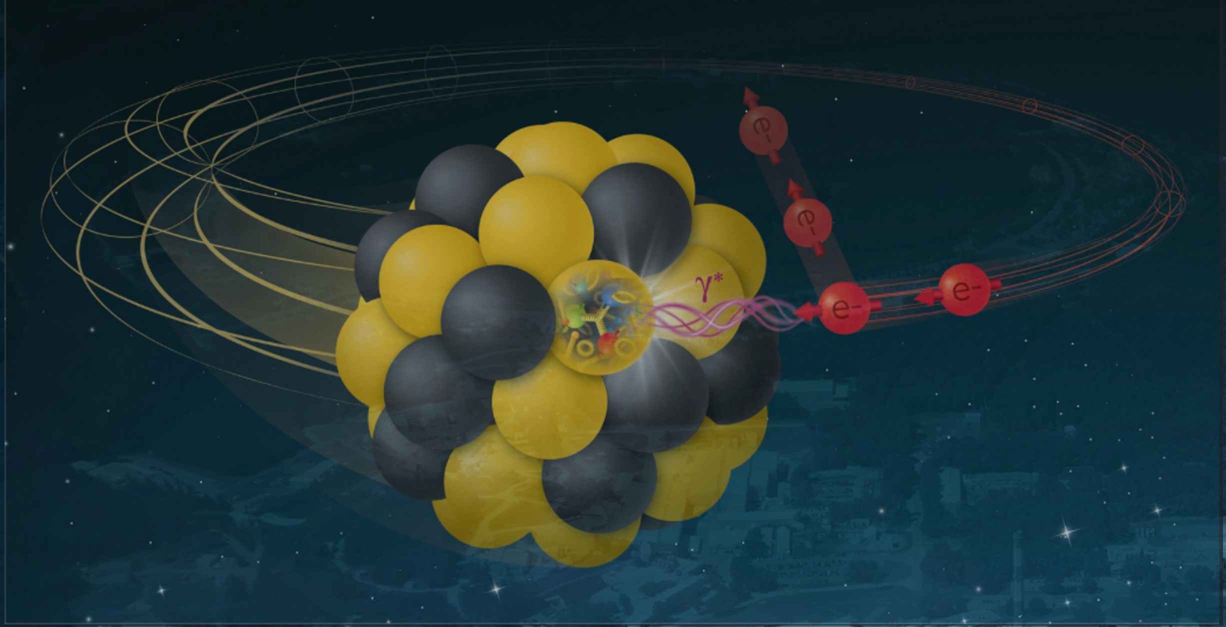


The EIC project & collaboration

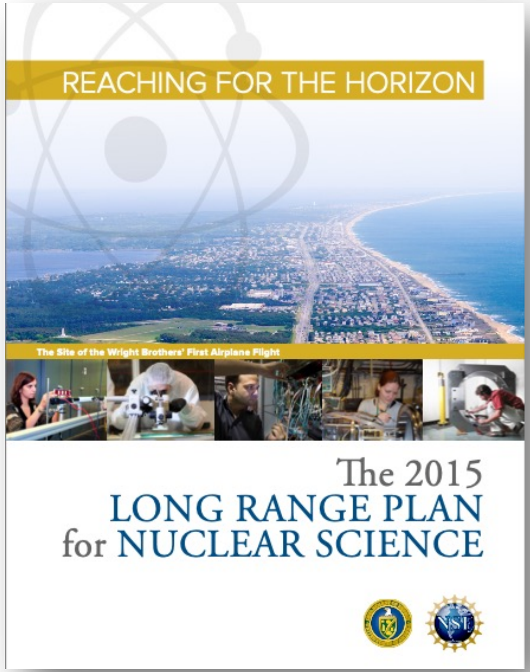
Maria Chamizo-Llatas
Deputy Associate Laboratory Director, Nuclear & Particle Physics
Brookhaven National Laboratory

Community Report on Accelerator Roadmap, July 12-13, 2023, Frascati

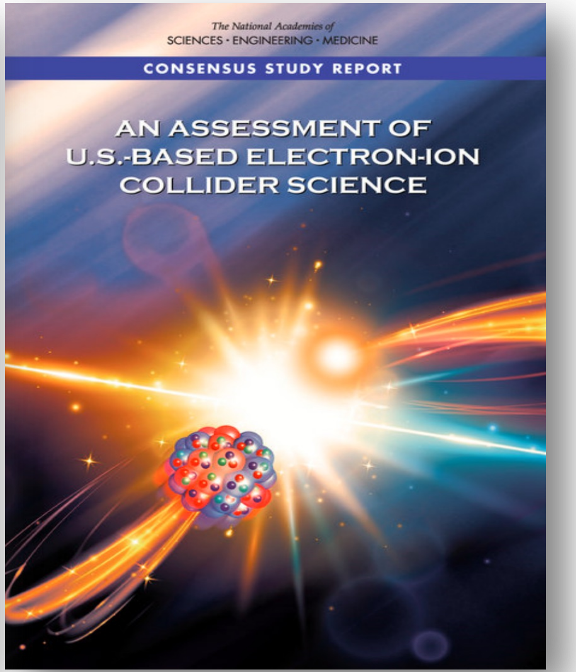
Electron Ion Collider

- Decade-long process prior to 2015 when the U.S. Long Range Plan in Nuclear Science recommended “**a high-energy high-luminosity polarized EIC as the highest priority for new facility construction…”**
- The 2018 U.S. National Academy of Science Committee Report assessment concluded “**an Electron Ion Collider (EIC) will uniquely address three profound questions about the nucleons – neutrons and protons – and how they are assembled to form the nuclei of atoms”**
- In Dec 2019 the U.S. Department Of Energy approved the EIC Mission Need (Critical Decision-0) and in 2021 the EIC project received approval for execution (Critical Decision-1) with a project cost range $1.7B-$2.8B

