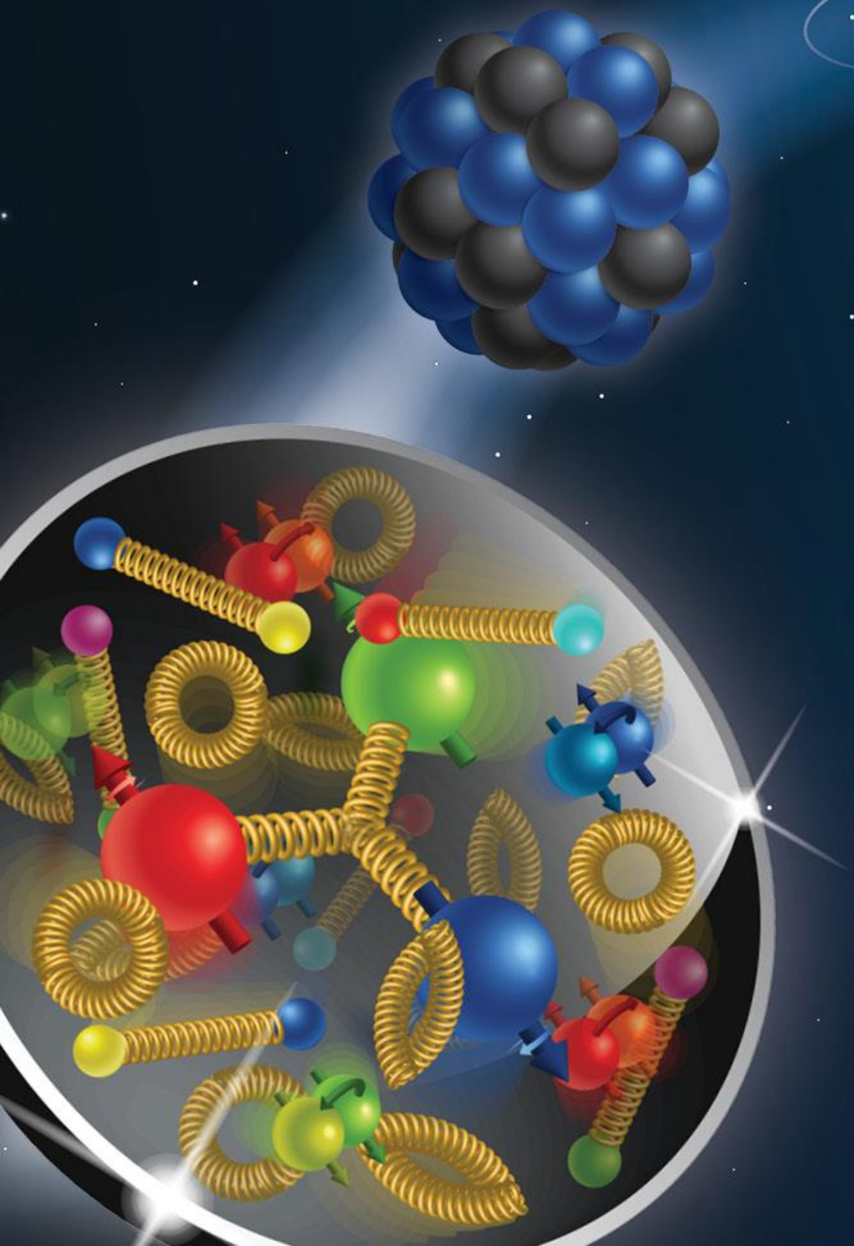


Status of R&D for EIC

Qiong Wu

EIC Accelerator Collaboration Workshop
October 7-9, 2020

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY
Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Introduction to EIC R&D
- Pre-project R&Ds
- Current R&Ds
- Off-project R&Ds
- Summary

Introduction

The R&D for EIC project

- Supports innovative and critical conceptual designs by **prototyping of components** where the design process with calculations, simulations and layouts is only one element and means to achieve the maturity required to carry out preliminary and final design and eventually construction of the project scope elements.

- May still include specific **calculation, simulation and layout** to support prototype construction

- The construction of prototype may include its specific conceptual, preliminary and final design which will usually, but not necessarily, be **different from the corresponding component** which is part of the project scope.

Introduction

- The R&D topics were chosen through out the overall EIC project range.
- Deliverable of the R&D should target on **reduce the gap between the state of art solution and the design goal of the project** and facilitate production development
- The R&D effort for EIC begin several years before the official starting date of the EIC project. The **pre-project R&D** efforts and results directly benefit the EIC project.
- In parallel to the current R&D topics, the EIC project also take full advantage of the RHIC operation for beam studies. **Off-project R&D** plays an important role in demonstrating hadron beam related issues within the current machine capability.

