AN OVERVIEW OF RF SYSTEMS FOR THE EIC

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Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

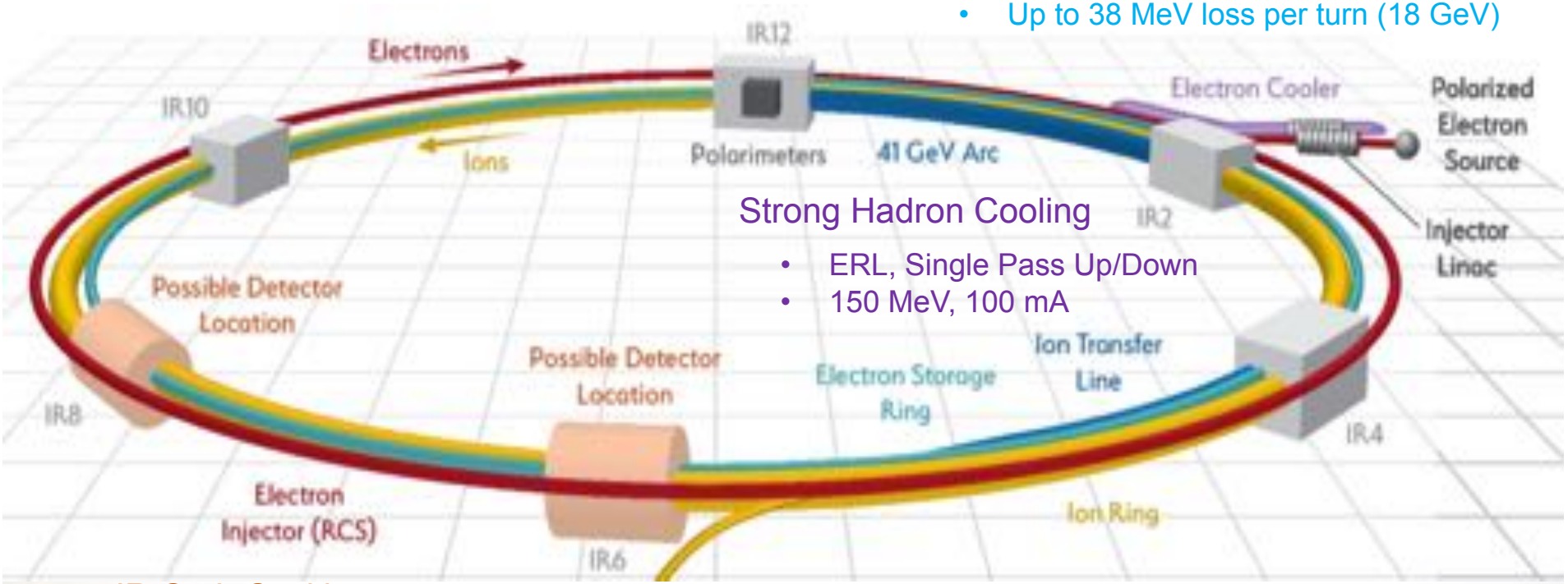
Introduction to EIC at BNL

Hadron Ring based on RHIC

- Up to 275 GeV Proton Store Energy
- 1 A maximum beam current
  - 1160 bunches, 11 nC per bunch

ESR: new electron Storage Ring

- 5 GeV – 18 GeV
- 2.5 A maximum beam current (10 GeV)
  - 1160 bunches, 28 nC per bunch
- Up to 10 MW synchrotron radiation power
- Up to 38 MeV loss per turn (18 GeV)



Strong Hadron Cooling

- ERL, Single Pass Up/Down
- 150 MeV, 100 mA

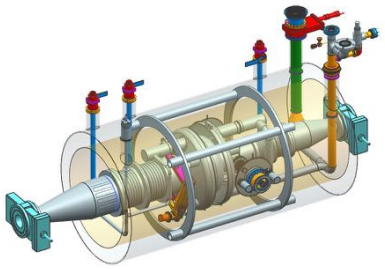
IR Crab Cavities

- 25 mrad crossing angle
- 8x Hadron Crab Cavities
- 6x electron Crab Cavities

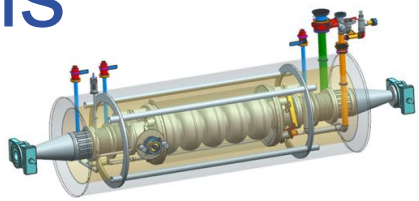
RCS: new Rapid Cycling Synchrotron

- 400 MeV – 18 GeV Full Energy e- Injector
- 1 Hz Repetition Rate
- 100 ms ramp
- Up to 28 nC per bunch