2015

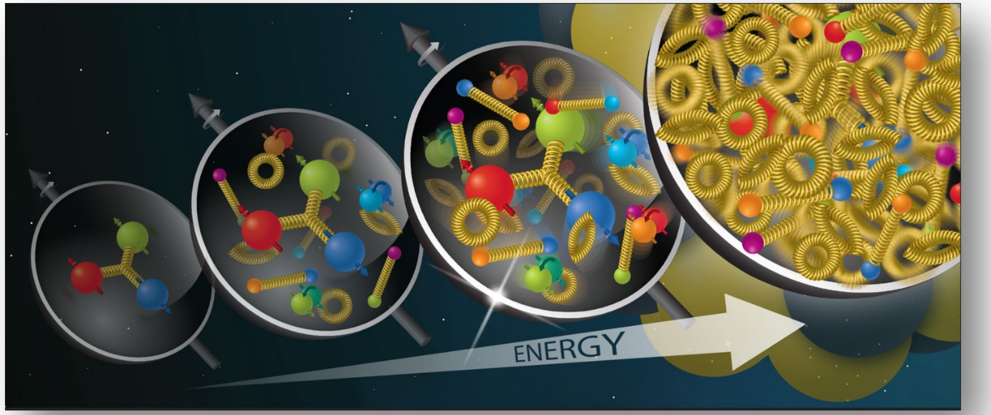


2018

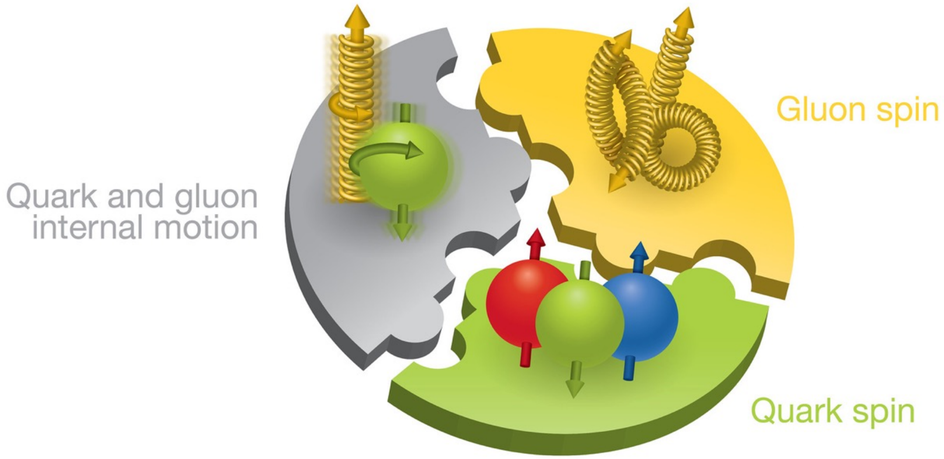


EIC science pillars

Origin of dense gluon matter (*gluon saturation*): study of the gluon density in the nucleon at high energies and if there is a cap on how high the gluon density can rise

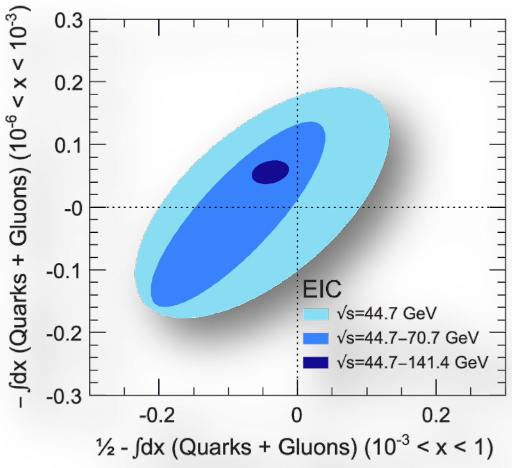


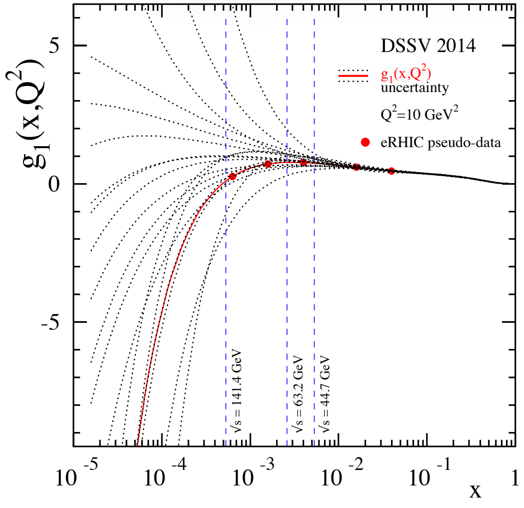
Origin of the nucleon spin: exploration of how the spin of sea quarks, and spin of sea gluons and their orbital motion generate the total spin of the nucleon

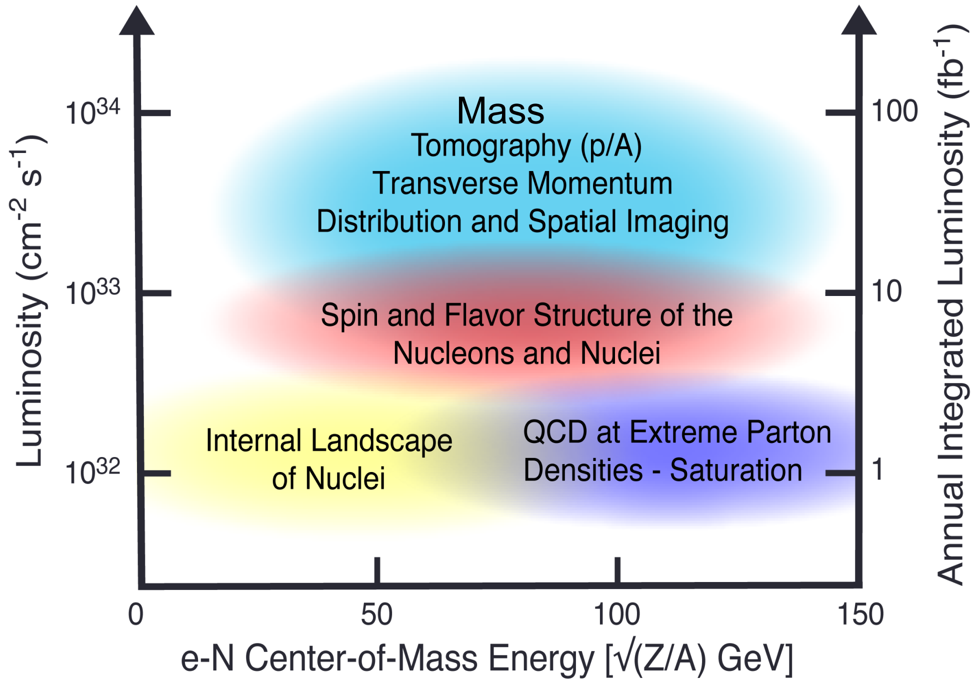


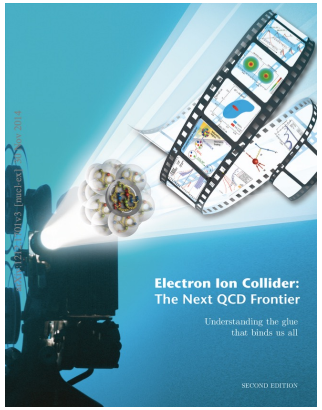
Origin of the nucleon mass: understanding how the quark-gluon interactions generate the bulk of the proton mass