Pre-project R&D

Many R&D projects started years before, but their results would greatly benefit the EIC project:

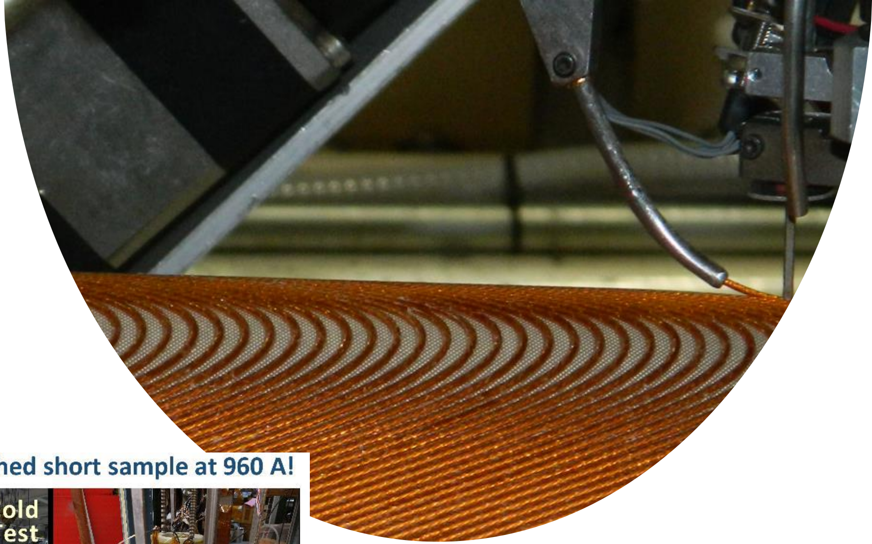
- Direct Wind Double Helix Coils (LDRD)
- Crab Cavity for LHC (HEP LARP, AUP)
- 650 MHz 5-cell Cavity Prototype (LDRD)
- HOM Beamline Absorber (LDRD)
- High Power FPC (LDRD)
- Polarized Electron Gun (EIC FOA)
- Electron Source Development (EIC FOA, BES SBIR)

<u>Nomenclatures:</u>

- LDRD – Laboratory Directed Research and Development
- HEP – High Energy Physics Office (Office of Science, DOE)
- BES – Basic Energy Science Office (Office of Science, DOE)
- FPC – Fundamental Power Coupler
- HOM – Higher Order Mode
- FMD – Fundamental Mode Damper
- SBIR – Small Business Innovation Research
- LARP – US Large Hadron Collider Accelerator Research Program
- AUP – US Large Hadron Collider Accelerator Upgrade Project

Tapered Direct Wind Double Helix Coils

- Inner IR magnets have severe space constraints:
  - large aperture
  - high gradient
  - avoid crosstalk
- Tested successfully 7/16/2020
  - Length: 0.45m
  - Gradient (center): 45T/m
  - Inner radius: 30 – 40mm

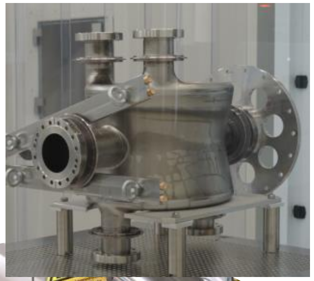


No training, reached short sample at 960 A!

Tapered Quadrupole

Crab Cavity for LHC

- High gradient crab cavity for LHC Hi-Lumi program, which is the first proton crabbing device
- Design started in 2008
- RF design for vertical and horizontal deflecting cavity initiated at BNL, ODU, SLAC, and Univ. Lancaster, worldwide collaboration there after
- Successful vertical test of proof-of-principle cavities around 2013
- 6 prototypes tested successfully with Higher Order Mode coupler
- Beam test in SPS at CERN in 2018

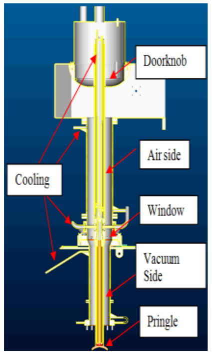


650 MHz 5-cell SRF Cavity

- For previous HSR and cooling designs
- Design focus for 650 MHz 5-cell cavity was to well damp the HOMs.
- Enlarged beam tube to propagate all the HOMs but attenuate the fundamental mode.
- 1 copper cavity with detachable beampipe was fabricated for HOM study; 1 niobium cavity was fabricated for SRF performance study
- First cavity in BNL HPR system
- The cavity voltage reached 18.2 MV in 2018

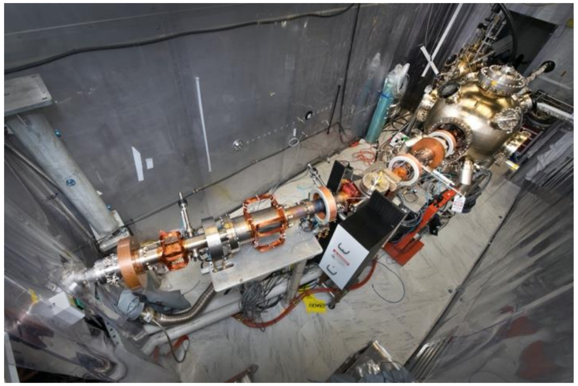
HOM Beamline Absorber

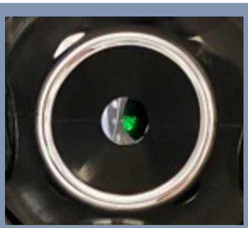
- 20 kW Beamline HOM Absorber for ESR SRF Cavity @ 591 MHz
- 80 kW HOM power/cavity distributed onto 4 absorbers
- Room temperature with water cooling
- Mechanical and thermal FEA simulations completed
- Final machining of first high power assembly is finished
- Low-power testing with copper cavity and high-power testing with 1MW klystron are planned



High Power FPC

- Demonstrated proof-of-principle of the Waveguide Tuner (Q_{ext} adjustable by a factor of 20) and FPCs (400 kW CW, full reflection, various phases)
- Testing 500 kW waveguide tuner with a 500 kW fixed power coupler.
- Solution to long lifetime of RF window is planned next.





