EIC-FCC synergies

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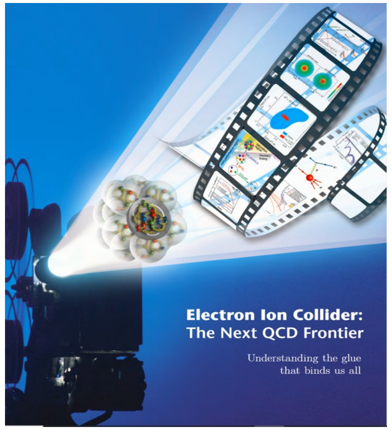
EIC science

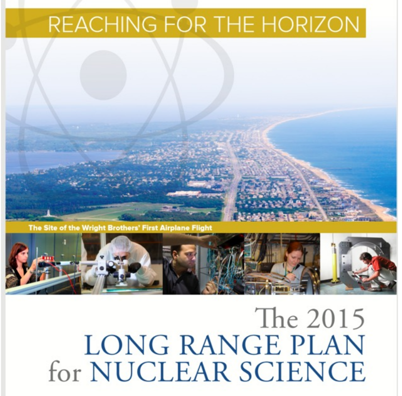
U.S. National Academy of Science Committee Report (2018) assessment:

- An Electron Ion Collider (EIC) will uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms

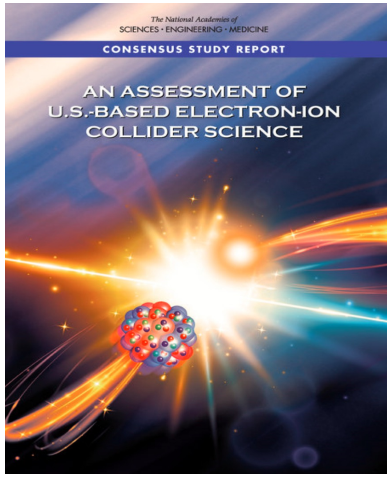
2012



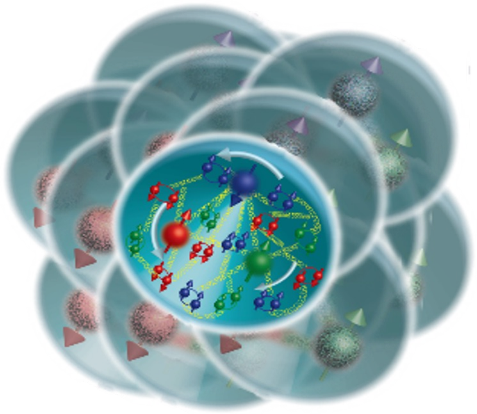
2015



2018



- How does the **mass** of the nucleon arise?
- How does the **spin** of the nucleon arise ?
- What are the emergent **properties of the dense systems of gluons** ?



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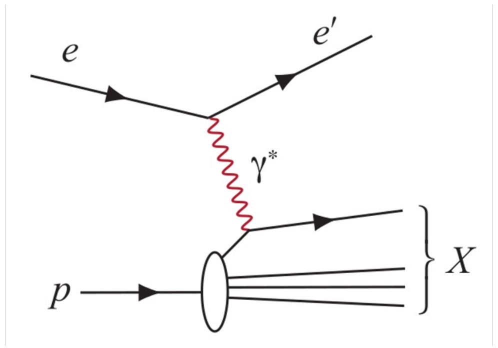
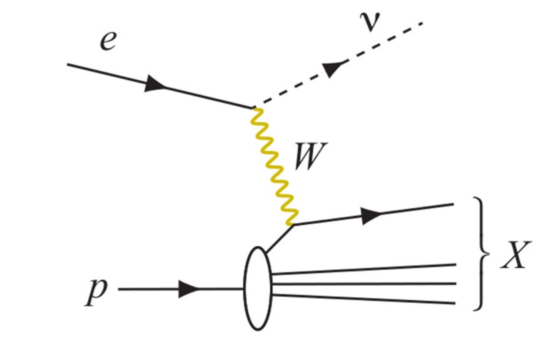
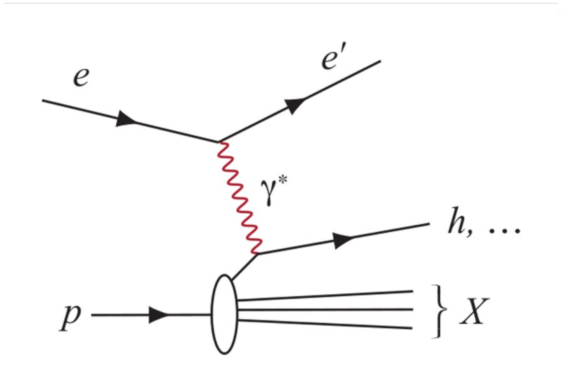
EIC experimental process



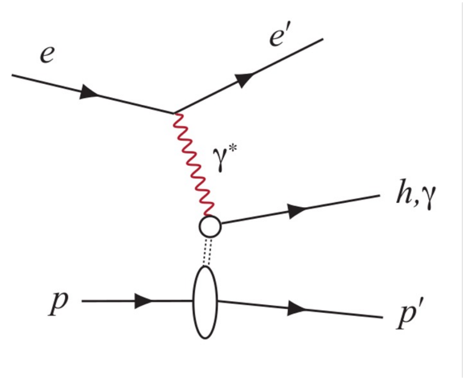
Neutral Current DIS



Charged Current DIS



Semi-Inclusive DIS



Deep Exclusive Processes

Parton Distributions in nucleons and nuclei

Spin and Flavor structure of nucleons and nuclei

Tomography Transverse Momentum Dist.

QCD at Extreme Parton Densities - Saturation

Tomography Spatial Imaging

- Large range of center of mass energies: E_{cm} = from 20 to 140 GeV
- Hadron beam species from protons up to Uranium
- Compact and hermetic detector(s)

