the HSR





Since the electron revolution frequency is fixed, the hadron orbit must be adjusted with energy to keep the collisions in synch.

Strategy for Hadron Cooling

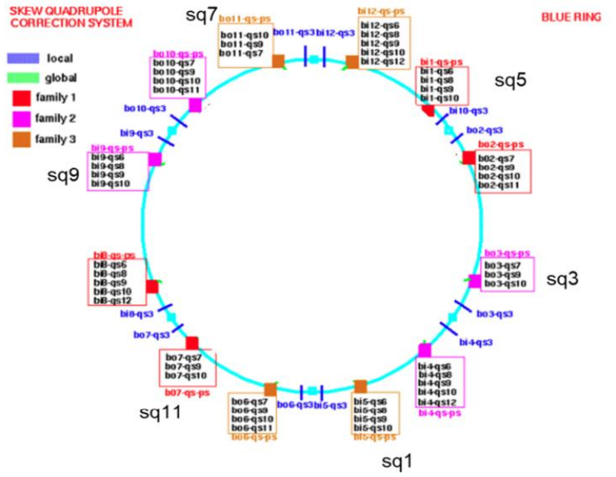
- The SHC-related risk was identified as ‘HIGH’
- To mitigate this risk, we are adding an injection electron cooler for hadrons (at 25 GeV/u) to create ‘flat’ bunches. This is a proven and tested technology. We propose to remove the SHC system from the project baseline.
  - The average luminosity would drop by a factor of two per our model, but the proposed KPPs and the MNS goals can still be met even without the SHC system.
- This downgrades the hadron cooling risk from HIGH (SHC) to LOW (Injection cooler).
- The High-Energy Cooling technology development will continue as an off-project R&D program, supported by the EIC Accelerator Collaboration.

EIC priorities for APEX studies

1. Transition crossing
2. Flat beam acceleration and dynamics
3. Electron cooling (studies toward cooling at 25 GeV)
4. Beam instabilities and RHIC Yellow ring impedances
5. Optics with large radial orbit offsets

Flat beams

- Emittance ratio of 11:1 is required for reaching design luminosity with equal proton beam divergencies at the IP.
- Required emittances are formed at 24 GeV with by using the Injection cooler.
- The HSR will reuse the RHIC decoupling system, with adding new skew-quadrupoles in the IR6 area to help with the detector solenoid compensation.
- On the HSR acceleration ramp the coupling feedback will be used, which is a routine operation tool used to maintain good decoupling on RHIC ramps



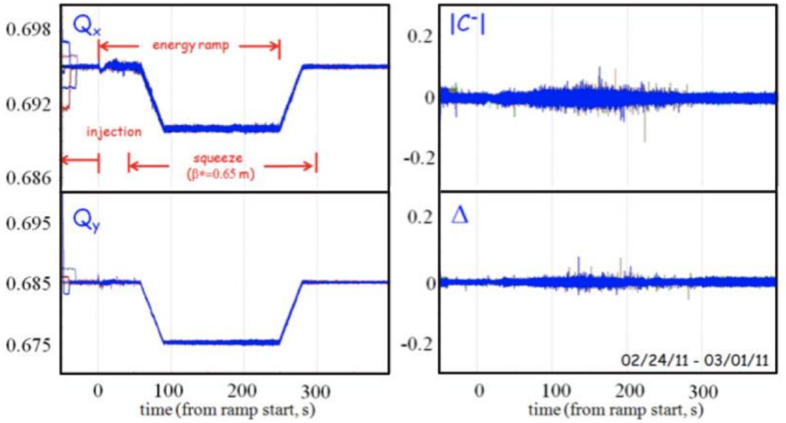
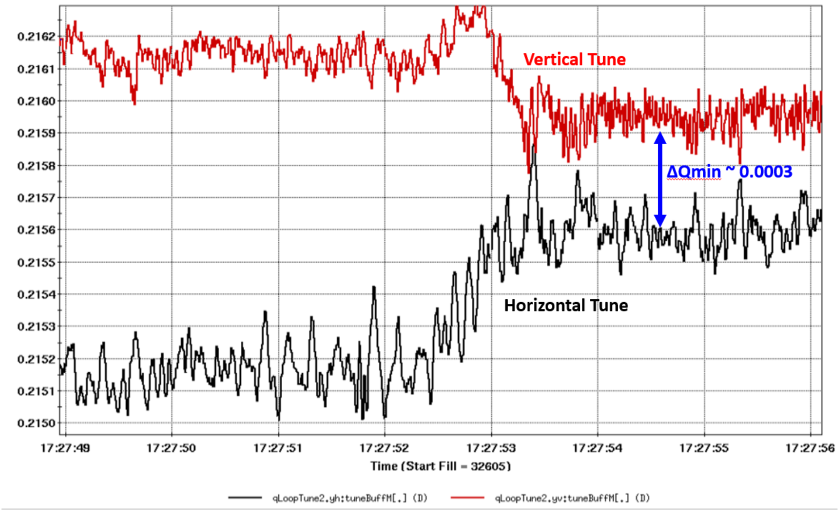


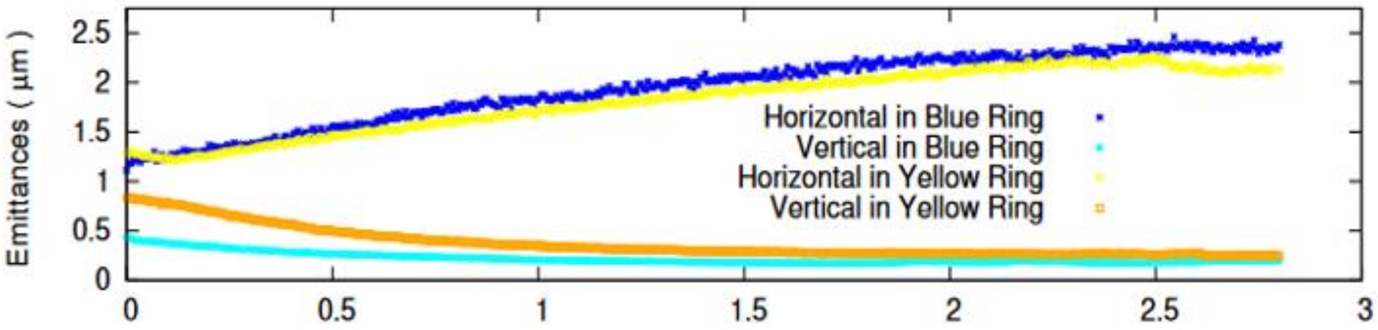
Figure 3: Superposition of measurements from multiple ramps of the betatron tunes (left) and coupling (right) measured with tune/coupling feedback in run-11.

Experiments to Demonstrate Flat Beams

- A series of experiments have been performed in RHIC to verify the capability of reaching the flat beam.
- Preserving flat beam during acceleration will be studied in a beam experiment in the coming RHIC run: stochastic cooling will be used on Au ion beam at 31 GeV/u, followed by the acceleration to 100 GeV/u



Simulation studies concluded that at the HSR design tunes (0.228,0.210) one needs $|C^-|=\Delta Q_{min} < 0.002$ to reach and maintain the required emittance ratio.
During beam experiment in 2017 reaching ΔQ_{min} well below 0.001 was demonstrated.



Beam experiment in 2023 demonstrated the emittance ratio 11:1 with Au ions at 100 GeV with the help of vertical stochastic cooling.