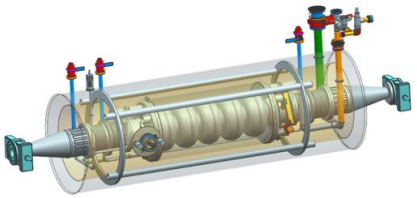
EIC RF systems



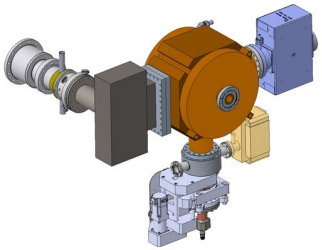
Electron - 591 MHz electron storage cavity



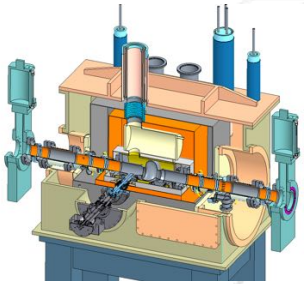
Hadron - 591 MHz bunch compression cavity



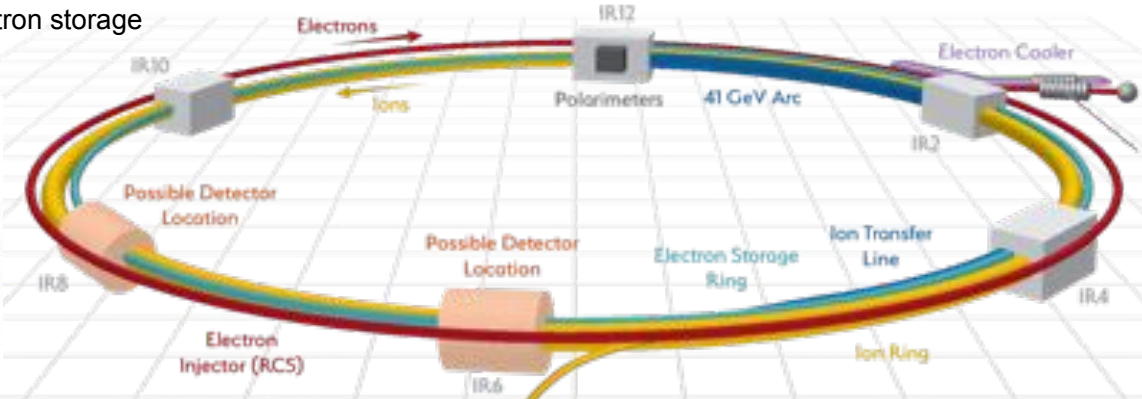
Hadron Cooling - 591 MHz acceleration cavity

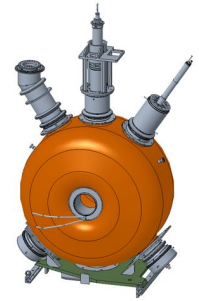


Injector - 571 MHz bunch compression cavity



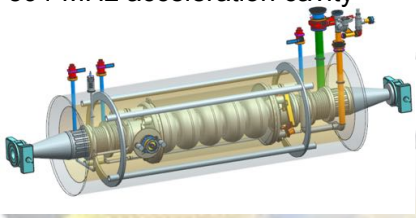
Electron - 1773 MHz 3rd harmonic cavity

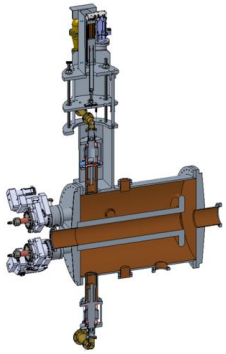




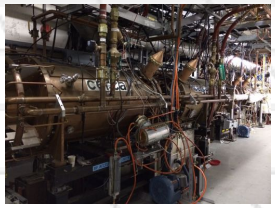
Hadron - 197 MHz bunch compression cavity