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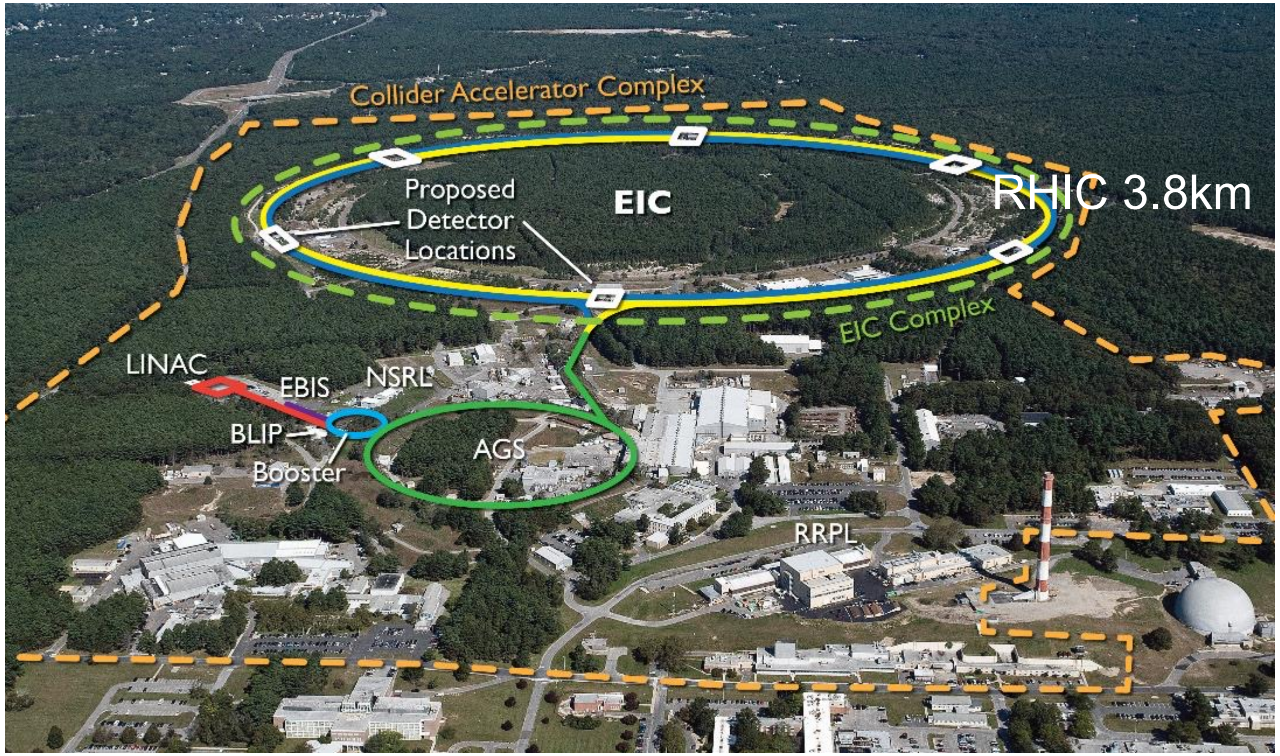
EIC design

EIC Design based on existing RHIC facility

- **Hadron storage Ring (RHIC Rings) 40-275 GeV** (**existing**)
  - 1160 bunches, 1A beam current (3x RHIC)
  - bright vertical beam emittance 1.5 nm
  - Strong hadron cooling
- **Electron storage ring 2.5–18 GeV** (**new**)
  - many bunches,
  - large beam current, 2.5 A ➔ 9 MW S.R. power
  - S.C RF cavities
  - Polarized bunches (up to 70%)
- **Electron rapid cycling synchrotron 0.4- 18GeV** (**new**)
  - 1-2 Hz
  - Spin transparent due to high periodicity
- **High luminosity interaction region(s)** (**new**)
  - $L = 10^{34} cm^{-2} s^{-1}$
  - Superconducting magnets
  - 25 mrad Crossing angle with crab cavities
  - Spin Rotators (longitudinal spin)
  - Forward hadron instrumentation



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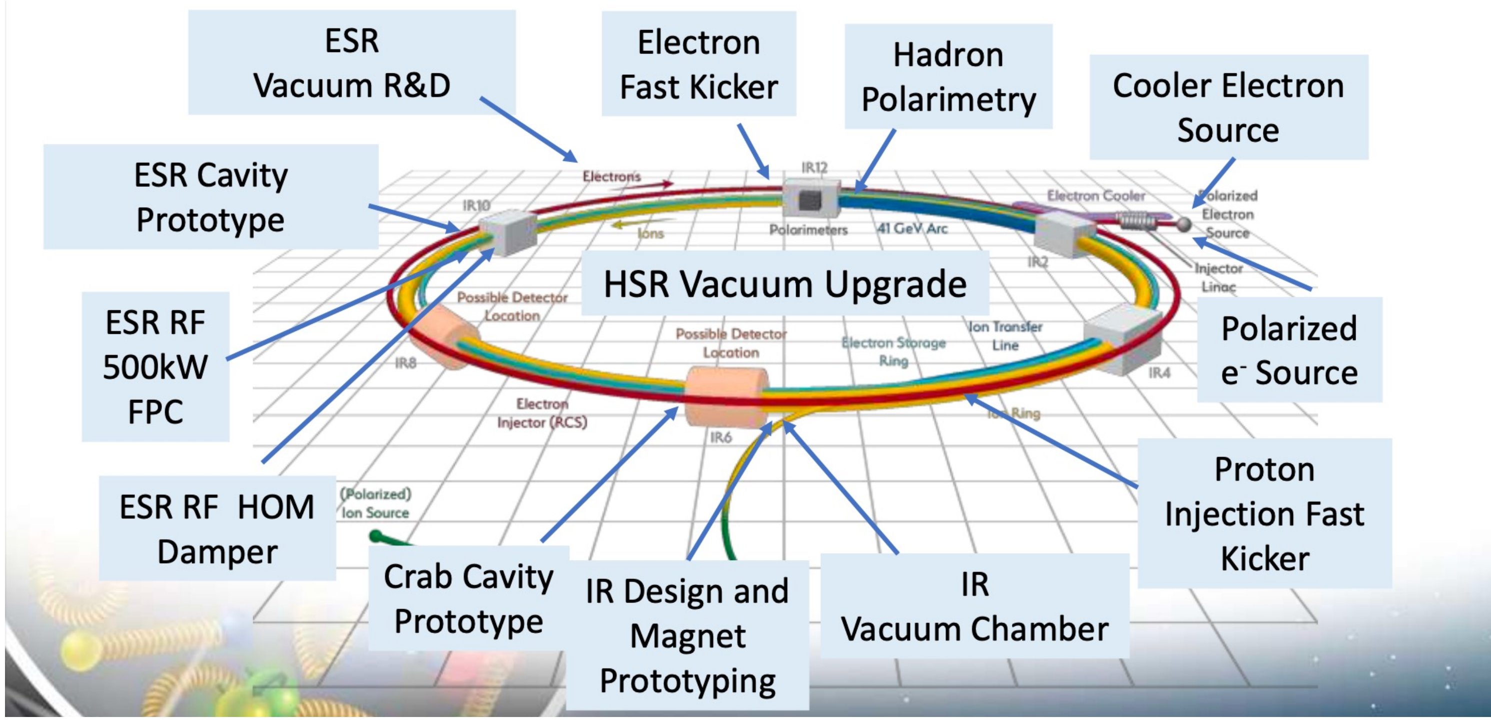
Key updates towards the EIC

ESR=Electron Storage Ring
HSR=Hadron Storage Ring

- EIC challenging design parameters require much accelerator R&D, prototyping, synergistic with other facilities.
- Areas of common interest between the EIC and FCC-ee have been identified and are being addressed through joint workshops



