Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Challenges and R&D Developments for the Electron Ion Collider

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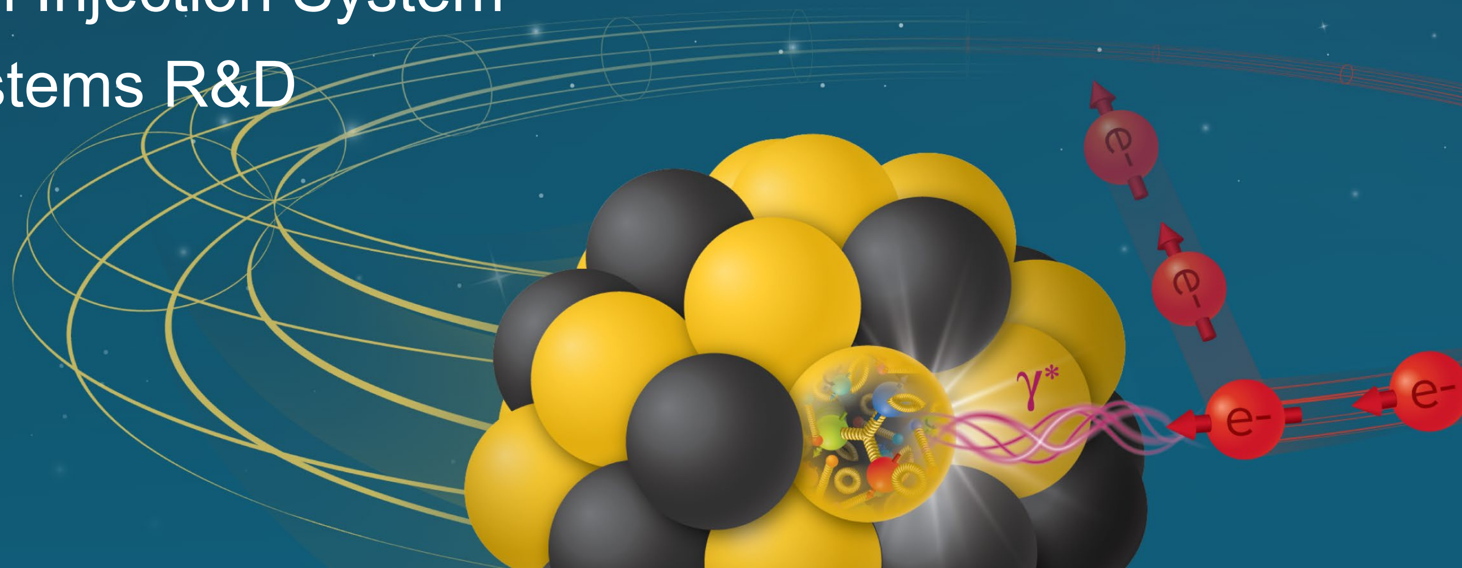
APES Seminar @ FRIB

January 10, 2025

Electron-Ion Collider



Previous EIC related APES talks

- **12 April 2024**
  Hadron Storage Ring of Electron-Ion Collider
  Dr. Vadim Ptitsyn, Brookhaven National Laboratory
- **8 March 2024**
  Strong Hadron Cooling for the Electron-Ion Collider
  Erdong Wang, Brookhaven National Laboratory
- **23 February 2024**
  Electron Synchrotron for EIC
  Vahid Ranjbar, Brookhaven National Laboratory
- **9 February 2024**
  Beam-Beam Effects in Future EIC
  Yun Luo, Brookhaven National Laboratory
- **22 April 2022**
  Overview of the Electron-Ion Collider (EIC)
  Christoph Montag, Brookhaven National Laboratory

Outline

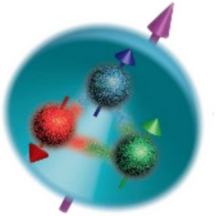
- Introduction to the Electron Ion Collider (EIC)
- Challenges
  - Hadron Storage Ring
  - Electron Storage Ring
  - Electron Injection System
  - Interaction Region
- R&D Projects
- Summary

Introduction to EIC

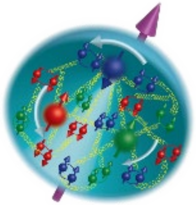
Introduction to EIC

"The EIC will be a discovery machine, providing answers to long-elusive mysteries of matter related to our understanding the origin of mass, structure, and binding of atomic nuclei that make up the entire visible universe."

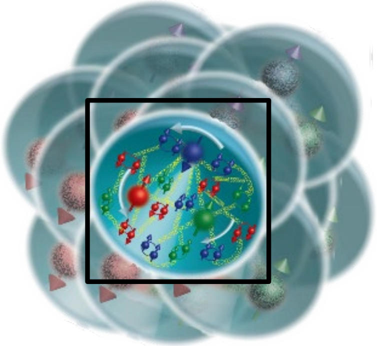
The Proton (1975)



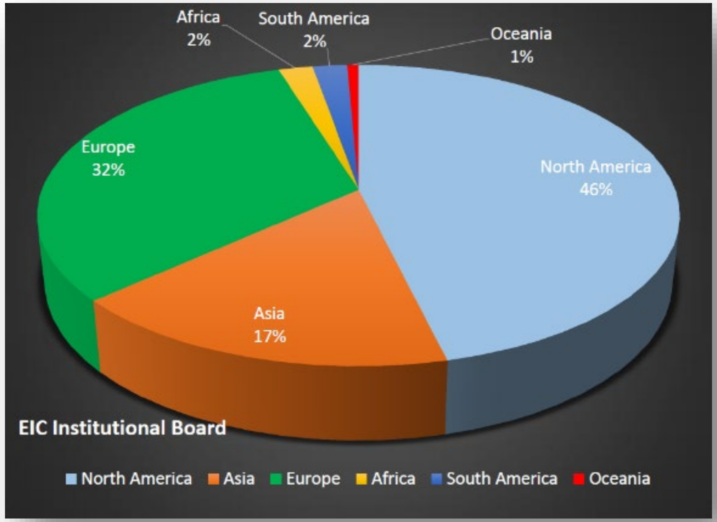
The Proton (2015)



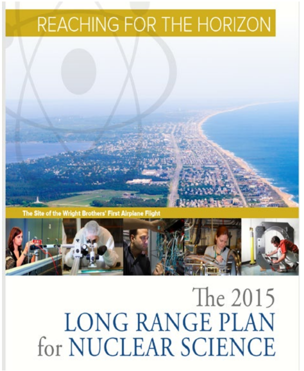
The Proton in a nucleus

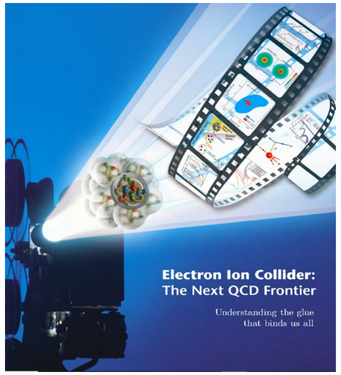


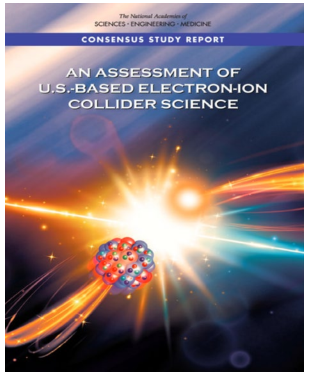
EIC User Group
1186 members
245 institutes
33 countries



The EIC will, for the first time, provide a complete view of the nucleus.







Importance of EIC

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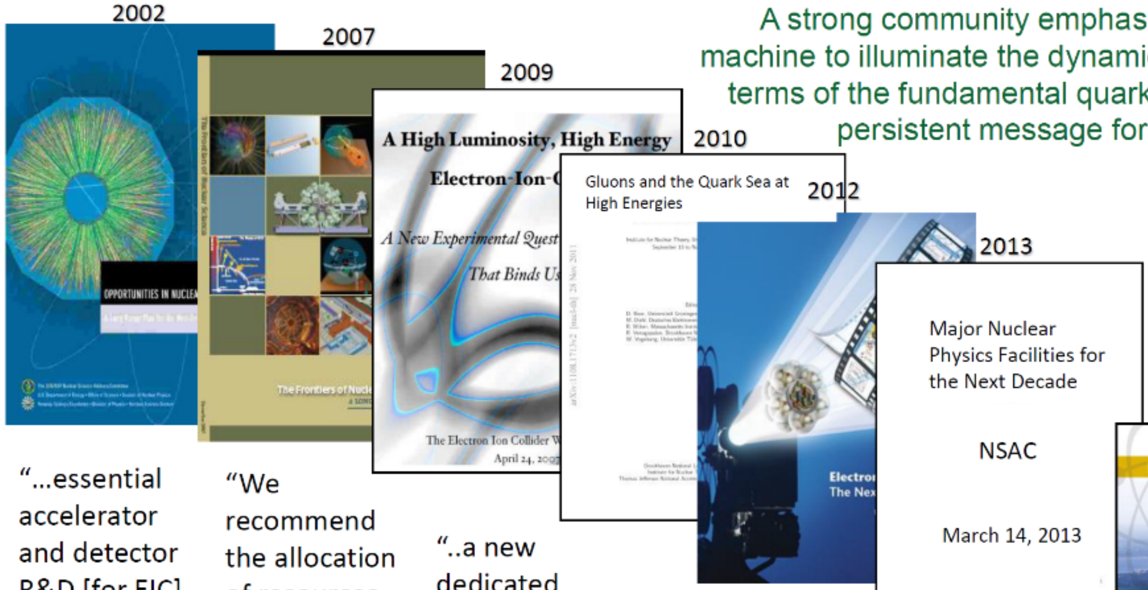
Mission Need Development

A strong community emphasis on the urgent need for a machine to illuminate the dynamical basis of hadron structure i terms of the fundamental quark and gluon fields has been a persistent message for almost two decades



"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

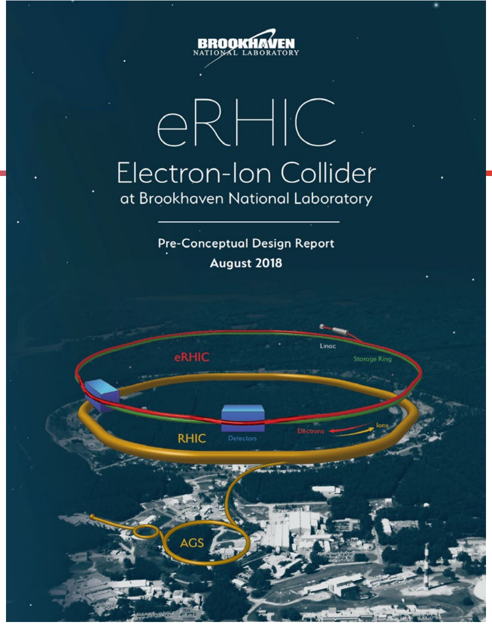
"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

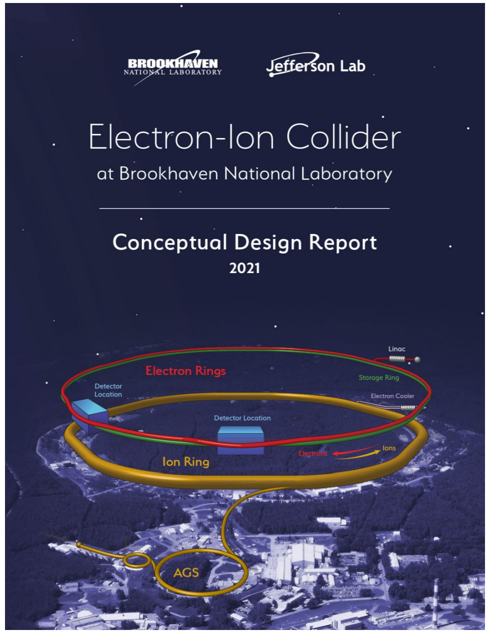
"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

"..a new dedicated facility will be essential for answering some of the most central questions."

"The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider."

Electron-Ion Collider *absolutely central* to the nuclear science program of the next decade.





EIC NSAC/NAS Science Pillars

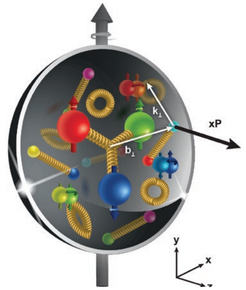
SPIN is one of the fundamental properties of matter.
All elementary particles, but the Higgs carry spin.
Spin cannot be explained by a static picture of the proton
It is the interplay between the intrinsic properties and interactions of quarks and gluons

The EIC will unravel the different contribution from the quarks, gluons and orbital angular momentum.

Does the mass of visible matter emerge from quark-gluon interactions?

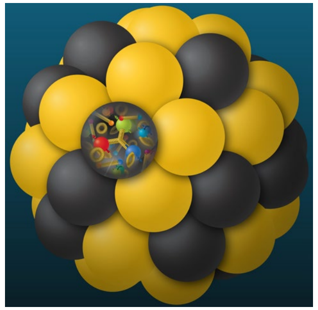
Atom: Binding/Mass = 0.00000001
Nucleus: Binding/Mass = 0.01
Proton: Binding/Mass = 100

For the proton the EIC will determine an important term contributing to the proton mass, the so-called "QCD trace anomaly



How are the quarks and gluon distributed in space and momentum inside the nucleon & nuclei?

How do the nucleon properties emerge from them and their interactions?
How can we understand their dynamical origin in QCD?
What is the relation to Confinement

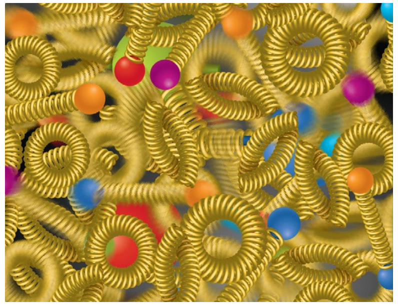


Is the structure of a free and bound nucleon the same?

How do quarks and gluons, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

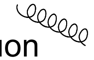
How do the quark-gluon interactions create nuclear binding?



How many gluons can fit in a proton?

How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

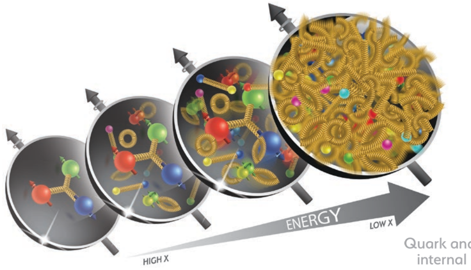
What happens to the gluon density in nuclei? Does it saturate at high energy?