Rapid Cycling Synchrotron - 591 MHz acceleration cavity

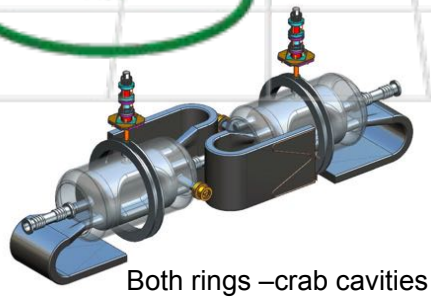




Hadron – 49.2 MHz and 98.5 MHz bunch splitter cavity



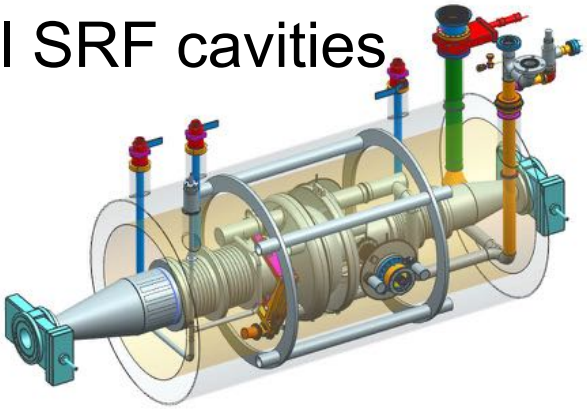
Hadron – 24.5 MHz acceleration cavity



Both rings –crab cavities

ESR RF system

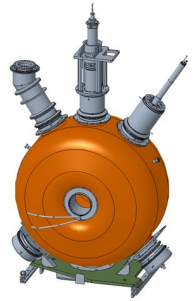
- Up to **68 MV** using new **591 MHz** 1-cell SRF cavities
  - maintain 1% Bucket height from 5-18 GeV
- Naturally short bunch length ~1cm
- **10MW** maximum beam power
- **2.5A** maximum current



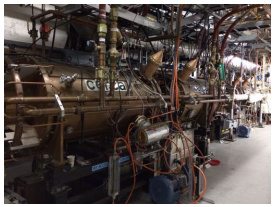
- Two fundamental power couplers per cavity, **~400kW** ea.
- Strong beam loading requires large detuning frequency (~revolution frequency), additional RF controls.
- Transient beam loading will be significant.
- At lower energy we can use reverse-phasing method, reducing detuning frequency and transient modulation.

HSR RF system

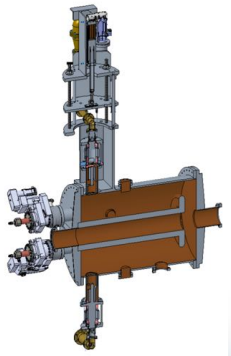
- Keep existing 6 MV 6x197 MHz NCRF system
- Re-tune existing 2x 28 MHz system to 24.6 MHz
- Add 2x 49.2MHz and 2x 98.5MHz NCRF for binary bunch splitting
- Add **20 MV 591 MHz** SRF system
- Up to **1A** beam, up to 1160 bunches
- Optimum detuning for reactive power (like LHC)
- Beam loading transient and collective effects studies started



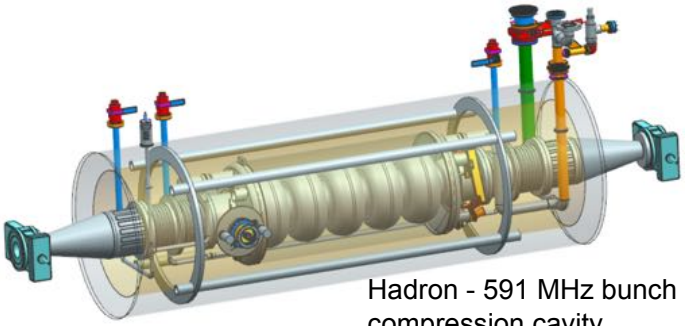
Hadron - 197 MHz bunch compression cavity