A few selected topics will be discussed in this presentation

FCC-EIC Joint & MDI Workshop (Oct 2022), FCC-EIC Beam Instrumentation Workshop, EIC Workshop Promoting Collaboration on the EIC (Oct 2020), First annual US FCC workshop (May 2023)

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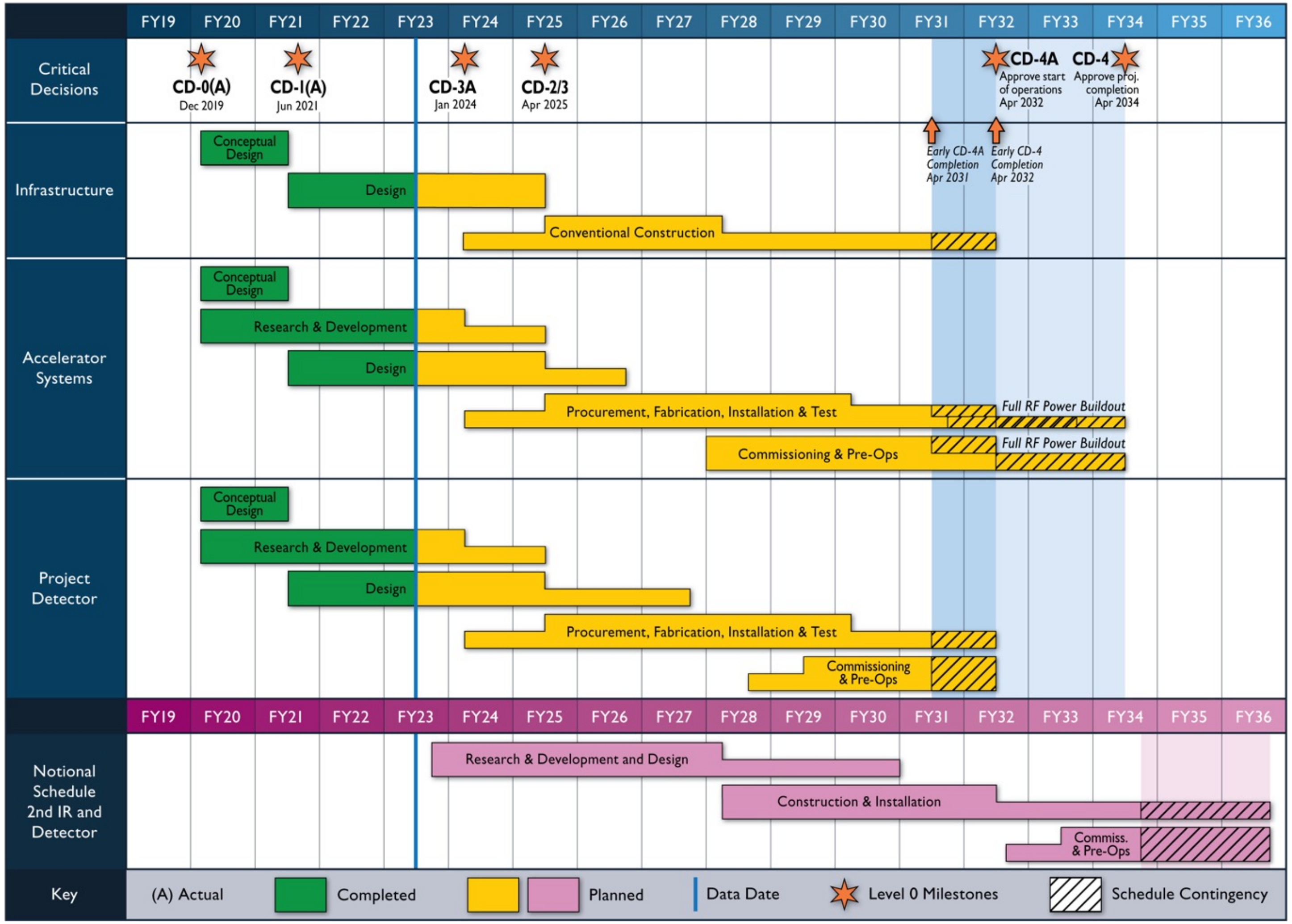
EIC schedule

- The US Department Of Energy approved the **EIC accelerator and one detector** in Dec 2019 (CD-0)
- EIC is currently in the design and prototype phase
- Baseline/start of construction approval expected April 2025
  Start of operations ~2033
- Second interaction region and second detector delayed by ~5 years



