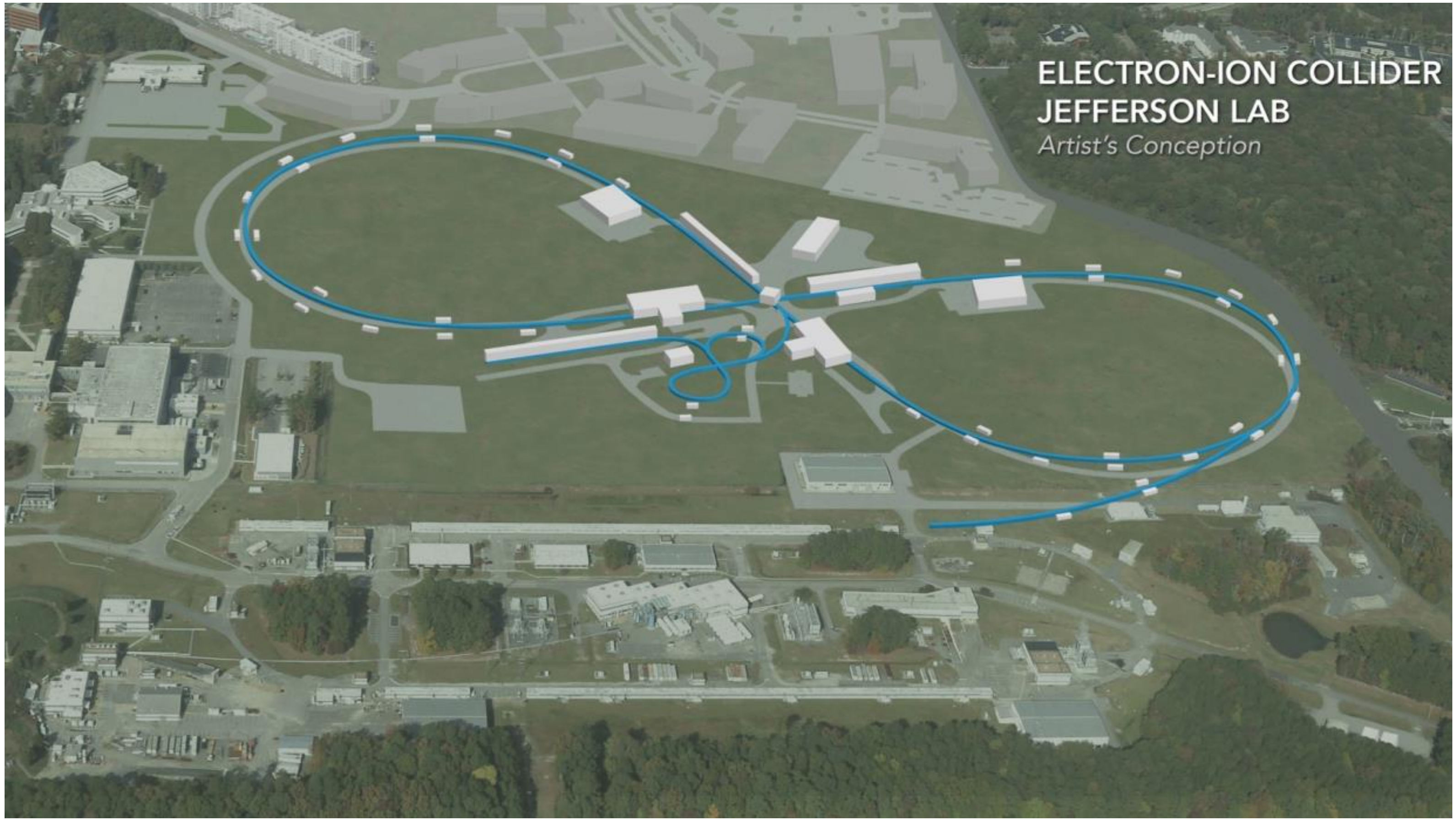
JLEIC: A High Luminosity Polarized Electron-Ion Collider at Jefferson Lab

Yuhong Zhang

for the JLEIC collaboration



Outline:

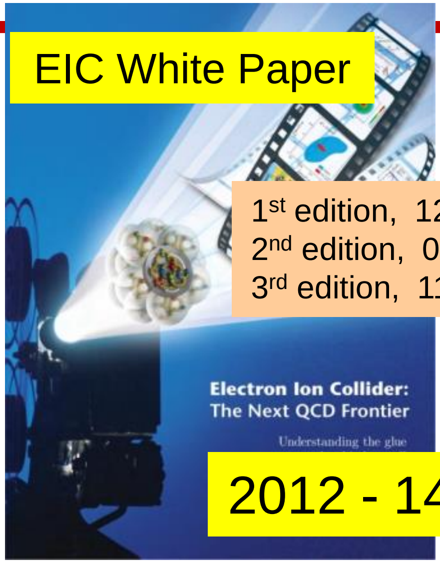
- Introduction
- Design Concepts & Performance
- Design and Accelerator R&D
- Summary

Introduction

- The international nuclear science community envisions a high luminosity polarized electron-ion collider for exploring the future QCD frontier
- ***JLEIC*** is a proposed ***J***efferson ***L***ab ***E***lectron-***I***on ***C***ollider to respond this science need
- JLEIC is designed for delivering ultra high performance including high luminosity, high polarization and full detector acceptance
- The JLEIC design concept has been stable over the last 10 years, a proof of its maturity
- Implementation of this design concept has been continuously updated and optimized to *enhance machine performance*, *mitigate technical risks* and *reduce costs*
- Key accelerator and detector R&D are in progress by a collaboration of US and international scientists and engineers
- A comprehensive pre-Conceptual Design Report (*pre-CDR*) for JLEIC was recently completed.

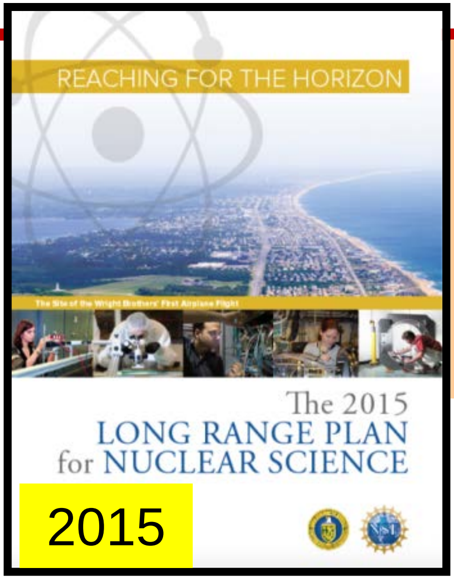
US EIC Milestones

EIC White Paper



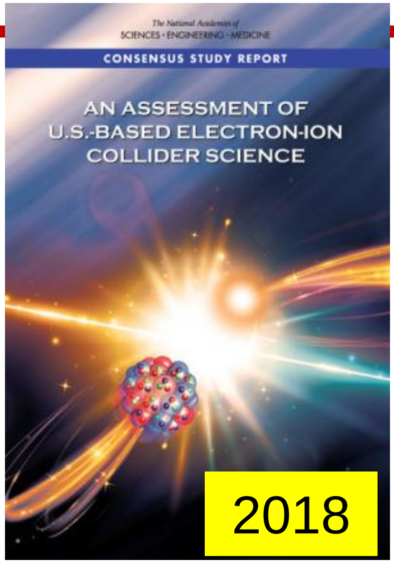
1st edition, 12/07/2012
2nd edition, 02/03/2013
3rd edition, 11/30/2014

2012 - 14



2015

Recommendation 4:
A high-energy high-luminosity polarized electron-Ion collider for new facility construction following the completion of FRIB



2018

"The realization of an EIC is absolutely crucial to maintaining the health of the field of nuclear physics in the U.S. and would open up new areas of scientific investigation."

NAS EIC Assessment Findings

Finding 1 (Science): An EIC can uniquely address three profound questions about nucleons—neutrons protons—and how they are assembled to form the nuclei of atoms: How does the mass of the nucleon arise? How does the spin of the nucleon arise? What are the emergent properties of dense systems of gluons?

Finding 2 (Accelerator): These three high-priority science questions can be answered by an EIC with highly polarized beams of electrons and ions, with sufficiently high luminosity and sufficient and variable center-of-mass energy.

Finding 3: An EIC would be an unique facility in the world, and would maintain U.S. leadership in nuclear physics.

Finding 4: An EIC would maintain U.S. leadership in the accelerator science and technology of colliders, and help to maintain scientific leadership more broadly.

Finding 5: Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.

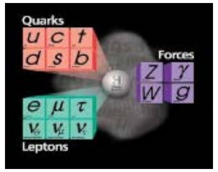
Finding 9: The broader impacts of building an EIC in the U.S. are significant in related fields of science, including in particular the accelerator science and technology of colliders and workforce development.

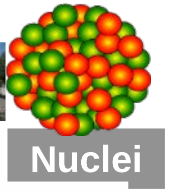
EIC Science

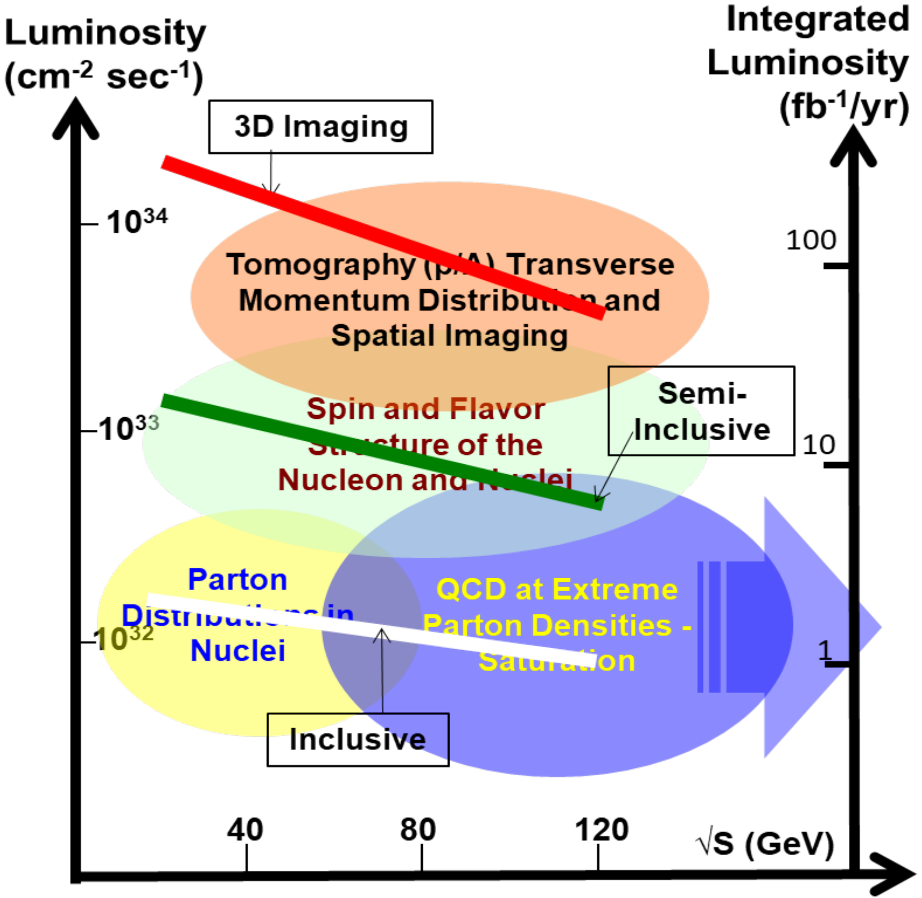
A Gluon Microscopy for Understanding the Glue that Binds Us All

