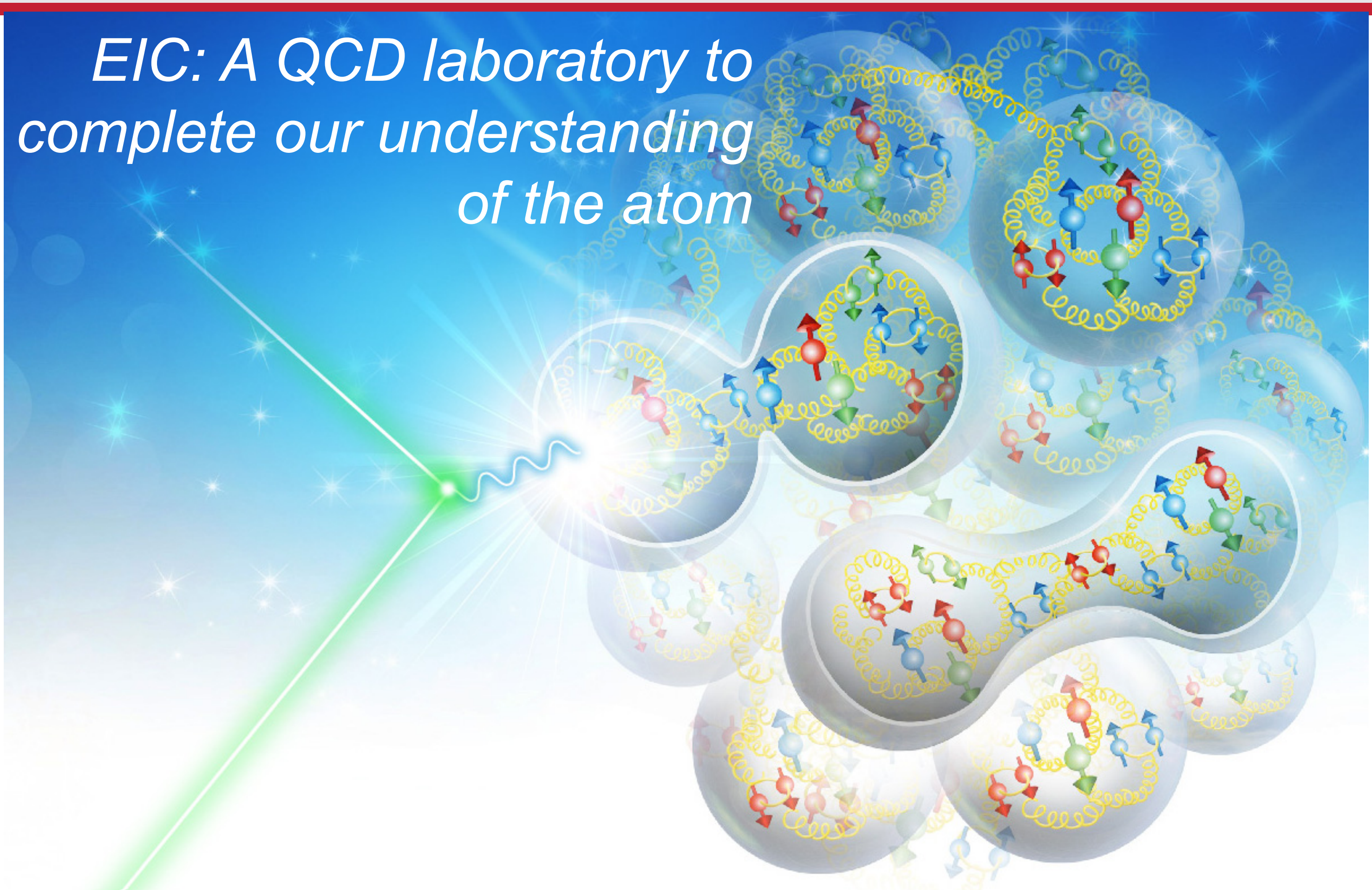
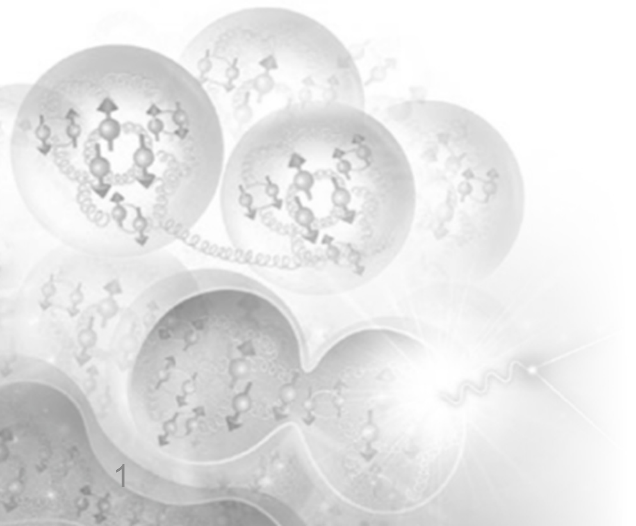
The US Electron-Ion Collider Accelerator Designs