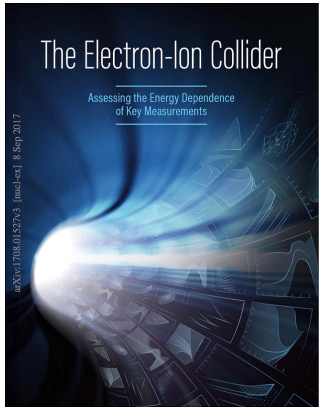
EIC science highlights



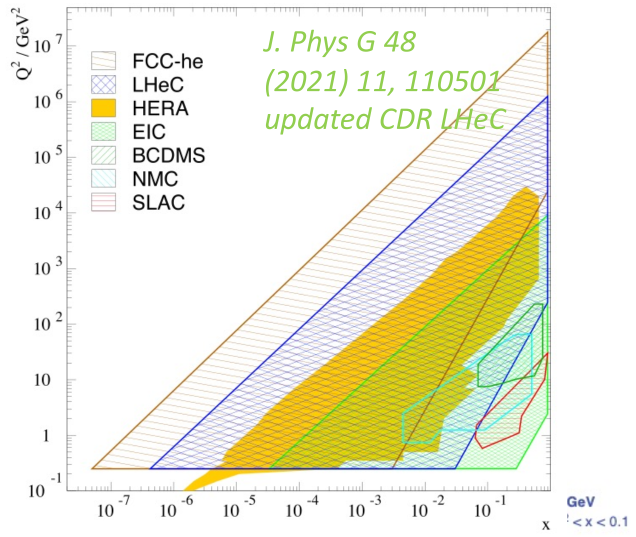


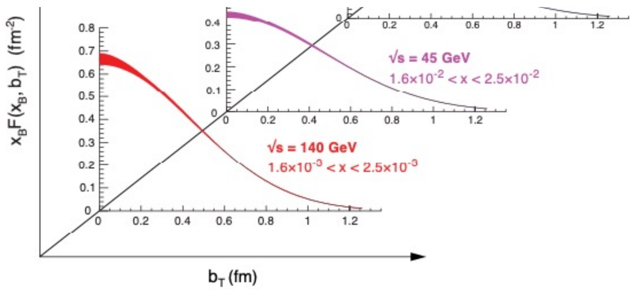






arXiv:1212.1701 arXiv:1708.01527





Unique and diverse scientific program complementary to other facilities world-wide

EIC design

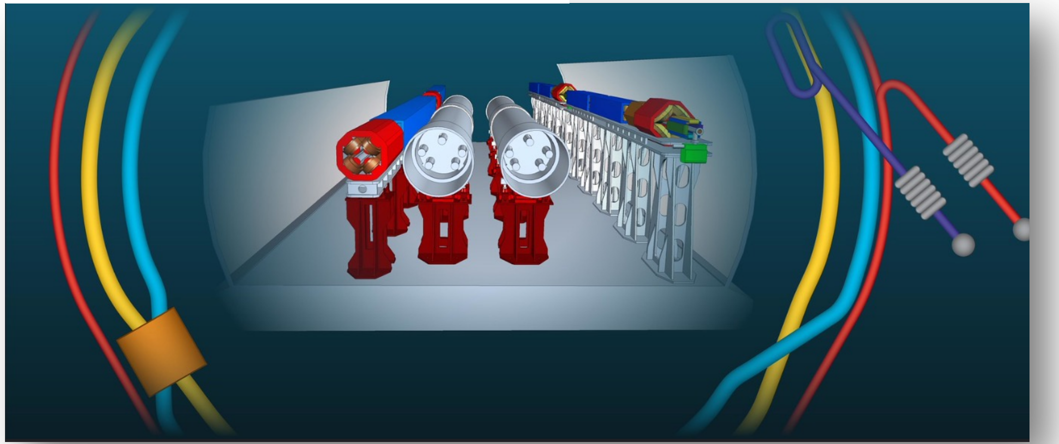
The EIC design is based on the existing Relativistic Heavy Ion Collider (RHIC), the only US collider in operation (until 2025)

- Large range of center of mass energies: 20-140 √(Z/A) GeV
- Hadron beam species from protons up to Uranium
- Polarization up to 70%
- Luminosity $10^{34} cm^{-2} s^{-1}$

Hadron Storage Ring, E=40-275 GeV (**existing**)
Electron storage ring, E= 2.5–18 GeV (**new**)
Electron rapid cycling synchrotron, 0.4- 18GeV (**new**)
Interaction region (IR) with one detector (**new**) (capability for implementing a second IR and second detector)
Polarized electron source, injector Linac, electron cooler complex (**new**)