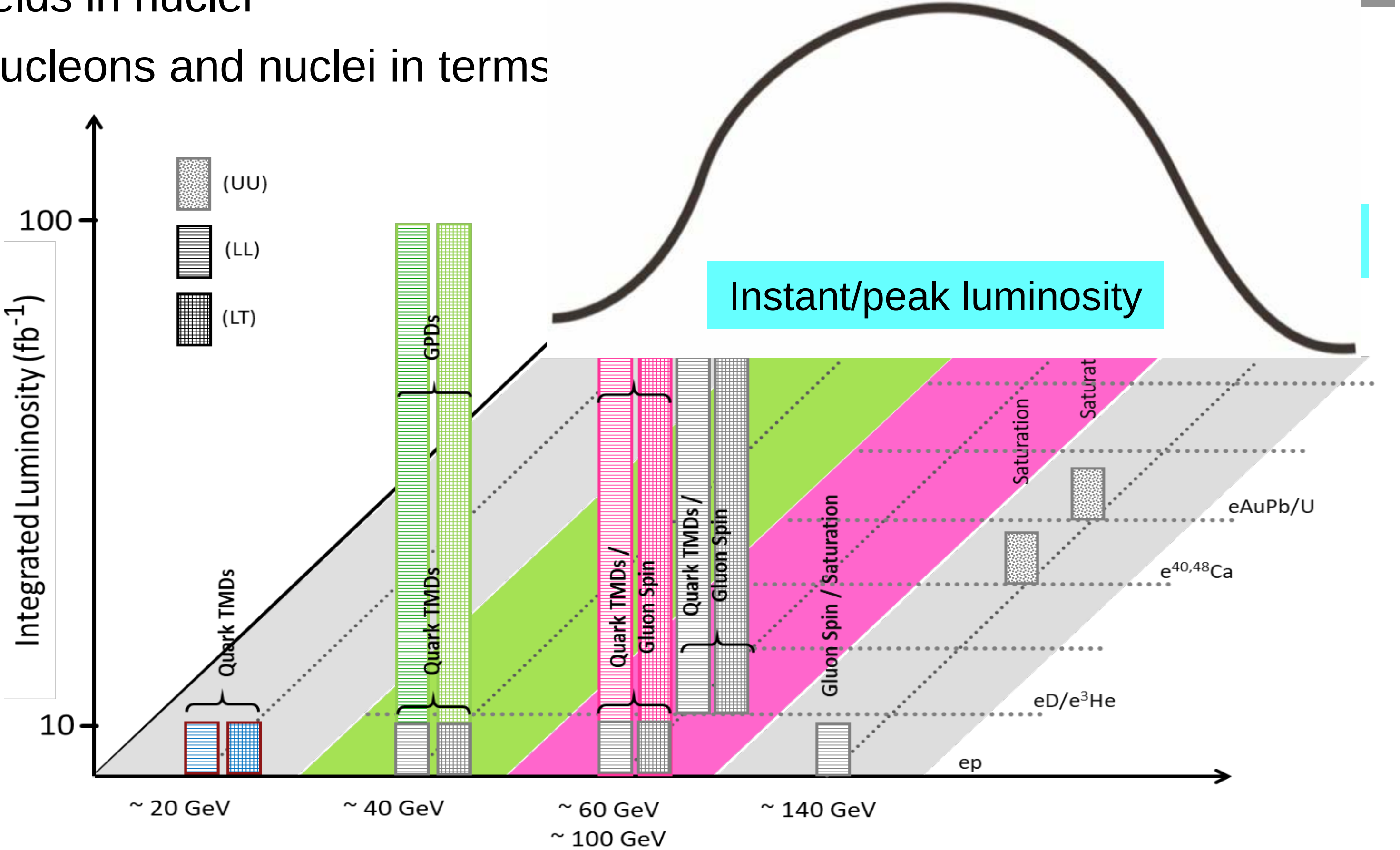
A versatile range of *beam species, kinematics, polarizations, high luminosity* is required to

- *Precisely image sea quarks & gluons in nucleons & nuclei,*
- Explore the new QCD frontier of strong color fields in nuclei
- Resolve outstanding issues in understanding nucleons and nuclei in terms



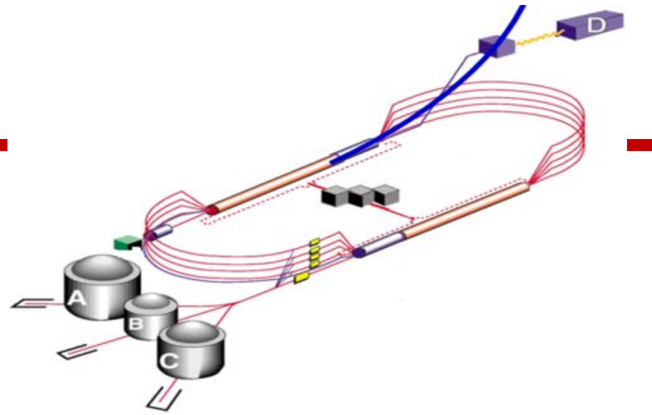




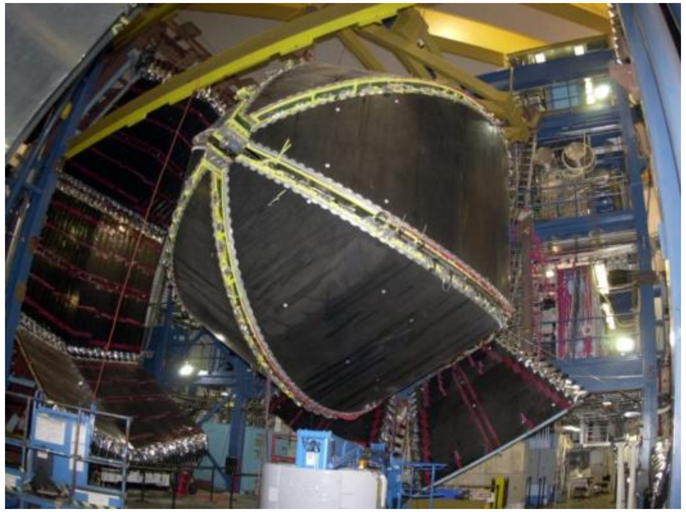


EIC Integrated luminosity needs vs. energy ranges and ion species for White Paper science program. Dual columns with different hashing represent different polarization (LL and LT) – each requiring integrated luminosity proportional to the height of the bar. Measurements that can be done concurrently are superimposed on taller columns.

Why EIC Should be Built at Jefferson Lab

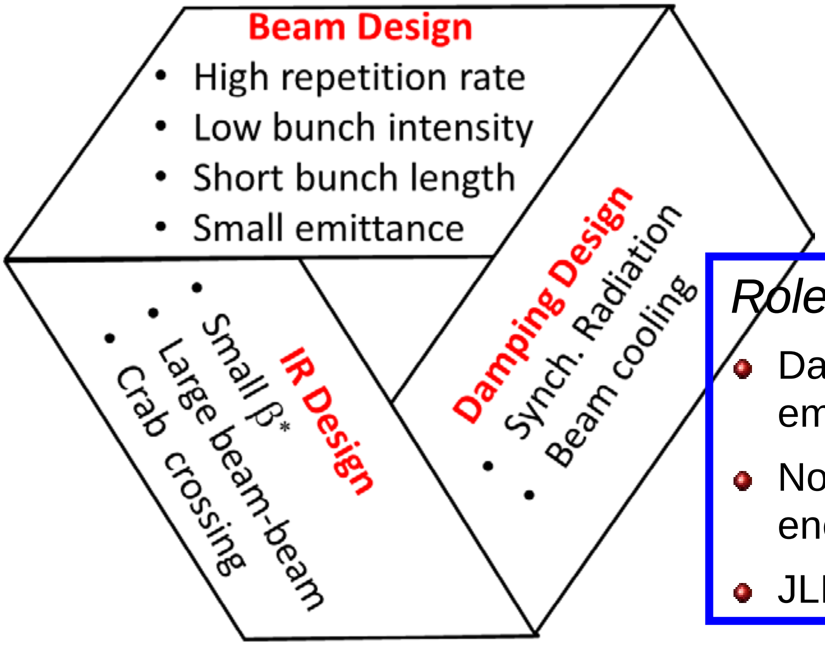


- Large established *user community* in the field
- *CEBAF – world highest Energy CW SRF Linac* as s a full energy injector
  - High bunch repetition rate CW beam (up to 1.5 GHz)
  - Maintains high current in the collider ring using demonstrated top-up injection
- *New* collider complex
  - Modern design and technology
  - Flexibility to optimize (some other existing hadron facilities 50+ years old)
- Opportunity of applying *new advanced technologies*
  - Novel high luminosity concept (based on high rep rate colliding beams)
  - Novel figure-8 for high polarization of any particles including deuterons
  - Deep cooling of hadron beam
- Balance of good machine performance and low technical risk
- Large established user community in the field
- Physics driven machine design
  - Luminosity optimized around the CM range of physics interest
  - Deeply integrated detector and machine design for full acceptance



Concepts for High Performance: Many Short Bunches + Figure-8 Rings

- *Conventional* approach for hadron colliders
  - Few colliding bunches ➔ low bunch frequency
  - High bunch intensity ➔ long bunch ➔ large β^*
- Approach: *high bunch rep-rate + short bunch beams* (standard for lepton colliders, KEK-B >2x10^{34}/cm^2/s)
- JLEIC is based on CEBAF, *already* up to 1.5 GHz
- *New green field* ion complex can be designed to deliver high bunch repetition rate