Ultimate Accelerator Performance for NAS Science

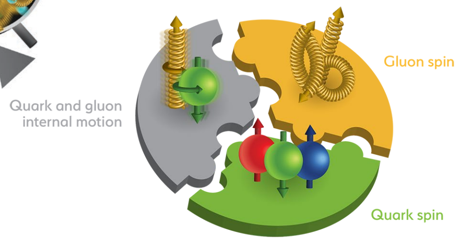
wide center-of-mass energy √s: ~20 – 140 GeV :

- map the out nucleon and nuclei structure from high to low x



polarized electron and hadron (p, He-3) beams:

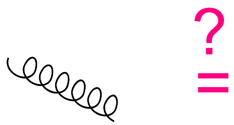
- access to spin structure of nucleons and nuclei
- Spin vehicle to access the spatial and momentum structure of the nucleon in 3d
- Full specification of initial and final states to probe q-g structure of NN and NNN interaction in light nuclei



nuclear beams: d to Pb

- accessing the highest gluon densities → saturation
- quark and gluon interact with a nuclear medium

gluon emission gluon recombination

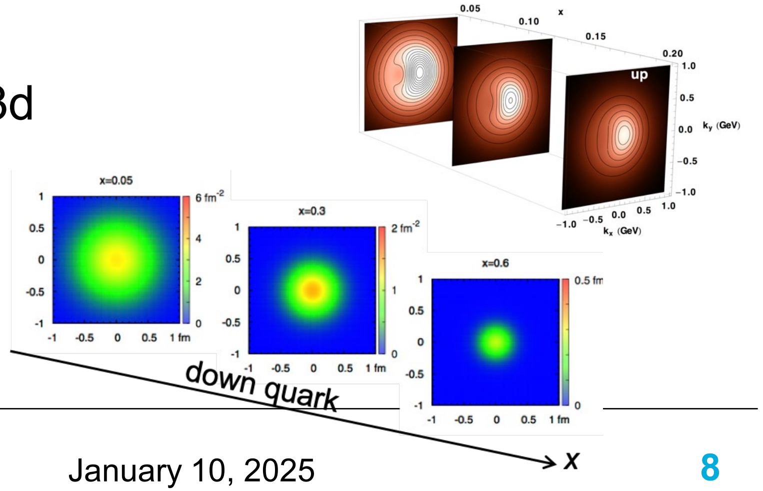


high luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$:

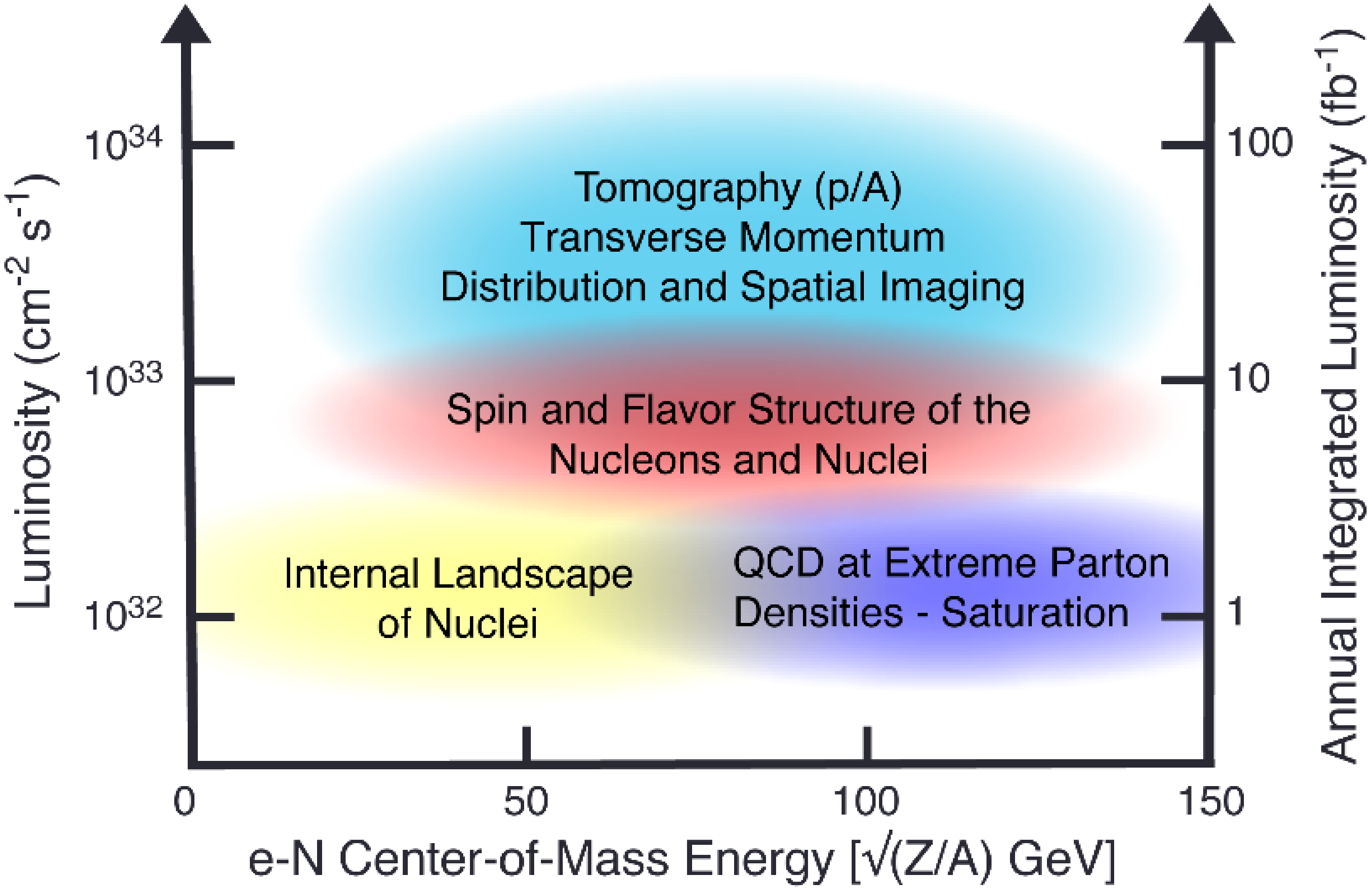
- mapping the spatial and momentum structure of nucleons and nuclei in 3d
- access to rare probes, i.e. Ws

large acceptance (0.2 – 1.3 GeV) through forward focusing IR magnets

- spatial imaging of nucleons and nuclei



EIC Science Reach



Spin

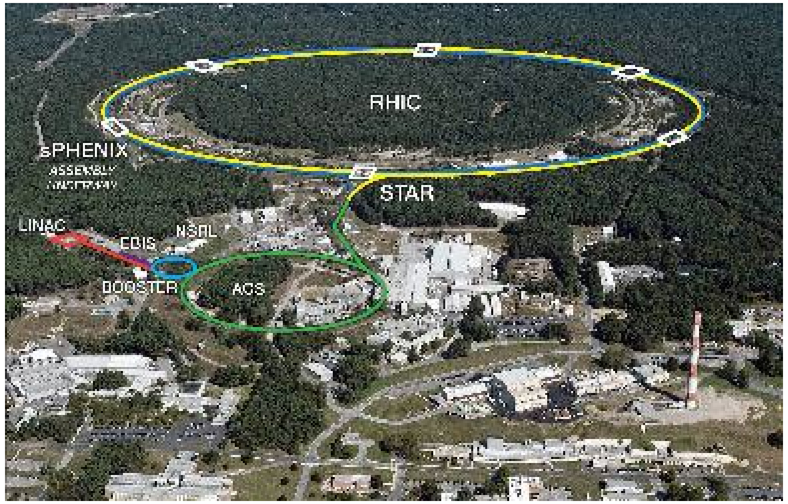
Mass

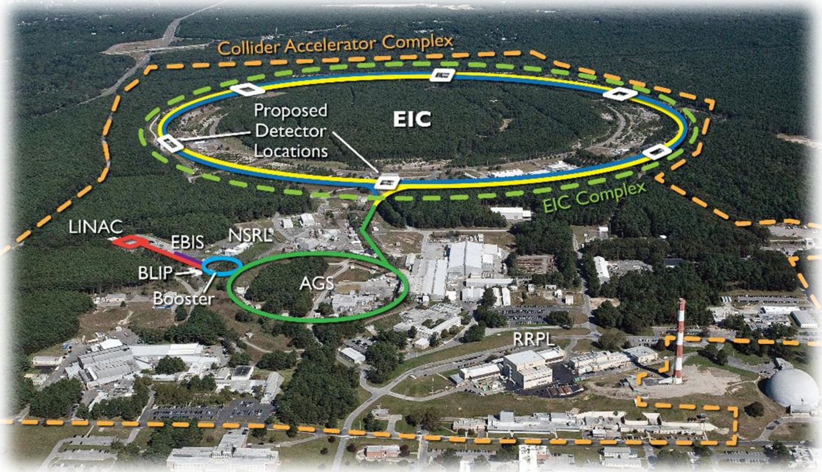
3D Imaging

Quarks, Gluons & Nuclei

Dense gluon systems

RHIC to EIC





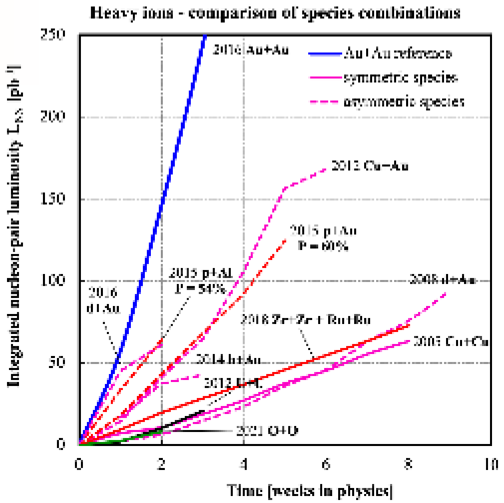
Relativistic Heavy Ion Collider (RHIC)

- is the first machine in the world capable of colliding heavy ions.
- primarily uses ions of gold but can operate and detect collision with a wide range of ion species from helium to uranium.
- is the world's only machine capable of colliding high-energy beams of polarized protons.

Based on the exciting discoveries of:

- "Perfect" liquid nature of the early universe, quark-gluon plasma (QGP) (DOI:10.1016/j.nuclphysa.2005.03.085)
- Heaviest antimatter nucleus ever detected, likely to stand for foreseeable future (DOI:10.1038/nature10079)
- First facility to clearly see the transition to quark-gluon matter (DOI:10.1103/PhysRevLett.112.162301)
- and many more

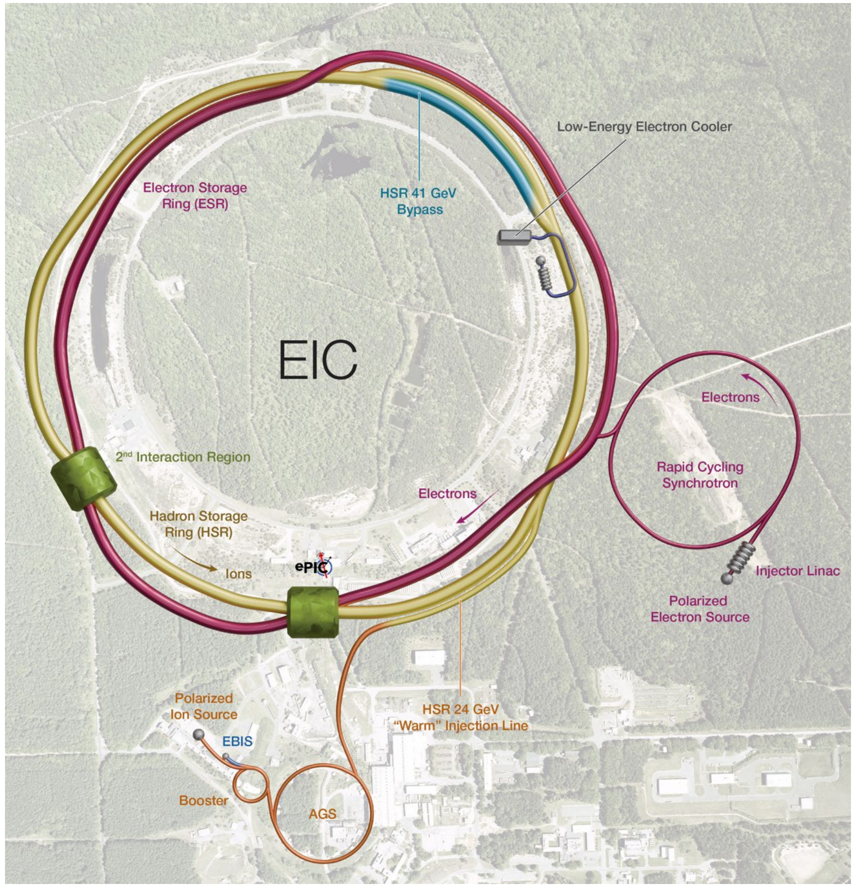
We move forward to build a new game-changing machine for the international nuclear physics community – the EIC.



The Electron Ion Collider Platform

Ultimate EIC Performance Parameters:

- High Luminosity: L= $10^{33} – 10^{34}$cm-2sec-1, 10 – 100 fb-1/year
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: Ecm = 20 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Forward Acceptance and Good Background Conditions
- Possibility to Implement a Second Interaction Region (IR)



Accelerator Status in a glance:

✓ Polarized ion/proton source

✓ Ion injection and initial acceleration systems – Linac (200 MeV), Booster (1.5 GeV), AGS (25 GeV)

UPGRADE Hadron Storage Ring (40-275 GeV) – HSR

NEW Electron Pre-Injector (750 MeV) – EPI

NEW Electron Rapid Cycling Synchrotron (750 MeV – top energy) – RCS

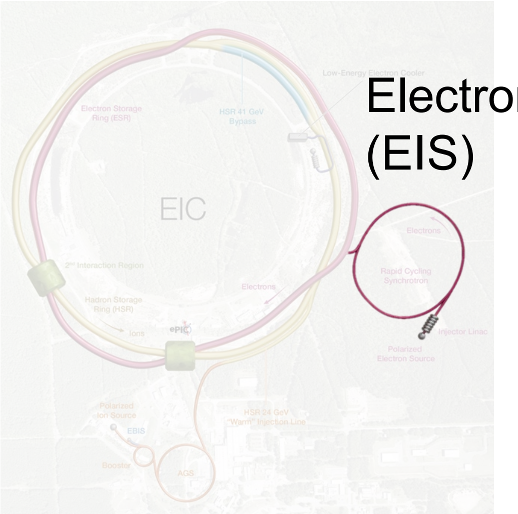
NEW Electron Storage Ring (5 GeV – 18 GeV) – ESR

NEW High Luminosity Interaction Region(s) – IR

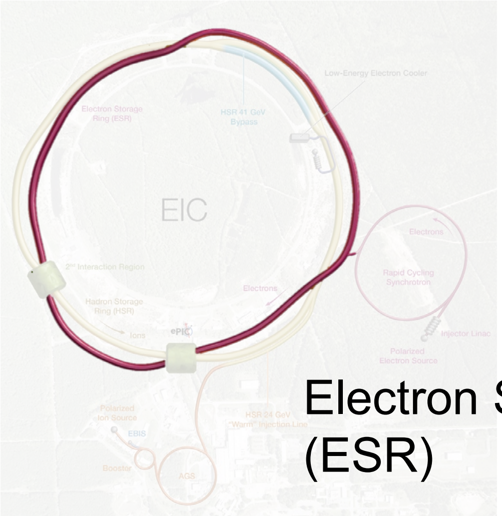
NEW Strong Hadron Cooler System – SHC

Challenges

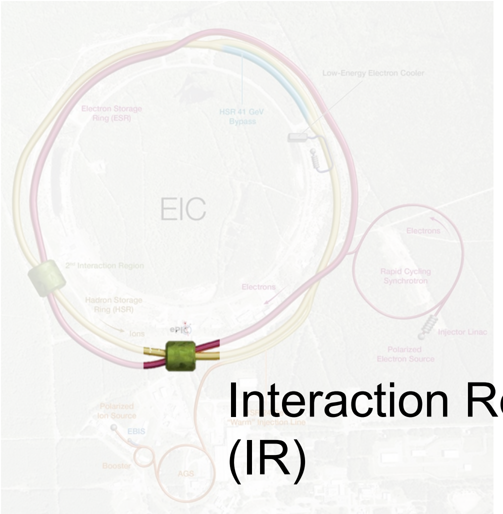
Hardon Storage Ring
(HSR)



Electron Injection System
(EIS)



Electron Storage Ring
(ESR)