for JLEIC and eRHIC design teams

Andrei Seryi

Jefferson Lab





NAPAC2019

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U.S. DEPARTMENT OF ENERGY | Office of Science

THE US ELECTRON-ION COLLIDER ACCELERATOR DESIGNS

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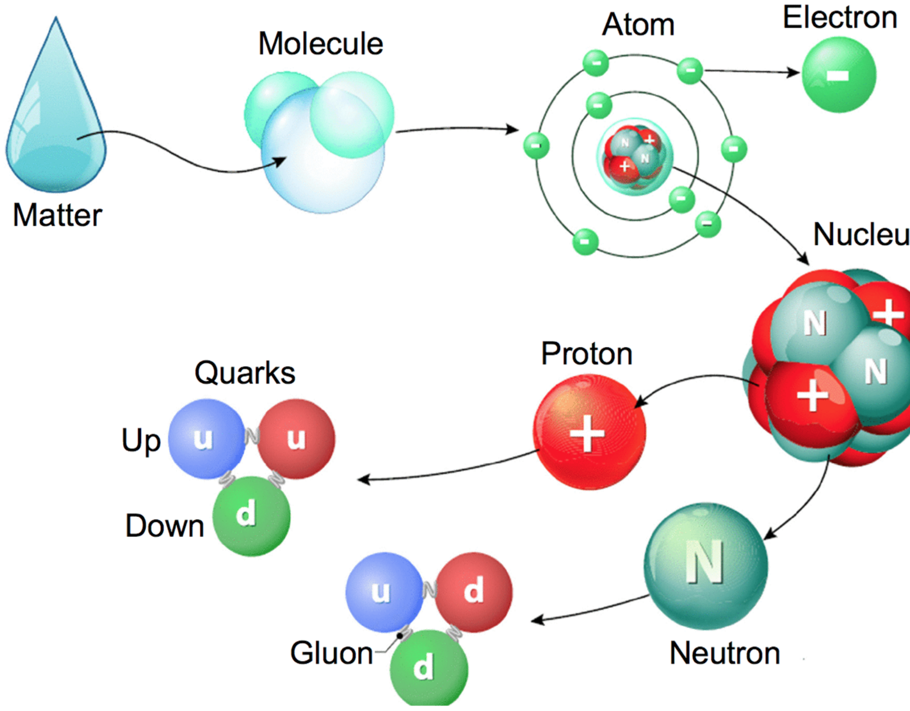
Abstract

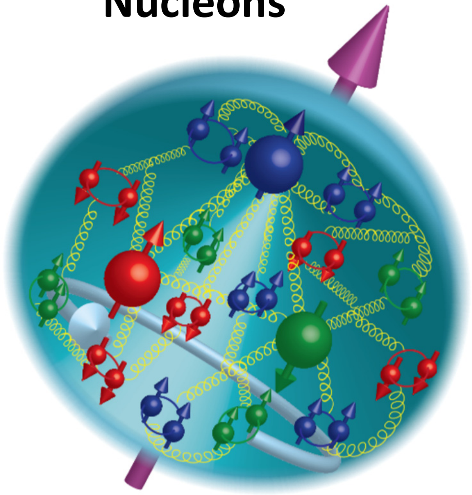
With the completion of the National Academies of Sciences Assessment of a US Electron-Ion Collider, the

as described in the White Paper [4] include: "highly polarized (~70%) electron and nucleon beams; ion beams from deuteron to the heaviest nuclei (uranium or lead);