Relativistic Heavy Ion Collider

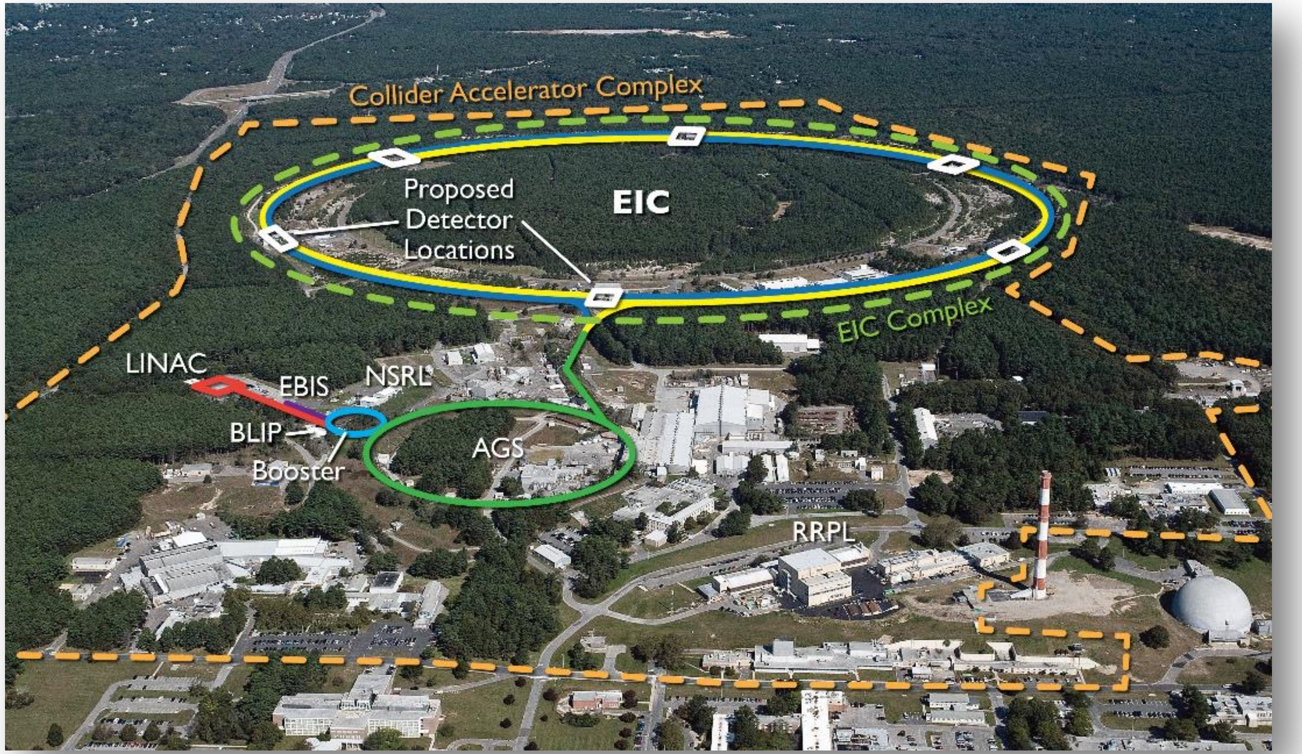
EIC tunnel cross-section



EIC design parameters

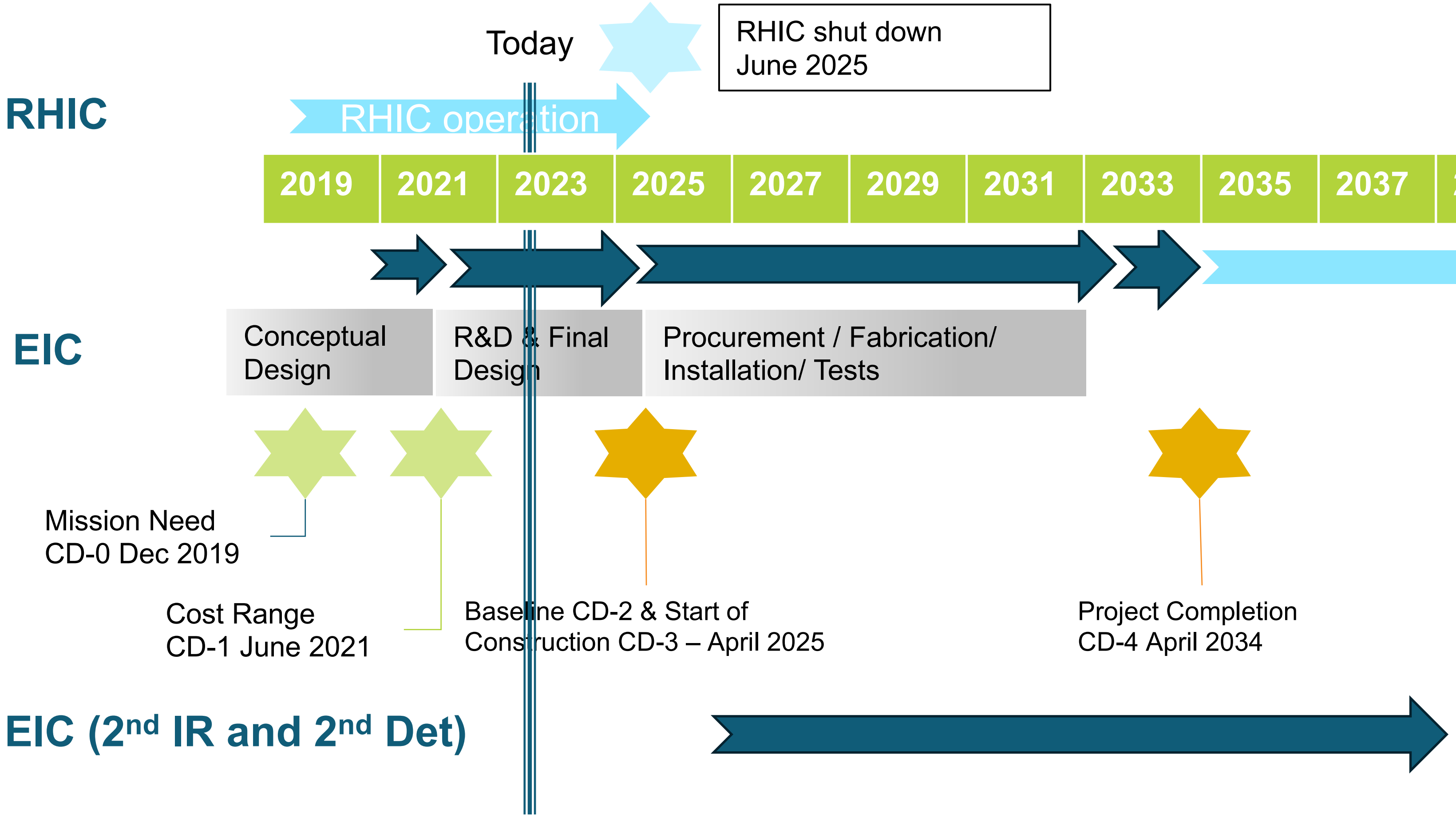
	Electrons	Protons
Beam energies	2.5 - 18 GeV	41- 275 GeV
Center of mass energy range	E_{cm} = 20-140 GeV	

	Electrons	Protons
Beam energies	10 GeV	275 GeV
Center of mass energy	E_{cm} = 105 GeV	
number of bunches	nb =1160	
crossing angle	25 mrad	
Bunch Charge	$1.7 \cdot 10^{11}$e	$0.7 \cdot 10^{11}$e
Total beam current	2.5 A	1 A
Beam emittance, horizontal	20 nm	9.5 nm
Beam emittance, vertical	1.2 nm	1.5 nm
β- function at IP, horizontal	43 cm	90 cm
β- function at IP, vertical	5 cm	4 cm
Beam-beam tuneshift, horizontal	0.073	0.014
Beam-beam tuneshift, vertical	0.1	0.007
Luminosity at E_{cm} = 105 Gev	**$1 \cdot 10^{34} cm^{-2} s^{-1}$**	



Very challenging electron/hadron beam parameters, with twice electron beam current compared to the FCC-ee (Z pole) and three times the RHIC hadron beam current

EIC timeline



The EIC is in the R&D and final design phase

Early ‘30s: Start of operations

Delayed by ~ 5 years (currently no funds identified)

The EIC is the only collider that will be built and start operation in the next decade

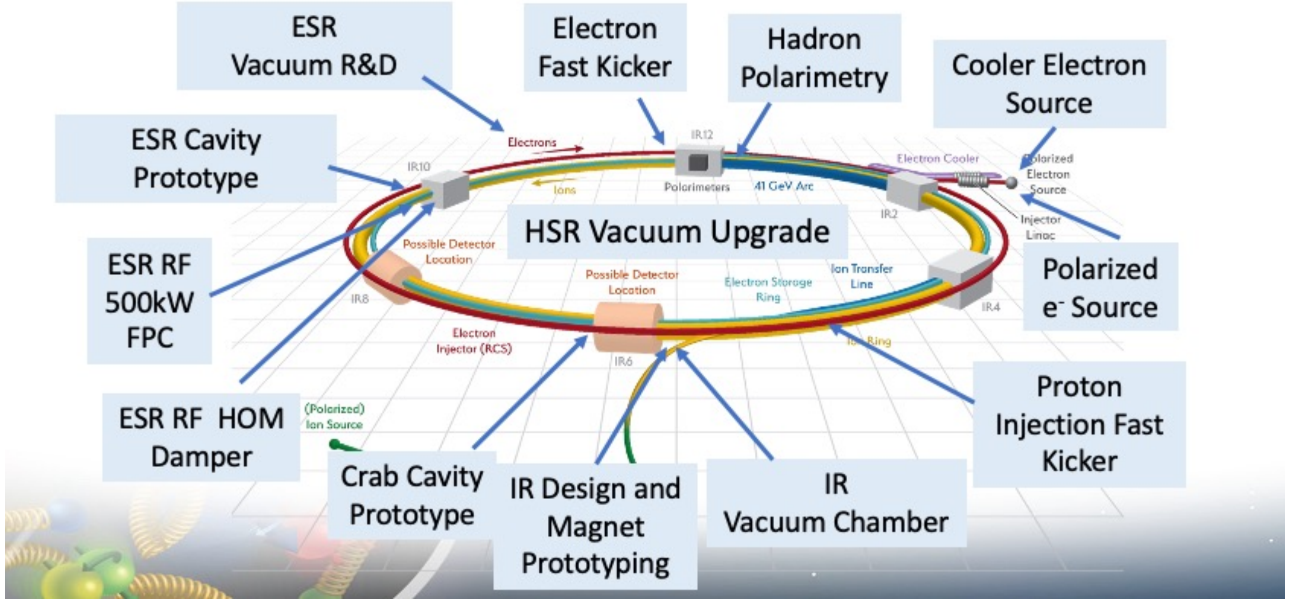
Key updates towards the EIC

The EIC R&D phase is development of prototypes of novel, challenging, or critical components before final design and production of components in industry or in-house

The EIC design parameters benefits from accelerator R&D synergistic with other facilities worldwide, and with the priorities identified in the European Accelerator Roadmap.