Polarized Electron Gun

- Currently located at Stony Brook University
- Funding through BNL
- Polarized source:
  - 7 nC @ 1 Hz
  - Lifetime in mA
- New features: active cooling, large cathode, 400 kV with SF6 free
- Assembly under conditioning

Polarized Electron Source (ESR)

- Related to the electron gun R&D
- Goal: Test this new cathode in DC gun and SRF gun
- Developed a GaAs surface treatment procedure, obtain clean and smooth surface
- Developed a Robust Cs-O-Te activated GaAs photocathode development, and characterization using LEED, LEEM, SR-XPS

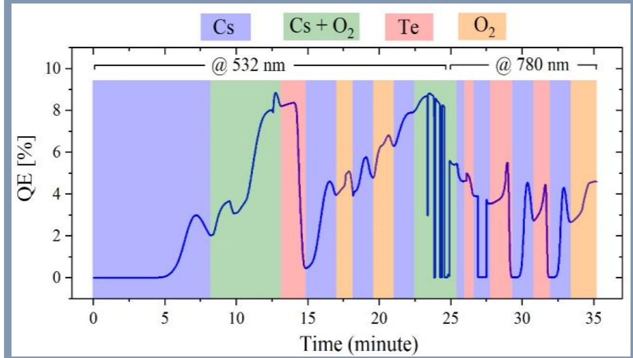
Publications:

- J. Biswas, et. al, Journal of Applied Physics **128**, 045308 (2020)
- J. Biswas, et. al, AIP Advance (2020) in review

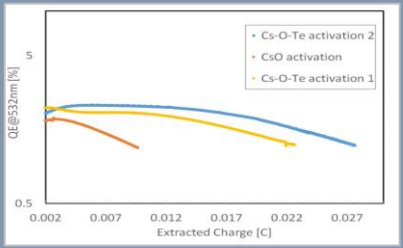
Unpolarized Electron Source (Cooler)

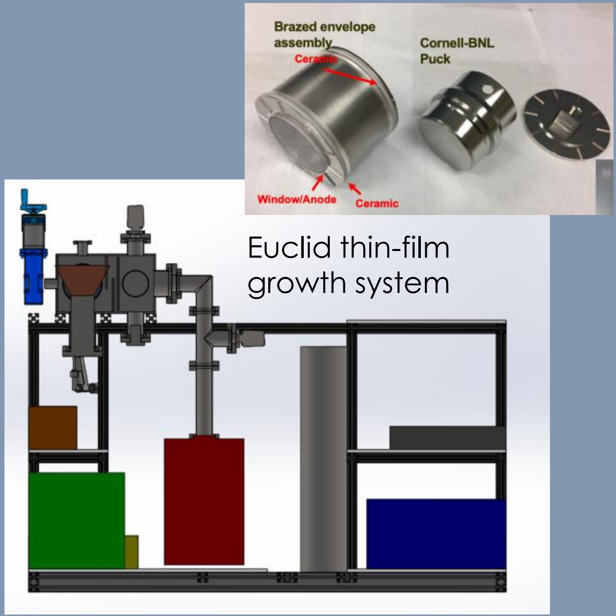
- BNL is working with Euclid Techlabs, LLC on investigating thin-film protection schemes for bi-alkali antimonide photocathodes
- BNL is working with Photonics and RMD on developing capsule sealed multialkali photocathode
- Both cathode R&Ds benefit to EIC cooler

More details in *EIC Cooling R&D Status* (E. Wang, Thursday 16:35 GMT-5)



Cs-O-Te activation on GaAs





Pre-project R&D → Current EIC R&D

Pre-project R&D

- Direct Wind Double Helix Coils
- Crab Cavity for LHC
- 650 MHz 5-cell cavity prototype
- HOM Beamline Absorber
- High Power FPC
- Polarized Electron Gun
- Electron Source Development