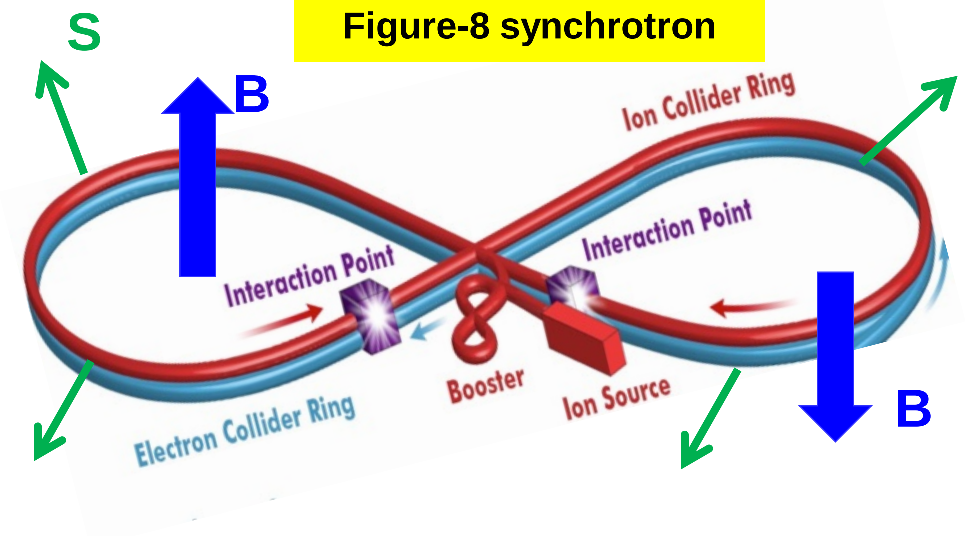


Role of cooling of ion beams

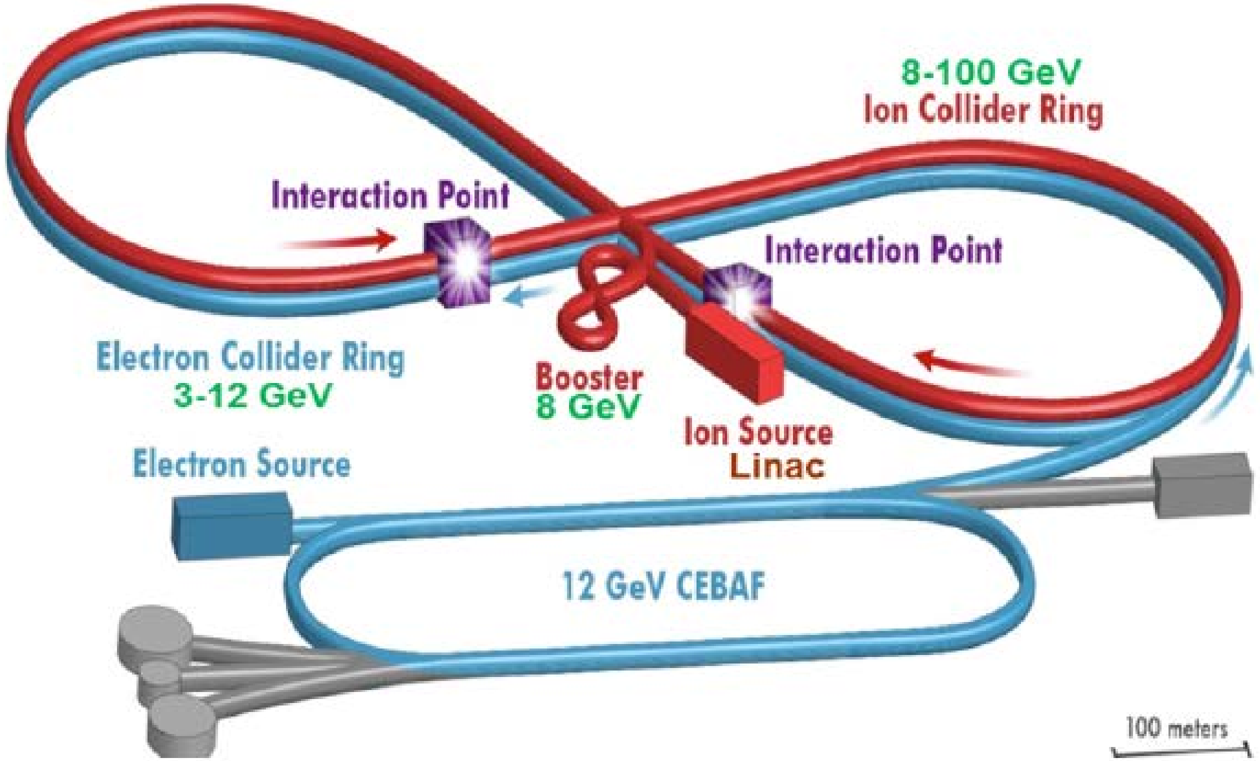
- Damping is critical for beam formation, emittance reduction and preservation
- No SR for ions in JLEIC medium energy range
- JLEIC relies on *electron cooling*

- Adopted a figure-8 topology for ion rings
  ➔ *Enabled by a* ***green field*** *collider ring design*
- Spin precessions in the left & right parts of a figure-8 ring ***exactly cancelled*** ➔ spin tune is ***zero***
- Does not cross spin resonance during energy ramp
- Spin can be controlled and stabilized by compact spin rotators, no need of Siberian Snakes
- The ***only way*** to accelerate/store polarized deuterons in medium energy range (gyromagnetic ratio *g-2* too small)

Figure-8 synchrotron



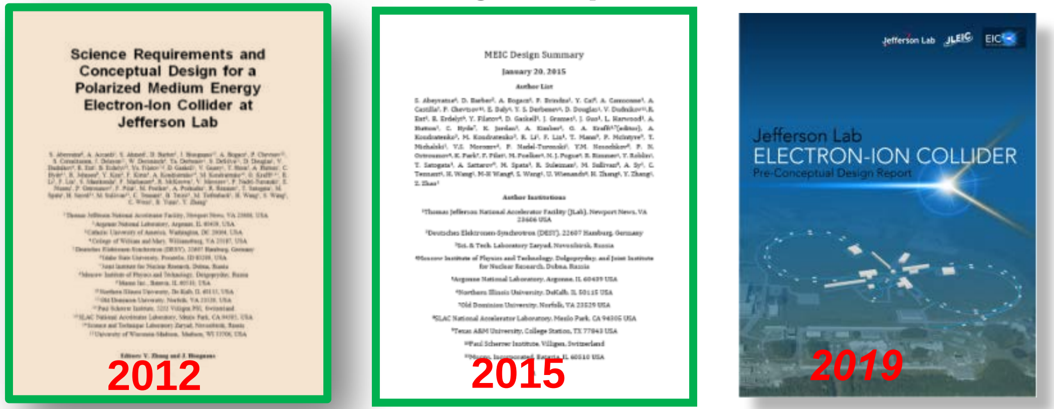
JLEIC Layout



- Electron complex
  - CEBAF as a full energy injector
  - Collider ring
- Ion complex
  - Ion sources and linac
  - Booster (8 GeV, figure-8)
  - Collider ring (up to 100 GeV, figure-8)
- IP/detectors
  - Two, full acceptance
  - Horizontal crossing, w/ crab cavities

CEBAF fixed-target program compatible with concurrent JLEIC operations

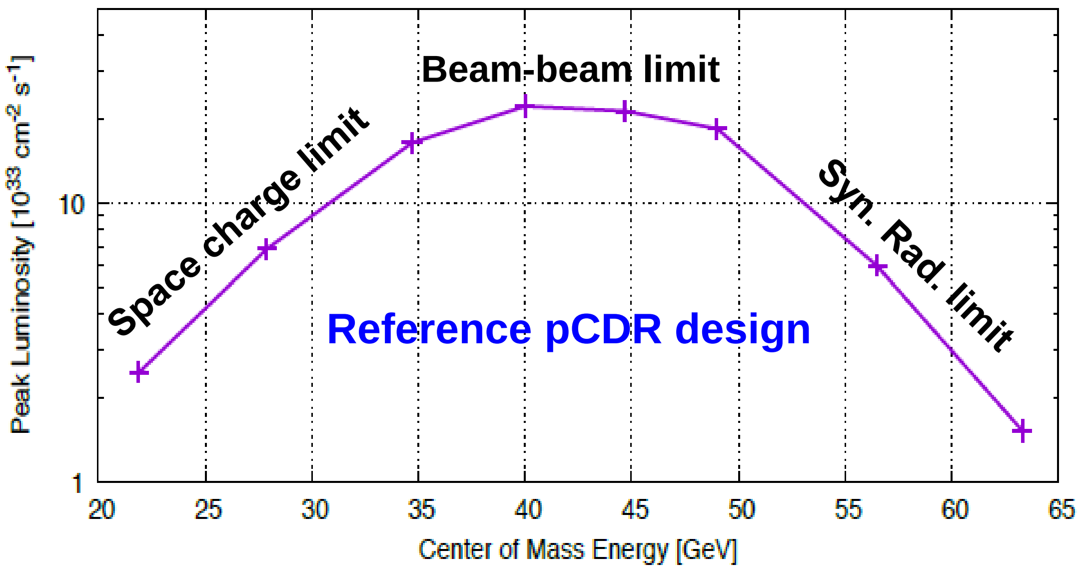
Design Report

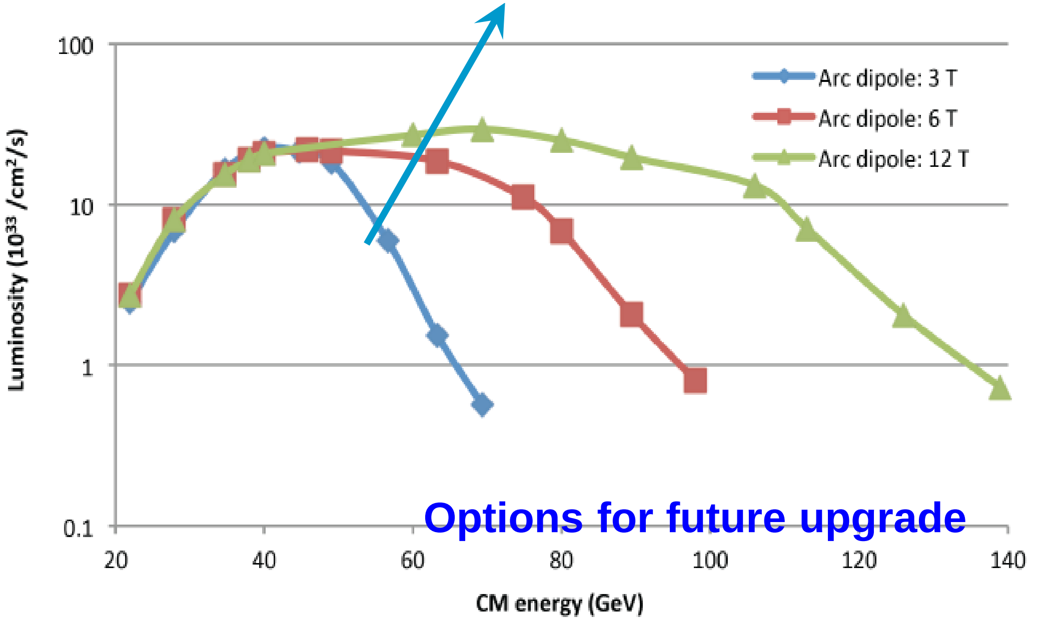


JLEIC *e-p* Parameters and Luminosity Performance

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	e	p	e	p	e
Beam energy	GeV	40	3	100	5	100	10
Collision freq	MHz	476		476		476	
Particles/bunch	10^{10}	0.98	3.7	0.98	3.7	0.98	0.93
Beam current	A	0.75	2.8	0.75	2.8	0.75	0.71
Polarization	%	80	80	80	80	80	75
Bunch length,RMS	cm	1	1	1	1	1	1
Norm. emitt., h./v.	µm	0.3	24	0.5/0.1	54/10.8	0.9/ 0.18	432/ 86
β*, Horiz, & verti.	cm	8	13.5	6/1.2	5.1/1	10.5/2.1	4/0.8
Beam-beam, v.		0.015	0.09	0.015	0.068	0.002	0.009
Laslett tune-shift		0.06		0.055		0.03	
Detector space, up/down	m	3.6/7	2.96/ 2.2	3.6/7	2.96/ 2.2	3.6/7	2.96/ 2.2
Hourglass(HG)		1		0.87		0.86	
Lumi/IP, 10^{33}	$cm^{-2}s^{-1}$	2.5		21.4		1.7	

Similar high performance for electron-ion (*e-A*) collisions

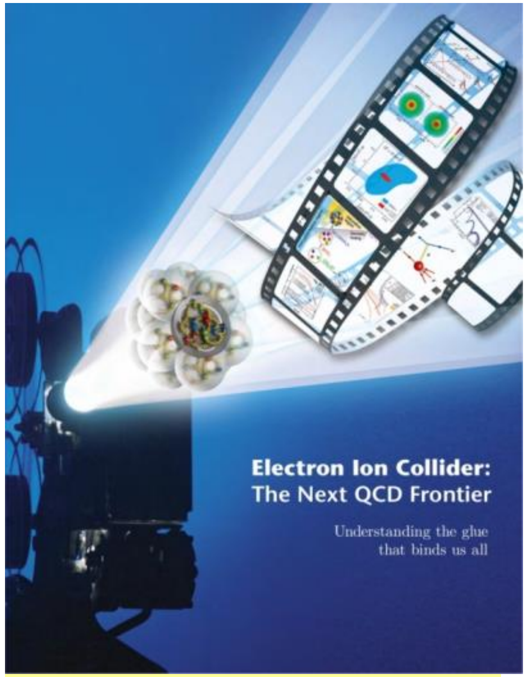




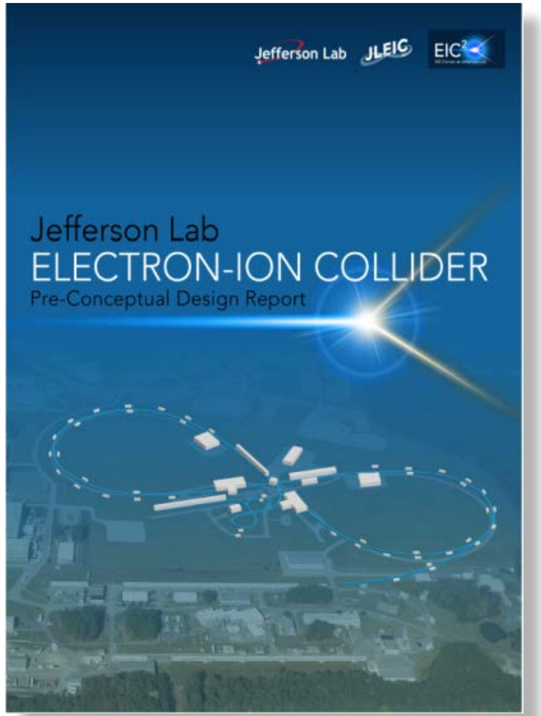
Achieved Goals in Reference pCDR Design

Consistent with the EIC White Paper requirements

- **Energy**
  - Coverage of CM energy from 15 to **65** GeV
  - Electrons 3-12 GeV, protons 20-100 GeV, ions 12-40 GeV/u
- **Ion species**
  - Polarized light ions: p, d, ^{3}He, and possibly Li
  - Un-polarized light to heavy ions up to A above 200 (Au, Pb)
- **Support 2 detectors**
  - Full acceptance capability is critical for the primary detector
- **Luminosity**
  - 10^{33} to 10^{34} $cm^{-2}s^{-1}$ per IP in a *broad* CM energy range
- **Polarization**
  - At IP: longitudinal for both beams, transverse for ions only
  - All polarizations >70%
- **Capability for upgrade to higher CM energy ~ 140 GeV**