Hadron – 24.5 MHz acceleration cavity



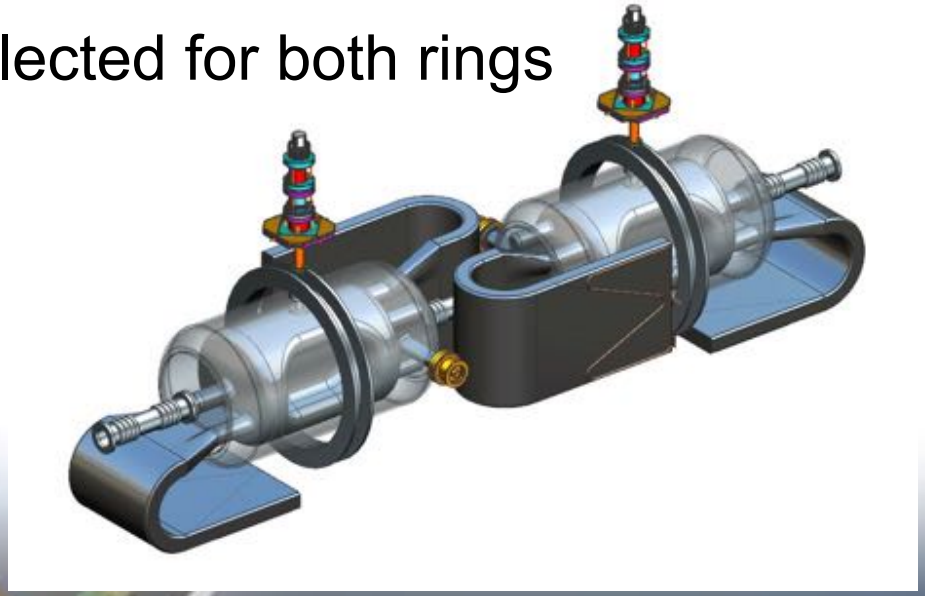
Hadron – 49.2 MHz and 98.5 MHz bunch splitter cavity



Hadron - 591 MHz bunch compression cavity

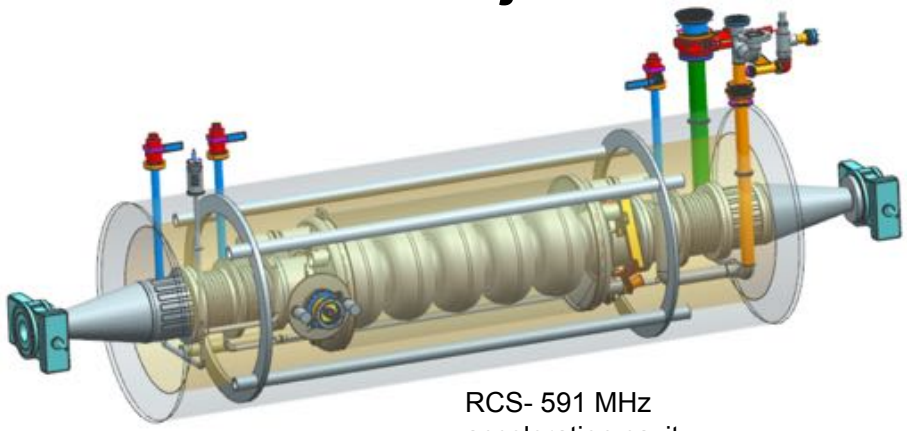
Crabbing Systems

- New SRF crabbing systems for both rings
- Large voltage needed for **25 mRad** crossing angle
- ESR system **394 MHz 2.9 MV** each side
- HSR system **197 MHz 34 MV** each side
  - Need second harmonic for **linearization**
- IR 6 total **8x 197 MHz** cavities, **6x 394 MHz** cavities
- RFD type selected for both rings

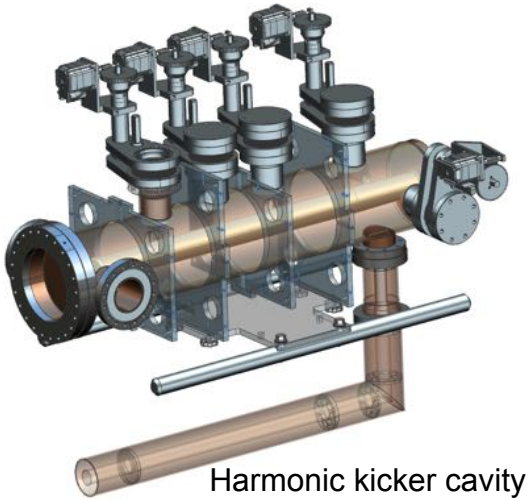


RCS

- Requires rapid acceleration of one or two high charge bunches per cycle for full energy injection
- **3x 591 MHz 5-cell** cavities, same as HSR and ERL
- Bunch merging to achieve peak bunch charge
- Harmonic injection kicker into RCS
- Fast kickers for injection into ESR