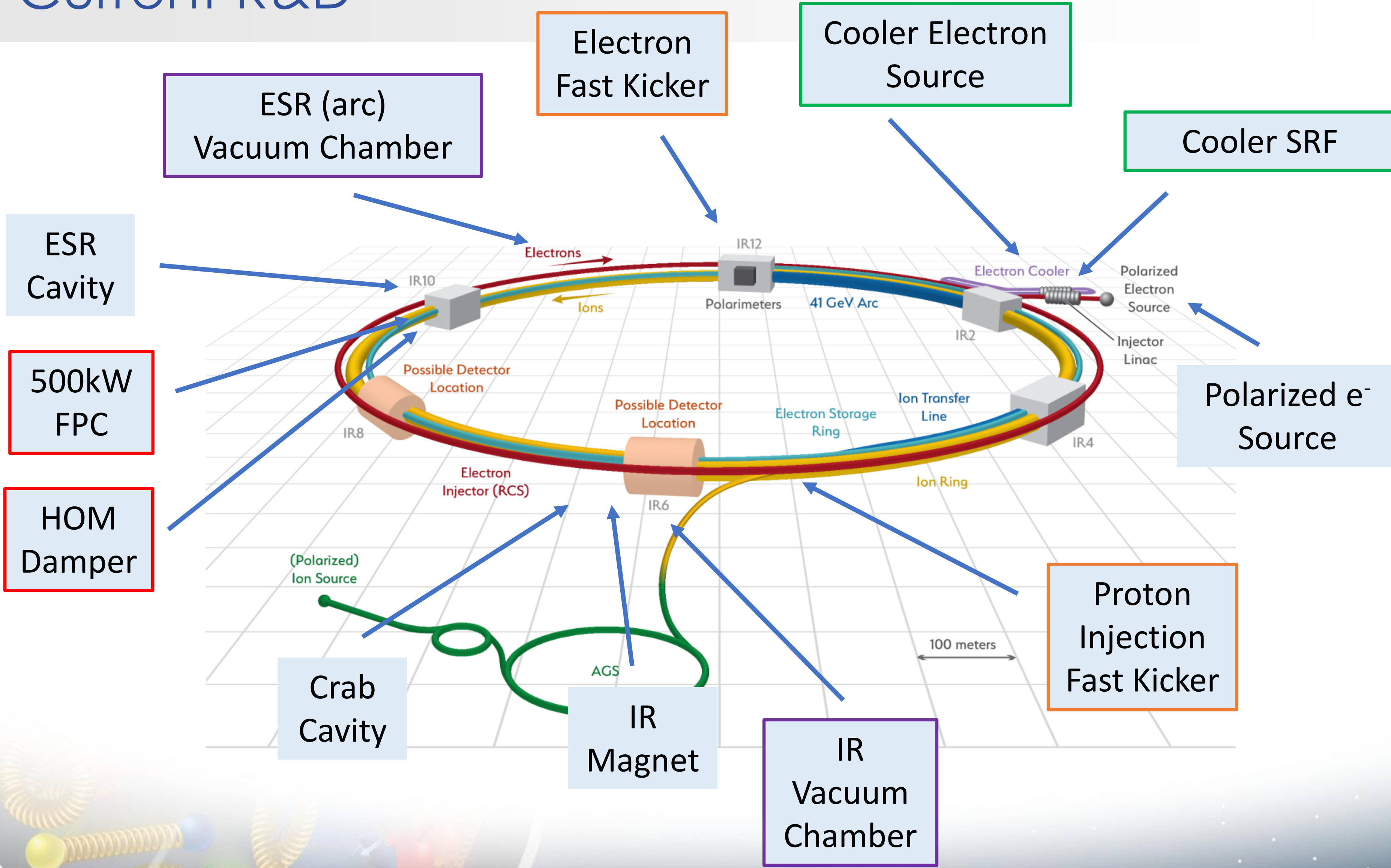
Current EIC R&D

- IR Magnet
- Crab Cavity for EIC
- SRF Cavity for ESR
- HOM Beamline Absorber
- High Power FPC
- Polarized Electron Gun
- Cooler Electron Source

+

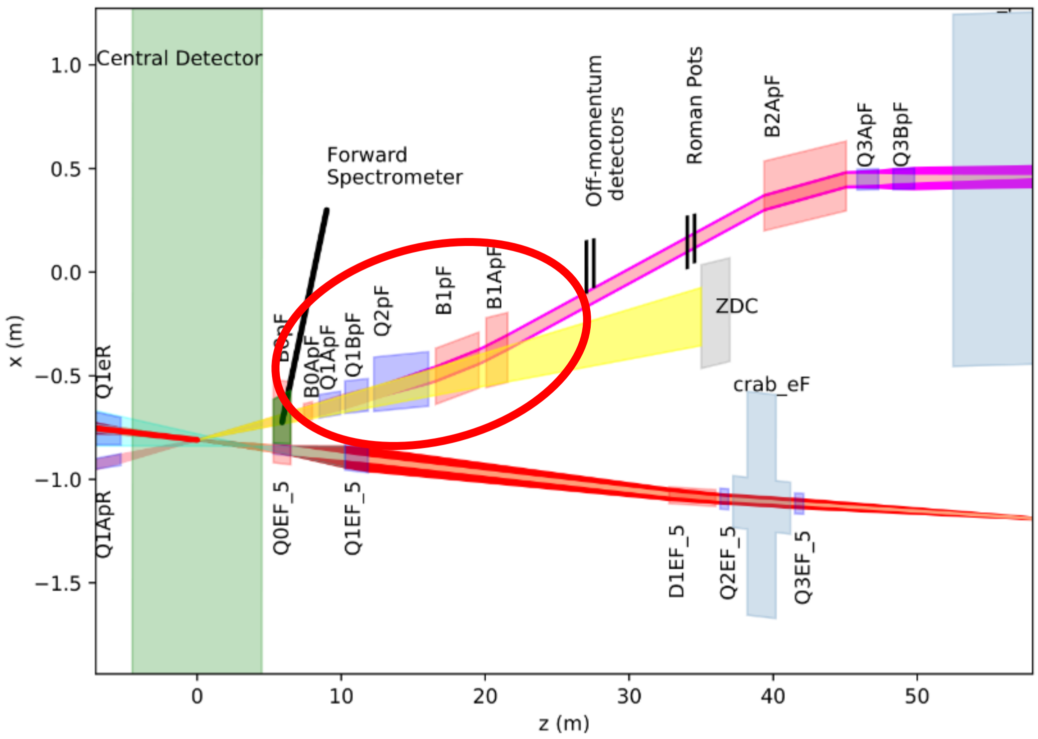
- Proton Fast Kicker
- Electron Fast Kicker
- Cooler SRF
- Electron Vacuum Chamber
- IR Vacuum Chamber