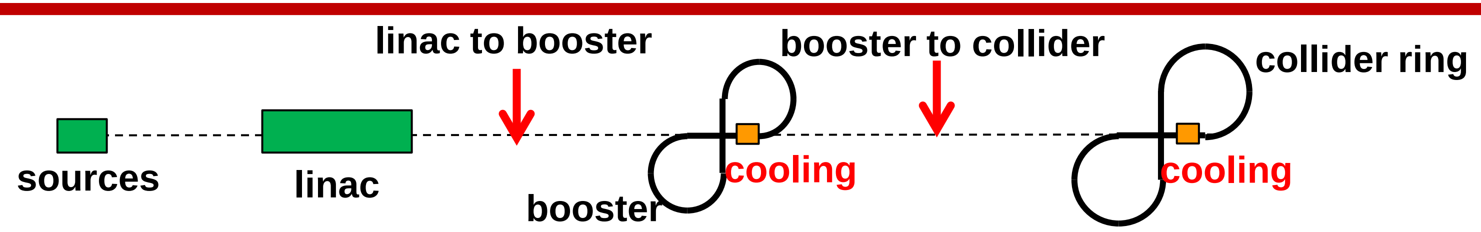
EIC Science White Paper

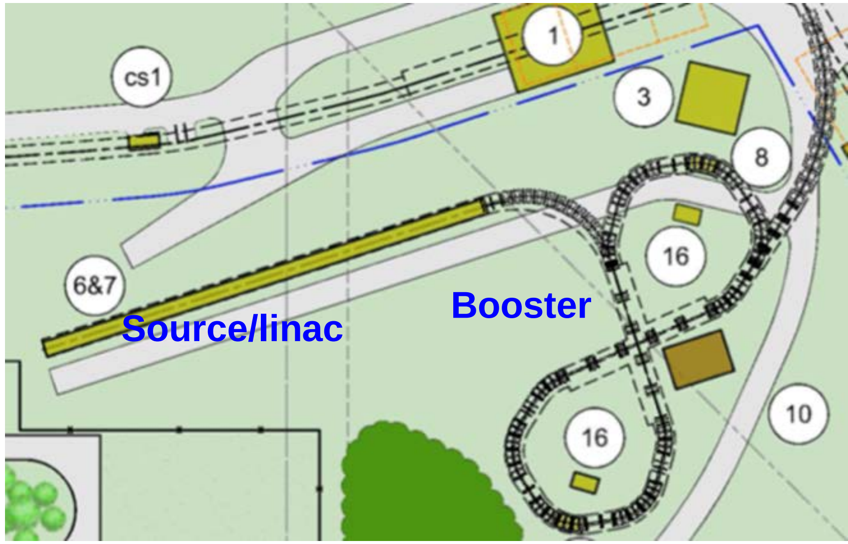


JLEIC pCDR

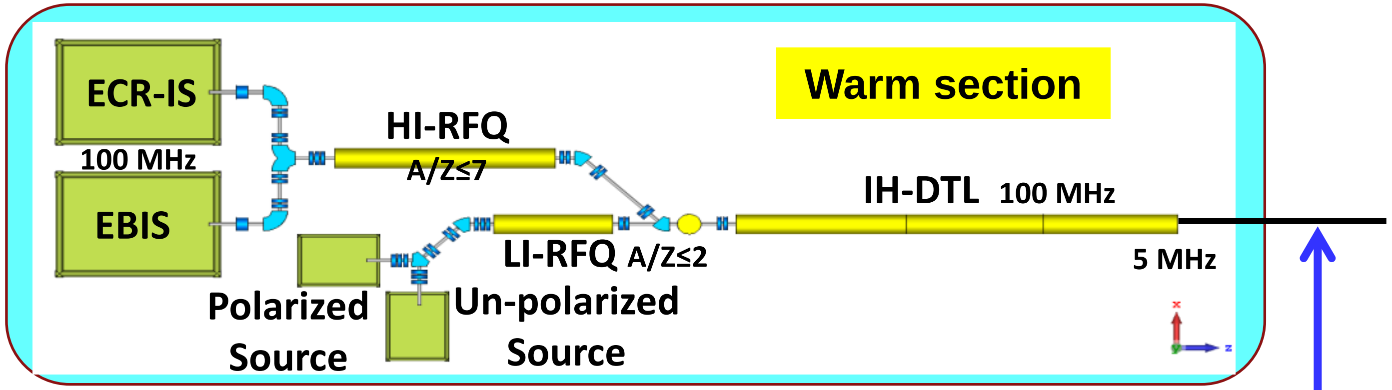
JLEIC Ion Injector: Warm/SRF Ion Linac

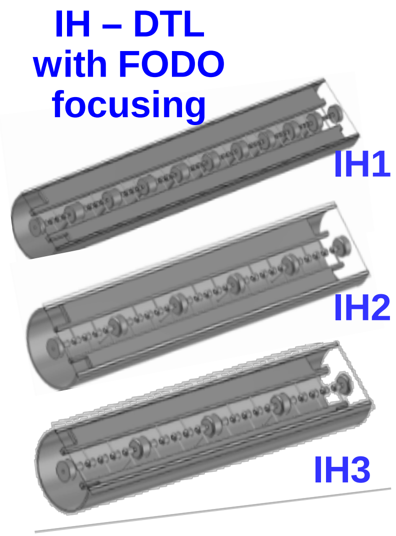
JLEIC ion injector complex





- Two RFQs, separate LEBTs and MEBTs for light ions (A/q~2) & heavy ions (A/q~7) (different current/emittance requirements)
- RT Structure: IH-DTL with FODO focusing lattice (significantly better beam dynamics)
- SRF section made of 3 QWR and 9 HWR modules
- Stripper section for heavy-ions after 2nd QWR module
- Pulsed linac: up to 10 Hz rep rate and ~ 0.5 ms pulse length

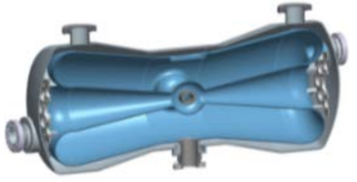




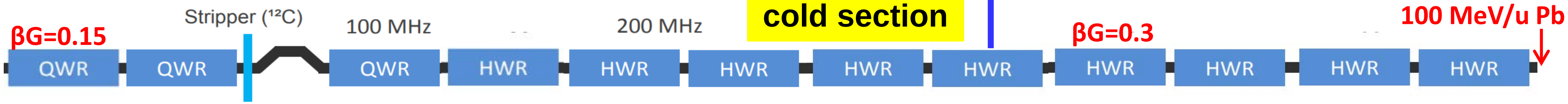
Options for RFQ:
4-vane bolted

Quarter Wave Resonator (QWR)

End of ion linac
280 MeV protons
100 MeV/u Pb



Half-Wave Resonator (HWR)

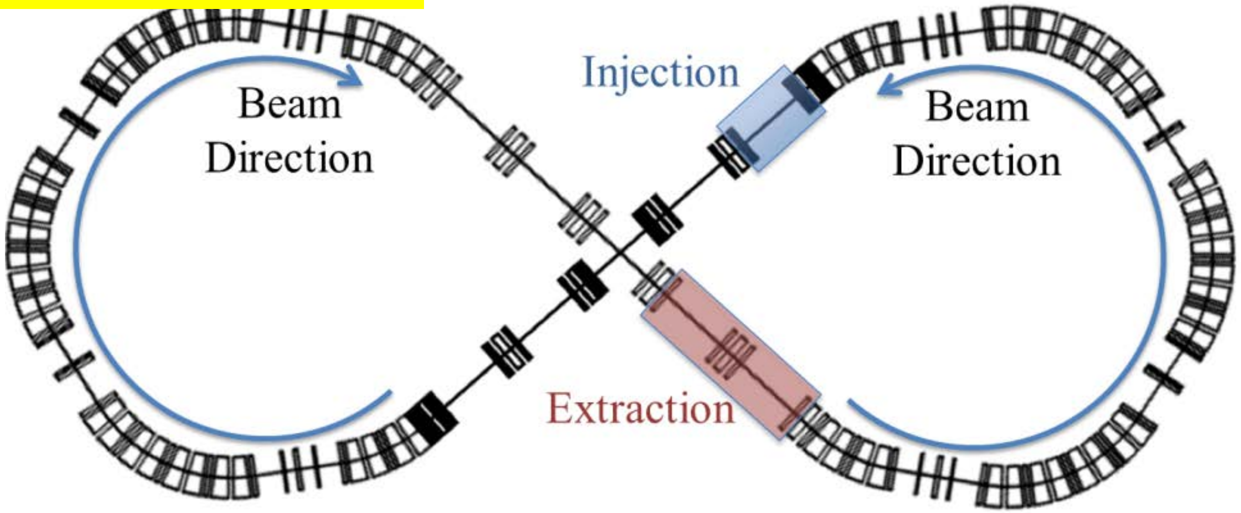


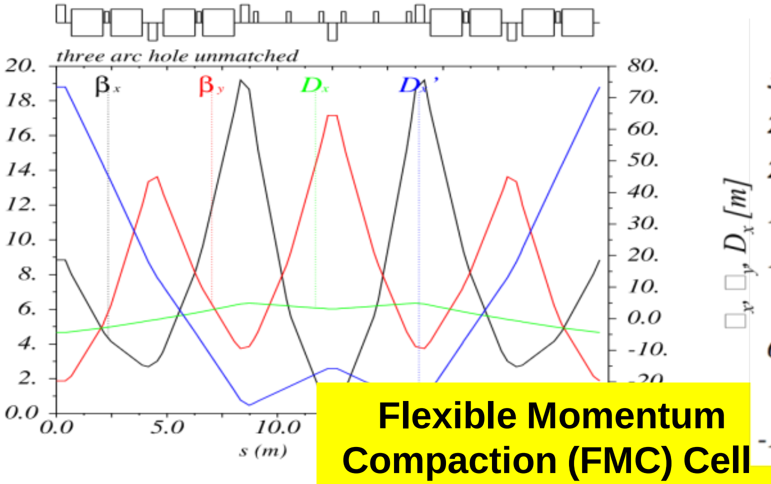
JLEIC Ion Injector: Booster

- Figure-8 shape for high polarizations
- Extraction kinetic energy: 7.9 GeV
- Cos-theta SC Magnets: up to 3 T, ramping ~1 T/s
- Circumference: 313 m
- No transition crossing (γ_T=18.65)