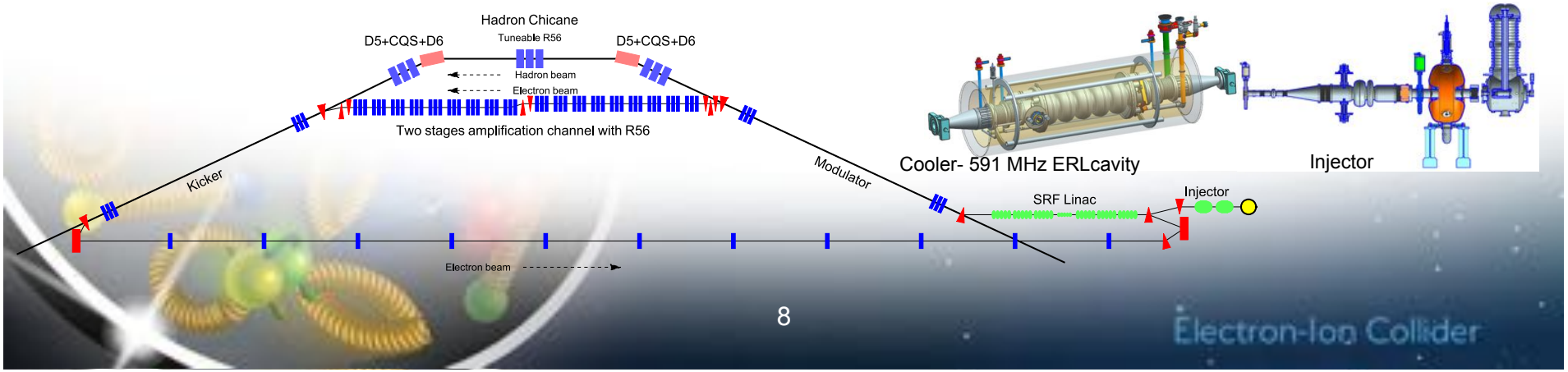
RCS- 591 MHz
acceleration cavity



Harmonic kicker cavity

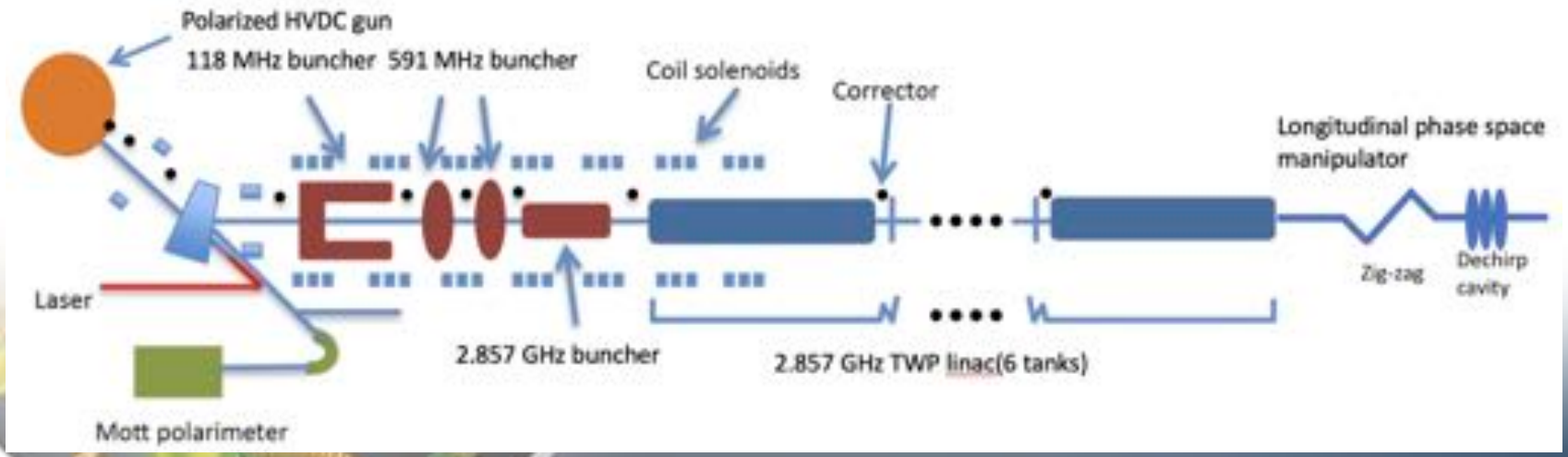
High energy electron cooling

- Single Pass **150 MeV ERL**, 98.5 MHz bunch frequency
- **8 x 591 MHz, 5-cell** elliptical + **1.77 GHz** third harmonic
- Maximum 180 MV installed voltage, Eacc **15.8 MV/m**
- 8 x 591 MHz, **65 kW CW**, SSA RF Power Amplifiers
- **1 nC** per bunch, **~100 mA** single pass current
- Injector: DC photocathode gun, 197 MHz buncher, 591 MHz acceleration, 1.77 GHz linearizer.