Current R&D



Electron Fast Kicker
Cooler Electron Source
Cooler SRF
ESR (arc) Vacuum Chamber
ESR Cavity
500kW FPC
HOM Damper
Polarized e⁻ Source
Proton Injection Fast Kicker
Crab Cavity
IR Magnet
IR Vacuum Chamber
Electrons
IR12
IR10
Ions
Polarimeters
41 GeV Arc
Electron Cooler
Polarized Electron Source
Injector Linac
IR2
Possible Detector Location
Possible Detector Location
Electron Storage Ring
Ion Transfer Line
IR8
IR4
Electron Injector (RCS)
IR6
Ion Ring
(Polarized) Ion Source
AGS
100 meters

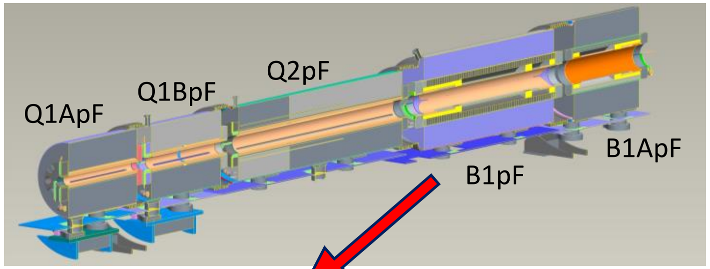
IR Magnet

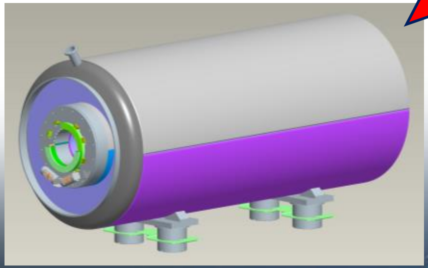


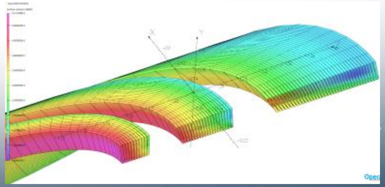
Name	R1	length	B	grad	B pole
	[m]	[m]	[T]	[T/m]	[T]
B0ApF	0.043	0.6	-3.3	0	-3.3
Q1ApF	0.056	1.46	0	-72.608	-4.066
Q1BpF	0.078	1.61	0	-66.18	-5.162
Q2pF	0.131	3.8	0	40.737	5.357
B1pF	0.135	3	-3.4	0	-3.4

More details in *EIC First IR Design* (H. Witte, Thursday 07:05 GMT-5)

- Hadron forward magnets
  - Challenging in terms of field an aperture
- Magnet R&D
  - Reduce risk for most challenging magnets
- Choice: B1pF
  - Large aperture
  - High field
  - Largely compatible with existing equipment (curing & collaring press)



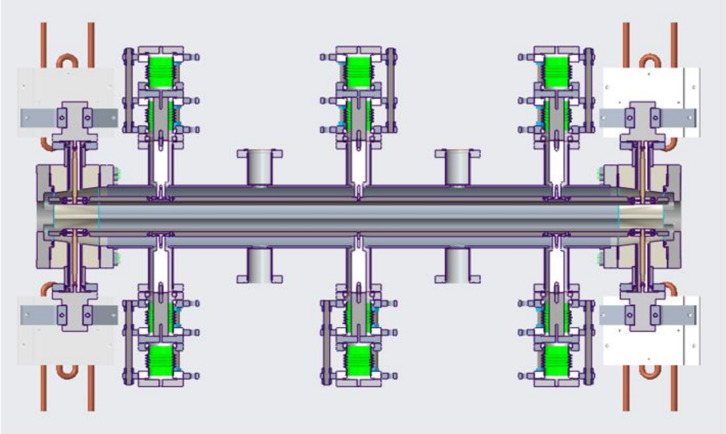




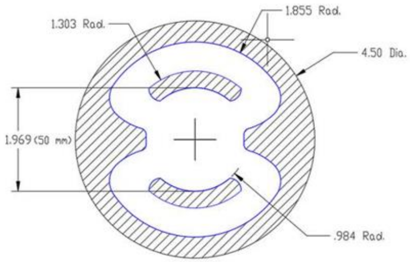
Fast Kickers

- Proton injection and electron extraction kickers
- Rise time of approximately 10 ns to a 500 A; flattop of 20 to 50 ns.
- Pulsed voltage of approximately 25 kV will be required