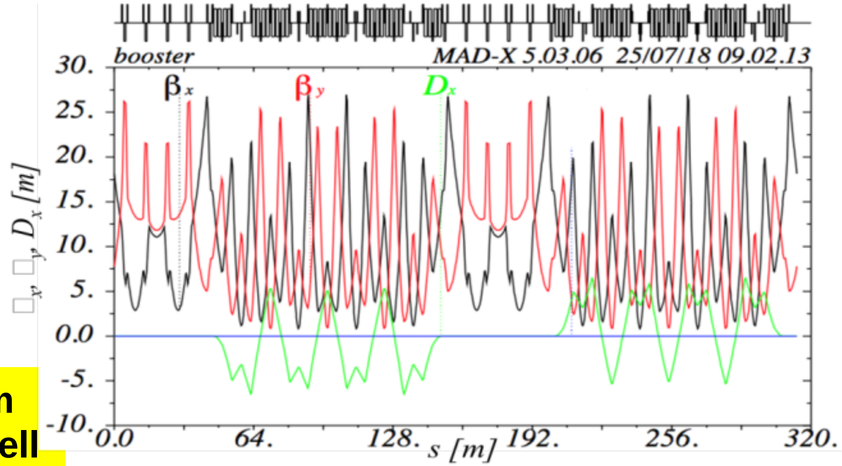
Element	Length (cm)	count	T (max)	T/m (max)	T/m^2 (max)
Dipole	142.18	64	3		
Quadrupole	40	70		29.57	
Quadrupole	80	12		24.27	
Sextupole	20	64			210

Circumference: 313 m





Flexible Momentum Compaction (FMC) Cell

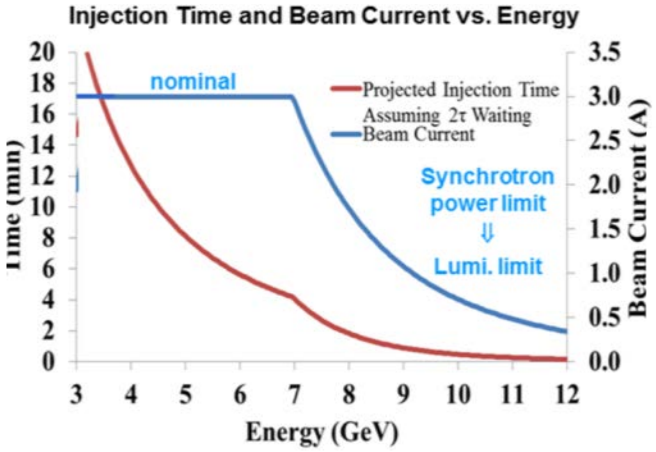


JLEIC Electron and Ion Collider Rings

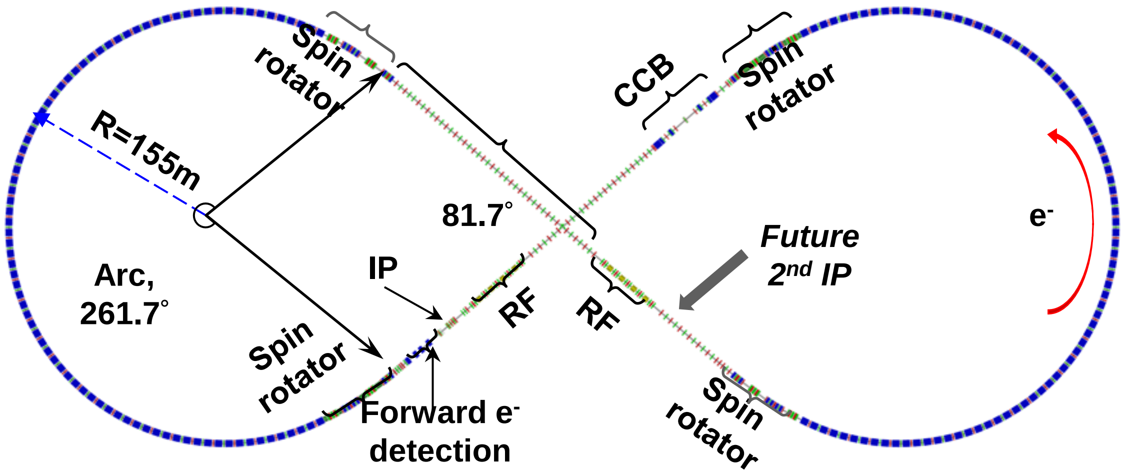
- Two rings stack vertically
- Horizontal crab crossing at IPs
- Electron vertical chicane
- Supports two IPs, fit to JLab site
- Beamline/optics design completed (including low-β insertion, etc.)

		p	e
Circum.	m	~2257	
Crossing	deg	77.4	
Lattice		FODO	
Dipole/quad	m	8/0.8	5.4/0.45
Cell length	m	22.8	15.2
Max. dipole	T	3	~1.5
SR power	kW/m		10
Transition γ_{tr}		12.5	32.0

Electron beam
— 3 A at up to 7 GeV
— Emittance 54 µm@5 GeV
— SR density < 10 kW/m
— Total power up to 10 MW

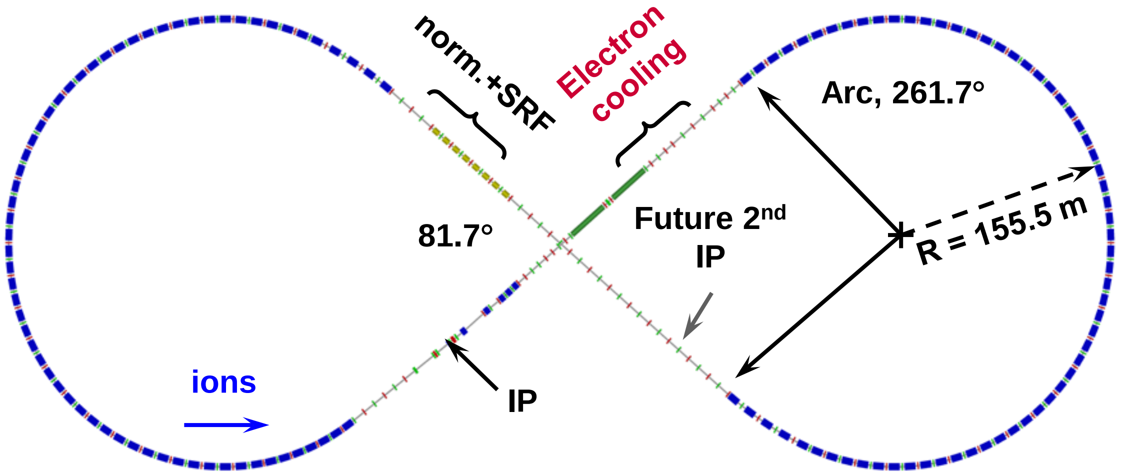


Electron Collider ring w/ major machine components



- 12GeV CEBAF as a full energy (polarized) injector
- Capability of top-off injection or continuous injection

Ion collider ring w/ major machine components



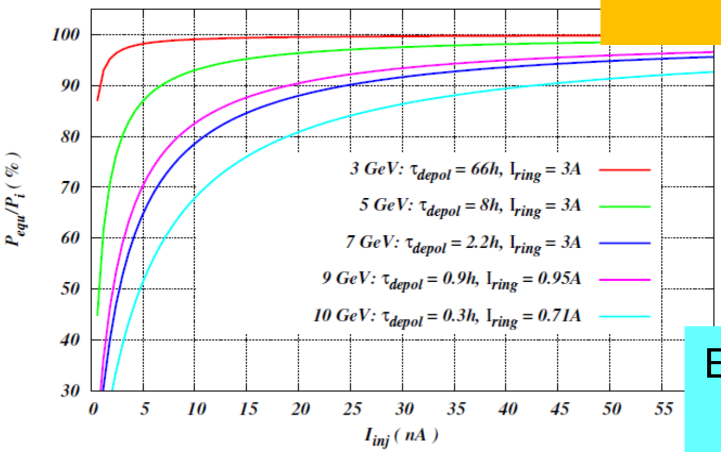
JLEIC Electron and Proton/Light Ion Polarization

Electron Polarization Design

- Polarized (~85%) source and CEBAF linac
- Vertical in arcs, longitudinal in straights, by *Universal Spin Rotator*
- Spin in one direction in the whole ring (parallel to dipole field in one arc, antiparallel in another arc)
- *Spin flip*: charging helicity of laser in the photo-gun
- *Continuous injection* of a low current (~50 nA) beam from CEBAF

Energy (GeV)	3	5	7
Lifetime (hrs)	116	9	1.7

Polarization lifetime with continuous injection



Expect to achieve
85% at 3 GeV
~80% at 10 GeV

Ion Polarization Design

- Figure-8 concept: spin tune energy independent
- Spin stabilization by small fields: ~3 Tm vs. < 400 Tm for deuterons at 100 GeV
- Enable acceleration/storage of polarized deuterons
- Frequent adiabatic spin flips

spin rotator

...of small rotations about different axes, ...polarization orientation at any point

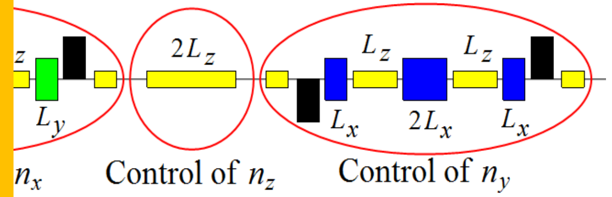


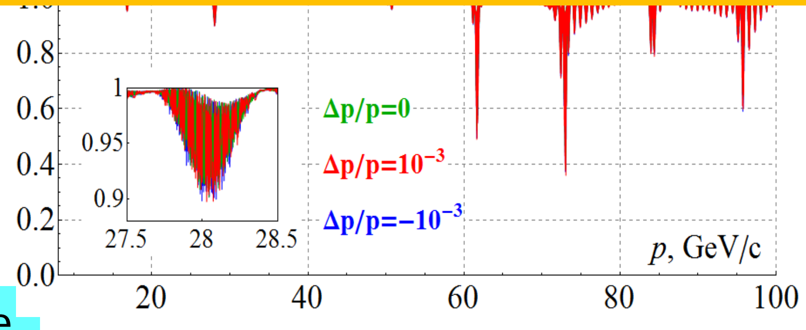
Figure-of-Merit (FOM) ~ $P_e^2 \cdot P_p^2 \cdot L$

For the polarization part

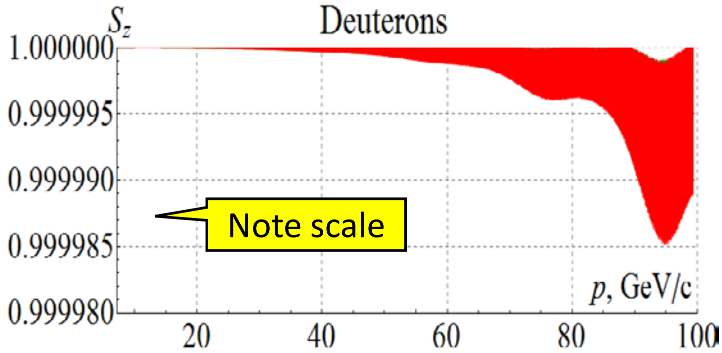
EIC White Paper: $P_e^2 \cdot P_p^2 = 0.24$

JLEIC expected: $P_e^2 \cdot P_p^2 = 0.46$ to 0.52

(Approx. a factor of 2)



Zgoubi simulation



Electron Cooling and DC/ERL Coolers

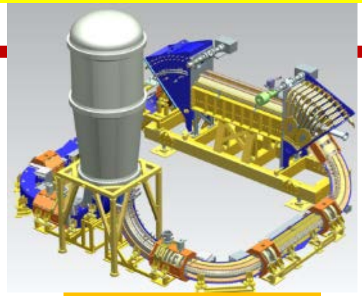
- **Cooling of JLEIC proton/ion beam**
  - Achieving very small emittance (***order of magnitude reduction in all dimensions***)
  - Achieving short bunch length **~1 cm** (with strong SRF)
  - Suppressing IBS induced emittance degradation
- **JLEIC: *conventional electron cooling***

  Well established technology (in the low energy DC regime)
- **Multi-step scheme**
  - high cooling efficiency at low energy and small emittance

$$\tau_{cool} \sim \gamma^2 \frac{\Delta\gamma}{\gamma} \sigma_z \varepsilon_{4d}$$