Nucleons and Nuclei – fundamental questions



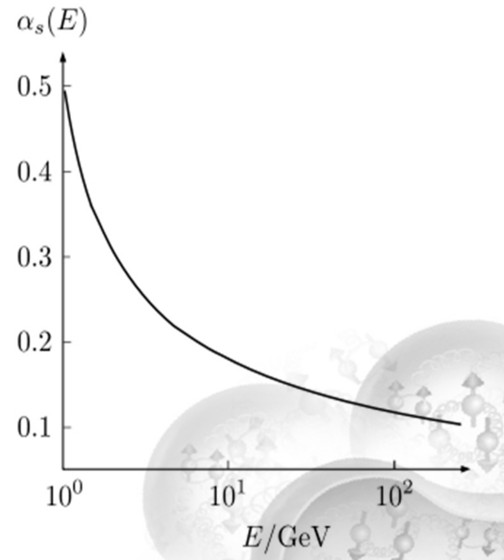
Nucleons



Mass
Spin
Bulk
NN interactions
…

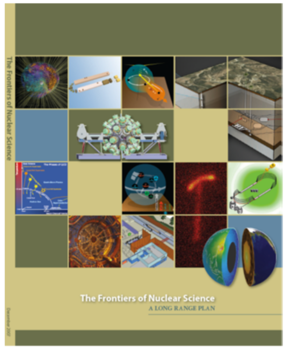
Arise out of quarks and gluons interacting through Quantum Chromodynamics (QCD)

We have limited quantitative idea of how this happens because QCD is strongly coupled in the energy regime of the mass of Nucleons.



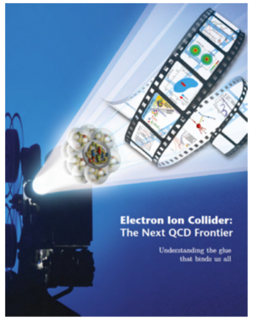
Nucleons and Nuclei and their properties can be thought of as *emergent phenomena* of QCD
We know this happens—the Quest is to understand exactly *How*.

Electron-Ion Collider Planning

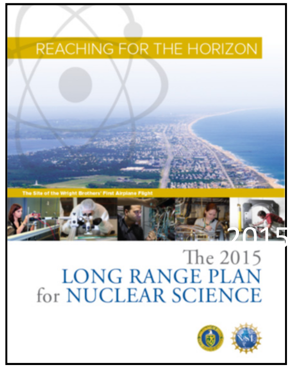


Federal Nuclear Science Advisory Cmte 2007 Long-Range Plan

“An Electron-Ion Collider (EIC) with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier”