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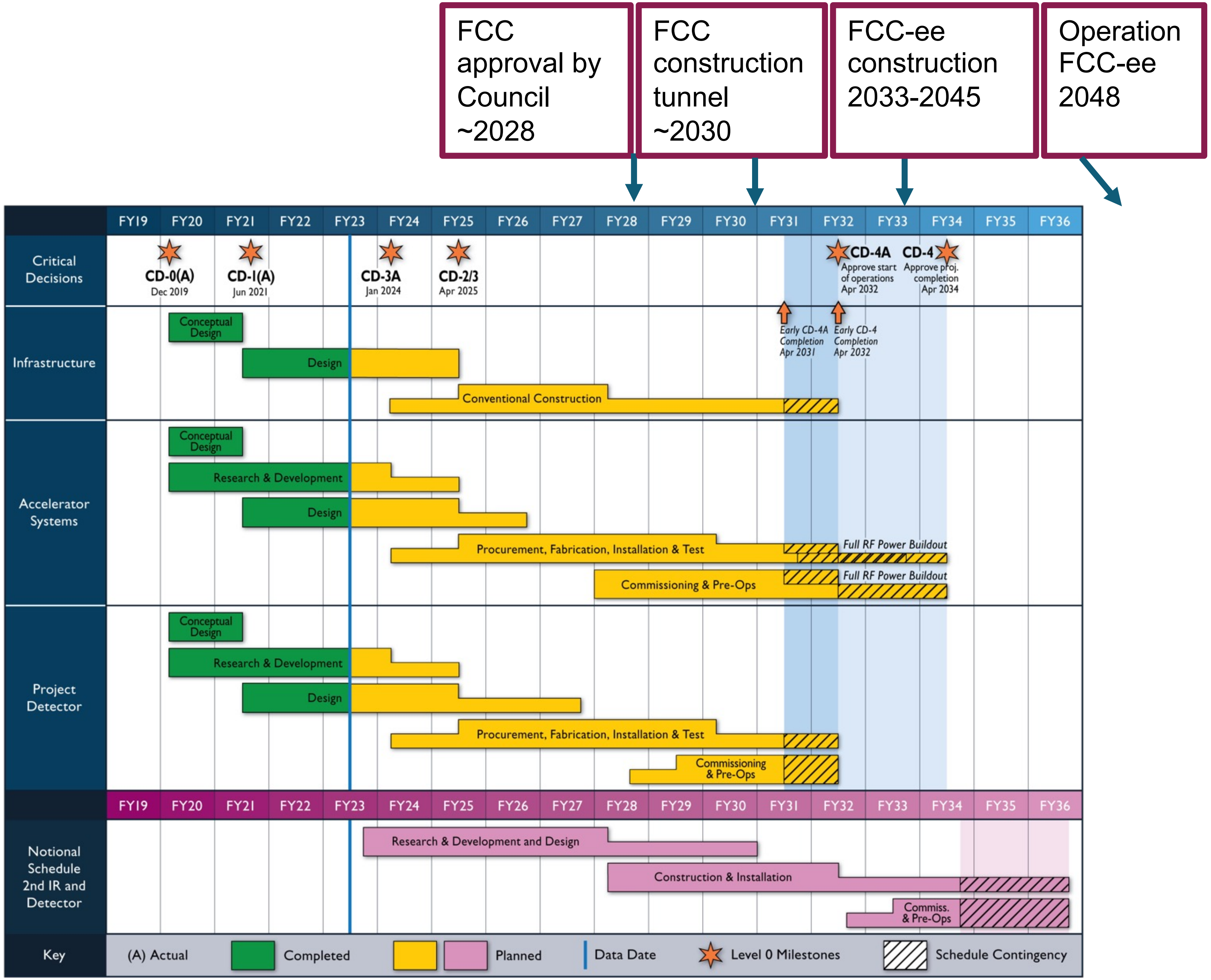
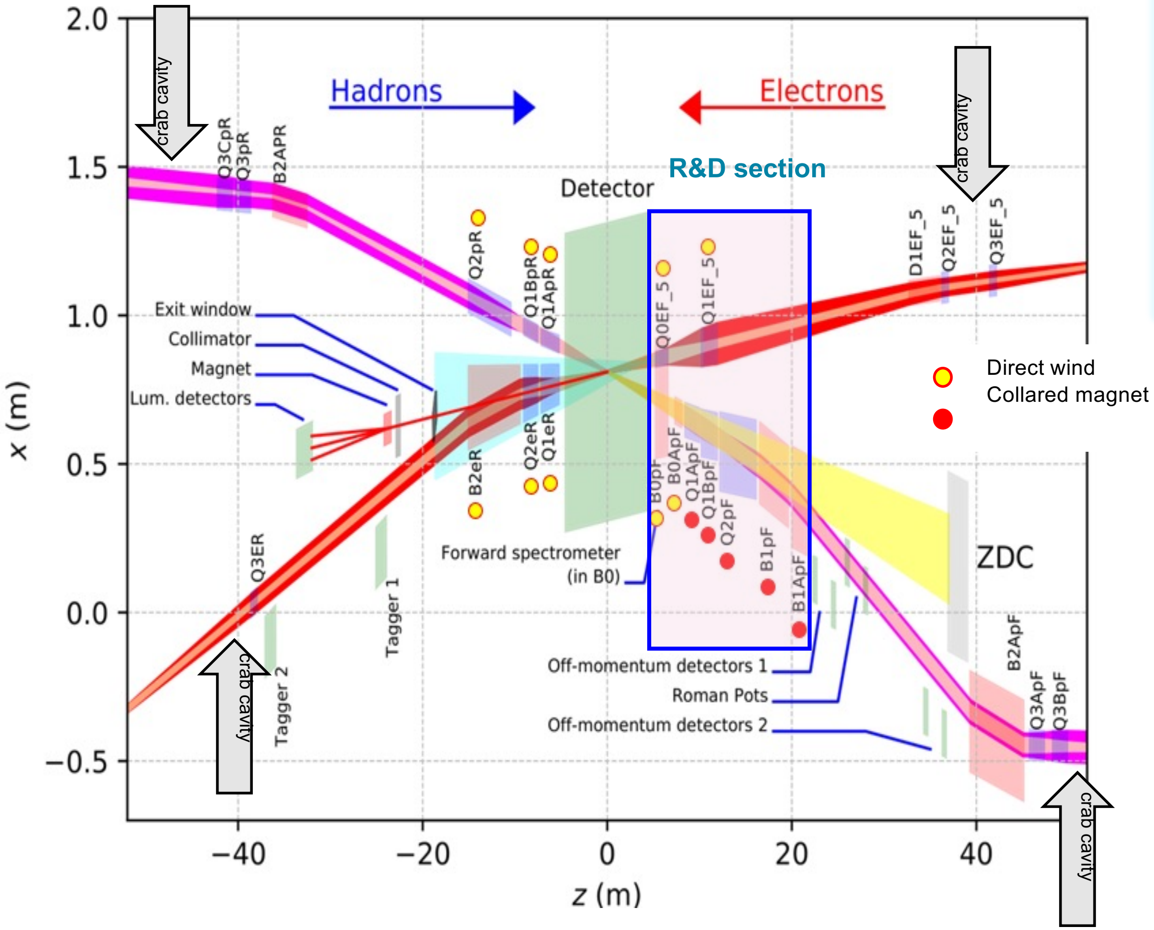


EIC: Interaction Region Design

Layout of the EIC Interaction Region



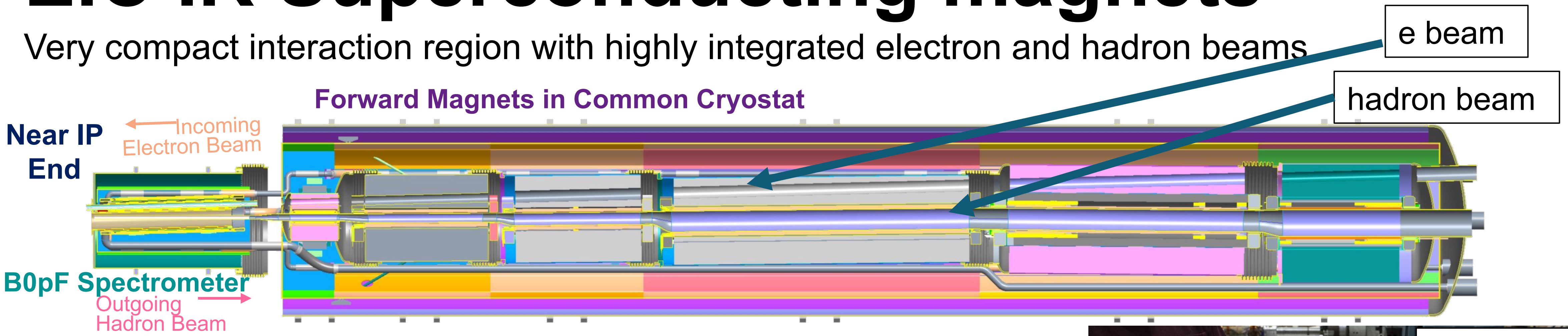
A.Drees/B.Parker/H.White/S.Berg

Very complex interaction region:
- 25 mrad crossing angle, 10ns bunch spacing
- Crab cavities
- Compact superconducting final focusing magnets
- Spin rotators: strong solenoids
- Large acceptance for forward scattered hadrons