Parallel-Plate Strip Line	Hadron Injection Kicker
Beam Energy [GeV]	24
Risetime [ns}	10-12
Falltime	Non -critical
Flattop [ns]	20-50
Gap Height [cm]	5
Gap Width [cm]	3
Voltage per plate [+/- kV]	25
Current [Amps]	500
Number of sections	20 tanks 40 pulsers



kicker longitudinal cross-section



transverse cross-section

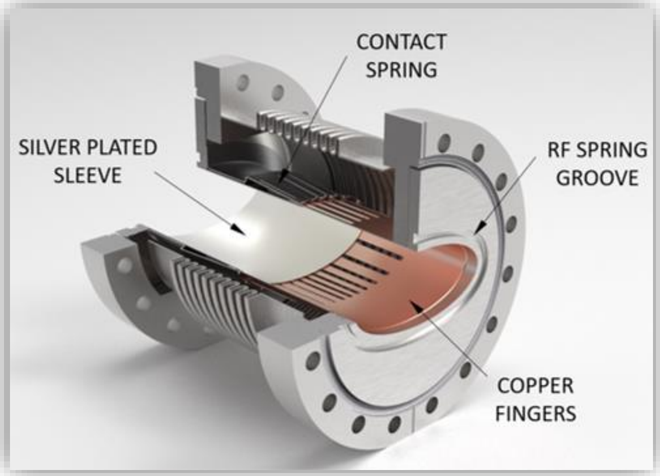
Pulser tested up to 50 kV, 100 Hz Burst Mode

50 Ω High Voltage Feedthrough:
Max. operating voltage:
50 kV, 10 ns; 30kV, 100 ns.

Vacuum Chambers

Electron Vacuum chambers

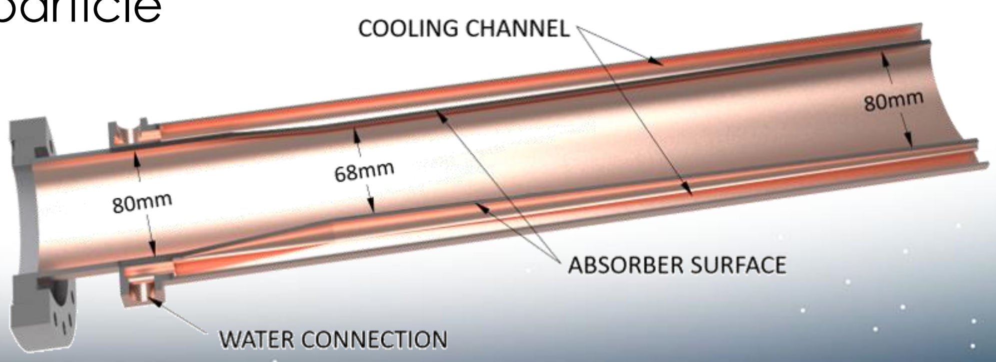
- Large aperture to accommodate all possible beam size at different energies
- Cooling of high radiation power (4-9 W/mm^2) – Radiation and FEA based thermal simulations
- Low impedance RF shielding bellows



Interaction Region Vacuum chambers

- 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

Model for electron bending section vacuum chamber



More details in *EIC E-Ring Vacuum System* (C. Hetzel, Thursday 14:35 GMT-5)

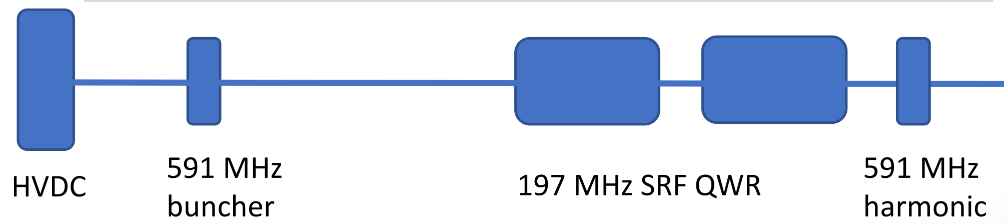
Cooler Components

Electron Source

- Need a test to demonstrate high charge/ high current e-beam
- Demonstrated 50 W in green (BNL, Cornell)
- Lifetime:
  - 70 mA for 2 days (Cornell Univ.)
  - 20 mA for 2 weeks (BNL)
- By increasing the multialkali cathode area, it looks promising to get reasonable charge lifetime with good vacuum

	parameters
Cathode QE(%)	1%-8%
Average current [mA]	120
Average laser power [W]	23-3
Pulse energy [nJ]	230-30
Charge lifetime [C/mm]	20000/2.5
Extrapolated Cl [C/mm]	80000/5~ 9 days

Schematic drawing of the Cooler injection section



Cooler RF Components

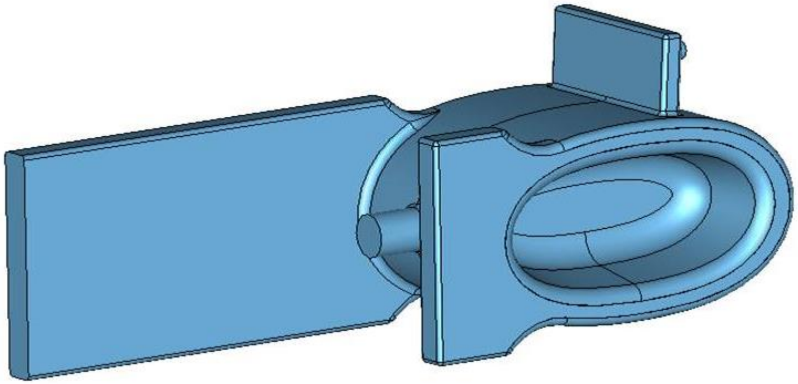
- 197 MHz SRF QWR
- 200 kW FPC at such low frequency
- Still under paper study with optimization of the Cooler lattice design