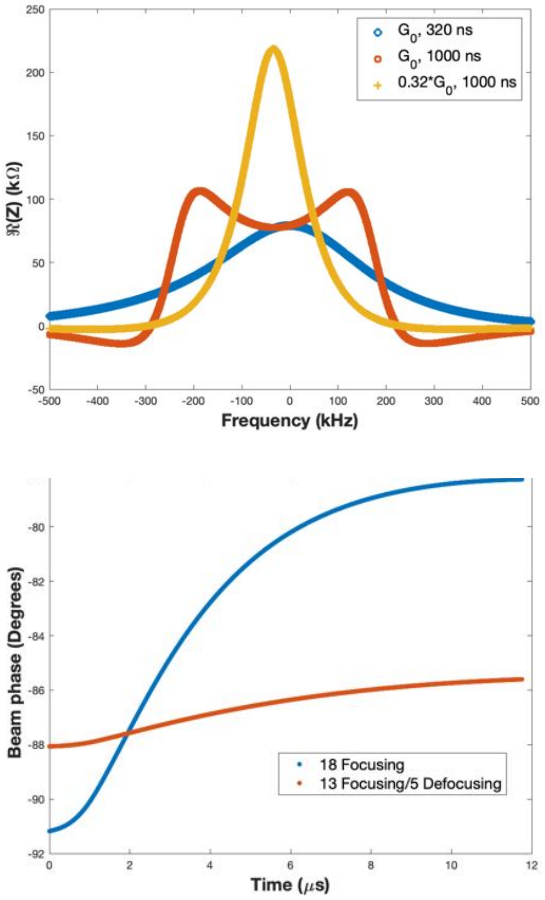
Polarized electron injector

- 350 kV DC photocathode gun
- 118 MHz buncher
- 591 MHz buncher
- 2856 MHz SLAC-type linac to 400 MeV
- 1182 MHz de-chirper



Notable challenges

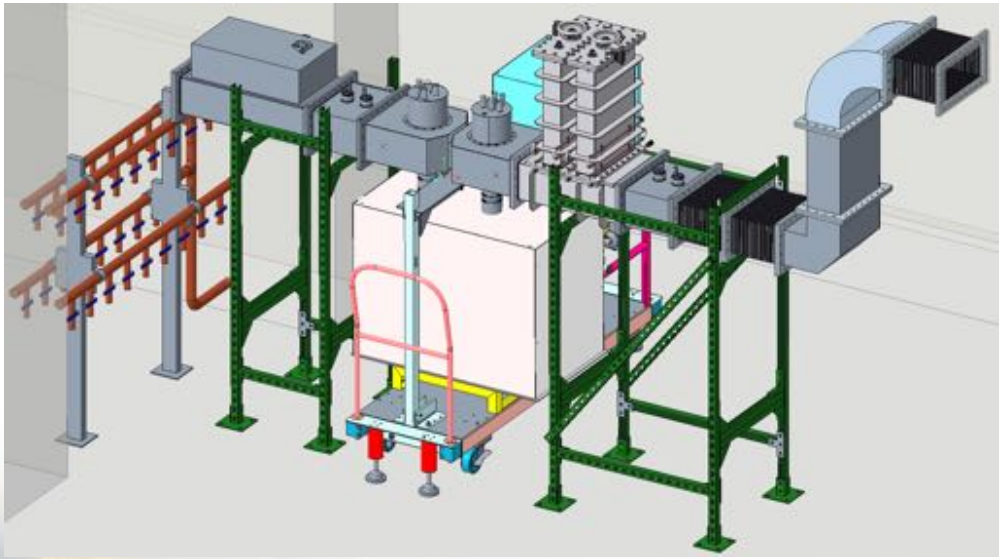
- High currents
  - HOM power, BBU, RF stability, resonant heating
- High bunch charge
  - Single bunch instabilities, wakefields, CSR, resistive wall heating
- High beam power
  - RF power, couplers, collimators
  - Gap transients
- Crabbing
  - High voltage, HOMs, linearity, synchronization, noise