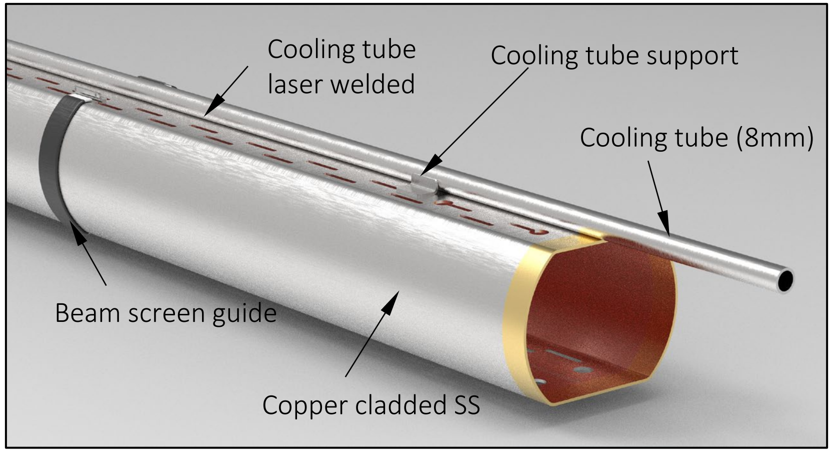
Interaction Region
(IR)

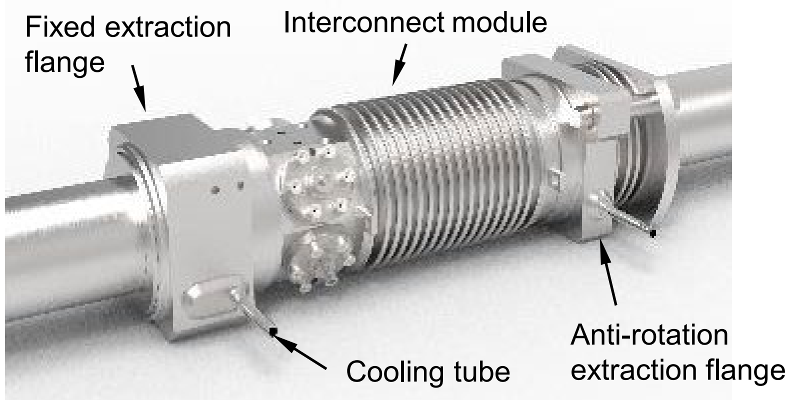
Hardon Storage Ring (HSR)

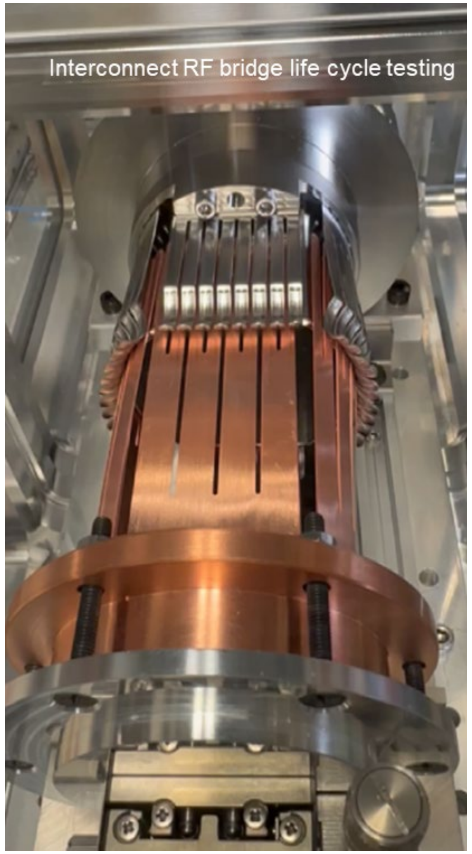
Challenges

Hadron Storage Ring Vacuum Chamber

- Tripled beam current, shorter bunch length, shorter bunch distance
- A beam screen with low impedance that can be inserted in the beam pipes of the RHIC arc dipoles with minimal dust formation. Develop a coating recipe for the beam screen that provide low SEY.







- The current beam screen solution is copper coating on stainless steel tube with an amorphous carbon layer on the top.
- The beam screen is actively cooled with circulated helium.
- Large sagitta in arc dipoles (48.5 mm over 10 m length)
- There are a total of 469 magnets to insert the beam screens, which accumulate to nearly the entire HSR circumference.
- Impedance and electron cloud are evaluated
- Installation of the beam screen with precise alignment is required. Mockup tests are designed and monitored for particulate generation.

Hadron Cooling

$$N_b = 1160;\ f_0 = 78.3\ \text{kHz}$$

$$L = \frac{N_e N_p}{4\pi\sigma_h\sigma_v} N_b f_0 \approx 1\times10^{34}\ \text{cm}^{-2}\text{s}^{-1}$$

HERA main parameters

Parameter	Unit	Protons	Electrons
Beam energy	GeV	920	27.5
Beam current	mA	100	45
Circumference	m	6336	
Number of colliding bunches		174	
Number of non-colliding bunches		6	
Bunch charge	$10^{10}e$	7.3	3.3
Horizontal emittance	nm	4	20
Vertical emittance	nm	4	3
Beta x at IP	m	2.45	0.62
Beta y at IP	m	0.18	0.26
Luminosity	10^{31} cm^{-2}s^{-1}	5.3	
Luminosity life time/run time	hr.	9	
Luminosity per run	pb^{-1}	0.5	
Bunch length	cm	16	0.9
Hour glass reduction of luminosity	%	94.3	
Number of interaction points		2	
Horizontal beam–beam tune shift/IP		0.0023	0.03
Vertical beam–beam tune shift/IP		0.0007	0.03

EIC main parameters

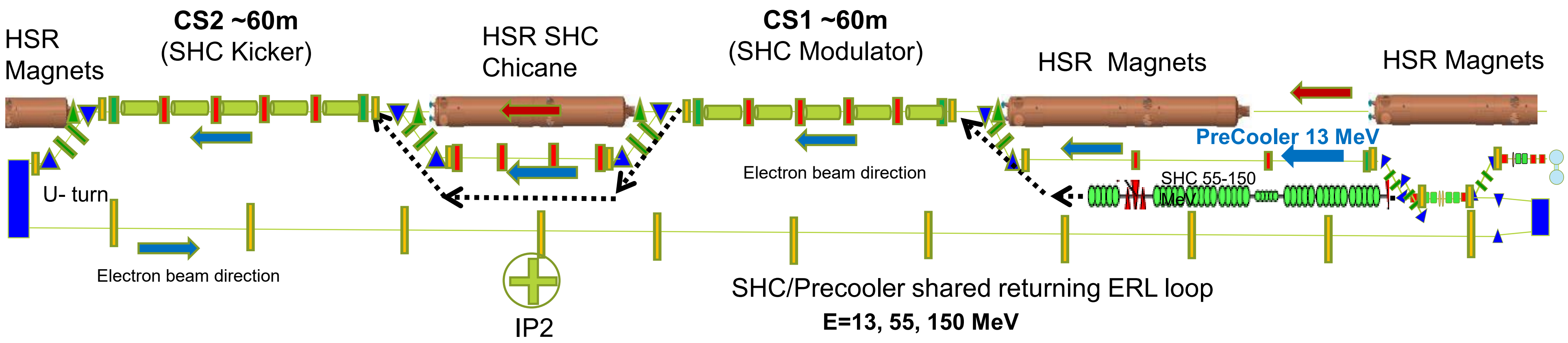
Parameter	proton	electron
Ring circumference [m]	3833.8451	
Particle energy [GeV]	275	10
Lorentz energy factor γ	293.1	19569.5
Bunch population [10^{11}]	0.688	1.72
RMS emittance (H,V) [nm]	(11.3, 1.0)	(20.0, 1.3)
β^* at IP (H, V) [cm]	(80, 7.2)	(45, 5.6)
RMS bunch size σ^* at IP (H, V) [μm]	(95, 8.5)	
RMS bunch length σ_l at IP [cm]	6	0.7
Beam-beam parameters (H, V)	(0.012, 0.012)	(0.072, 0.1)
RMS energy spread [10^{-4}]	6.8	5.8
Transverse tunes (H,V)	(29.228, 30.210)	(51.08, 48.14)
Synchrotron tune	0.01	0.069
Longitudinal radiation damping time [turn]	-	2000
Transverse radiation damping time [turn]	-	4000
Luminosity [10^{34}cm^{-2}s^{-1}]	1.0	

Compared to HERA, the EIC design implements two new critical ideas:

1. Flat proton bunches at collisions (to match the electron beam dimensions) – this helps with the peak luminosity
2. Continuous proton beam cooling during collisions to maintain matched beam dimensions – this helps with the average luminosity

SHC: Background Info

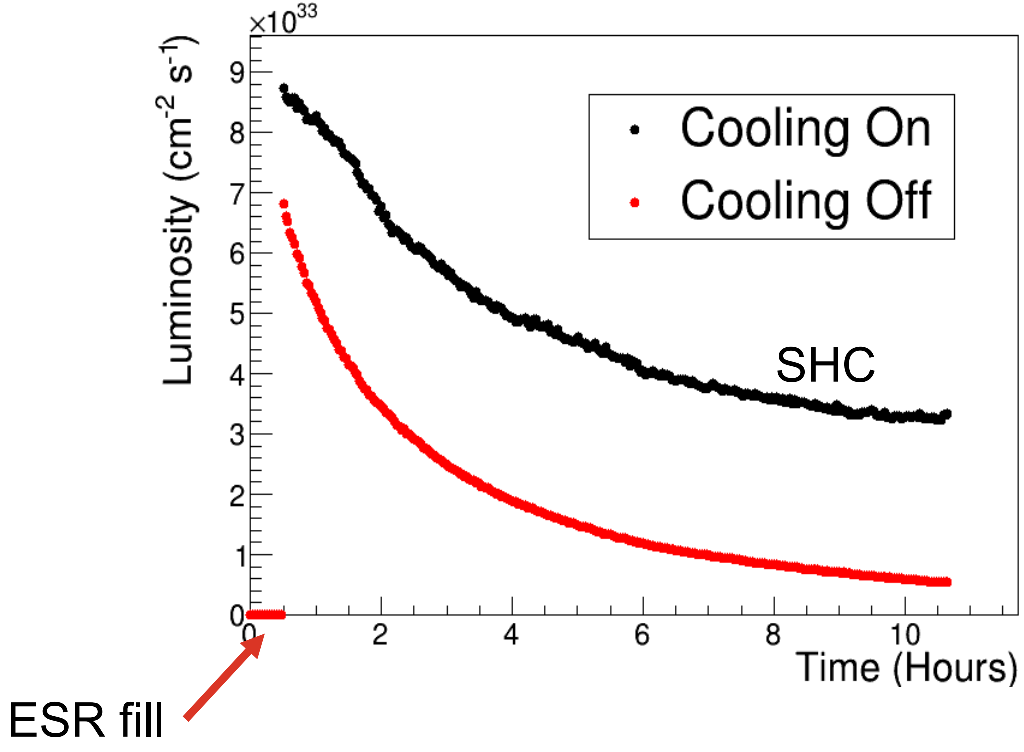
- 2021: The EIC CDR focuses on SHC as a preferred alternative to (1) create flat bunches and (2) maintain emittance during collisions.
- 2023: We realize that SHC is too slow to create flat bunches at collision energy. Added a low-energy electron cooler (13 MeV) at injection, combined with SHC-CEC.

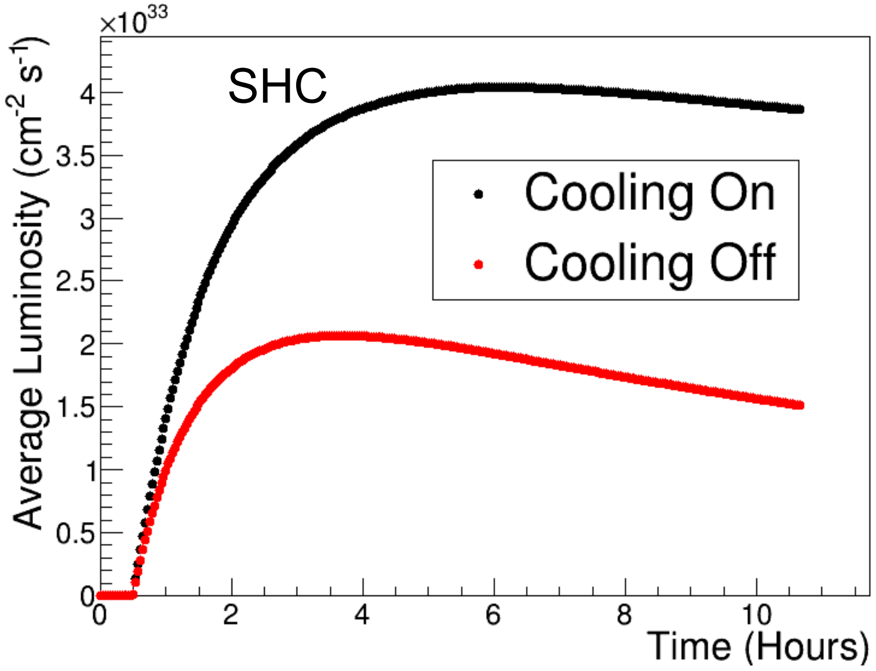


- 2024: SHC has remaining unresolved technical challenges. We developed a detailed luminosity model with and without SHC at collisions. Model assumes flat bunches, created by a low-energy electron cooler.