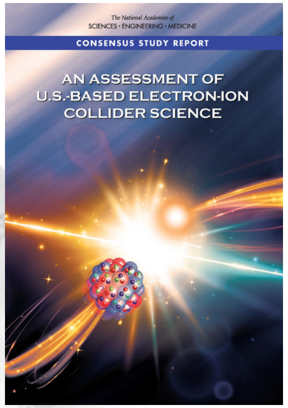


2013 EIC White Paper



Federal Nuclear Science Advisory Cmte 2015 Long Range Plan

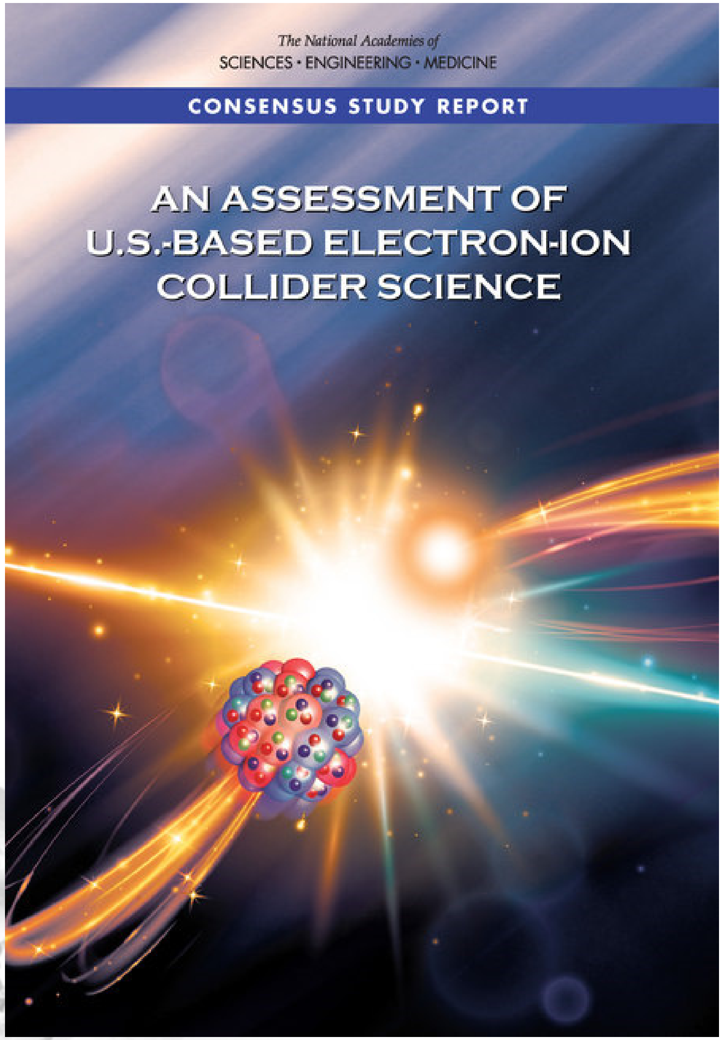
“We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.”



National Academies of Sciences – Assessment of U.S. Based Electron-Ion Collider Science (2018)

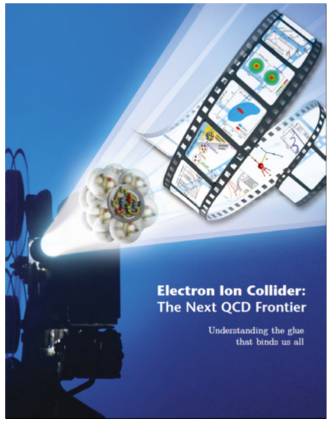
“…the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today.”

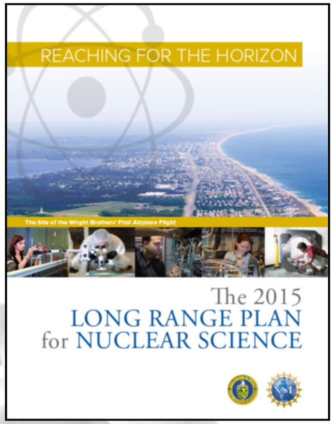
National Academies of Sciences Report Summary



- The committee unanimously finds that the science that can be addressed by an EIC is compelling, fundamental and timely
- The unanimous conclusion of the Committee is that an EIC, as envisioned in this report, would be a unique facility in the world that would boost the U.S. STEM workforce and help maintain U.S. scientific leadership in nuclear physics
- The project is strongly supported by the NP community
- The technological benefits of meeting the accelerator challenges are enormous, both for basic science and for applied areas that use accelerators, including materials science and medicine