The EIC and FCC-ee have identified common accelerator-based challenges being collaboratively addressed.

Overview of EIC R&D and pre-production prototypes



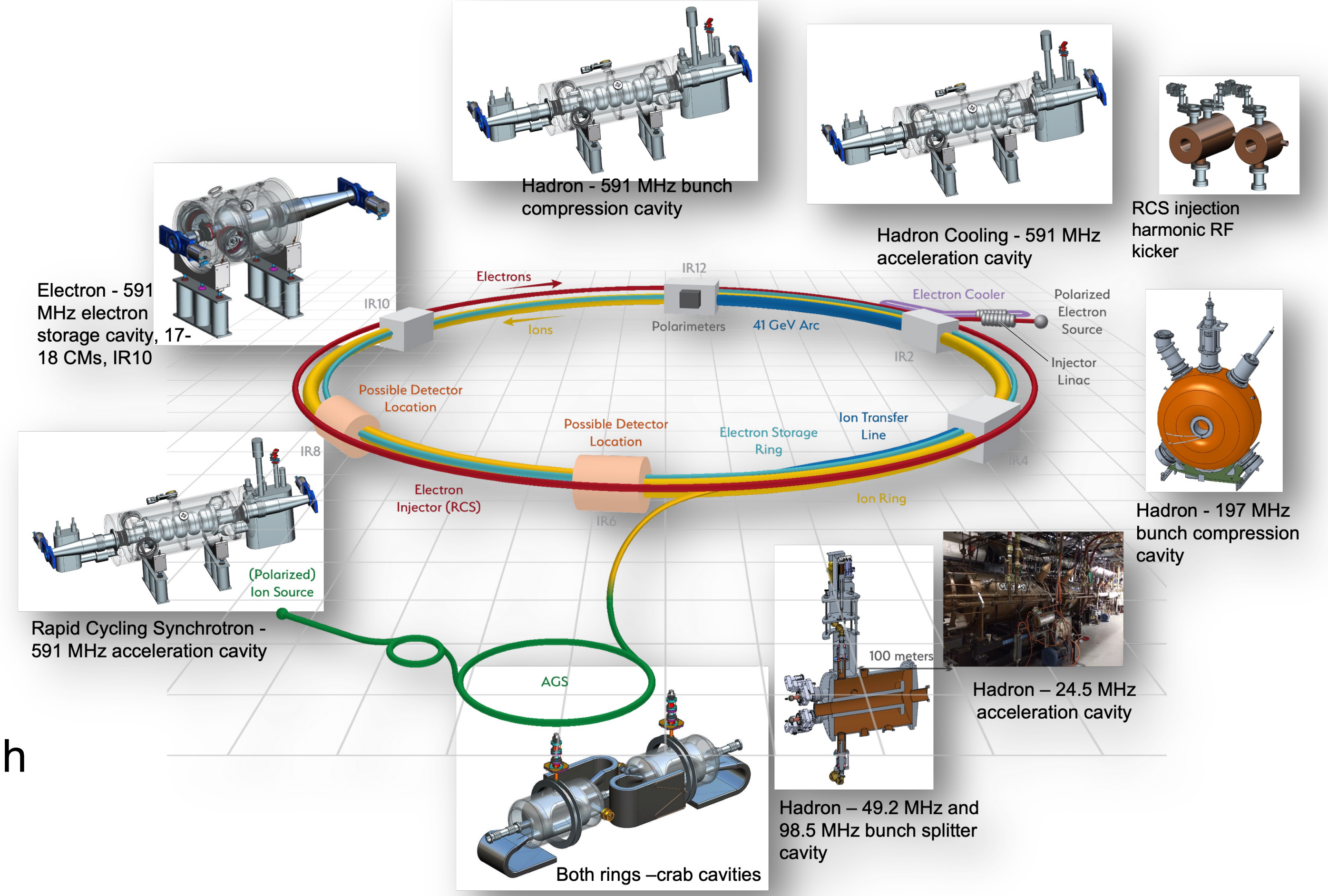
Selected examples in next slides

EIC RF

Challenges

- NC RF bunch compression, bunch splitter
- SRF to replenish 9MW synchrotron radiation power
- SRF crab cavities to rotate bunches at the interaction point
- SRF for Energy Recovery Linac electron cooler and rapid cycling synchrotron

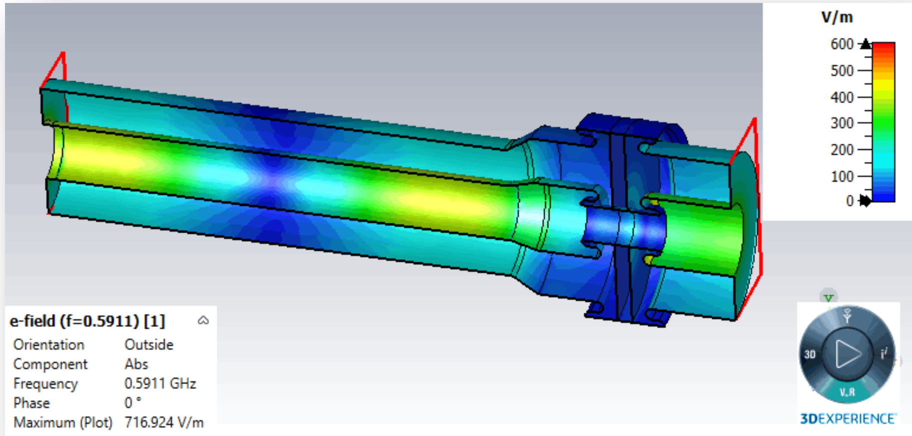
SRF cavities, 197, 394, 591, 1773 MHz with high Residual Resistance Ratio, fine grain, different cryomodules design, impedance limitations.



EIC: RF Technologies – high power SRF

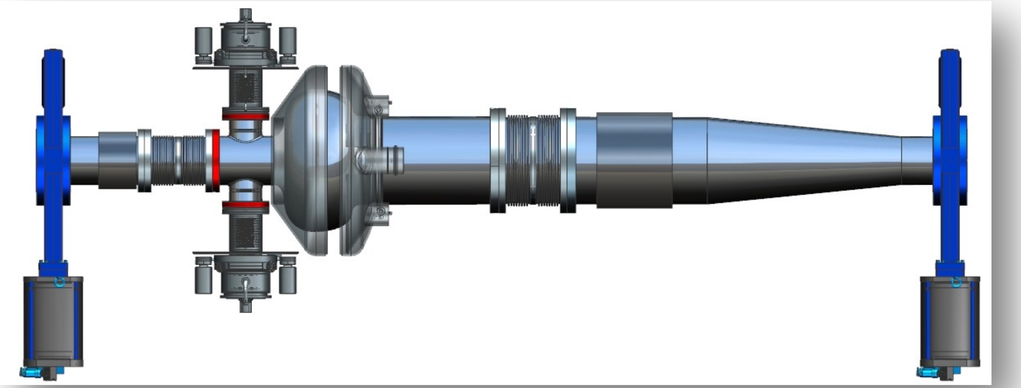
Highest Continuos Wave Power Fundamental Power Coupler