Luminosities w/wo SHC for 275 GeV p on 10 GeV e (example)

Starting collisions with “flat” proton bunches

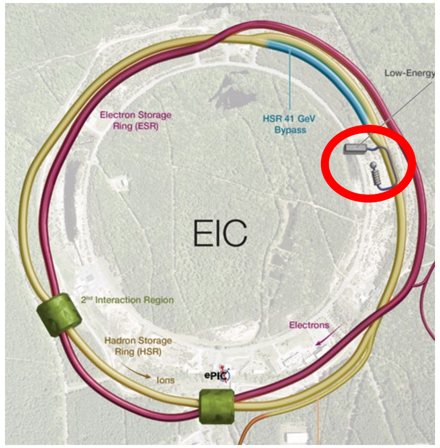




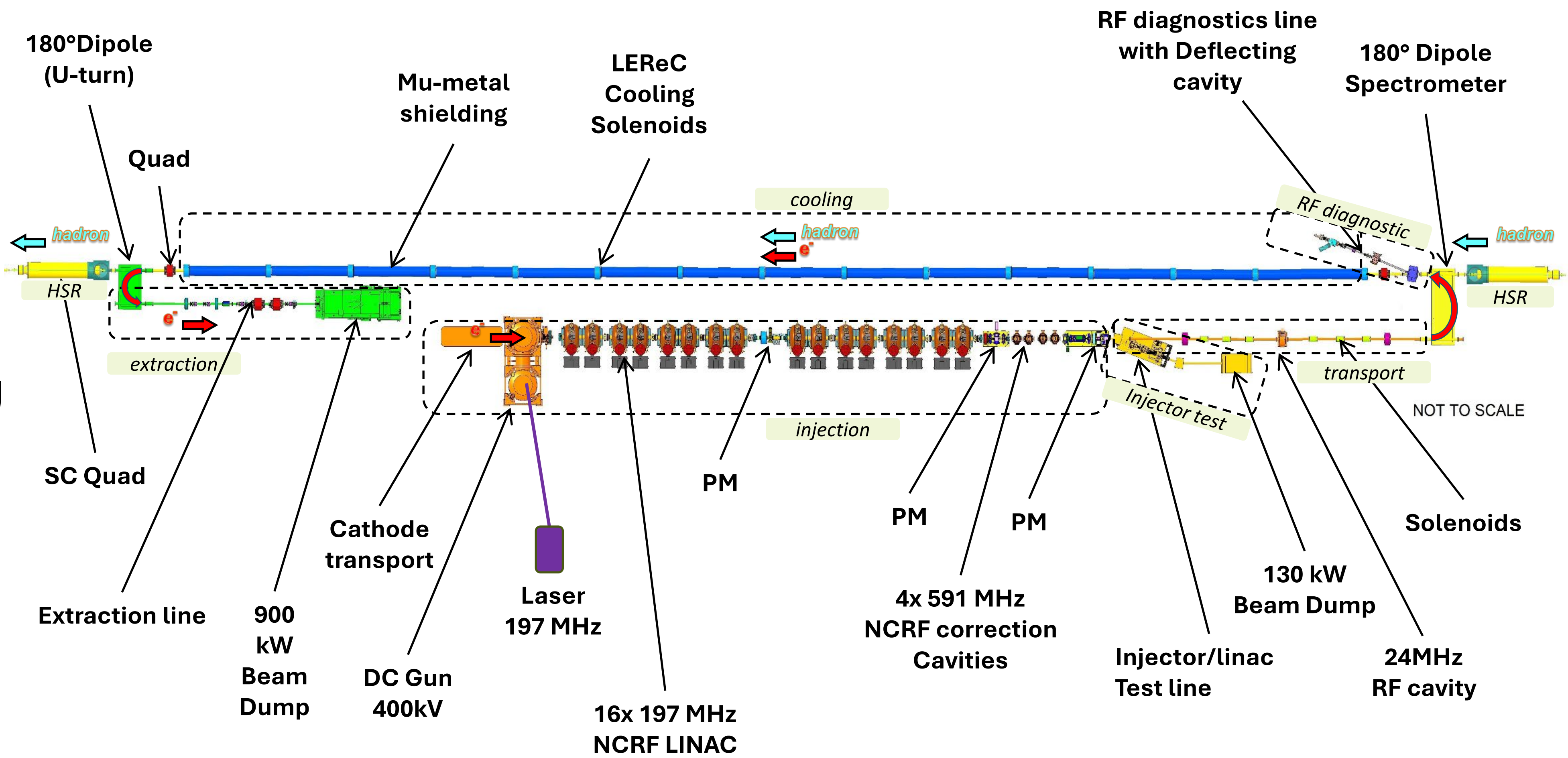
$$\text{Ave. lumi} = \frac{\text{Integral}}{\text{store length} + 2.5\ \text{hr}}$$

- Each store starts with 30 min precooling and 30 min to fill the ESR ring (~1200 bunches);
- In addition, we assume a 2-hour turnaround time for filling hadrons, precooling, and ramping

Producing 'flat' Proton Bunches

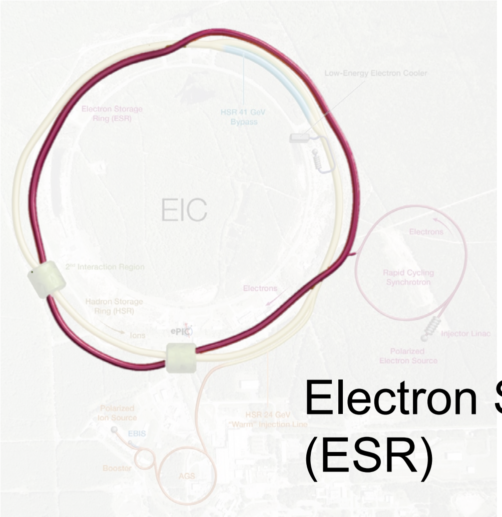


LEC layout
(all within the existing RHIC Tunnel)



Not to scale

Challenges



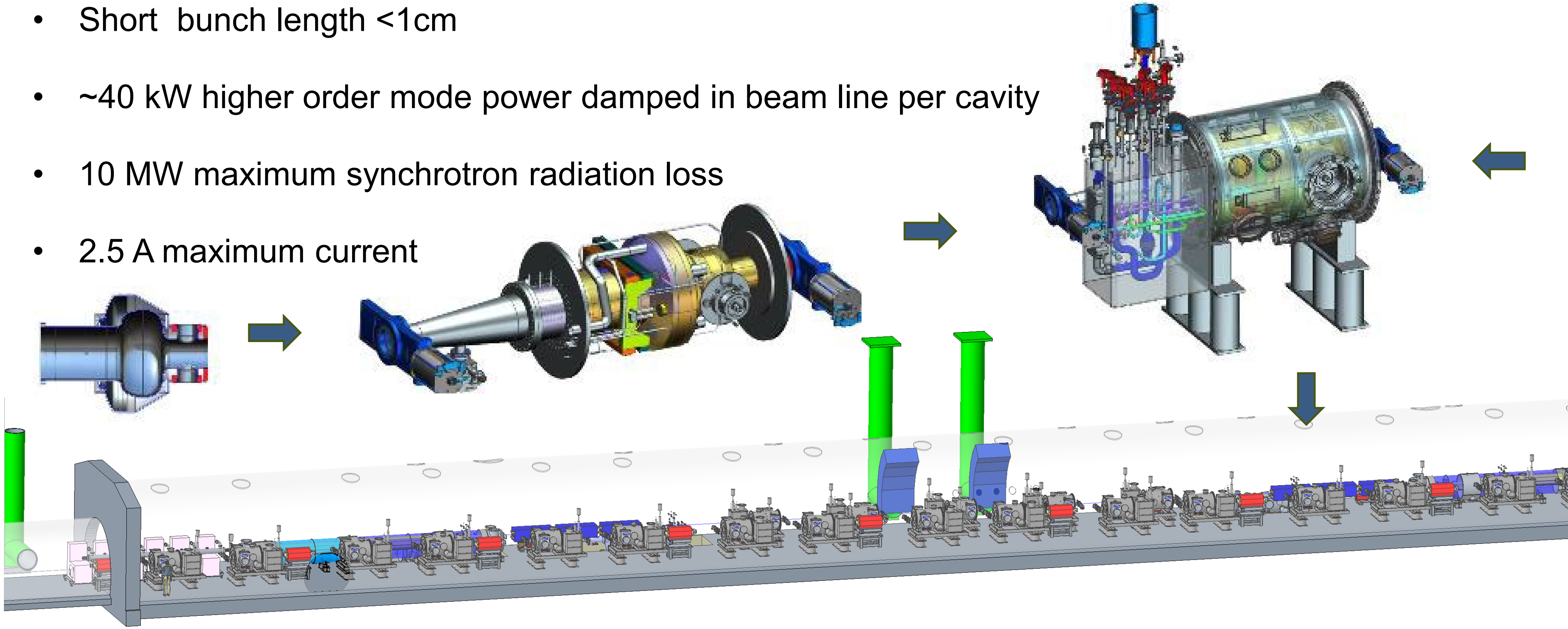
Electron Storage Ring (ESR)

ESR Main Cavity

Main cavity for the Electron Storage Ring:
- Superconducting cavity operating with extremely high power and heavy absorption of unwanted higher order modes
- Compensating for synchrotron radiation loss and extracted higher order mode RF power

Providing 68 MV using 17 single cell elliptical SRF cavities @ 591 MHz

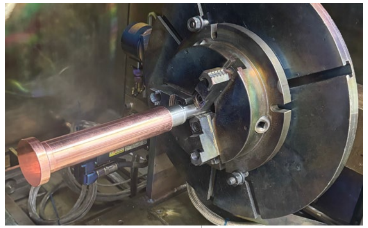
- Short bunch length <1cm
- ~40 kW higher order mode power damped in beam line per cavity
- 10 MW maximum synchrotron radiation loss
- 2.5 A maximum current

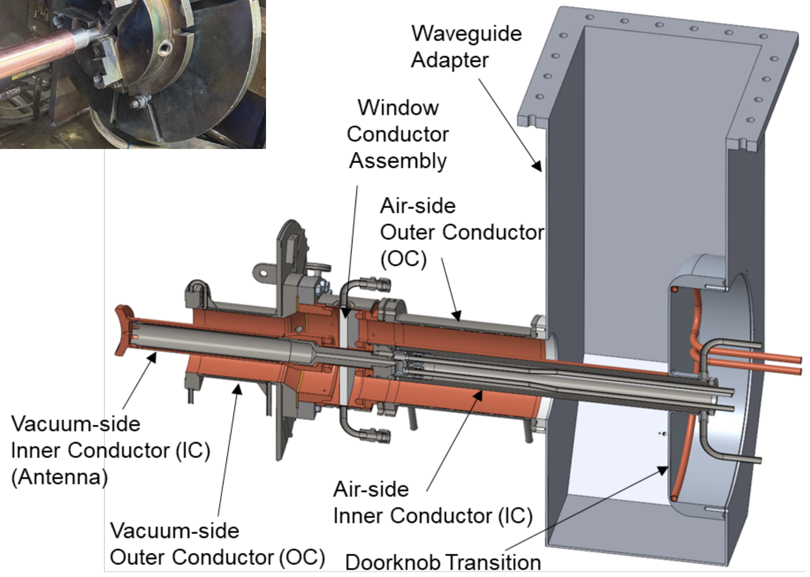


Solid state amplifier in units of 400 kW

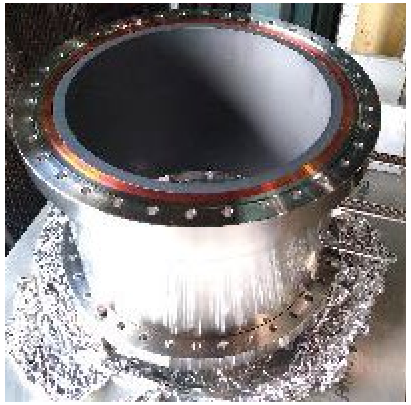
FPC and HOM Absorber for the ESR Main Cavity

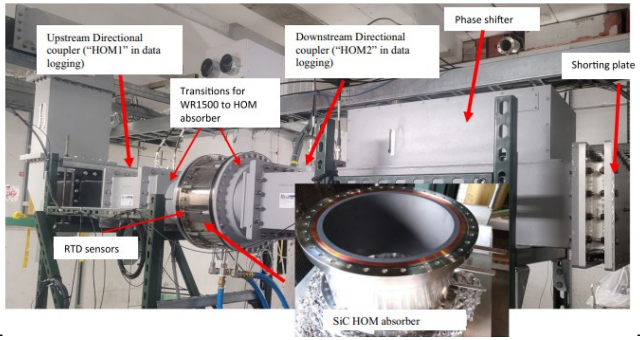
- A high power (CW 500 kW standing wave) alumina window Fundamental Power Coupler (FPC) was designed for EIC ESR SRF cavity. (*W. Xu, Phys. Rev. Accel. Beams 25, 061001 (2022)*)
- Testing of the prototype FPC has reached above 450 kW CW.
- 2 FPC's per cavity, each operating at 379 kW for ESR.



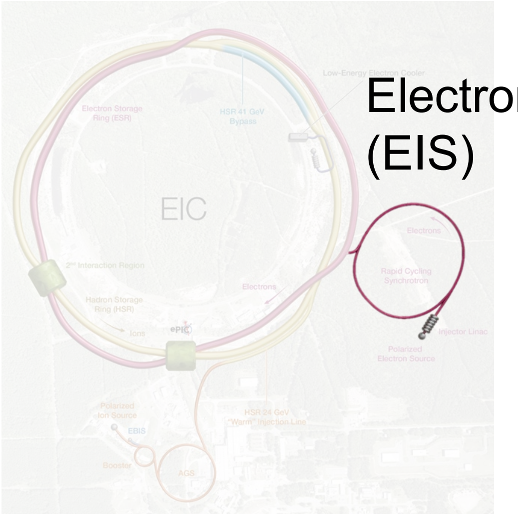


- In EIC ESR, the most challenging scenario for HOM damping is to damp the 72.7 kW HOM power in the 10 GeV case, which has the shortest bunch length and highest beam current.
- A beamline absorber prototype was fabricated with SiC, and inner diameter = 308 mm, length = 240 mm, and thickness = 14 mm
- Final test of the absorbers has reached 102.9 kW of absorbing power, the average power flux over the rf surface is 0.44 W/mm^2, and the error is 2.1%. (*W. Xu, Phys. Rev. Accel. Beams 27, 031601 (2024)*)





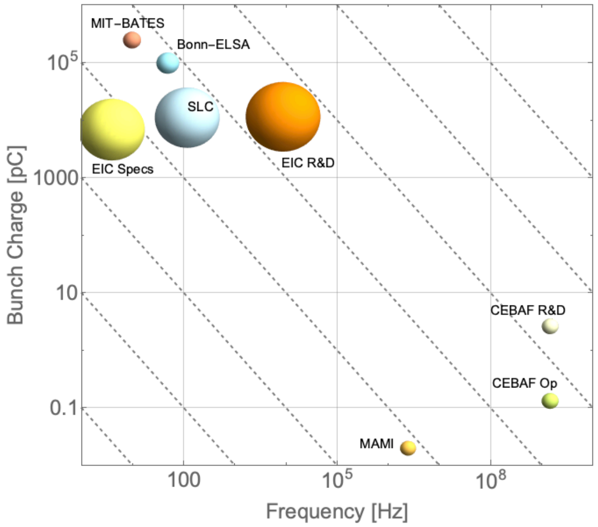
Challenges

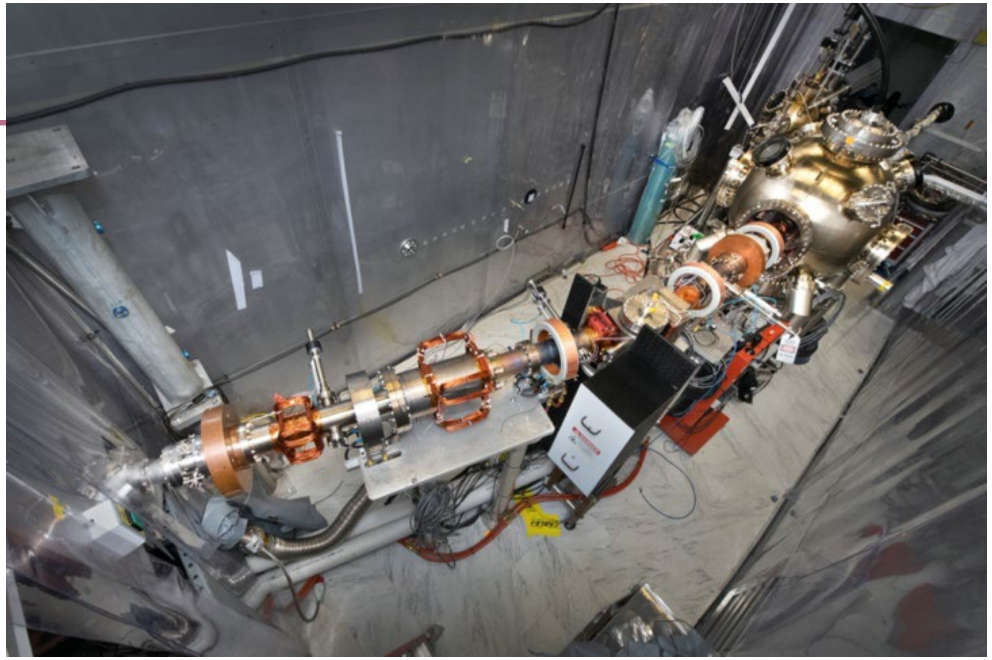


Electron Source

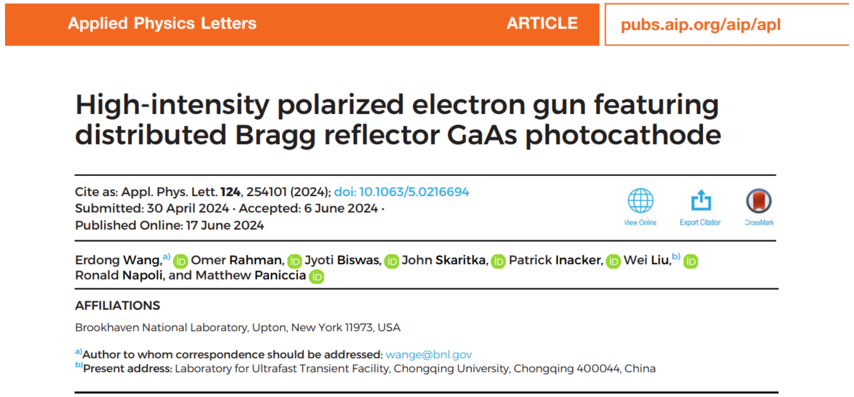
Polarized electron source
- High charge polarized electron bunch
- Stable operation continuously for more than one week

	EIC	R&D achieve in stable operation
Bunch charge [nC]	7	7.5 (max 11.6)
Peak current [A]	3.8	4.8 (No SCL)
Average Current	56 nA	76 uA
Polarization [%]	> 85%	86%





- Long term stable operation @ 5000 bunches/s with **7.5 nC per bunch.**
- More than **1e9 bunches continuously** generated from a single cathode. **No decay** observed after apply 3kV bias voltage on the anode.
- Maximum operation reached 11.6 nC per bunch.
- Lifetime determined by the outgassing from Faraday Cup.