Electron Ion Collider Requirements





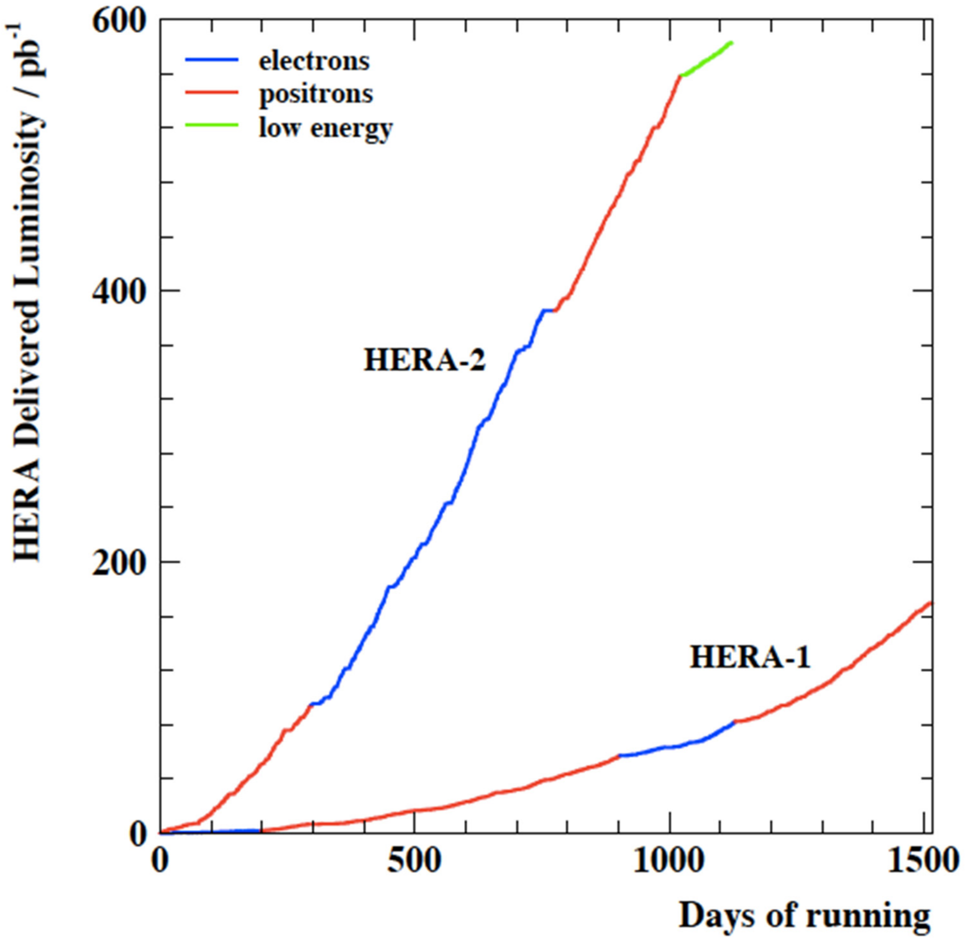
Established in Community White Paper*, re-emphasized in 2015 NSAC LRP, and NAS study

- Polarized (~70%) electrons, protons, and light nuclei
  - High polarization essential to deliver the physics in a timely manner
  - For many measurements statistical uncertainty ~ $1/(\mathbf{L} \times \mathbf{P_e}^2 \times \mathbf{P_p}^2)^{1/2}$
- Ion beams from deuterons to the heaviest stable nuclei
  - Protons, deuterons, light nuclei, through U or Pb
- Variable center of mass energies ~20-100 GeV, upgradable to ~140 GeV
  - Not a collider to achieve highest possible CoM energy
  - Highest luminosity demands in mid energy range
- High collision luminosity ~$10^{33\text{-}34}$ cm^{-2} s^{-1}
  - “Factory”-like luminosity, factor of 100-1000 beyond HERA
- Possibly have more than one interaction region

*A. Accardi et al. , “Electron Ion Collider: The Next QCD Frontier - Understanding the Glue that Binds Us All”, Eur. Phys. J. A52 , p. 268 (2016), https://doi.org/10.1140/epja/i2016-16268-9

HERA

- The first and only lepton-hadron collider, DESY, Hamburg, Germany
- Proposed in 1981, approved 1984
- Operated for physics 1992-2007
- Collided 27.5 GeV spin polarized leptons (e+; e-) with 920 GeV protons
- Reached a luminosity of $5x10^{31}$ cm^{-2} s^{-1}
- Many lessons from HERA are relevant for EIC
  - Vertical beam-beam tune shift for lepton beam reached values planned for EIC
  - The necessity to minimize synchrotron radiation in the IR, IR vacuum pressure, and to avoid halo of the proton beam