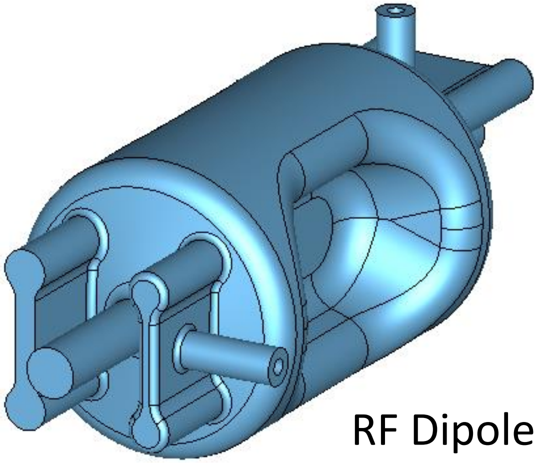
More details in *EIC Cooling R&D Status* (E. Wang, Thursday 16:35 GMT-5)

Crab Cavity

- 197 MHz SRF Crab Cavity for hadron ring
- 11.5MV deflecting voltage per cavity with 45MV/m and 80mT peak fields on Nb.
- 3.75kΩ longitudinal, 1.35MΩ/m transverse impedance budget (circuit definition) per cavity for HSR.
- May need second harmonic cavities
- Space constrain at Interaction Region, in both longitudinal and transverse directions
- Multipacting, multipole, and mechanical issues are under study

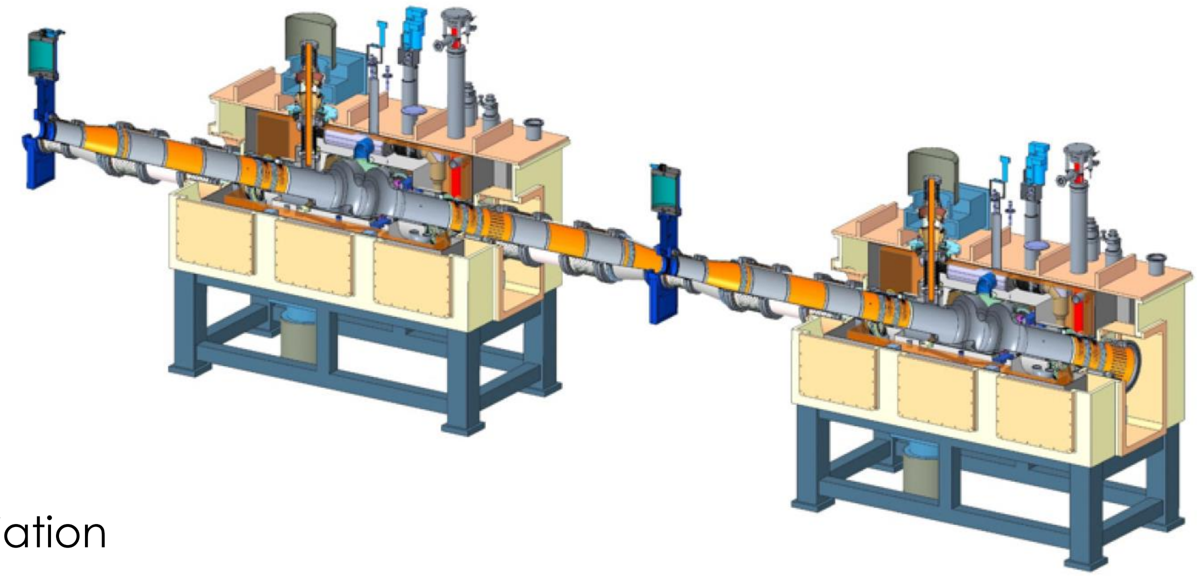
Double Quarter Wave Design





RF Dipole Design

Electron Storage Ring Main Cavity



2-cell ESR cavity (still under study) with HOM beamline absorber

- Challenges in the ESR
  - High bunch charge
  - High beam current
  - High synchrotron radiation
- 591 MHz 1-cell or 2-cell SRF system
- 16.0 MV/m CW
- Dipole impedance ≤ 50 MΩ/m total
- Longitudinal impedance ≤ 2×10^{13} ΩHz

R&D inherited from previous efforts

- To be continued as R&D:
  - Polarized Electron Source
  - Critical Cryomodule Components
    - 500 kW FPC for Electron Storage Ring
    - HOM Beamline Absorber

- Adjust goal to be further aligned with the scope of EIC

- Layout schedule to complete the goals

Current EIC R&D ⟷ Off-project R&D

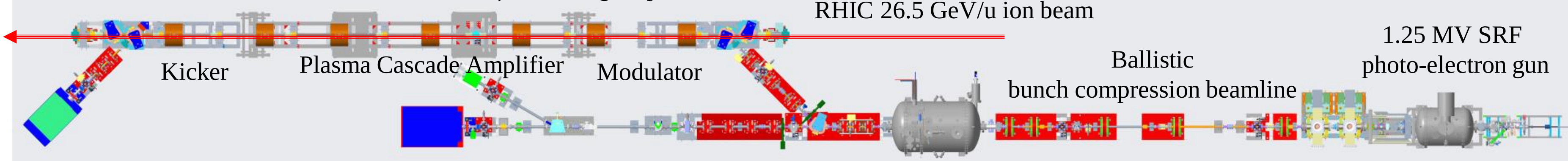
Accelerator **P**hysics **EX**periments @ RHIC