Applied Physics Letters ARTICLE pubs.aip.org/aip/apl

High-intensity polarized electron gun featuring distributed Bragg reflector GaAs photocathode

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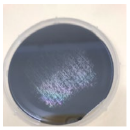
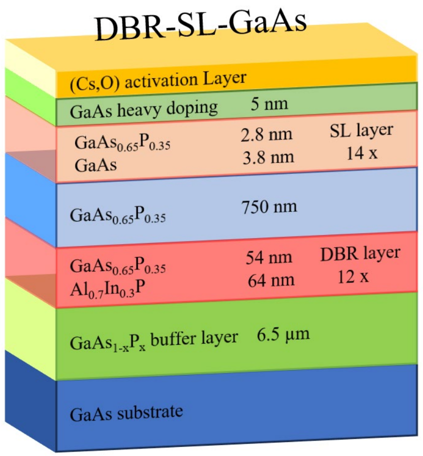
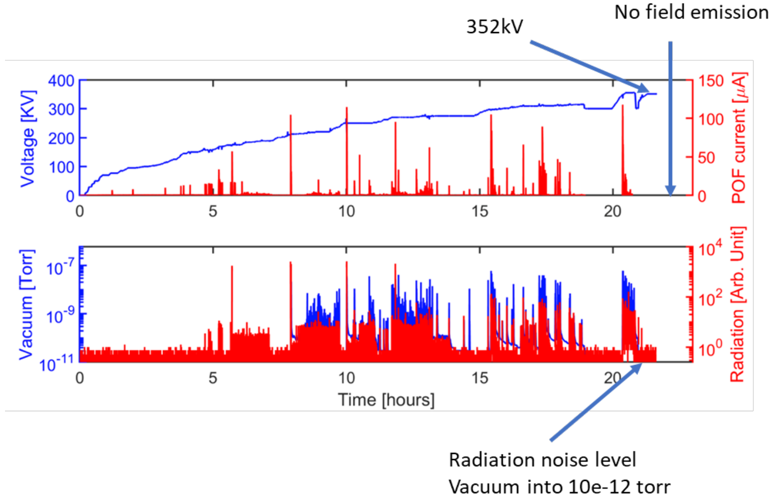
Electron Source

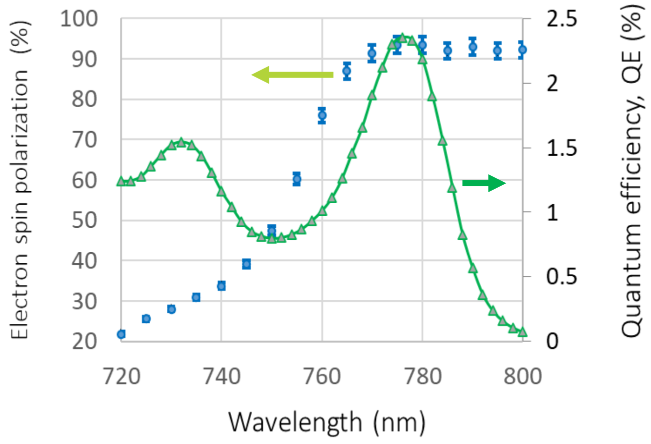
- The SBU HVDC gun has demonstrated
  - Highest voltage and cathode gradient of the polarized electron sources
  - Highest intensity with high rep rate polarized electron source
- The first Distributed Bragg Reflector (DBR) Super Lattice (SL) GaAs Cathode developed by the ODU/BNL/JLab collaboration have been tested in SBU gun. We achieved 5.5 nC bunch charge and the test is in progress. This is the first time for a DBR SL GaAs photocathode to be tested in a high voltage DC gun in the world.



distributed Bragg reflector (DBR) super lattice (SL) GaAs photocathode







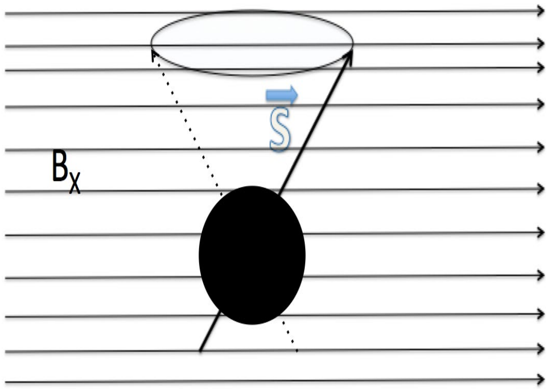
Spin Preservation in RCS

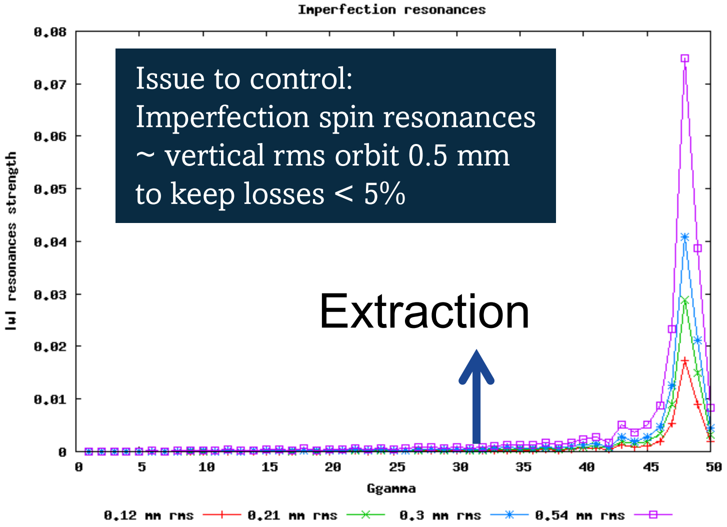
Spin resonance free lattice

- Transfer polarized electrons from the cathode to top energy without significant polarization loss by avoiding spin resonance conditions.
- Optimize lattice to relax the requirement on magnets and power supplies

- Spin precesses at a rate of Gγ in a planar dipole - dominated ring, where G is the anomalous g-factor. To accelerate from 750 MeV to 18 GeV requires the spin tune ramping from 1.702 < Gγ < 41.
- There are horizontal fields from imperfections and from focusing in the quadrupoles. If these horizontal fields occur with a frequency that matches the spin precessing frequency, they can cause the direction of the spin to change – **Spin Resonance**
- Strong intrinsic and imperfection Spin resonances occur at:
  - $G\gamma = nP \pm Q_y$
  - $G\gamma = nP \pm [Q_y]$ (integer part of tune)

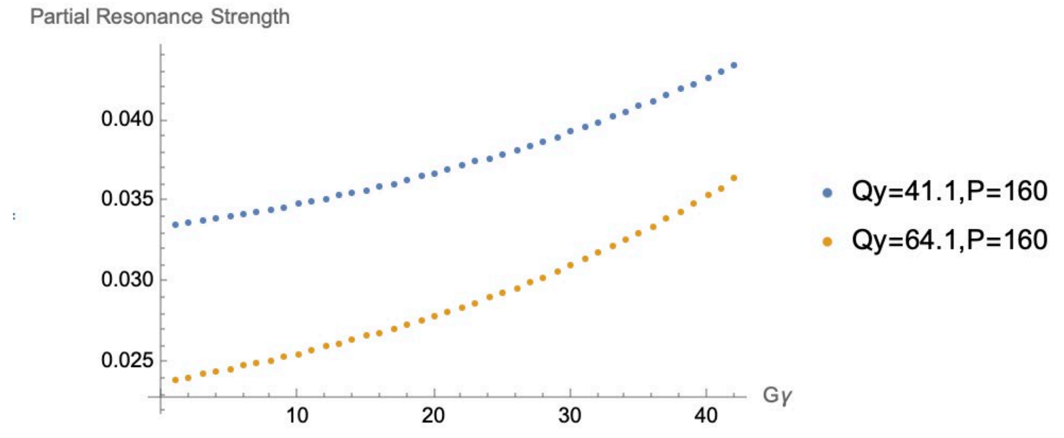
  Here **P** is the lattice Periodicity and **n** any integer and $\mathbf{Q_y}$ the vertical betatron frequency.
- To keep RCS compact we also like to minimize periodicity while also keeping phase advance per cell < 120 degrees for decent beam dynamics.
- These constraints can be summarized:
  41*3 = 123 < P

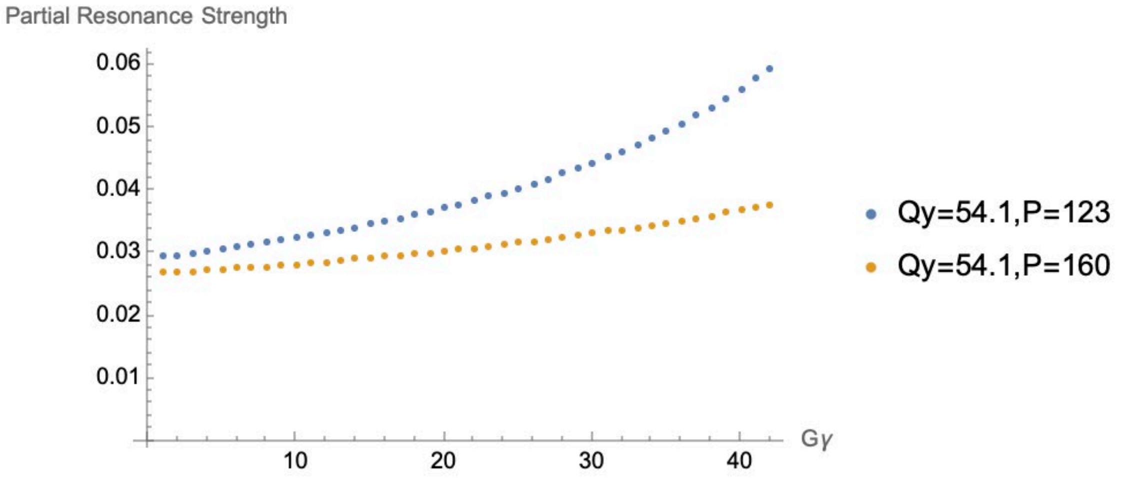




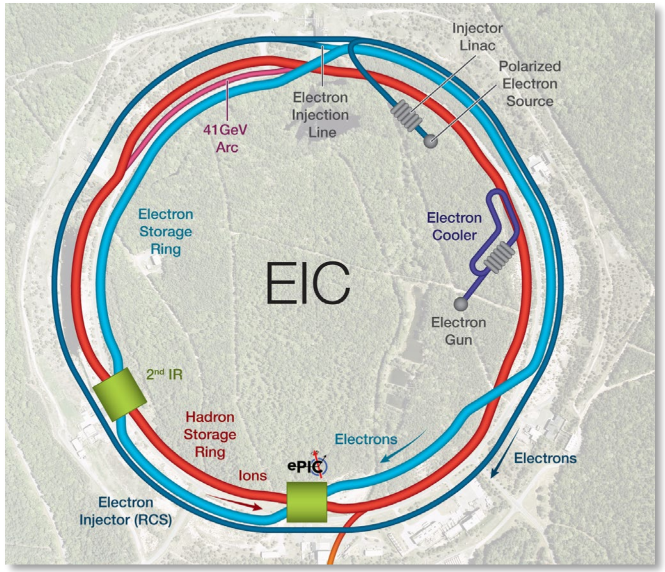
Importance of High Tune and Periodicity

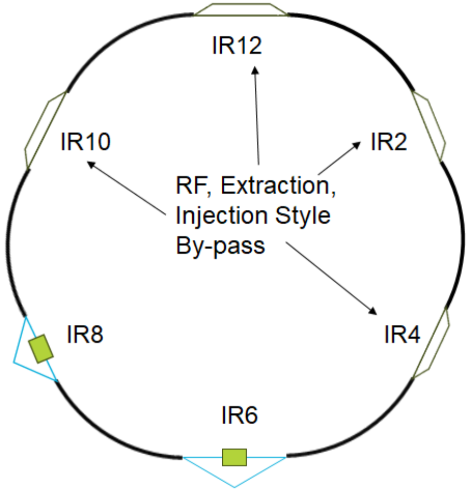
- Studies of lattices with various tunes and periodicities have shown that the response to imperfections for a fixed level of quadrupole misalignments scale with the tune and periodicity.
    - **The higher the tune and number of arc FODO cells the better the polarization response**
- This is confirmed by thin lens resonance analytical approximations
- We choose Qy= 58 and P=160





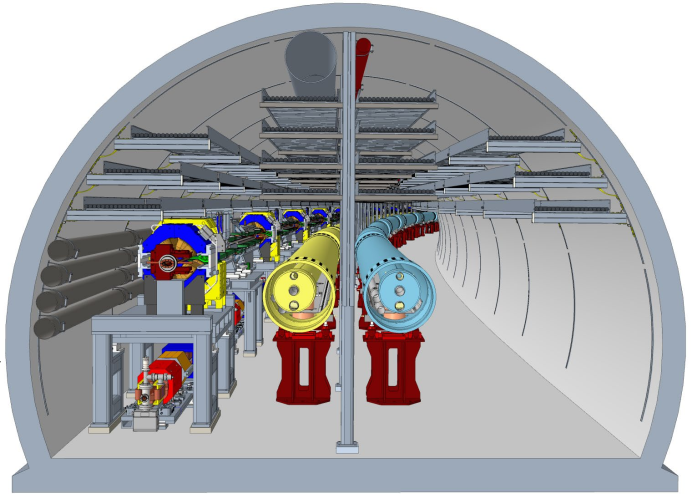
The Current Baseline: 400 MeV linac + RCS (0.4 -> 18 GeV)