Synergies :
- modeling and simulations for dynamic aperture, chromatic aberrations, beam-beam effects, bremsstrahlung, optics correction and feedback
- magnet designs and fabrication methods – coil configuration, field quality, coil forces, structural analyses
- quench protection, adjustable collimators
- luminosity monitors, control and measurements of beam losses and backgrounds, machine fault handling

EIC IR Superconducting magnets

Very compact interaction region with highly integrated electron and hadron beams



Synergies:

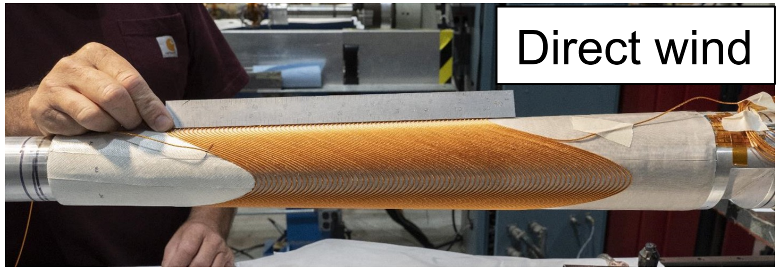
Direct Wind magnet technology (adapts to compact spaces, CCT-like local field adjustment)

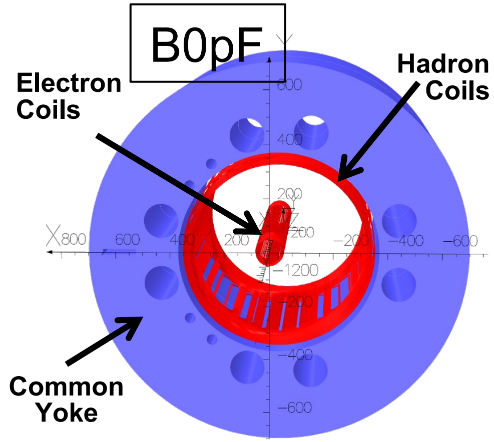
Collared magnet technology (warm e-beampipe, field crosstalk low)

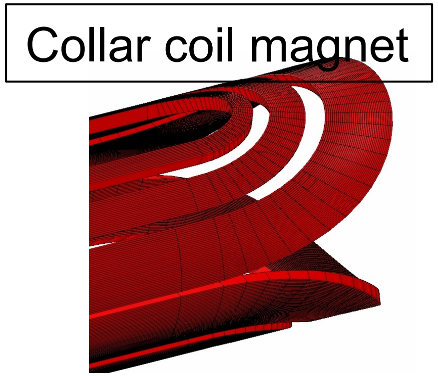
Complex magnet systems (integrate: 4.5K, 1.9K and warm systems, BPMs, current leads, low vibration supports)

Development, prototyping, manufacturing, quench protection, testing

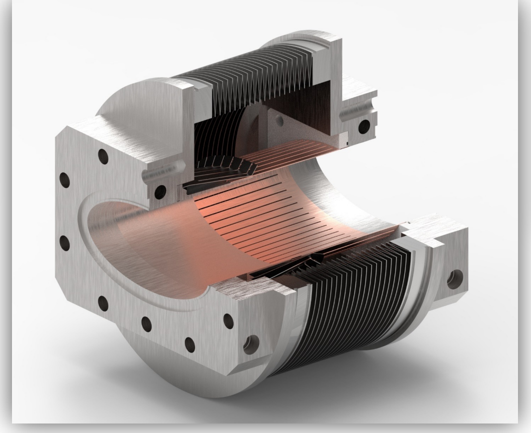
Crab Waist Sextupoles for SuperKEKB with optics correctors



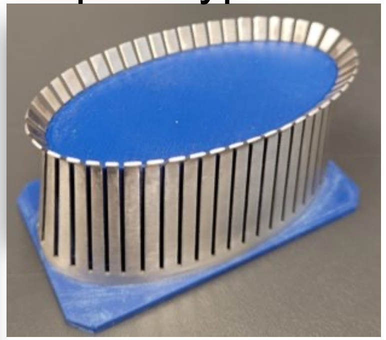




EIC vacuum systems



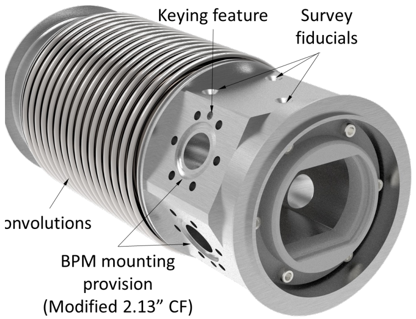
prototype



Challenges:
ESR: High beam current (2.5A), high bunch population (1.7×10^{11})
HSR: High beam current (1A), high bunch intensity (0.7×10^{11})

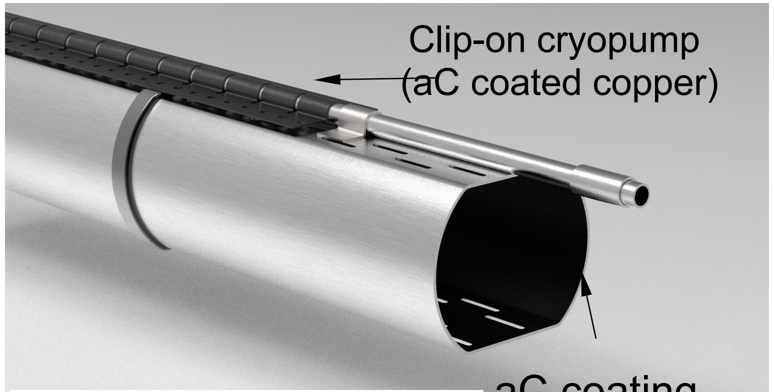
Synergies electron ring

- mechanical designs for shielded bellows
- spring and plating fabrication techniques



Synergies hadron ring

- development of chamber coatings with small secondary yield coefficient (SEY) to mitigate heat load and beam instabilities due to electron clouds
- low impedance beam screen designs and associated cooling techniques
- Vacuum Test Facility to evaluate residual resistance ratio (RRR), SEY, and adsorption capacity under cryogenic temperatures



HSR Beam Screen

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S.Verdu/C.Hetzel

EIC Collimation

Challenges:

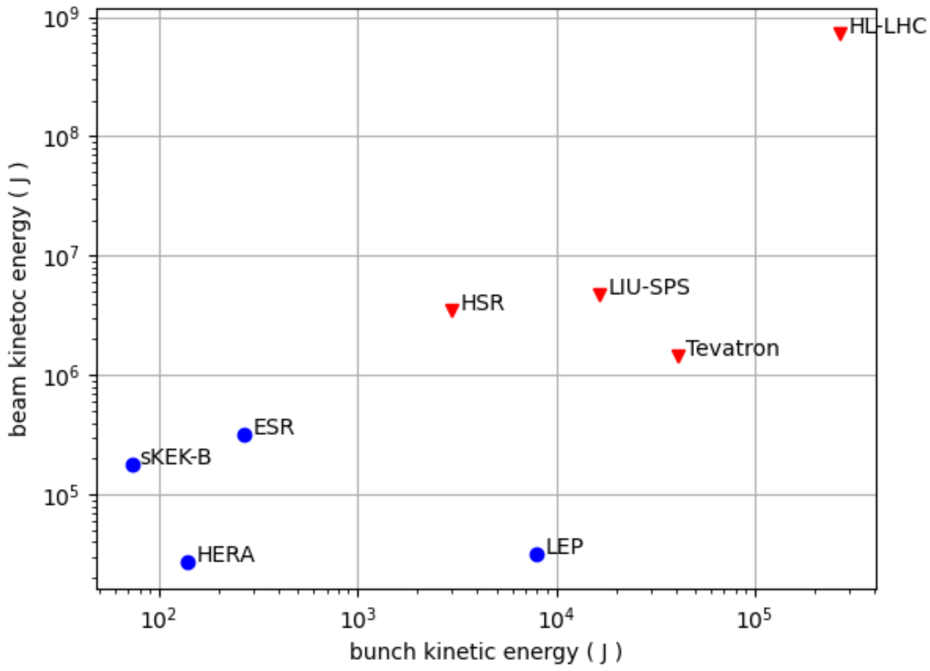
- HSR: 10 times the stored energy of RHIC, different loss behavior for proton/ions
- ESR: 2 times Super KEK-B target stored energy with 1/2 the bunches
- ESR: Electron bunches have a short polarization lifetime (~35 min and will be replaced every 10 minutes (250J) and dump in vacuum
- Impedance budget

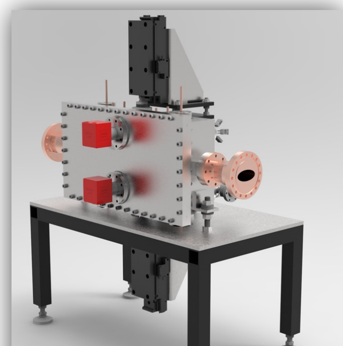
Synergies ESR

- Short super KEKB-like collimators
- Material studies for collimators and absorbers (coated carbon, composite materials – MoGr), impedance
- Simulations of SR, beam-beam, beam-gas, secondary particles (used CERN tools)

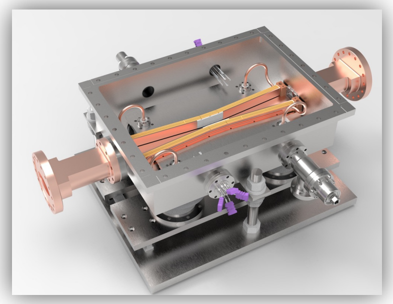
Synergies HSR

- Long large collimators LHC-like
- The jaws will be several meters long and made of amorphous Carbon
- Simulations, prototypes, failure scenarios





Vertical e-col



Horizontal e-col

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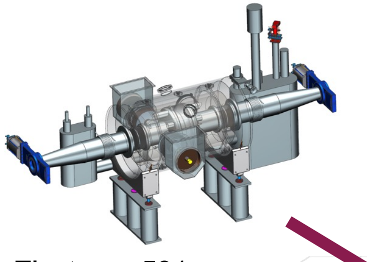
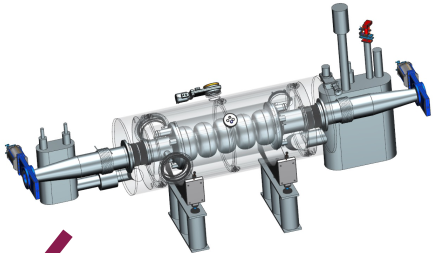
M. Valette

EIC RF systems

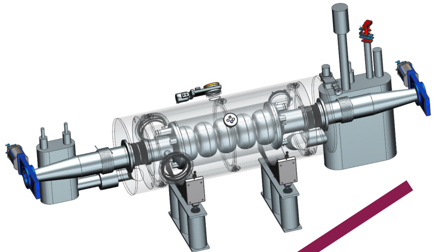


Electron - 591 MHz electron storage cavity

17 CM IR10



Hadron - 591 MHz bunch compression cavity 2 CM IR10

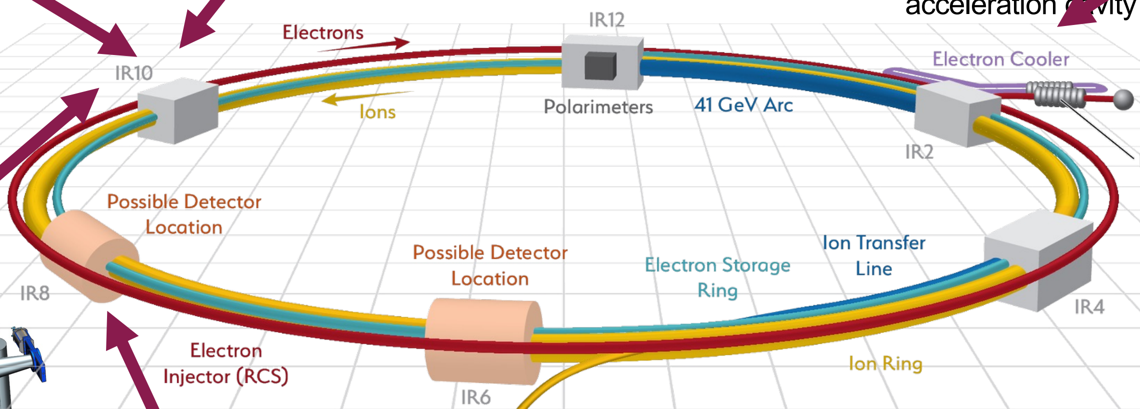


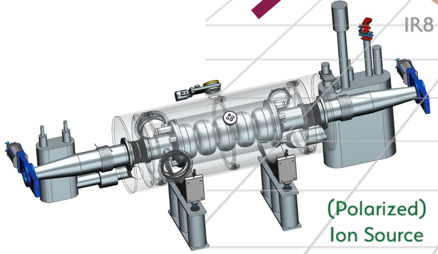
Hadron Cooling - 591 MHz acceleration cavity