Transmit 500 kW RF power at ~600 MHz



Higher-Order-Mode Absorber

Absorb > 40 kW with large diameter and high thermal conductance



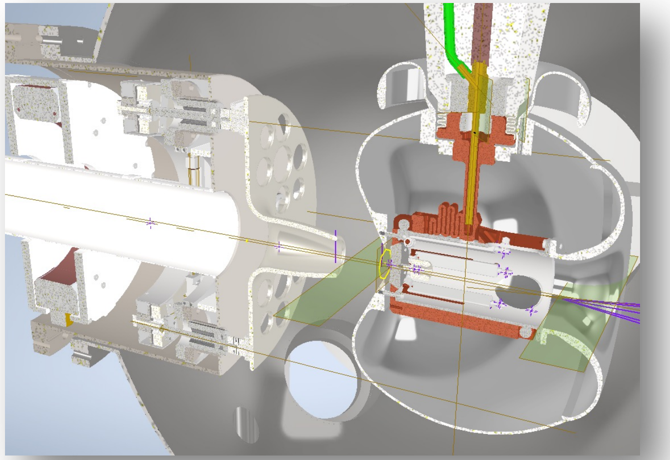
Opportunities

- electromagnetic analyses (wakefields)
- thermal analyses
- detailed mechanical engineering designs
- material evaluations and pressure fitting methods
- RF Test Facilities: high-power test stand

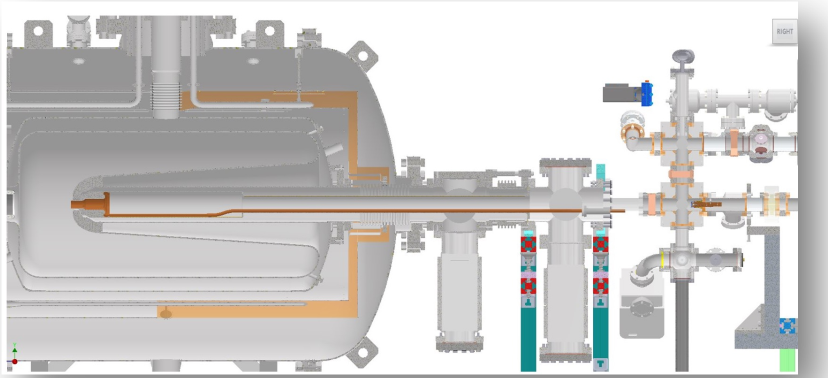
EIC Electron gun

Challenges: Development of an e- source that can deliver 100mA beam with 50,000C charge lifetime and build a DC gun with voltage achieving 500kV

Opportunities:
- photocathode research
    - high quantum efficiency
    - photocathode lifetime (e.g. cathode cooling)
- lasers and laser-cathode interactions
- gun cavity designs and extreme high vacuum (XHV) technologies
- modelling and simulations
- polarization



EIC gun: 500 kV, 100 mA

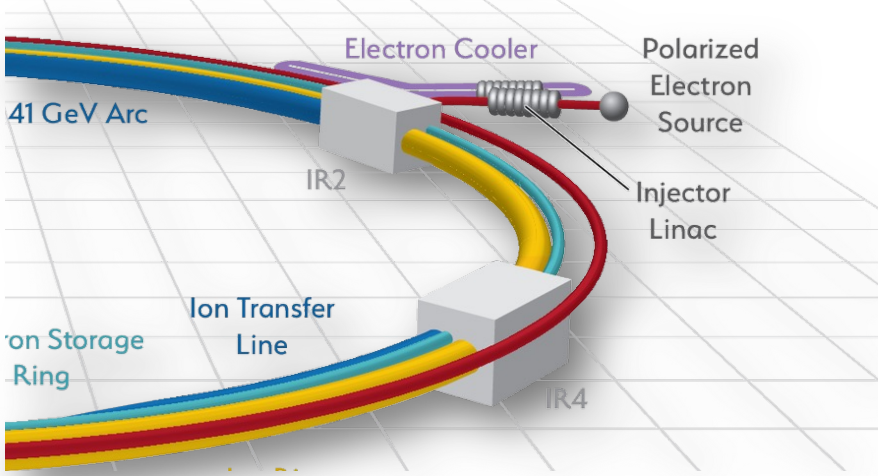


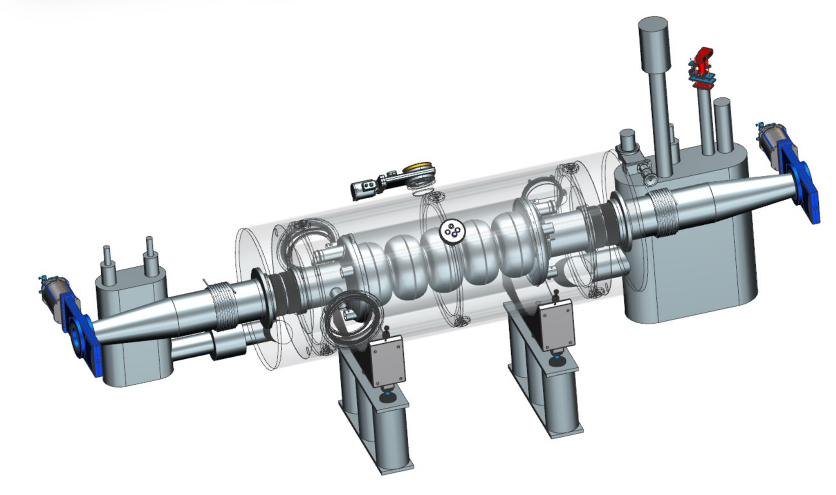
SRF gun R&D: > 1 MV, aim for 1-3 mA, >30 mA with 100 kW FPC

EIC – Energy Recovery Linac

EIC hadron beams need to be cooled to maintain bright beam emittance and peak luminosity of L $=10^{34} cm^{-2}s^{-1}$

- Two cooler schemes being considered:
  - A bunched beam electron cooler to pre-cool the beam at injection (12MeV electrons) to produce a flat beam with the required small emittance
  - A coherent electron cooler for high energy that maintains the small beam emittance in presence of intra-beam scattering during luminosity operation (150 MeV electrons)
- Both cooler systems are integrated in the same straight section and share components such as the electron gun, some superconducting cavities, and electron beam transport elements