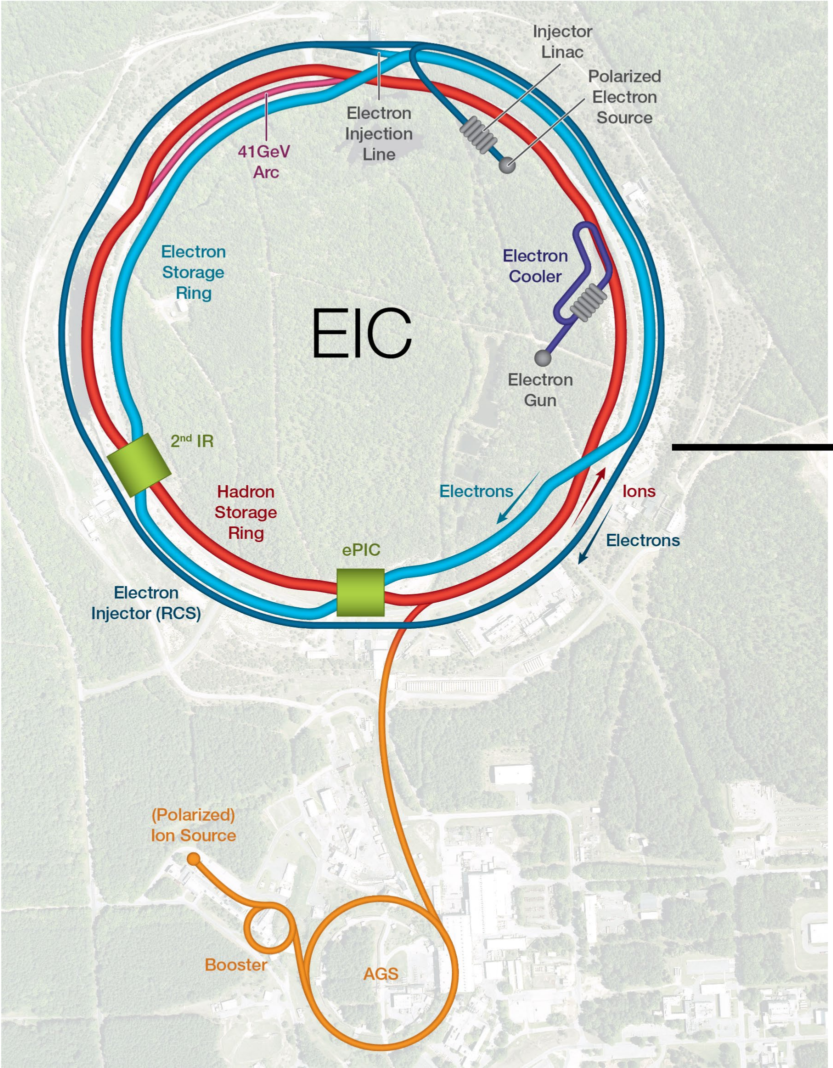


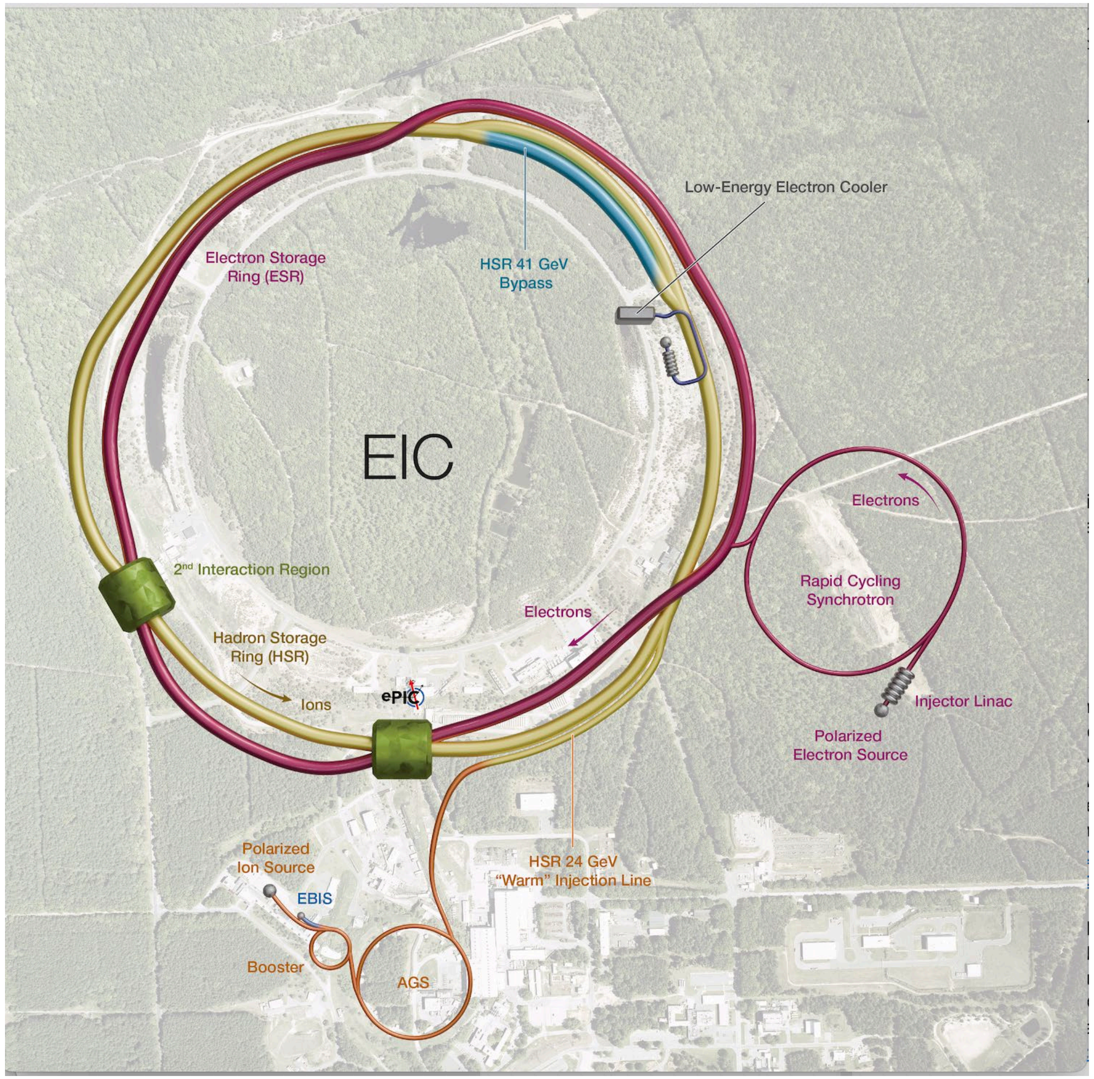
RCS Performance risks:

1. Magnetic (dipole) fields at injection are too low (~50 G).
   - Magnetic shielding requirements not well understood.
2. No synchrotron radiation damping at injection because of low beam energy.
   - Beam accumulation is challenging
3. Bunches are unstable because of high charge, long ring circumference, and low energy
4. The RCS placement into the existing RHIC tunnel is leading to a highly non-optimal design. Also, presents a challenge to installation and future EIC operations (maintenance and servicing of the RCS).

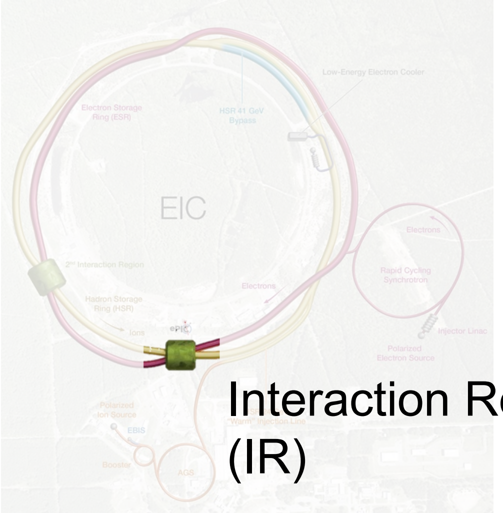


Moving RCS out of RHIC Tunnel

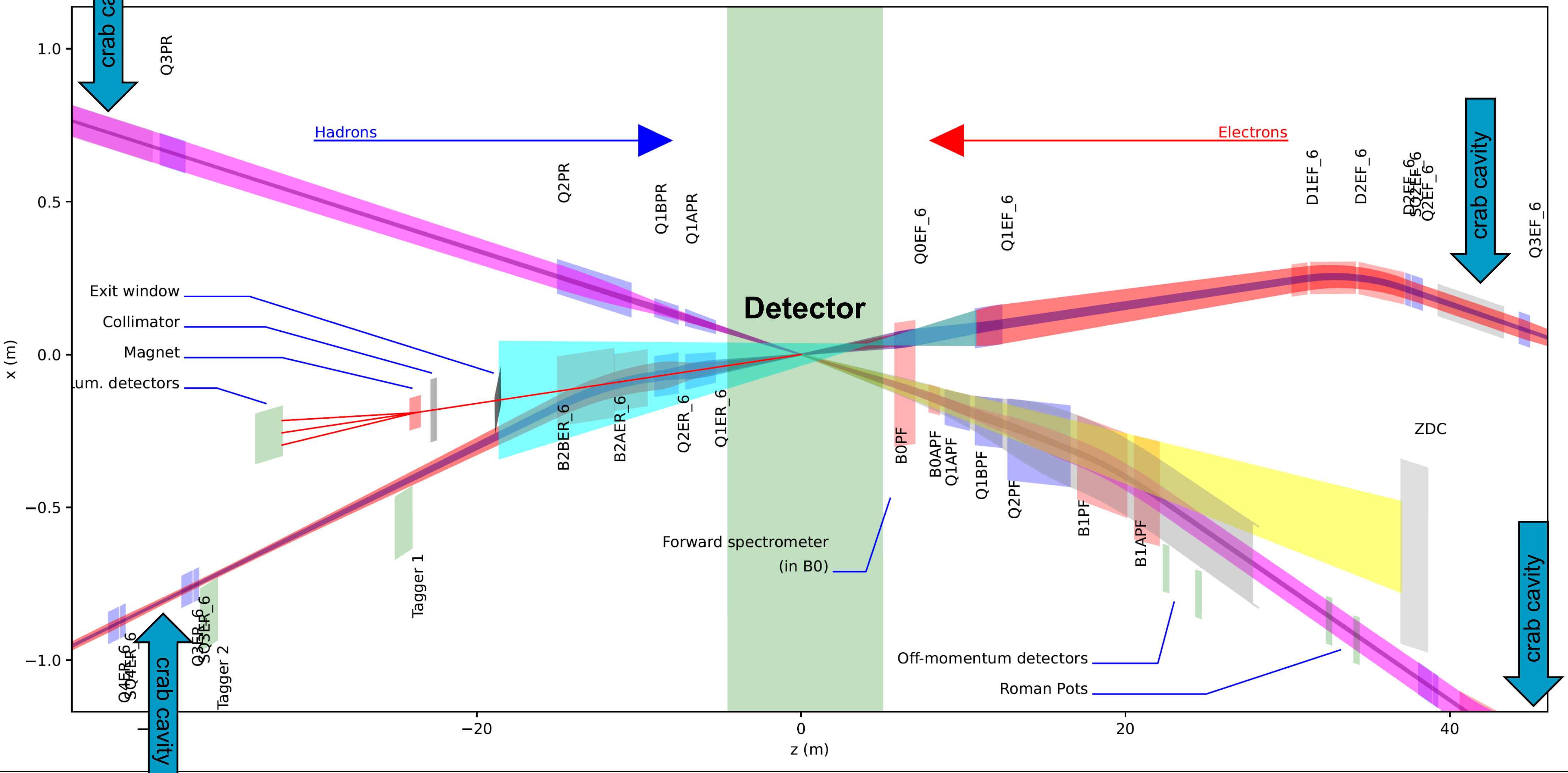




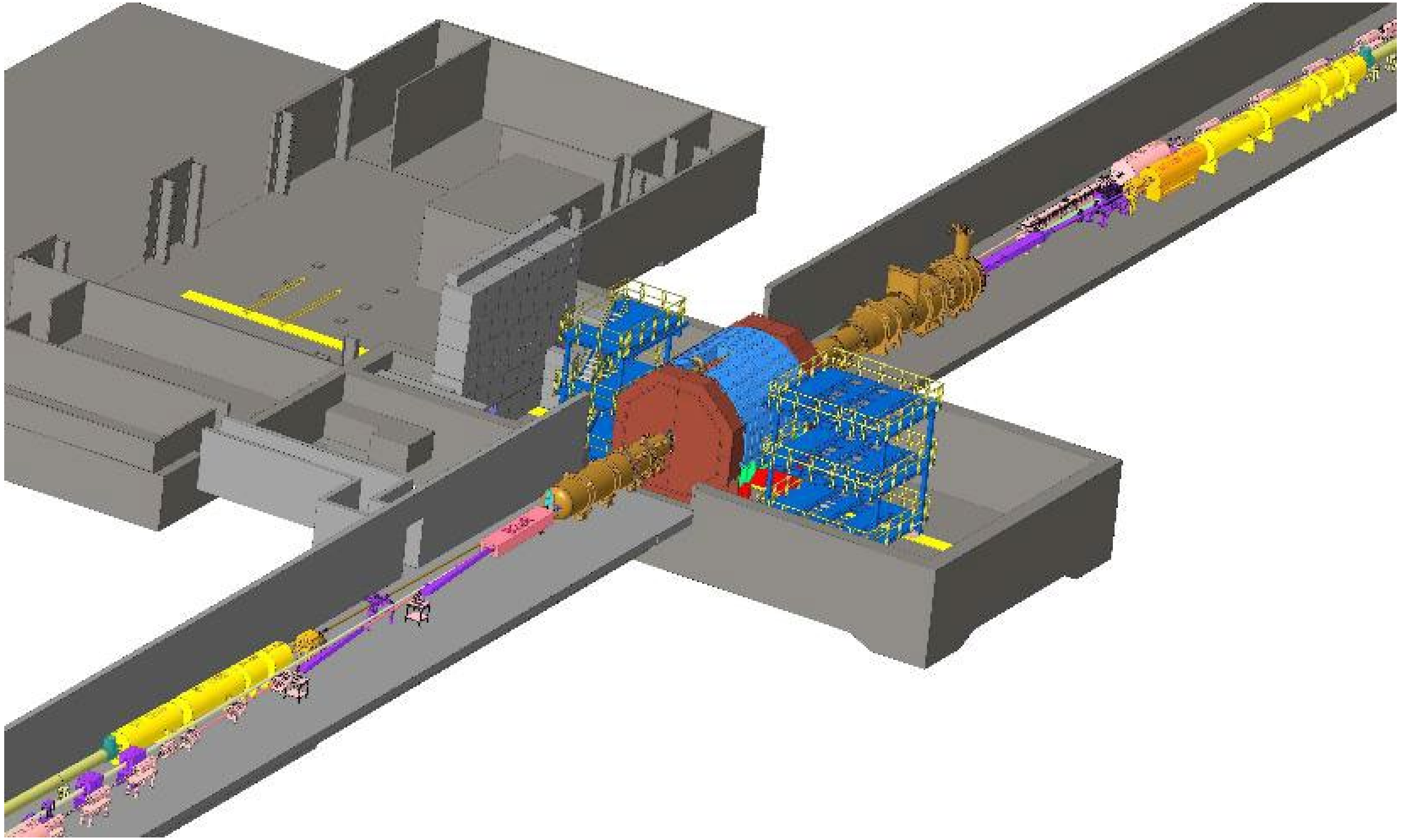
Challenges



Area of Interest: Interaction Region



The ePIC Detector is 90 Meters Long!