1773 MHz, 3rd Harmonic cavity 3 CM

8 CM electron cooler

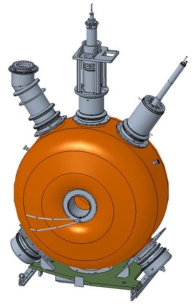
SRF



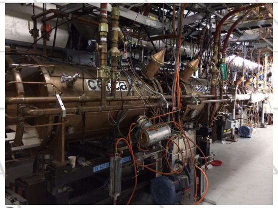


Rapid Cycling Synchrotron - 591 MHz acceleration cavity

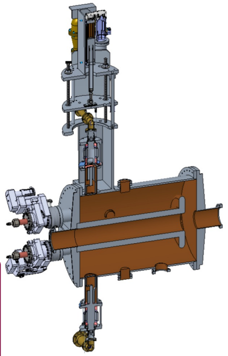
3 CM IR10



Hadron - 197 MHz bunch compression cavity

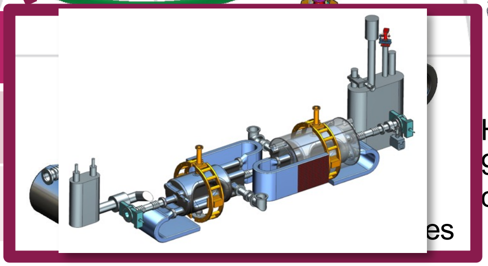


Hadron – 24.5 MHz acceleration cavity



Hadron – 49.2 MHz and 98.5 MHz bunch splitter cavity

Crab cavities (per IP)	HSR	ESR
197MHz	8 in 4 CM	-
394MHz	4 in 4 CM	2 in 2 CM



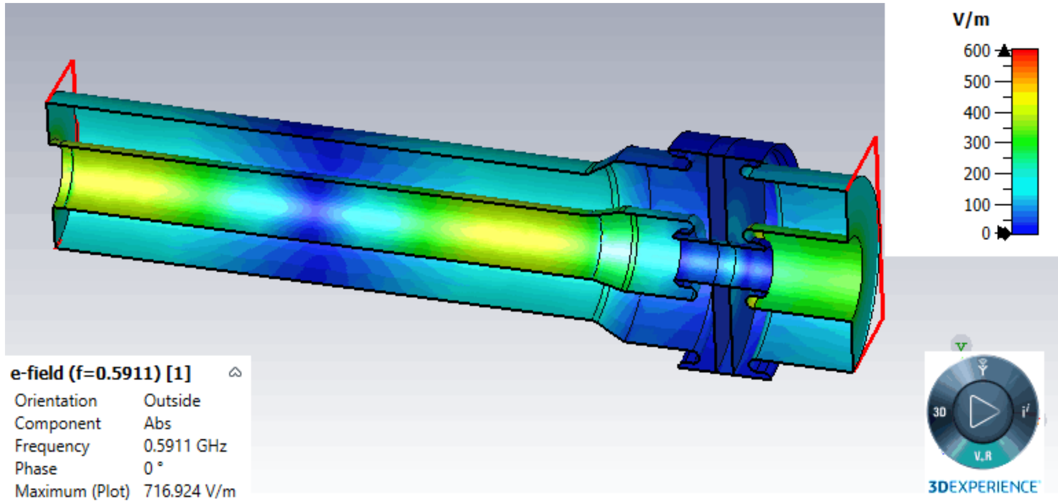
R.Rimmer eeFACT 2022

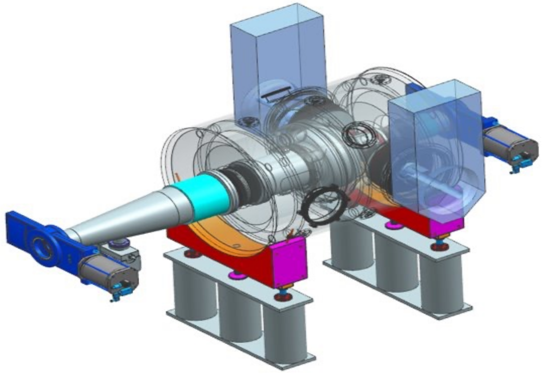
E.Daily

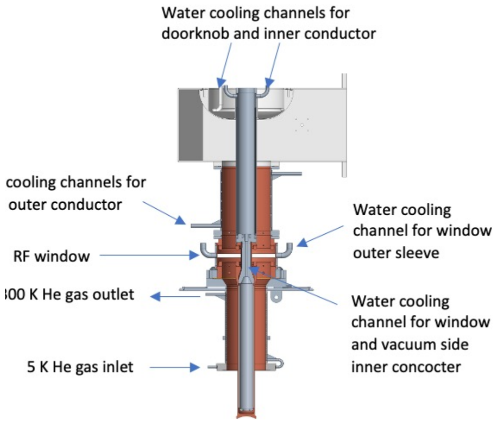
Electron Ion Collider: RF Technologies – high power SRF