High voltage DC Cooler: within state-of-art

4.3 MeV DC Cooler @Fermilab



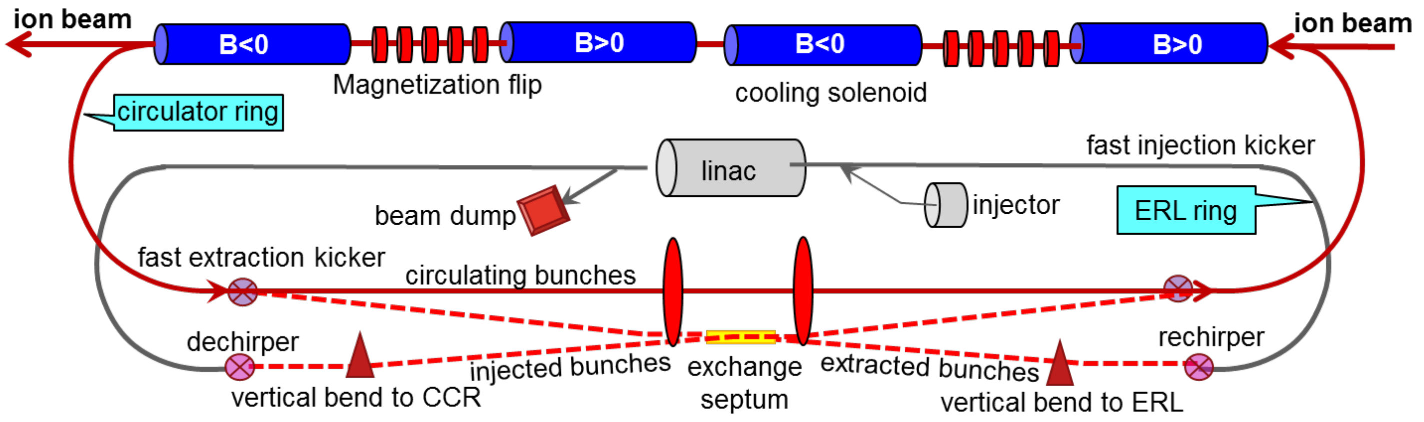
2 MeV DC Cooler @Jülich

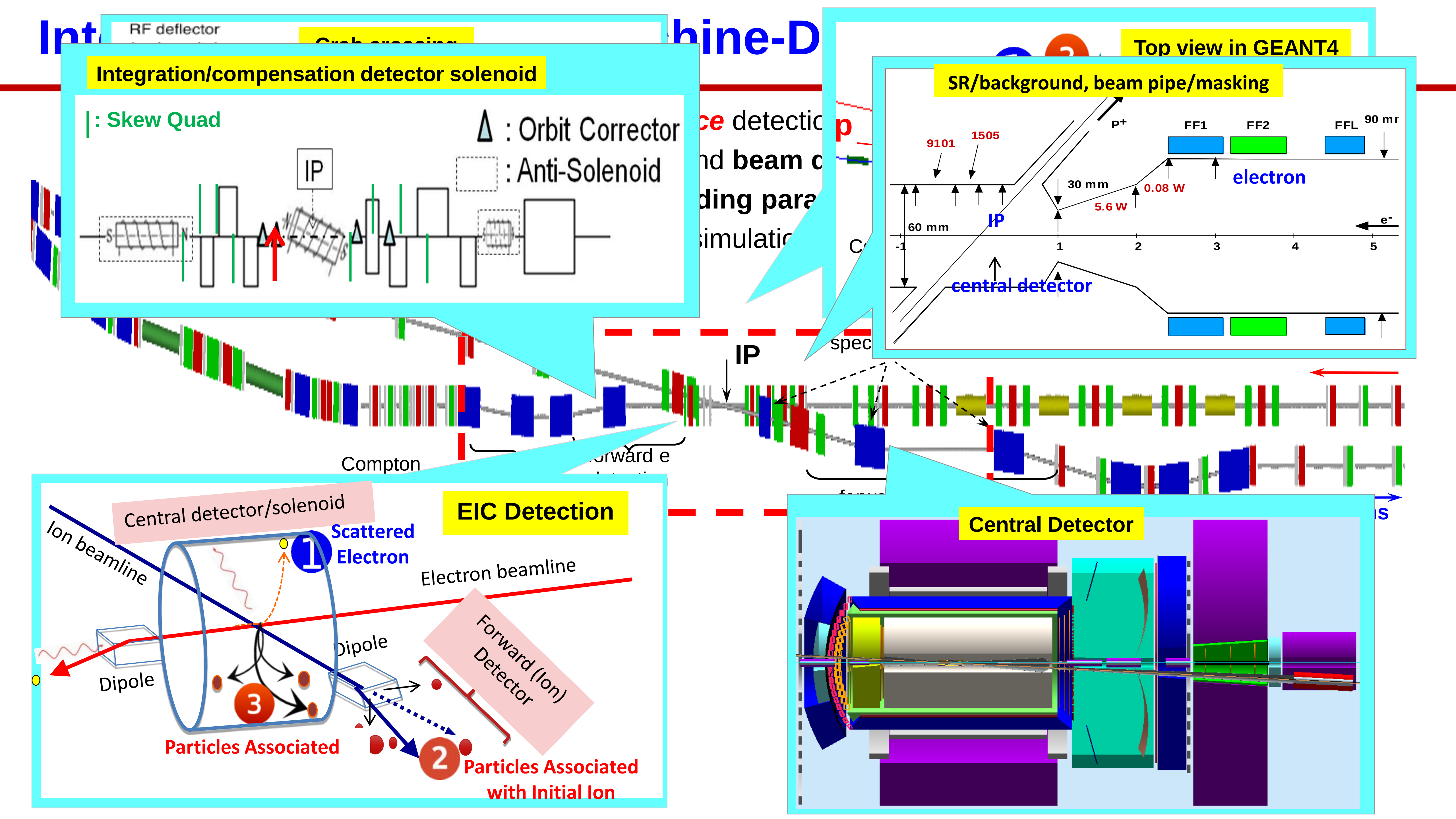
Multi-phased Cooling Scheme

Ring	Functions	Kinetic energy (GeV / MeV)			Cooler type
		Proton	Lead ion	Electron	
booster ring	Accumulation of positive ions		0.1 (injection)	0.054	DC
collider ring	Maintain emitt. during stacking	7.9 (injection)	2 (injection)	4.3 (proton) 1.1 (lead)	DC
	Pre-cooling for emitt. reduction	7.9 (injection)	7.9 (ramp to)	4.3	DC
	Maintain emitt. during collision	Up to 100	Up to 40	Up to 54.5	ERL

High Energy Magnetized Electron Cooler

- Same-cell energy recovery in 952.6 MHz SRF cavities
- Uses harmonic kicker to inject and extract from CCR (divide by 11)
- Assumes high charge, low rep-rate injector (w/ subharmonic acceleration and bunching)
- Use magnetization flips to compensate ion spin effects





RF deflector
Integration/compensation detector solenoid
|: Skew Quad
: Orbit Corrector
: Anti-Solenoid
IP
Top view in GEANT4
SR/background, beam pipe/masking
9101
1505
P+
FF1
FF2
FFL
90 mr
electron
30 mm
0.08 W
5.6 W
60 mm
IP
e-
-1
1
2
3
4
5
central detector
IP
spec
Compton
EIC Detection
Central detector/solenoid
Ion beamline
Scattered Electron
Electron beamline
Dipole
Dipole
Forward (Ion) Detector
Particles Associated
Particles Associated with Initial Ion
Central Detector

JLEIC *Prioritized* Pre-Project R&D Topics

Prioritization was endorsed by a DOE EIC R&D Community Review Panel (11/2016)

1. High priority

- Strong hadron cooling
- High current single-pass ERL for hadron cooling
- A high current magnetized electron injector
- Magnet design/prototyping for high acceptance IP
- An ERL-CC test facility using existing infrastructure (LERF) with magnetized beam & fast kicker
- Crab cavity operation in a hadron ring
- Complete and test of a full scale super-ferric magnet
- Gear change synchronization & impact on beam dynamics
- High power fast kicker for (2ns bunch spacing) feedback

2. High-medium priority

- Electron cooling simulations
- Fast kicker prototype for multi turn cooler
- Spin tracking in ion and electron rings
- Fast kicker proto-type/test for circulator cooler
- IR design and detector integration
- Super-ferric 3T fast ramping short dipole
- SRF cavity systems including crab cavity
- Polarized ion sources (D^-, $^3He^{++}$)
- Operating CEBAF in the JLEIC injection mode

3. Medium priority

- Nonlinear beam dynamics in collider rings
- Space charge in ion complex, beam formation
- Instability and feedback systems
- Ion & electron ring background & vacuum
- Bunched beam cooling experiment
- Fast kicker test with beam

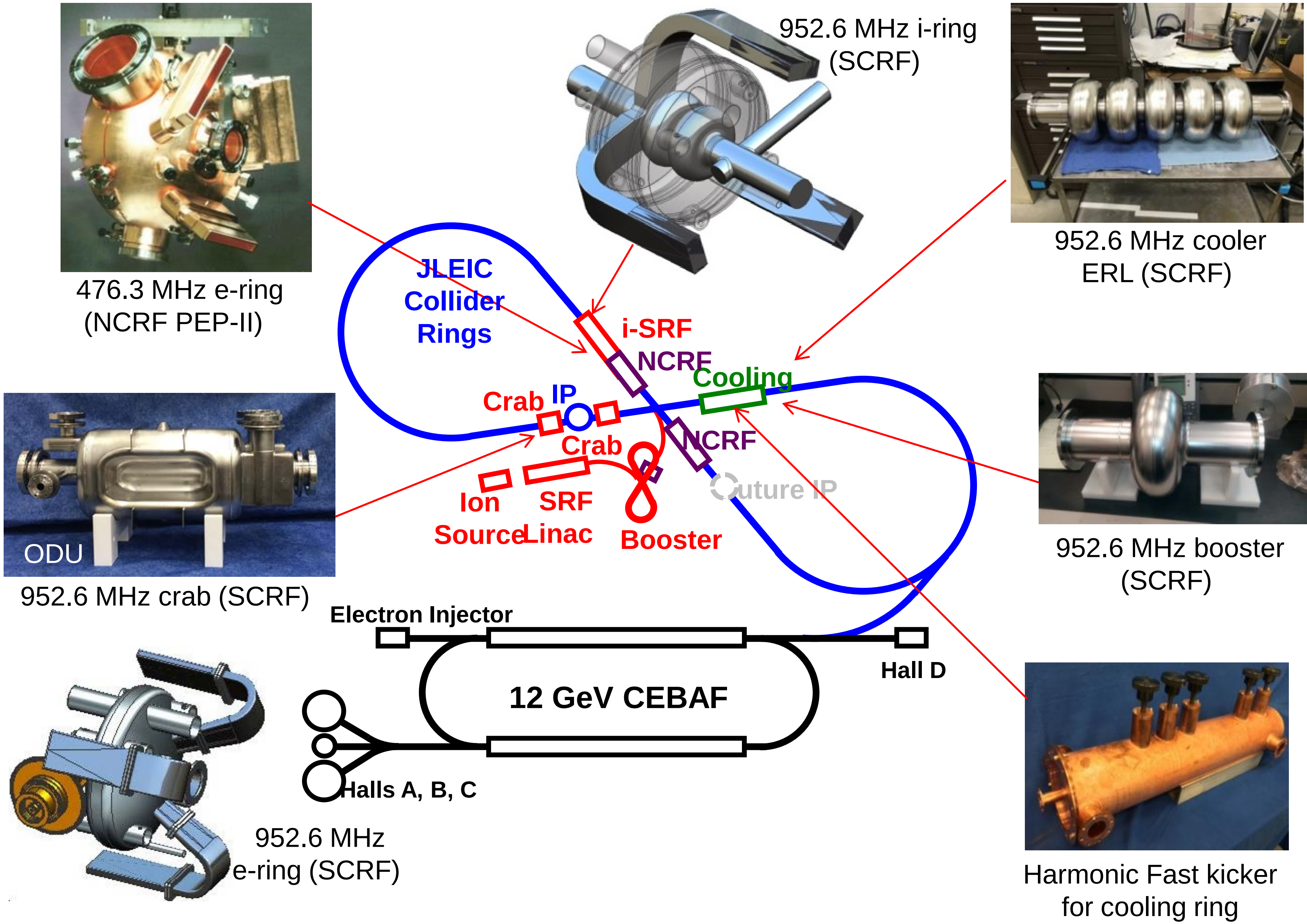
Blue font: lead institute

Presently DOE funded R&D activities (and collaborations)