The ePIC Detector

- Asymmetric beam energies
  - Requires an asymmetric detector with electron and hadron endcap
  - Tracking, particle identification, EM calorimetry and hadronic calorimetry functionality in all directions
  - Very compact Detector, Integration will be key
- Imaging science program with protons and nuclei
  - Requires specialized detectors integrated in the IR over 80 m
- Momentum resolution for EIC science
  - Requires a large bore 2T magnet (⌀ 2.4 m)

  (1.7 T magnet operation point, stretch goal 2T that has same geometry as the BaBAR magnet)
- Highest scientific flexibility
  - Requires Streaming Readout electronics model

hadronic calorimeters (HCAL)

Solenoidal Magnet

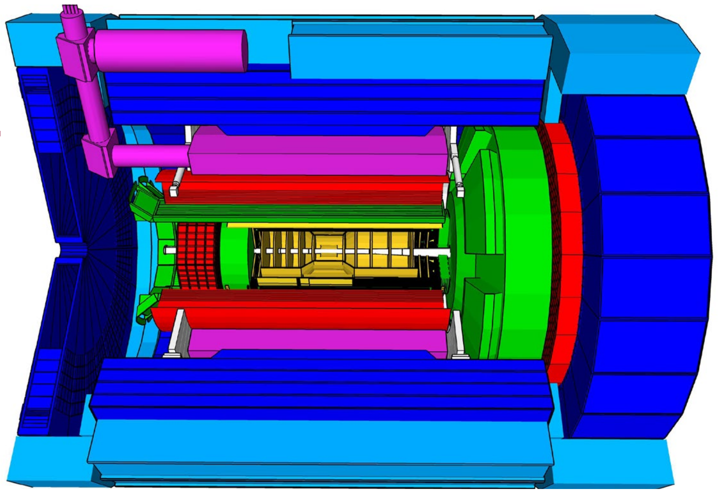
e/m calorimeters (ECal)

Time.of.Flight (ToF), DIRC, RICH detectors

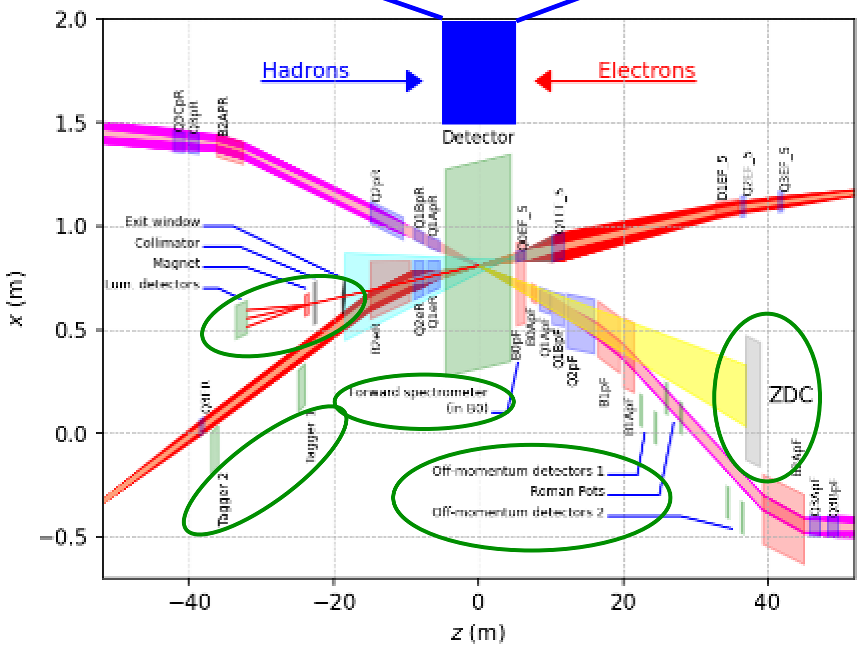
MPGD trackers

MAPS tracker

24 Subdetectors incl. Polarimeters + Electronics + Data Acquisition

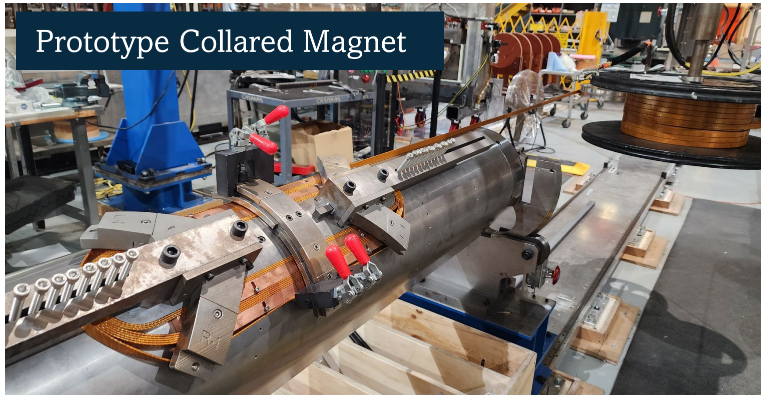


9.5 m

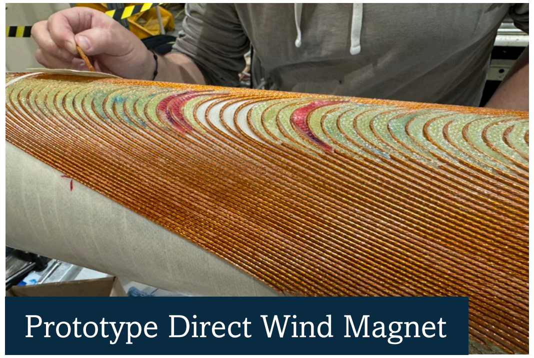


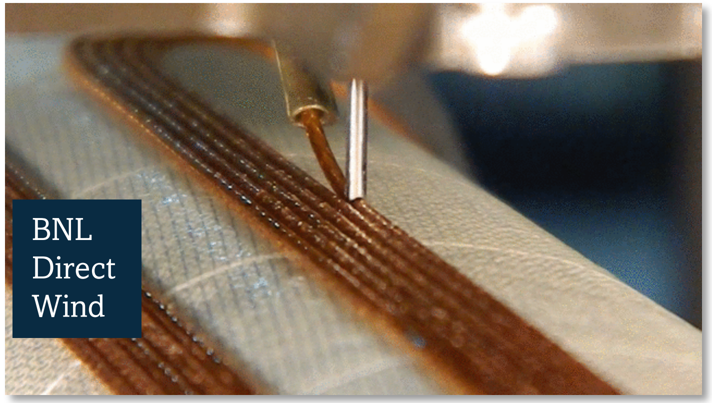
Superconducting IR Magnets

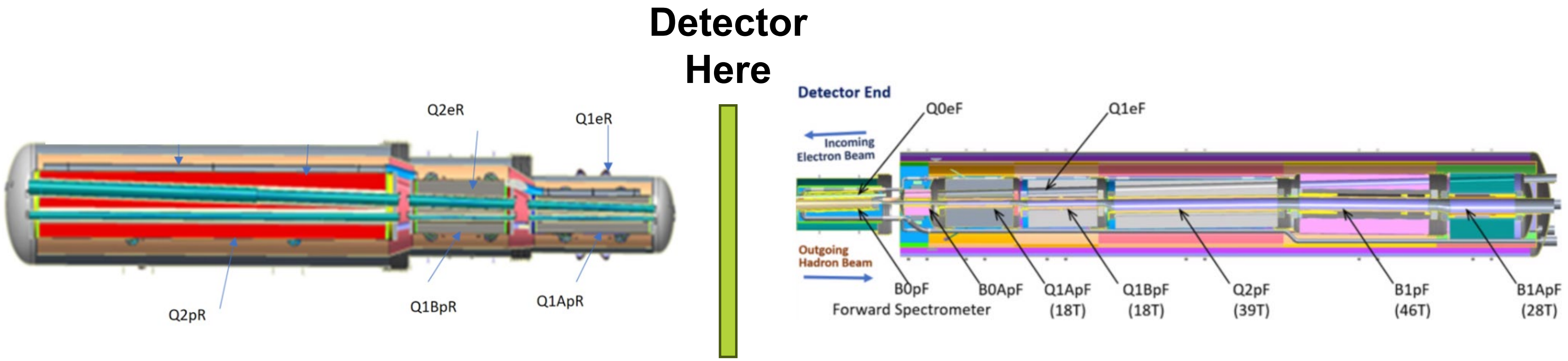
- 17 superconducting magnets with large apertures on the hadron forward side and high field/gradient requirements
- All hadron forward collared magnets are extremely challenging, due to the required aperture, field/gradient, and limited spacing – Prototype B1pF
- Some direct wind magnet designs are very challenging, due to the aperture and field requirements. Several employ a novel winding scheme (tapered CCT) – Prototype Q1ABpF



Name	Inner Radius [m]	Length [m]	Mag Field [T]	Field Grad [T/m]
B1pF	0.135	3	-3.4	0
Q1ApF	0.056	1.46	0	-72.6
Q1BpF	0.078	1.61	0	-66.2



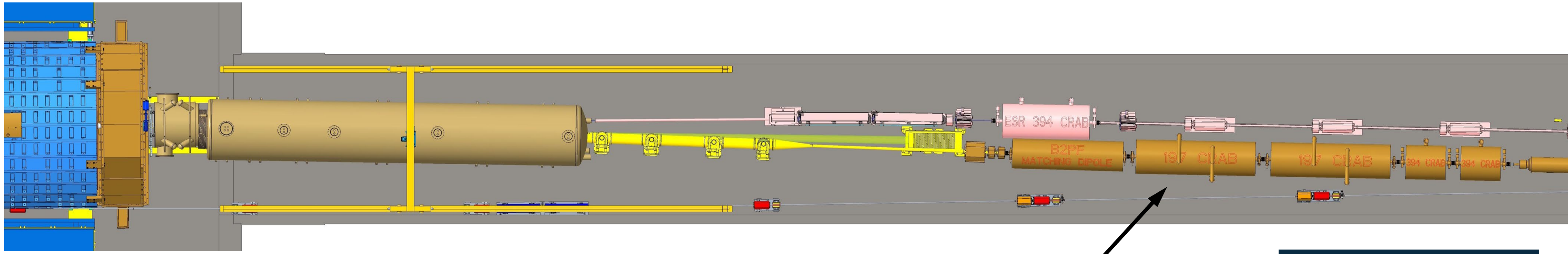




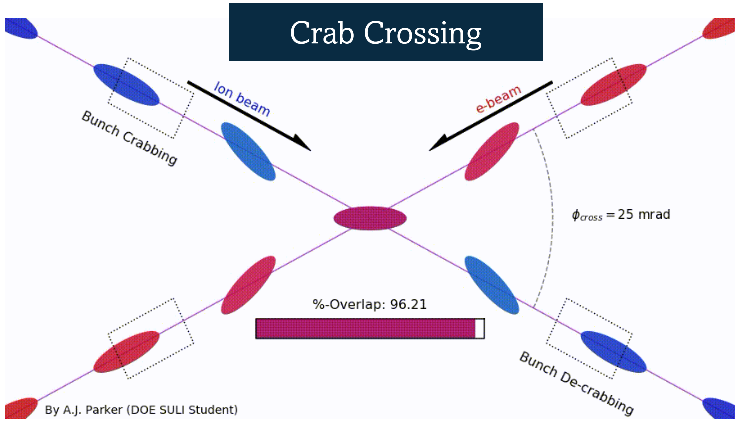
Superconducting Crab Cavities

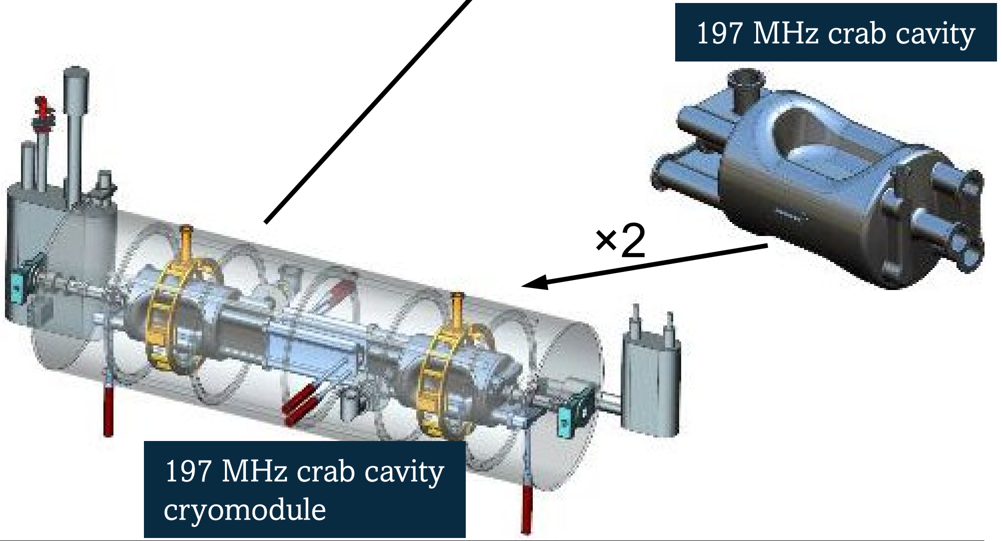
- Very rare type of cavity designed to apply a time dependent momentum kick to each bunch to compensate the geometric luminosity loss due to the crossing angle.
- Ideally, two sets of identical crabbing system installed symmetrically across the IP with 90 degrees phase advance, creating bunch tilting at IP with half of the crossing angle.
- The realistic challenges includes the sinusoidal nonlinear dependence, the non-ideal phase advances and phase/amplitude in RF control

- Full crab cavity system for hadron/proton:
  - 197 MHz crab cavity x4
  - 394 MHz crab cavity x2
- Full crab cavity system for electron:
  - 394 MHz crab cavity x1



Property	Value
Operating frequency [MHz]	197
Cryomodule length [m]	5.8
Cryomodule profile radius [m]	1.89
Voltage per cavity [MV]	8.5/11





Crab Cavities Noise

- Tighter requirement on the crab cavity noise, both phase noise and amplitude noise, compared with HL-LHC.
- Feedback system planned for HL-LHC to relax the tight tolerance. It shares the pickup with the transverse damper system and the signal is feed back to the crab cavity LLRF system to modify the phase and amplitude of crab cavity.