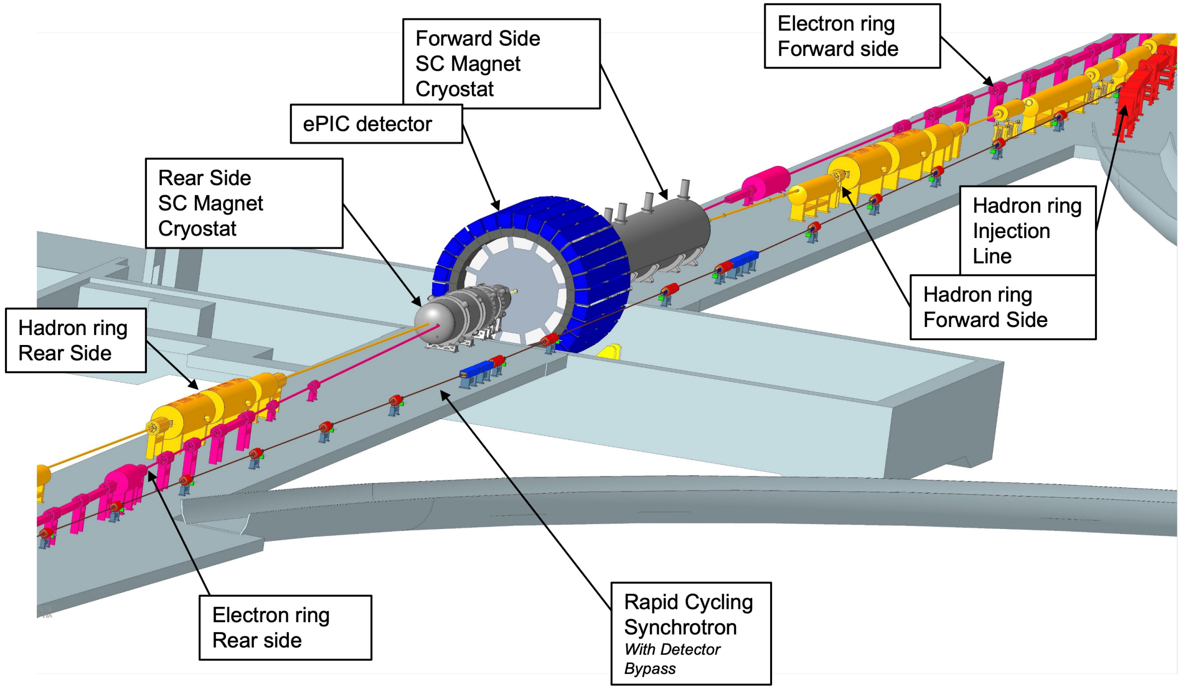


EIC Interaction Region Design

Very complex interaction region: 25 mrad crossing angle, 10 ns bunch spacing, SRF crab cavities, compact superconducting focusing magnets, spin rotators

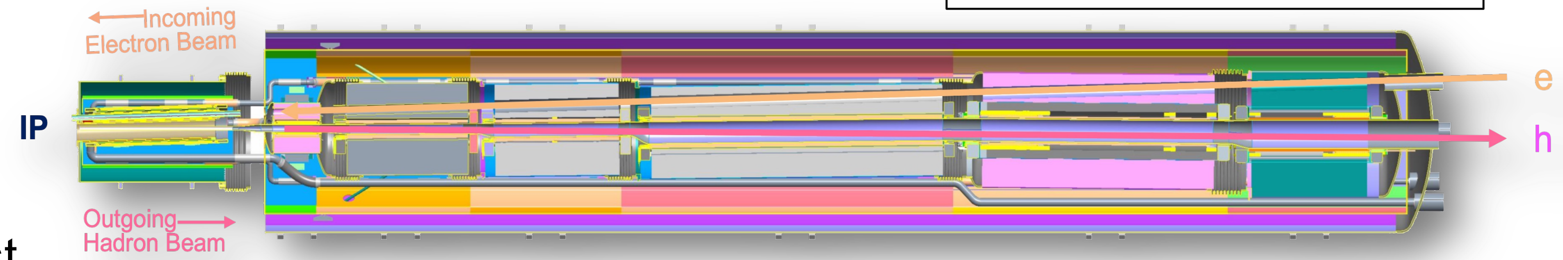
Opportunities:

- Modeling and simulations for dynamic aperture, chromatic aberrations, beam-beam effects, bremsstrahlung, optics correction and feedback
- Quench protection, adjustable collimators
- Luminosity monitors, control and measurements of beam losses and backgrounds, machine fault handling



EIC IR Superconducting Magnets

Final focusing magnets

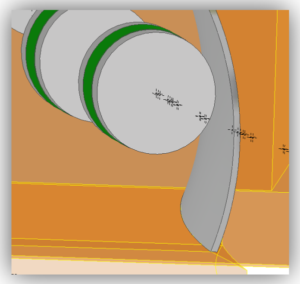


Challenges:
Highly integrated superconducting electron and hadron magnets (NbTi)

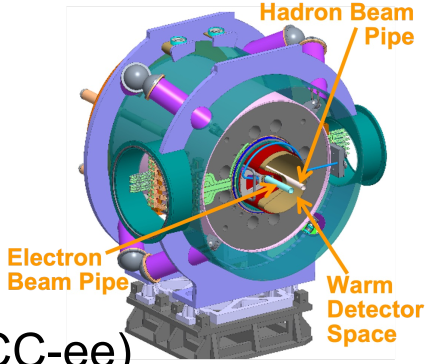
Need to prototype, manufacture and test multiple one of a kind magnets

Most magnets done using direct wind technique (collared technology for high field/high gradient)

Spin rotators



Spectrometer



Opportunities

- Magnet design and fabrication methods, Direct Wind technology for compact spaces (FCC-ee)
- R&D time for the second interaction region allows for other challenging magnet technologies like actively shielded Nb_3Sn magnets (e.g., FCC-eh/LHeC)

EIC as an international facility

- The DOE, BNL and TJNAF are working with international partners on a governance model intended to promote international partnerships in addressing the challenging topics relevant to the future of collider accelerators and detectors

- BNL is the host laboratory for the EIC facility and BNL and TJNAF together are the co-hosts of the EIC experimental program

- **EIC Advisory Board** provides guidance and advice to the BNL Director on the design and construction of the EIC accelerator facility. (ANL,BNL,CEA,CERN, FNAL, IN2P3, INFN,LBNL, TRIUMF, TJNAF, UK-STFC)

- **EIC Resources Review Board** provides coordination among funding agencies participating in the EIC experiment (s) (Canada-CFI, Czech, France- CEA/IN2P3,Italy-INFN, Korea, UK-STFC, US)

- The EIC Advisory Board at the June 2023 meeting recommended the creation of an **EIC Accelerator Collaboration**

EIC partnerships & collaboration

The EIC project welcomes participation in the areas of R&D, design, prototyping, and construction of the EIC accelerator and detectors

Partnerships are already forming with domestic and international partners:

ANL, CEA, CERN, FNAL, IN2P3-IJCLAB, INFN, LBNL, TRIUMF, UK-STFC

Active engagement with the community through EIC collaboration workshops, joint FCC-EIC workshops, bi-lateral discussions with interested partners and agency level interactions

- EIC FCC-EIC joint & MDI Workshop (Oct 2022) https://indico.cern.ch/event/1186798/
- EIC Worksshop – Promoting Collaboration on the EIC (Oct 2020) https://indico.cern.ch/event/949203/
- First annual US FCC workshop (May 2023) https://www.bnl.gov/usfccworkshop/

Summary

The EIC is the only collider that will be built and start operation in the next decade. It provides a unique opportunity to advance the state-of-the-art accelerator science and technology and test hardware prototypes