Highest CW Power Fundamental Power Coupler

Transmit 500 kW RF power at ~600 MHz

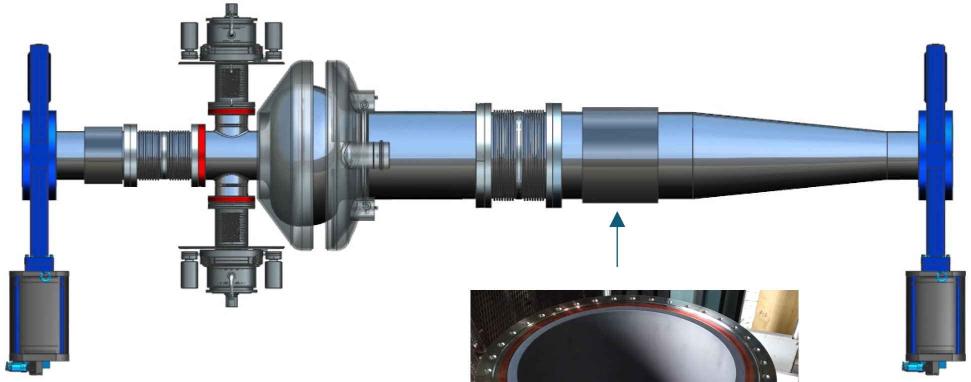


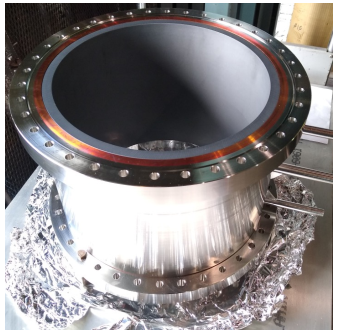




Higher-Order-Mode Absorber

Absorb > 40 kW with large diameter and high thermal conductance





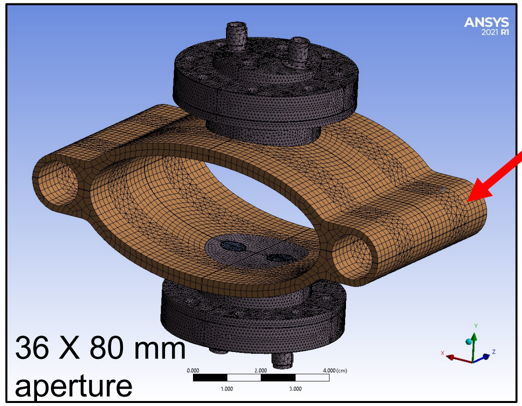
Synergies

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

Qiong Wu, Wencan Xu

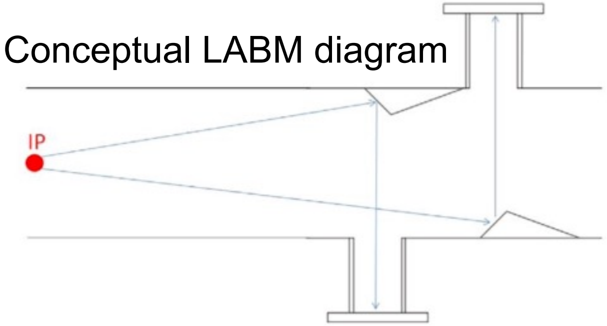
EIC Beam Instrumentation

- **Beam Position Monitors**
  - Button pick-up design
    - EM design/optimization
    - BPM assembly details: materials, cooling, dimensions
    - Prototyping, manufacturing, testing
  - BPM read-out electronics
    - DAQ & decimation concepts
    - Signal transmission & BW requirements/strategies
    - Back-end data collection
- **Beam Loss Monitors**
  - Challenges differentiating losses from multiple rings in the same tunnel
  - Machine protection strategies
- **Large angle beamstrahlung monitor**
  - Beam parameter measurements directly from the IP
  - Advance applied machine learning, neural networks, and AI tools
- **Crab angle measurements**
  - Technique development: SLM, head-tail, electro-optic, other
  - Detection & feedback methods for cavity control to ensure angle closure

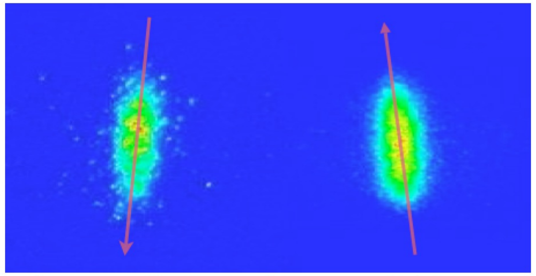


EIC ESR BPM conceptual design

Conceptual LABM diagram



Crab cavity bunch tilt angles measured at KEKB using synchrotron light monitor.



Abe, et al 2007

D. Gassner

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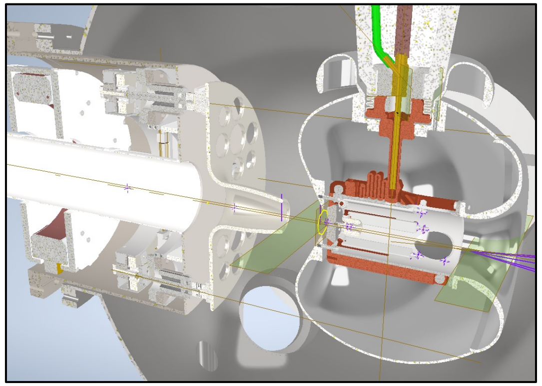
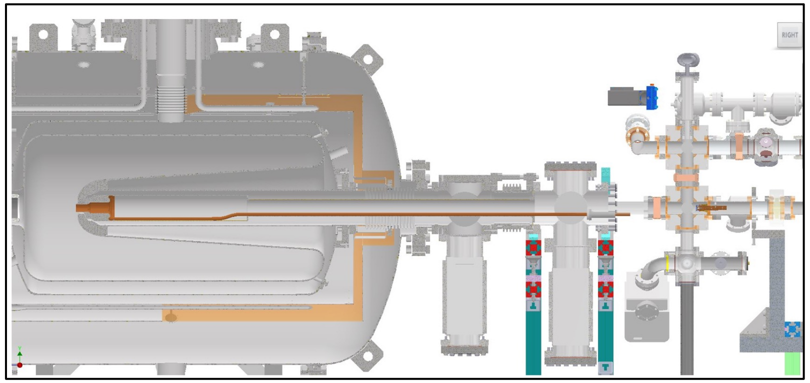
EIC Electron gun

Challenges: all aspects pertaining to high current, high brightness beams with both DC and SRF guns for high-power ERLs and the EIC

Synergies:
- 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

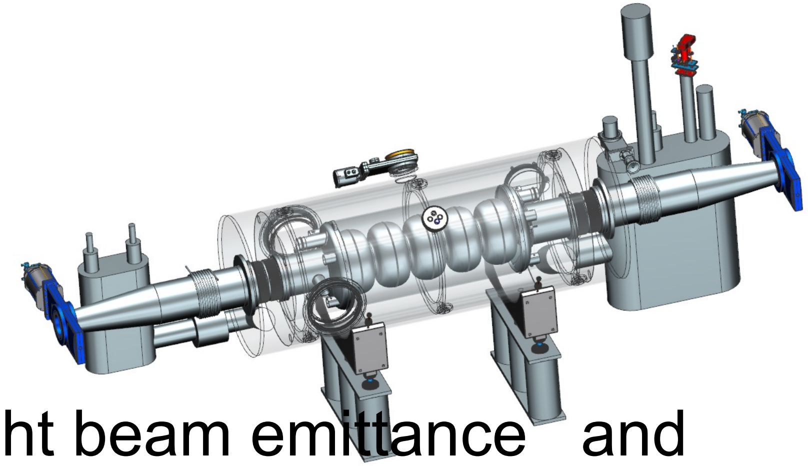


EIC gun: 400 kV, 100 mA



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

EIC – ERL



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 are foreseen that require SRF technology:

- 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

Synergies EIC-FCC

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

EIC partnerships

The design and construction of the Electron-Ion Collider provides an opportunity for the international community to collaborate and advance the state of accelerator and detector science and technology.

The DOE, BNL, and JLab are establishing a governance model intended to promote international partnerships in addressing the challenging topics relevant to the future of collider accelerators and detectors.

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

Summary

The EIC is a very complex collider with challenging design parameters that requires the intellectual contributions of the world-wide community.

The EIC-FCC-ee/eh feature similar challenges and a collaborative effort will benefit both colliders.

The EIC will be constructed now and start operation in the next decade. It will provide an invaluable opportunity to train the next generation of accelerator scientists on an operating collider as well as testing hardware prototypes.

Acknowledgements

I would like to warmly thank the colleagues that helped me in the preparation of this presentation and the people they represent:

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