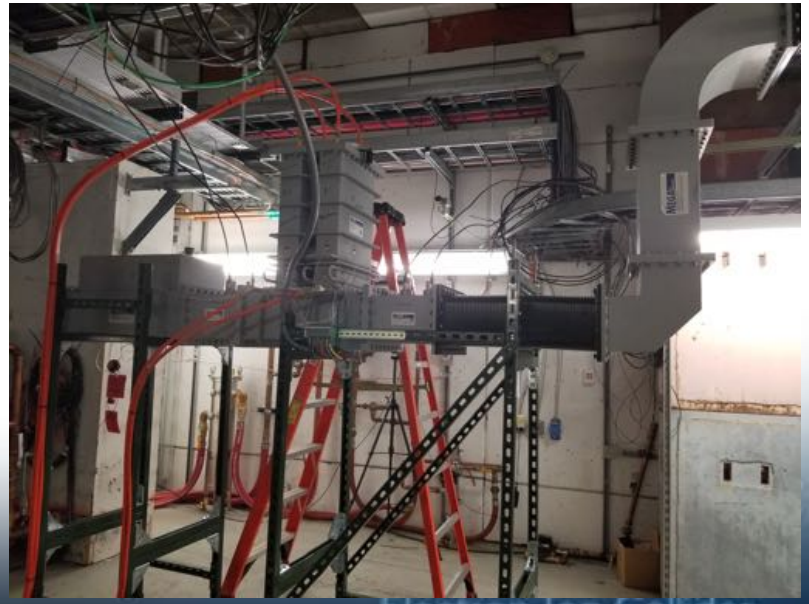


simulations of the RF system-beam interaction in the EIC electron ring

400 kW CW, Variable Q_{ext} Couplers

- Use existing fixed 500 kW CW coupler design.
- Vary Q_{ext} using adjustable waveguide tuner section.
- Initial funding by BNL LDRD.

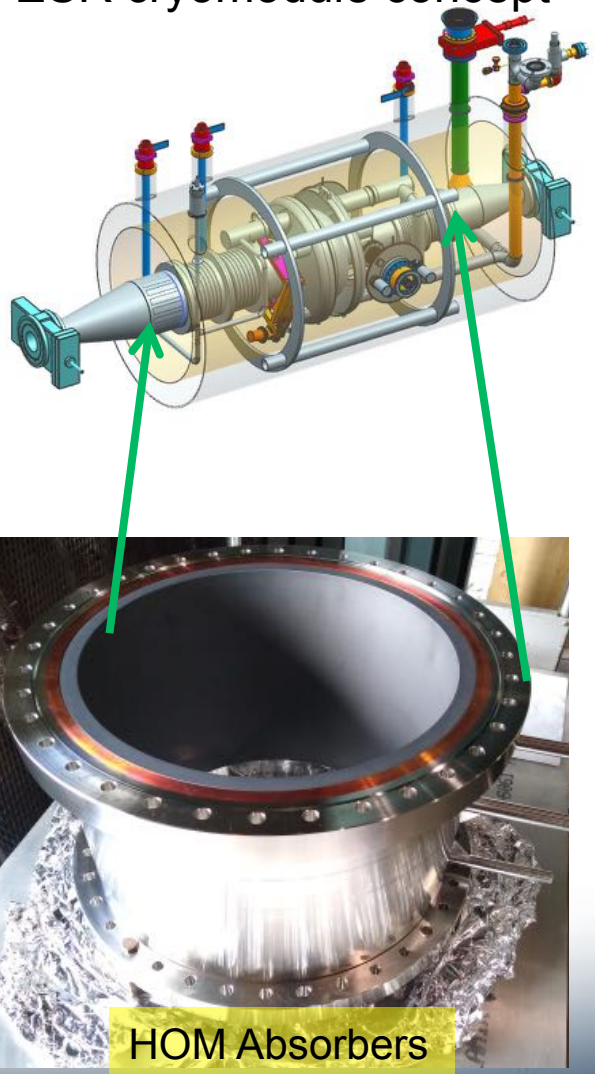




High Power SIC HOM Absorber

- Requirement and challenge
  - High power, broadband HOM damper
  - Large size of SiC HOM damper for low frequency
- Initial LDRD program on SiC HOM absorber:
  - Low power test on a cavity to test effective damping bandwidth
  - High power test to test the power handling capability
- Design approach:
  - Solid one-piece HOM damper, Simple shrink-fit assembly based on ANL design