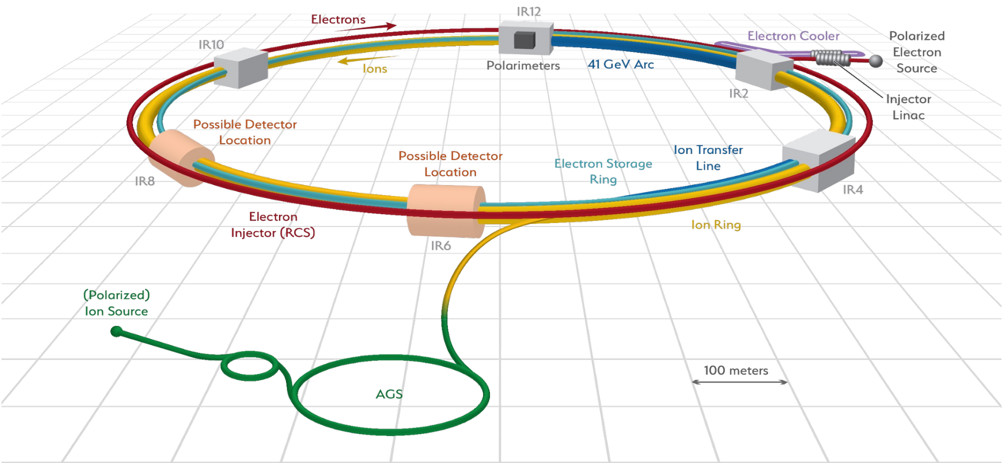
The EIC design parameters require R&D that is well aligned with the European accelerator R&D roadmap, and welcomes the intellectual contribution and expertise of the world-wide community

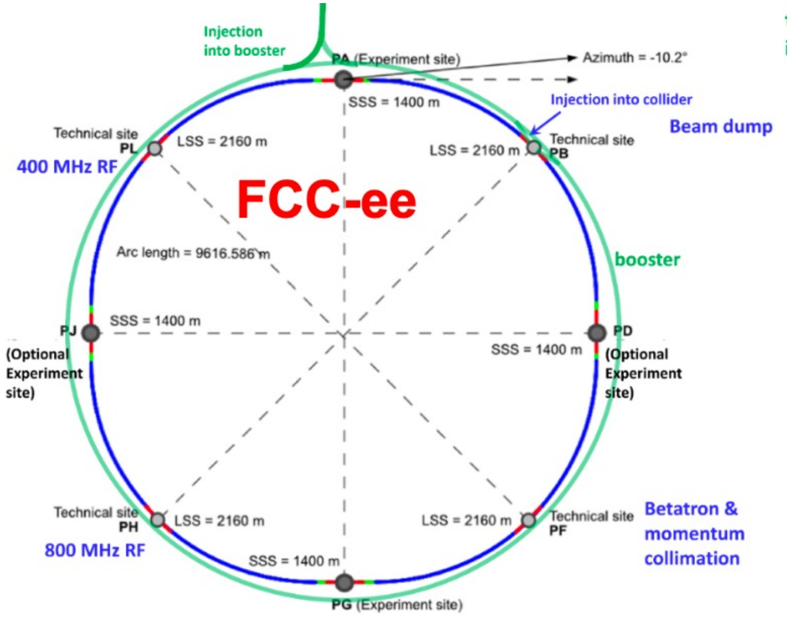
The EIC provides a unique opportunity to validate some of the technologies of the FCC and train the next generation of accelerator scientists

The EIC second interaction region and second detector schedule are opportunities for implementing other technologies that require longer R&D

Opportunities for collaboration FCC-EIC

- SRF cavities, cryomodules, electron gun (high current, high brightness beams), HOM
- IR region magnets, prototypes, production
- Beam dynamics
- Vacuum systems
- Beam instrumentation: SR monitors, BLM, BPMs, Beam feedback systems, crab angle measurements
- MDI, IR shielding
- Collimation
- Beam-beam interactions, beam-gas interactions
- Impedance model, instabilities, ion instability





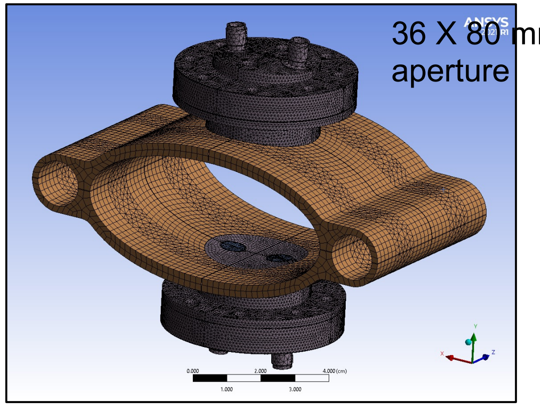
More information

Other EIC technologies

Vacuum systems: Development of chamber coatings with small secondary yield coefficient (SEY) to mitigate heat load and beam instabilities due to electron cloud, and test facilities

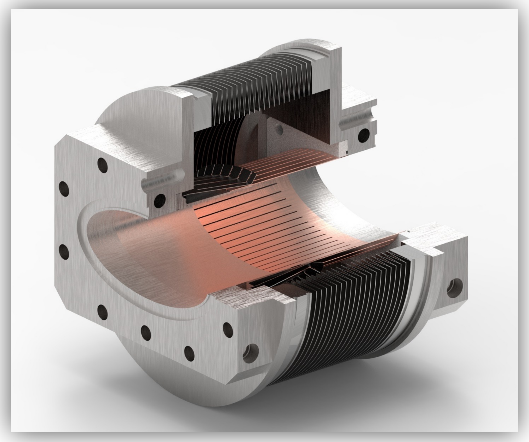
Collimation. Electron bunches have a short polarization lifetime (~35min) and will be replaced every 10 minutes (250J) and dump in vacuum→ Material studies and simulations for collimators and absorbers

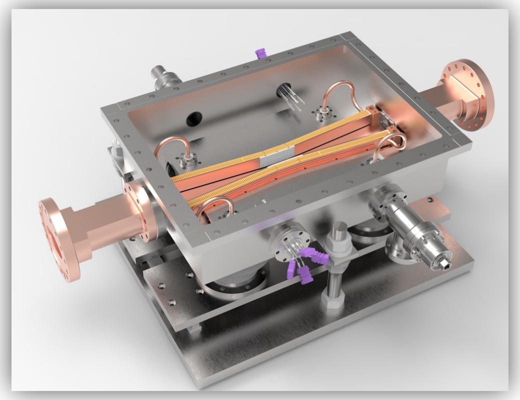
Beam instrumentation: SR monitors, BLM, BPMs, beam feedback systems, crab angle measurements



EIC electron beam BPM conceptual design

Electron storage ring RF shielded bellow





EIC Horizontal electron beam collimator

ePIC detector

- **Tracking:**
  - New 1.7T solenoid
  - Si MAPS Tracker
  - MPGDs (μRWELL/μMegas)
- **PID:**
  - hpDIRC, pfRICH, dRICH
  - AC-LGAD (~30ps TOF)
- **Calorimetry:**
  - Imaging Barrel EMCal
  - PbWO4 EMCal in backward direction
  - Finely segmented EMCal +HCal in forward direction
  - Outer HCal (sPHENIX re-use)
  - Backwards HCal (tail-catcher)