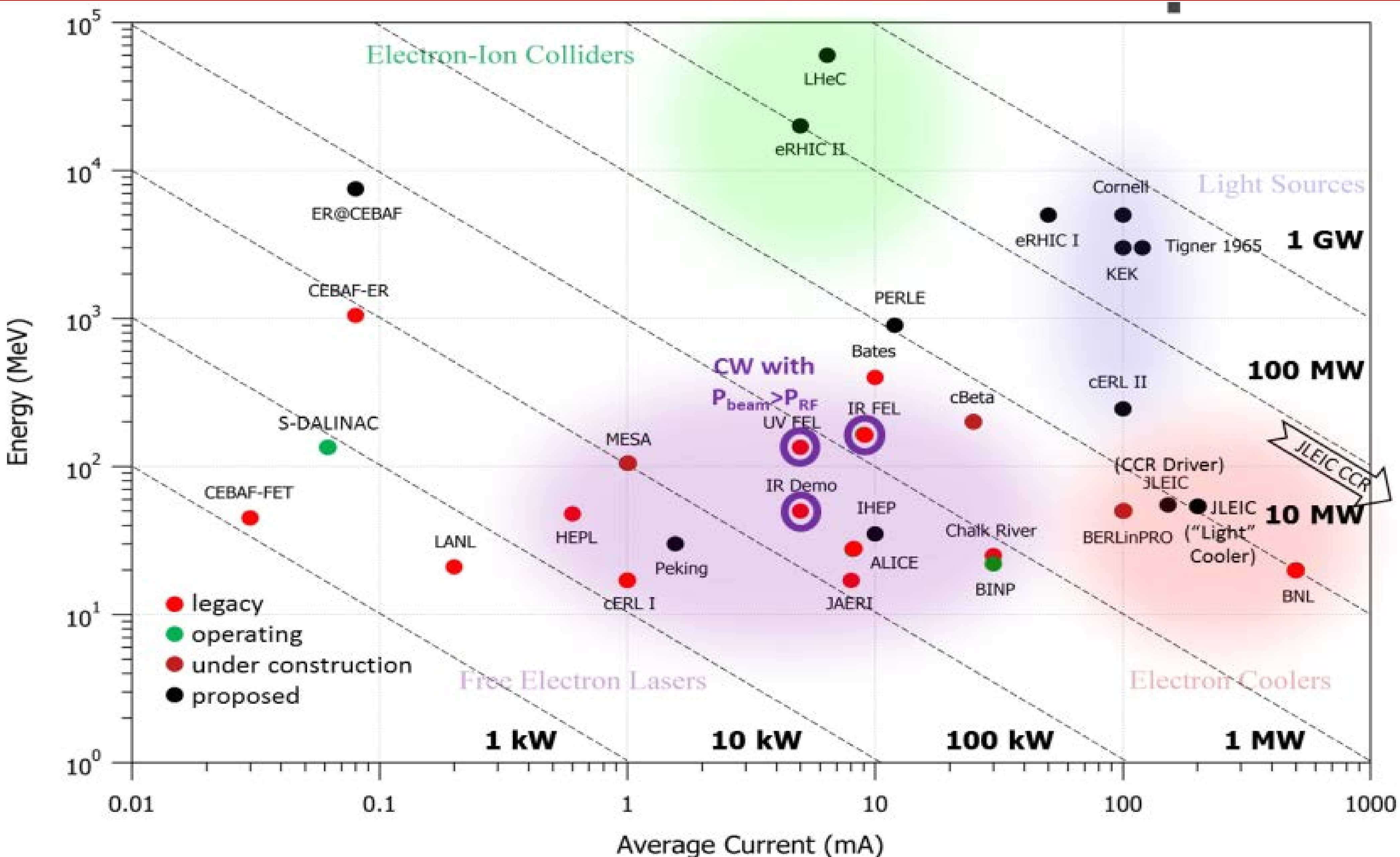
1. Crab cavity operation in a hadron ring (**ODU**, JLab, BNL)
2. Development of innovative high-energy magnetized electron cooling for an EIC (**JLab**, BNL, FNAL, ODU)
3. Strong hadron cooling with micro-bunched electron beams (**BNL**, JLab, SLAC, ANL)
4. High Gradient Actively Shielded Quadrupole (**BNL**, JLab, LBNL)
5. Validation of EIC IR magnet parameters & requirements using existing magnet results (**JLAB**, SLAC, LBNL)
6. Experimental verification of spin transparency mode in an EIC (**JLab**, BNL)
7. Alternative Approach for the JLEIC Ion Complex & Beam Simulation Tools for the EIC (**ANL**, JLab)
8. High Bandwidth Beam Feedback Systems for a High Luminosity EIC (**ANL**, JLab)

Development of RF cavities for JLEIC

- Define RF system requirements
- Support the pre-CDR
- Cooler ERL injector, and harmonic kicker
- New Ion ring cavities
- New e-ring cavities
- Cavity prototyping
- Fast feedback
- Impedance (incl. IR)
- CEBAF as injector

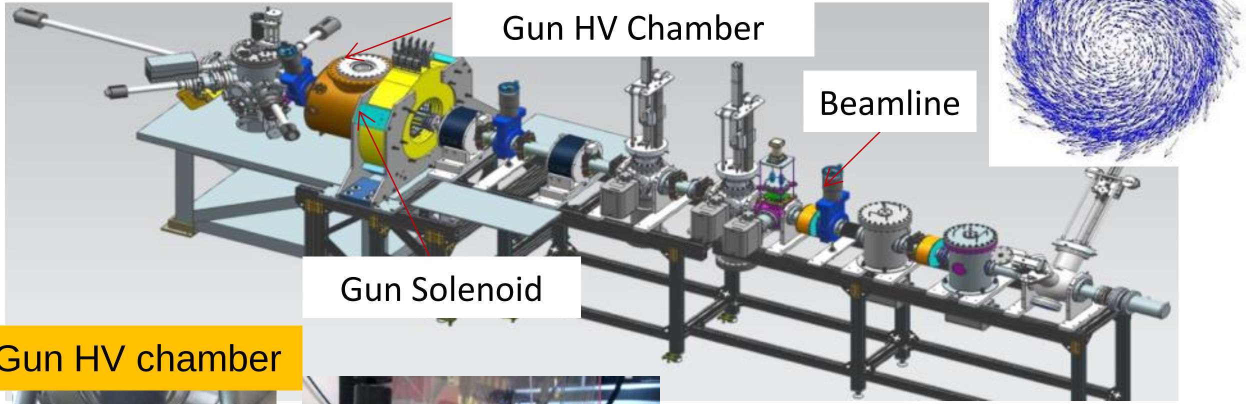


Landscape of ERL and State-of-Art



ERL Cooler R&D

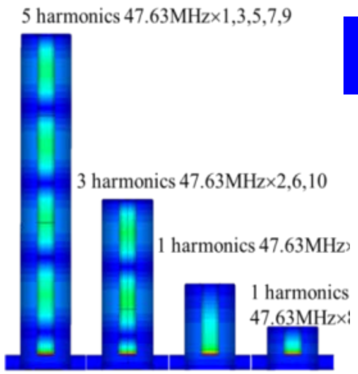
Magnetized source development and test stand



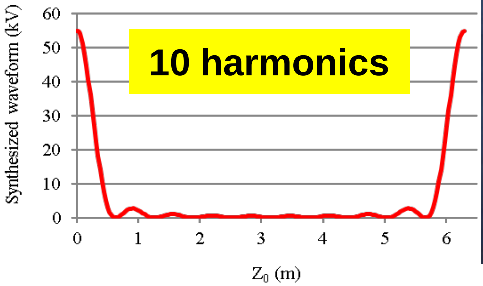
Gun HV chamber

Gun solenoid

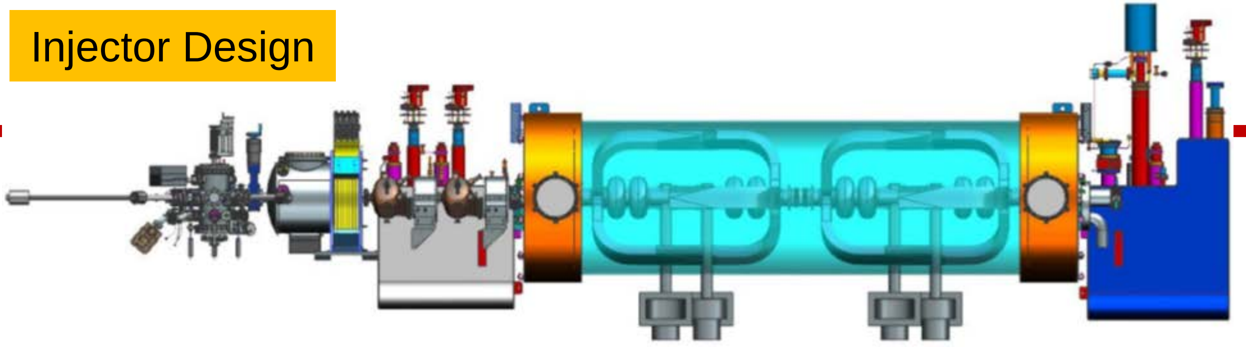
A successful demonstration of magnetized electron source (LDRD)



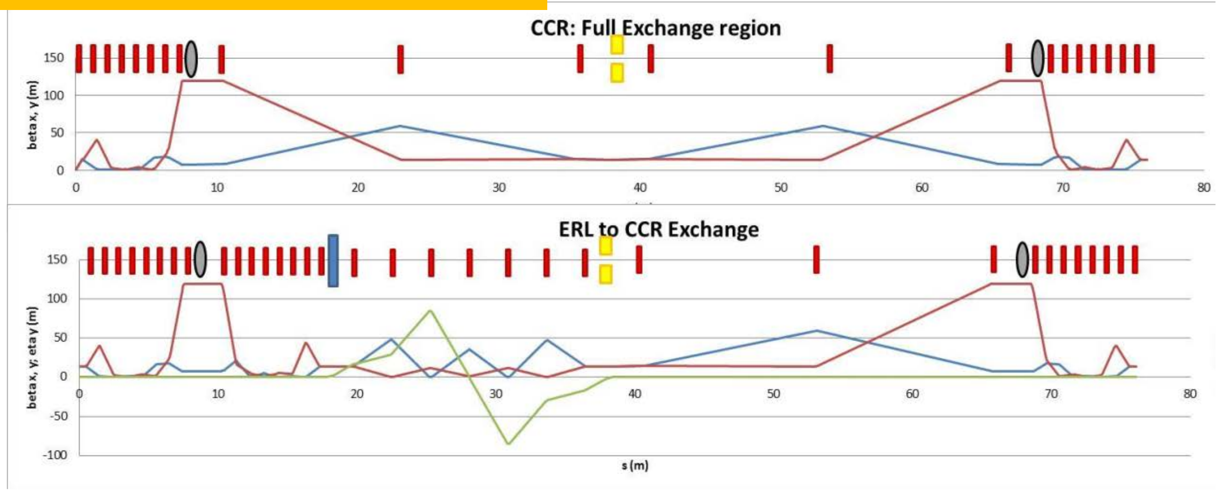
A proto-type was built and under tests



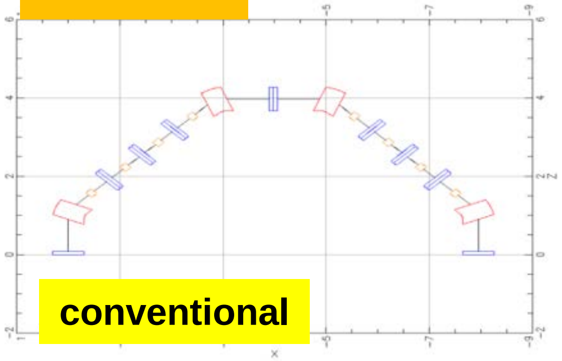
Injector Design



Circulator cooler ring design



CCR arc



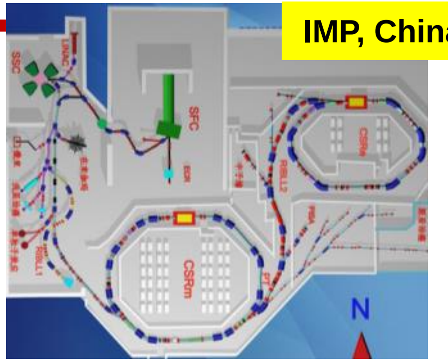
Faux Fixed Focus Alternating Gradient

Demonstration of Bunched Beam Electron Cooling

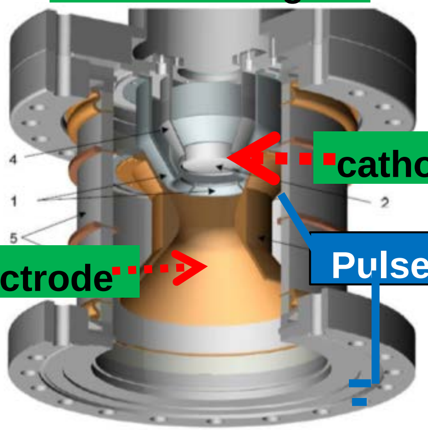
- All electron cooling to date achieved using a DC electron beam
- Cooling by a bunched e-beam is one critical R&D item for JLEIC
- ***Proof-of-Principle Experiment:*** utilizing an existing DC cooler, modulating grid voltage of a thermionic gun to generate a pulsed beam as short as 100 ns