ESR cryomodule concept



RF power options

Super-power klystrons

- Limited vendors, high cost, low efficiency

Combined IOT's

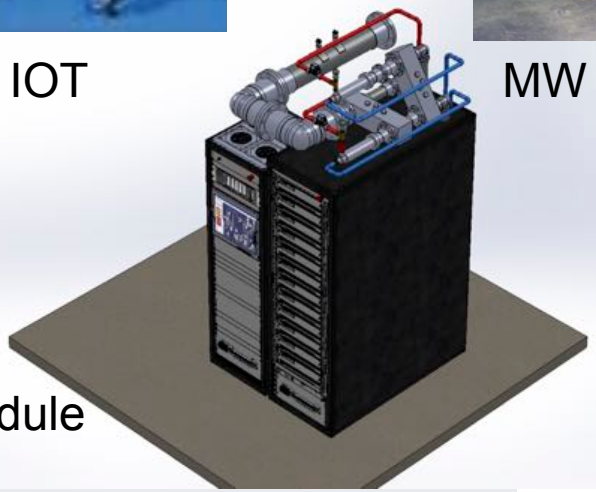
- Better efficiency, becoming obsolete

Combined SSA's

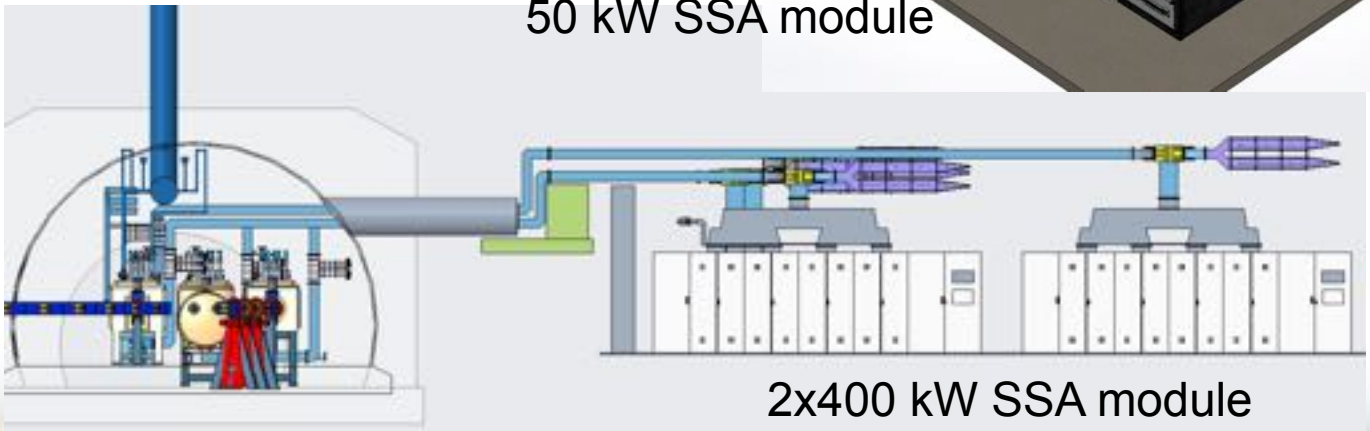
- High efficiency
- Reliability and redundancy
- Costs falling, supply growing

IOT

MW klystron



50 kW SSA module



2x400 kW SSA module

Approximately 70 ft, 22m.

Summary of RF systems for EIC

RF System	Sub System	Freq [MHz]	Type	Location	#
Electron Storage Ring	Fundamental	591	SRF, 1-cell	IR-10	17
RCS	Fundamental	591	SRF, 5-cell	IR-10	3
Pre-Injection LINAC	Buncher 1	118	Copper, ¼ Wave	IR-2	1
	Buncher 2	591	Copper, 1-cell	IR-2	2
	De-chirper	1182	Copper LINAC	IR-2	1
	400 MHz LINAC	2856	SLAC type LINAC	IR-2	6
Hadron Ring	Capture / Accel	24.6	Copper, Quarter Wave	IR-4	2
	Bunch Split 1	49.2	Copper, Quarter Wave	IR-4	2
	Bunch Split 2	98.5	Copper, Quarter Wave	IR-4	2
	Bunch Comp. 1	197	Copper, 1-cell	IR-4	6
	Bunch Comp. 2	591	SRF, 5-cell	IR-10	1
Crab Cavity	Hadron	197 + 394	SRF, RFD	IR-6	8 + 4
	Electron	394	SRF, RFD	IR-6	2
Hadron Cooling	NC Buncher	197	Copper, 1-cell	IR-2	1
	SRF booster.	591	SRF, 1.5-cell	IR-2	1
	ERL Linac	591	SRF, 5-cell	IR-2	8
	Third Harmonic	1773	SRF, 5-cell	IR-2	4

Conclusions

- EIC is an exciting new project
- Pushing the state of art on many frontiers
- RF systems being developed as an integrated set
- High degree of modularity in design

Thank You For Your Attention!

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