- Longitudinal HOM measurements
- Large space charge tune shift at injection
- Spin transparency experiment
- High-energy radial shift study
- Precision decoupling with small beta*
- Polarimeter experiments with light ions
  - p-Carbon Polarimeter
  - Jet Polarimeter

Off-project R&D

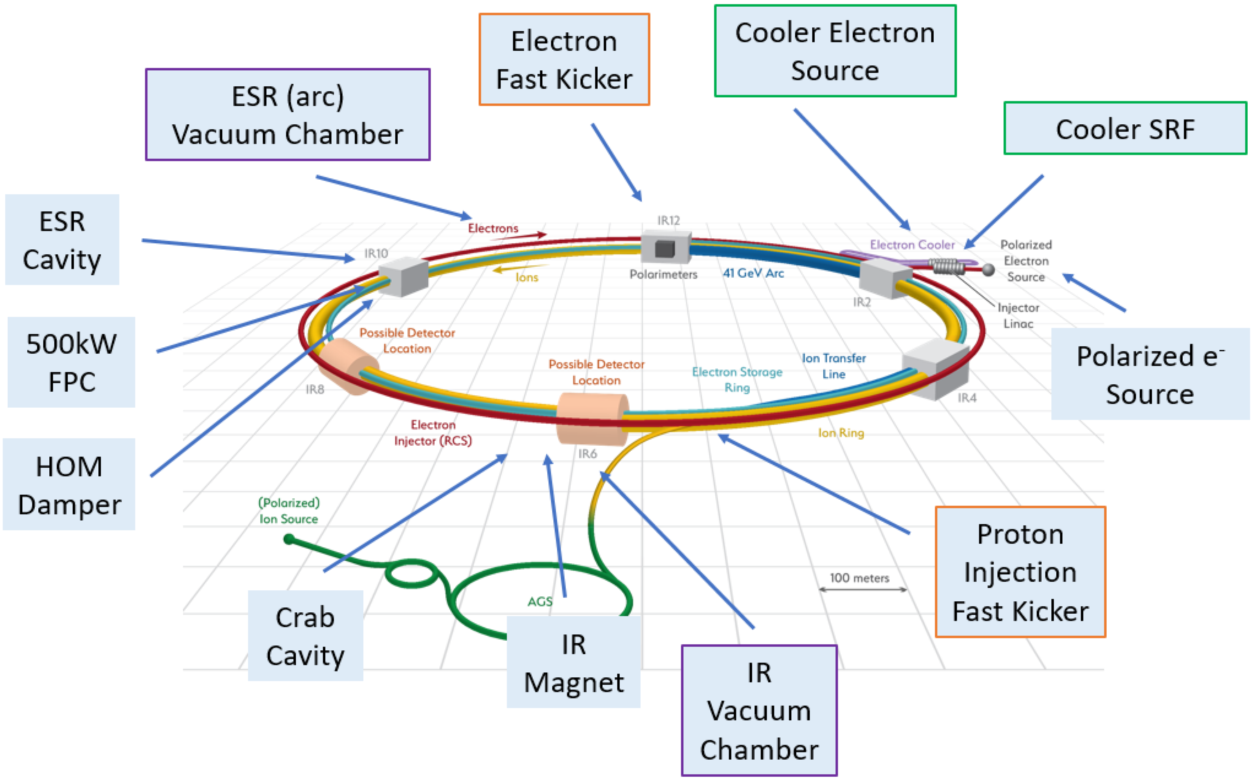
Coherent **e**lectron **C**ooling

Courtesy V.N. Litvinenko



- The CeC has a unique SRF electron gun generating record-low emittance with beam quality sufficient for current experiment and for future EIC cooler.
- Demonstrated:
  - Peak current of 50-100 A
  - Electron Energy up to 14.5 MeV
  - Merged with RHIC 26.5 GeV/u ion beam
  - Required beam emittances and energy spread
  - Low noise level in beam
  - Low loss propagation
- Current CeC system has 7 high field solenoids, 5 of which serve as a 4-cell Plasma-Cascade micro-bunching amplifier with 15 THz bandwidth and amplitude gain exceeding 100.
- The project plans are to demonstrate longitudinal CeC in 2021 and 3D (both longitudinal and transverse) CeC in 2022.
- The CeC group invites all interested parties to collaborate on this incredibly challenging project in any of relevant areas

More details in *Coherent Electron Cooling updates* (V. Litvinenko, Friday 08:10 GMT-5)



Summary

- The success of the EIC project relies on a successful R&D program
- The R&D program focuses on challenging components of the entire EIC design
- The EIC project started from an elevated level benefitting from the Pre-project R&D
- The off-project R&D experiments support the project with unique beam tests
- The R&D of the EIC project relies significantly upon collaborations, in the past and in the future

Acknowledgement

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Jefferson Lab

Steven Benson, Jiquan Guo, Joe Preble, Robert Rimmer, Todd Satogata

Thank you for providing the material and discussion for this talk

Thank you