Bunch length

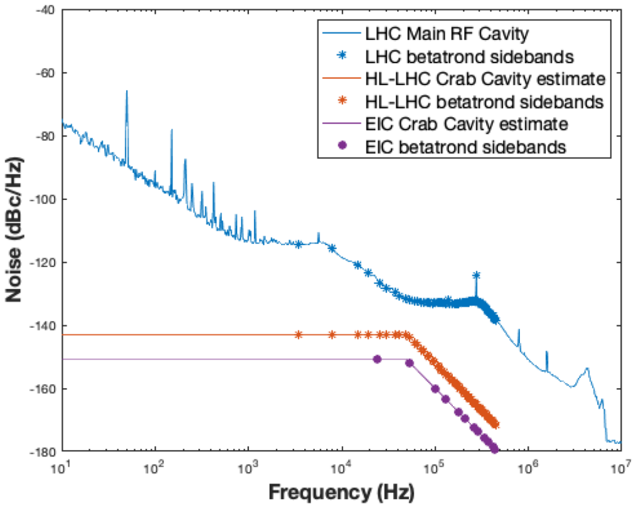
Phase noise

$$\frac{d\epsilon_x}{dt} = \beta_{cc}\left(\frac{eV_0 f_{\text{rev}}}{2E_b}\right)^2 C_{\Delta\phi}(\sigma_\phi)\sum_{k=-\infty}^{\infty} S_{\Delta\phi}[(k\pm\bar{\nu}_b)f_{\text{rev}}]$$

Amplitude noise

$$\frac{d\epsilon_x}{dt} = \beta_{cc}\left(\frac{eV_0 f_{\text{rev}}}{2E_b}\right)^2 C_{\Delta A}(\sigma_\phi)\sum_{k=-\infty}^{\infty} S_{\Delta A}[(k\pm\bar{\nu}_b\pm\bar{\nu}_s)f_{\text{rev}}]$$

Crossing angle and beta*



Linear theory of crab cavity noise: *P. Baudrenghien and T. Mastoridis, [Phys. Rev. Accel. Beams **18**, 101001 (2015)]*

Estimated tolerance for HL-LHC (<1%/hr emittance growth) and Hadron beam for EIC (Emittance growth comparable to IBS)

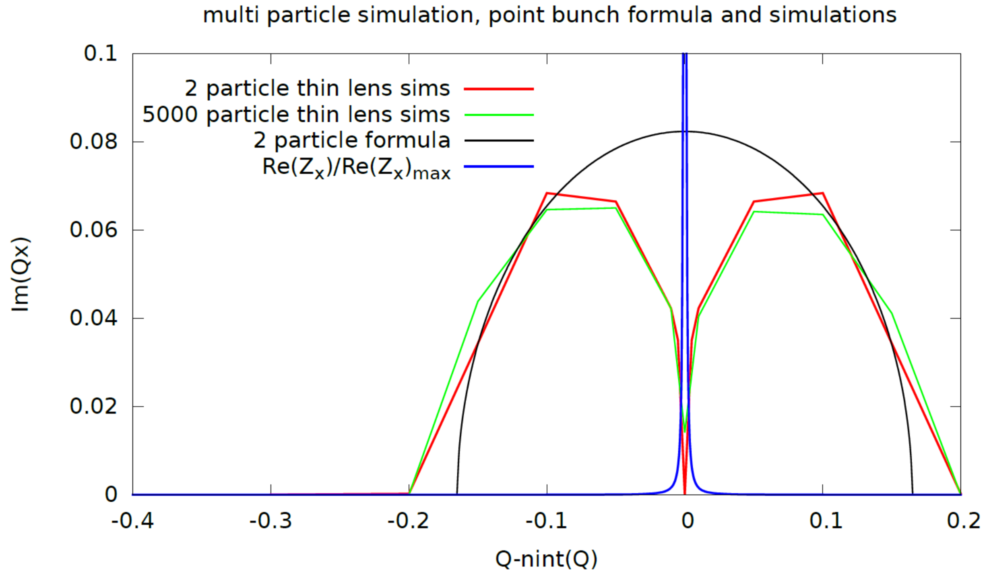
	$\sigma_{\Delta\phi}$(urad)	$\sigma_{\Delta A}$(1e-6)
HL-LHC	8.2	13.3
EIC 41 GeV Proton	3.1	10.1
EIC 100 GeV Proton	2.7	9.4
EIC 275 GeV Proton	1.8	7.1

Crab Cavities Feedback System

- The fundamental mode of the crab cavity has a large transverse impedance and the beta functions at the cavity are large.
- The HSR is a concern since there is no beam-beam damping during injection and ramping.
- Tuning the resonant frequency by 0.5% (1MHz) is very hard and risky.

- Plan to keep fixed resonant frequency with wideband feedback on with zero voltage setpoint during injection and ramping. $Q_{eff} \approx 300$.
- Beam-beam tune spread with $\Delta Q_{bb}=0.015$ stabilizes 1 IP.
- Stability with 2 IPs is under study. Octupoles may help.
- Dynamic aperture with large tune spread is a concern.
- Actively working with RF group to find a solution that works for all.
- Dampers that operate during injection and ramping are being studied.

Growth at 275 GeV with 197 MHz Crab Cavities alone, $Q=3x10^6$, feedback required



- *M. Blaskiewicz, Instabilities Driven by the Fundamental Crabbing Mode, BNL Tech Note BNL-222221-2021-TECH*
- *M. Blaskiewicz, EIC MAC Review, July 15, 2022*

R&D Projects

Other Challenges and World Leading Developments

ESR Cavity

Hadron Polarimetry

Cooling Gun

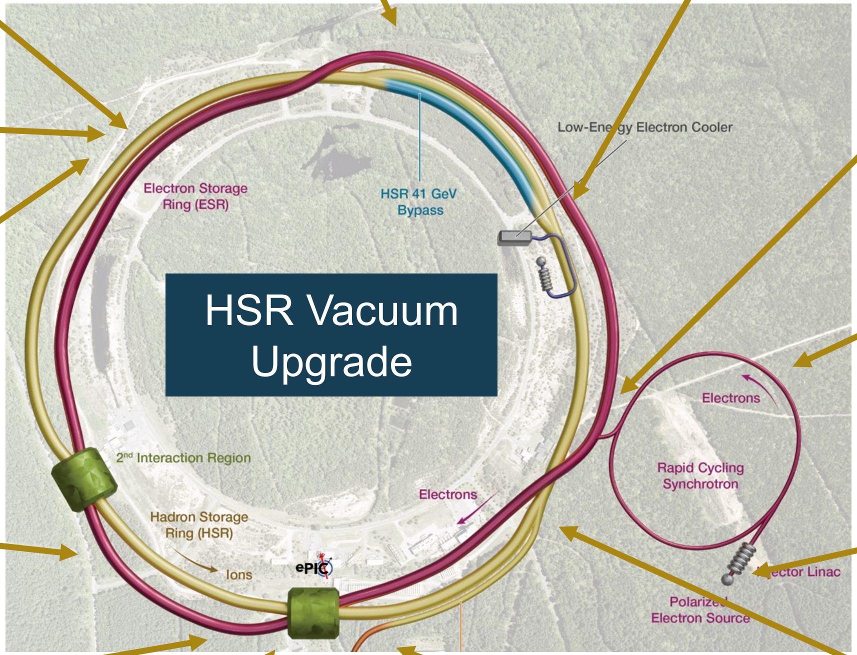
High Power Fundamental Power Coupler

Electron Fast Kicker

RCS Corrector Power Supply

HOM Absorber

HSR Vacuum Upgrade



ESR Arc Vacuum Chamber

Polarized Electron Source

Crab Cavity

Proton Fast Kicker

IR Vacuum Chamber

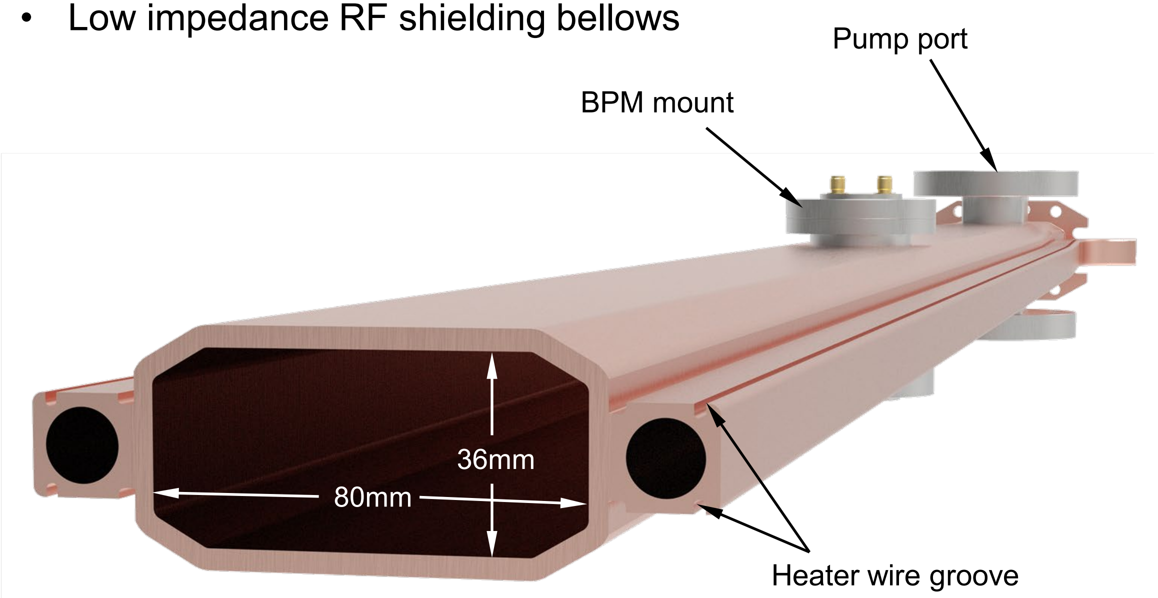
IR Design and Magnet Prototyping

Vacuum Systems Development

- ESR vacuum system needs to be able to provide low impedance for the high current short electron bunches as well as being able to dissipate up to 10 MW of synchrotron power which will be generated by the circulating beam.
- The central detector chamber will be a fragile ~9m beampipe made partially of beryllium which needs to be carefully integrated into an array of sensitive detectors.

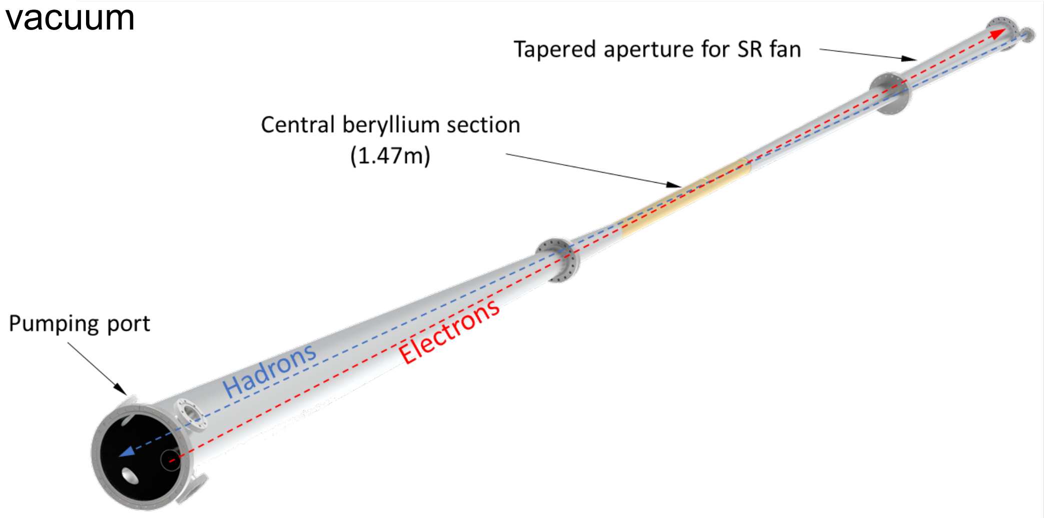
ESR Arc Vacuum Chambers

- OF copper extrusions
- Copper to stainless steel welding
- >1000 chambers to fabricate, process and integrate
- Low impedance RF shielding bellows



Interaction Region Main Detector Chamber

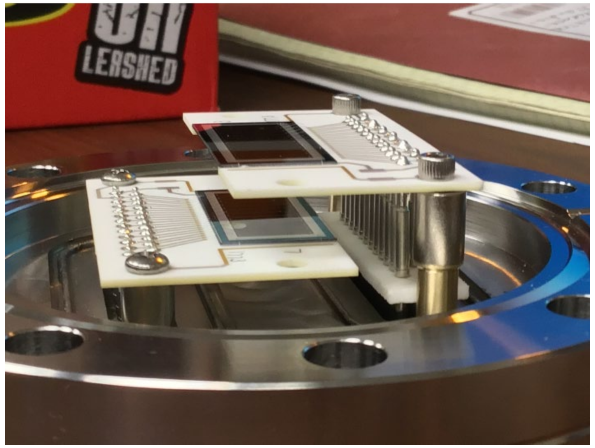
- Space constrains for the synchrotron radiation (SR) fan due to strong focusing
- Thin beam pipe wall to maximize particle penetration
- Low impedance design
- Low vacuum

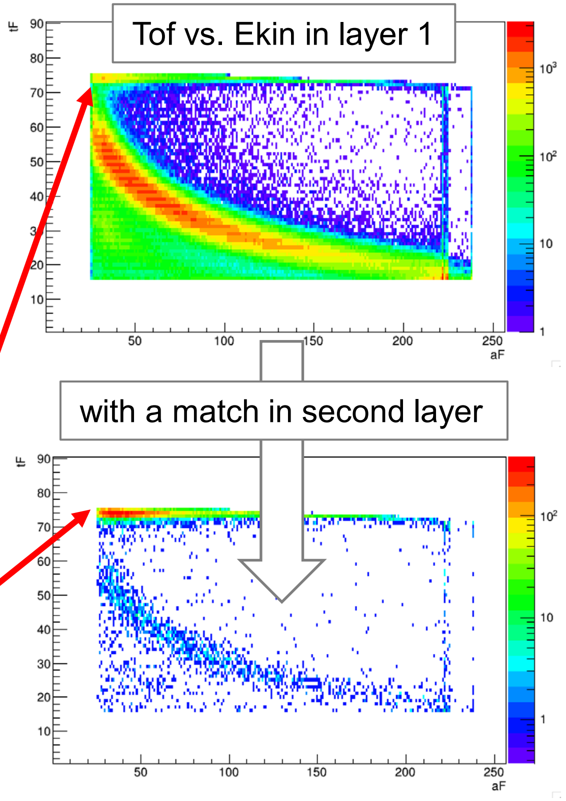


Hadron Polarimetry

- More stringent requirement of 1% for the systematic uncertainty of the polarization measurements be done bunch-by-bunch; bunch spacing EIC/RHIC ≈ 1/10
- The measurement of 3He beam polarizations was never done in a collider.
- Also, tagging breakup fragments of 3He nuclei is required for 3He beam absolute polarimetry. The expected increase of the heat

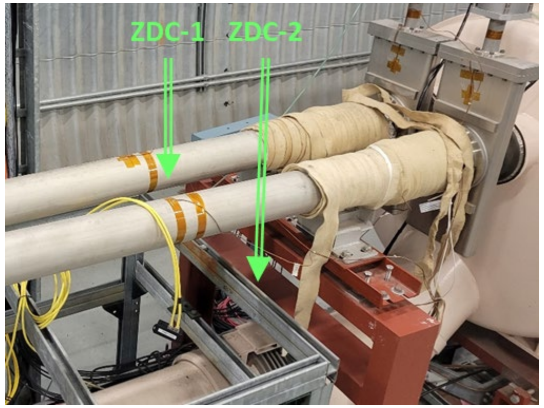
Second layer of Si-detectors as veto

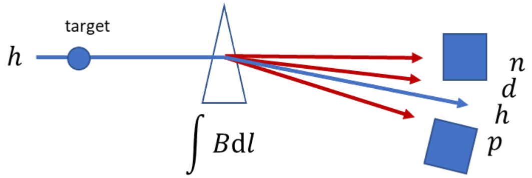




Pretty clean selection of beam induced prompts

The focus of the 3He polarization measurement is in the eliminating the breakup events of the 3He ions. Also, the underlying observable for the polarization measurement is not known experimentally for 3He.





- Experimental confirmation for magnitude of asymmetry
- Veto beam breakup with ZDC downstream of H jet target
  - Planned Accelerator Physics EXperiment with He3 beam in RHIC Run 2024
  - Pair of ZDC's are being installed in the tunnel and included in the H jet DAQ

Summary

- The Electron Ion Collider is a very large project for DOE Office of Nuclear Physics (NP) and Office of Science (SC). Current cost estimate around $3B.
- Two partner labs – Brookhaven National Laboratory and Thomas Jefferson National Accelerator Facility – teamed together in 2020 and formed the EIC Project Leadership Team. Both facilities contributed their expertise developed over the past decades.
- Challenges emerge in various sections including accelerator physics, detector physics, electrical and mechanical engineering, infrastructure, and project management.
- Technical challenges and must be resolved with cost-effective solutions under controllable risks.
- The EIC project is currently converging to a design with a clear path to reach the mission need.

Acknowledgement

- Thank you to all whose collective contributions were represented here.
- I am thankful for continuous and extended communications with Sergei Nagaitsev, Elke Aschenauer, and James Yeck.

Thank you! Questions?