- May 2016, 1st experiment: bunched beam cooling was observed
- Nov. 2016, machine development (improving beam diagnostics)
- April 2017, 2nd experiment: more measurements
- Sept. 2018, machine development (new BPM)
- Dec. 2018, 3rd experiment: more measurements (under analysis)

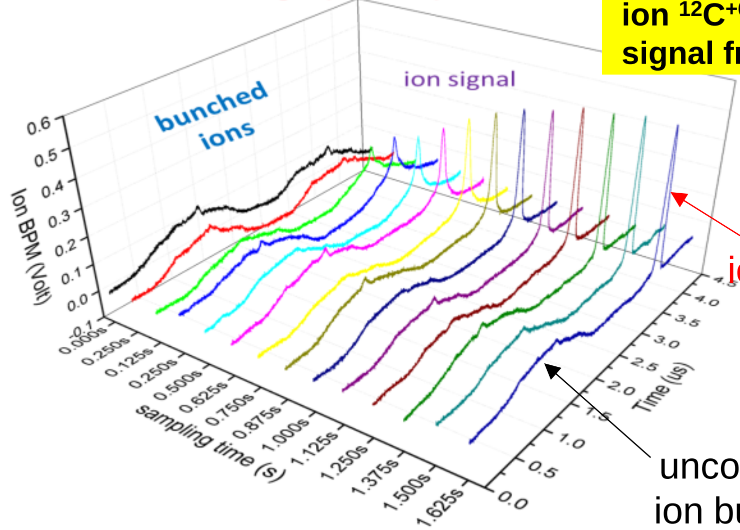
IMP, China

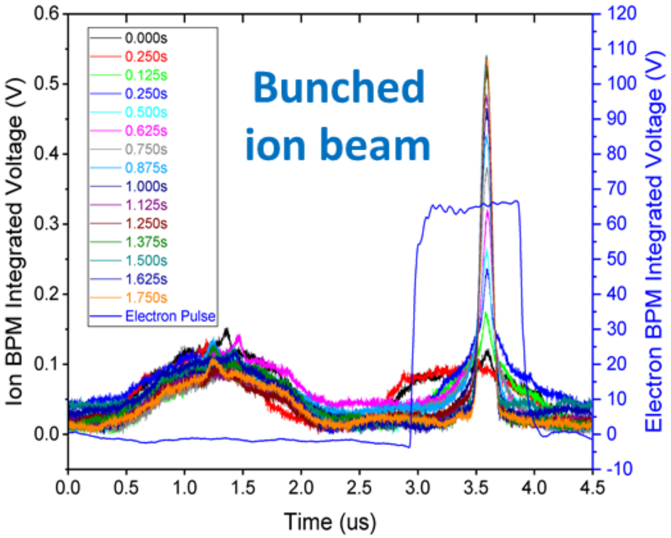


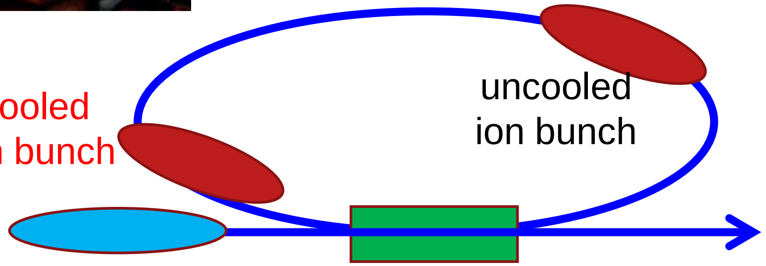
A collaboration of JLab and IMP (China)



Bunched Beam e-Cooling Observed!







JLab-IMP Cooling Collaboration

Y. Zhang (PI), A. Hutton, K. Jordan, T. Powers, R. Rimmer, M. Spata, H. Wang, S. Wang, H. Zhang, JLab

L. Mao (PI), J. Li, X. Ma, R. Mao, M. Tang, J. Yang, X. Yang, Y. Yuan, H. Zhao, H.W. Zhao, T. Zhao, IMP, China

Summary

- JLEIC design is driven by and optimized for EIC physics requirements
- JLEIC delivers high luminosity up to above 2×10^{34} /cm^2/s over a broad CM energy range
- JLEIC delivers high polarization based on a revolutionary concept of figure-8 ring
- JLEIC IR design supports full acceptance detectors critical to its science program
- The JLEIC team/collaboration is presently engaged in pre-project accelerator R&D
- JLab held 6 biannual JLEIC collaboration meetings, BNL/JLEIC held 2 EIC joint collaboration meetings

JLEIC Collaboration

For Accelerator and Detector only

S. Benson, A. Bogacz, P. Brindza, A. Camsonne, Ya. Derbenev, M. Diefenthaler, D. Douglas, R. Ent, R. Fair, Y. Furletova, R. Gamage, R. Geng, P. Ghoshal, J. Grames, K. Jorden, J. Guo, F. Hanna, T. Hiatt, H. Huang, A. Hutton, K. Jordan, A. Kimber, D. Kashy, G. Krafft, R. Li, F. Lin, M. Mamum, F. Marhauser, T. Michalski, V. Morozov, E. Nissen, G. Park, H. Park, M. Poelker, T. Powers, R. Rajput-Ghoshal, R. Rimmer, Y. Roblin, T. Satogata, A. Seryi, M. Spata, R. Suleiman, A. Sy, C. Tennant, H. Wang, S. Wang, M. Wiseman, R. Yoshida, H. Zhang, Y. Zhang – **JLab**

Y. Nosochkov, G. Stupakov, M. Sullivan, C. Tsai - **SLAC**

M. Blaskiewicz, H. Huang, Y. Luo, Q. Wu, F. Willeke – **BNL**

Z. Conway, B. Mustapha, U. Wienands, A. Zholents – **ANL**

Y. Hao, P. Ostroumov, A. Plastun , R. York - **Michigan State Univ.**

S. Abeyratne, B. Erdelyi , F. Piot - **Northern Illinois Univ.**,

J. Delayen, J. Silva, S. Sosa, B. Terzic - **Old Dominion Univ.**

J. Gerity, T. Mann, P. McIntyre, N. Pogue, A. Sattarov - **Texas A&M Univ.**

A. Kondratenko, M. Kondratenko - **Sci. & Tech. Laboratory Zaryad**, Russia

Y. Huang, X. Ma, L. Mao, Y. Yuan, H. Zhao, H.W. Zhao – **IMP**, China

J. Qiang, G. Sabbi - **LBNL**

D. Barber - **DESY**

K. Deitrick, - **Cornell Univ.**

Z. Zhao - **Duke Univ.**

P. Nadel-Turonski, - **Stony Brook Univ.**

G. Bell, J. Cary - **Tech-X Corp.,**

V. Dudnikov, R. Johnson - **Muons, Inc.**

D. Abell, D. Bruhwiler, I. Pogorelov - **Radiasoft,**

Yu. Filatov - **Moscow Inst. of Phys. & Tech.**, Russia

Gone but not forgotten

S. Ahmed, K. Beard, A. Castilla, P. Chevtsov, L. Merminga, F. Pilat, H. Sayed, M. Wang, G. Wei, B. Yunn,

Thank You for Your Attention !

NAS Assessment Findings

1. *(Science)* An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms: How does the mass of the nucleon arise? How does the spin of the nucleon arise? What are the emergent properties of dense systems of gluons?
2. *(Accelerator)* These three high-priority science questions can be answered by an EIC with highly polarized beams of electrons and ions, with sufficiently high luminosity and sufficient and variable center-of-mass energy.
3. An EIC would be a unique facility in the world, and would maintain U.S. leadership in nuclear physics.
4. An EIC would maintain U.S. leadership in the accelerator science and technology of colliders, and help to maintain scientific leadership more broadly.
5. Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.
6. The current accelerator R&D program supported by the Dept. of Energy is crucial to addressing outstanding design challenges.
7. To realize fully the scientific opportunities an EIC would enable, a theory program will be required to predict and interpret the experimental results within the context of QCD, and further, to glean the fundamental insights into QCD that an EIC can reveal.
8. The U.S. nuclear science community has been thorough and thoughtful in its planning for the future, taking into account both science priorities and budgetary realities. Its 2015 Long Range Plan identifies the construction of a high luminosity polarized Electron Ion Collider (EIC) as the highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams (FRIB) at Michigan State University.
9. The broader impacts of building an EIC in the U.S. are significant in related fields of science, including in particular the accelerator science and technology of colliders and workforce development.

Design Risk Evaluation and Mitigation with R&D

"*Jones Report*" of the Community Review of EIC Accelerator R&D for the Office of Nuclear Physics (2/13/2016)

- **"**JLEIC was generally seen by the panel as a medium risk option, assuming the JLab injector complex can serve as an on-energy injector for the electron ring. The hadron injector front-end has been well studied in the context of the Argonne Rare Isotope Accelerator (RIA) design; booster technology also seems to be fairly well established"

Proposed spin transparency test at RHIC

- "The figure-8 design of the storage rings, and in particular for spin preservation in the hadron ring, is a novelty in the accelerator landscape. Adopting this scheme for the JLEIC scheme bears therefore a non-negligible risk without experimental validation. However, given past validation of spin related accelerator tools (e.g., Siberian snakes) the likelihood of success appears rather high"

- ***"Medium risk*** for the machine proposed, with risks associated with the *machine-detector interface* for the number of bunches and some technical aspects of the *hadron cooling ERL system* and the first implementation of a *figure-8 machine*, "

R&D and beam tests at FAST & CBETA

- ***"Higher risk*** based on fundamental limitations on fully addressing the technical requirements presented in the long range plan"

Increase JLEIC CM energy to 100 GeV

Recent Study on High Energy (HE) JLEIC

- High CM energy helps to reach broad science
  (mitigate the biggest design risk)
- A working group was formed to study high energy JLEIC
- Approach:
  - Electron collider ring: no change
  - Ion collider ring: double arc SC dipole field to 6 T
  - Proton: 100 GeV→200 GeV   CM energy: ~100 GeV
- Based on the same design concepts (luminosity, polarization, IR)
  ➔ HE JLEIC should be able to deliver the similar high performance
- Accelerator and beam physics issues studied
  - Ion ring SC magnet,
  - Ion injection scheme and ion injector,
  - high energy cooling,
  - interaction region,
  - RF system
  - crab crossing,
  - detection acceptance

Findings of the study:

- There are technical solutions for all the issues studied, no show-stopper
- Same accelerator R&D, some of them are (incrementally) more challenging;
- The present R&D could be applied to high CM energy JLEIC
- Transition to a HE JLEIC should be straightforward