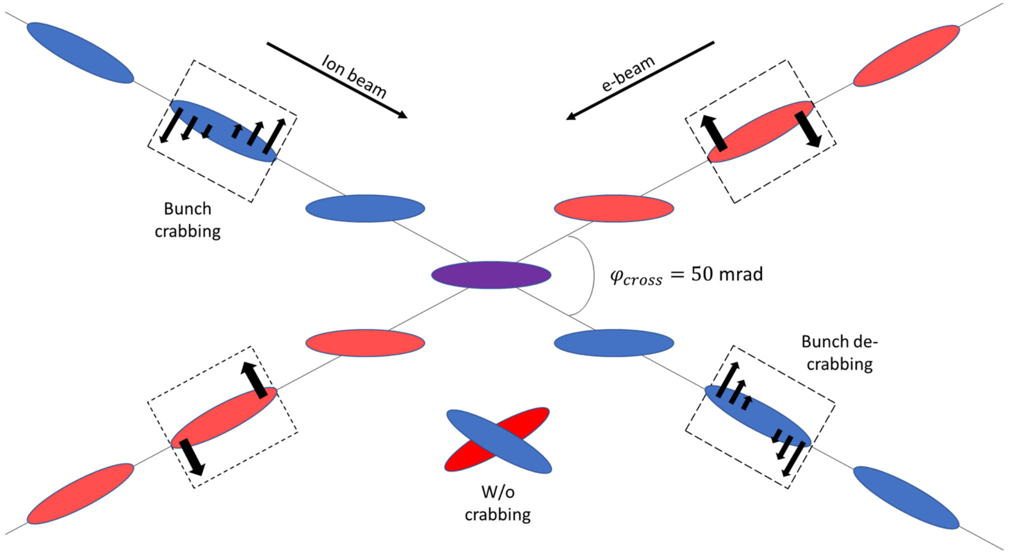
F. Willeke, HERA and the Next Generation of Lepton-Ion Colliders", in Proc. of EPAC'06 , Edinburgh, paper FRXBPA01

Lessons from B factories - KEK B and PEP-II

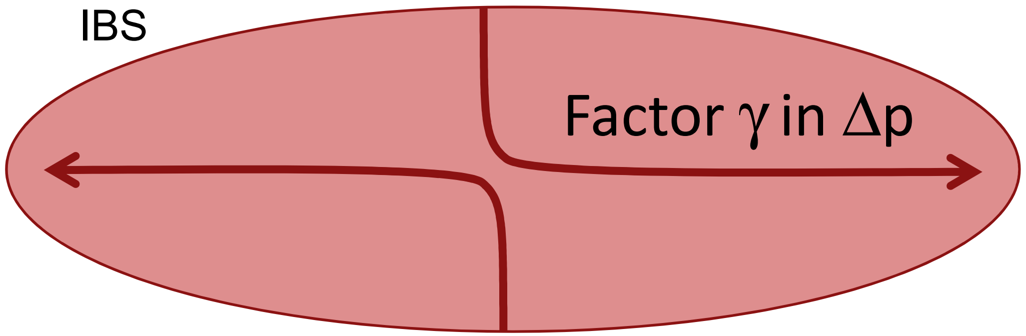
- When B factories design started ~1990, e+e- colliders barely reached 10^{32} $cm^{-2}s^{-1}$
- Aim: PEP-II and KEKB aimed in their design to luminosity of 0.3 – 1 x 10^{34} cm^{-2} s^{-1}
- Approach: build-in necessary features to achieve high Lumi into the design
  - Crossing angle and crab cavity; Local chromaticity correction; RF cavities and vacuum chamber compatible with ampere-scale beams; Bunch-by-bunch feedback; Continuous top-up injection
- Result: fast start-up – achieve design Lumi in 1.5-3 years
  with further efforts exceed design Lumi x2-4 times
- Lesson for EIC:
  - Despite of challenging requirements, it should be possible to design machine that will allow fast ramp-up to design luminosity
  - Should set a goal to achieve EIC design Lumi soon after the start
  - Necessary provisions/systems required for luminosity should be built-in into the design

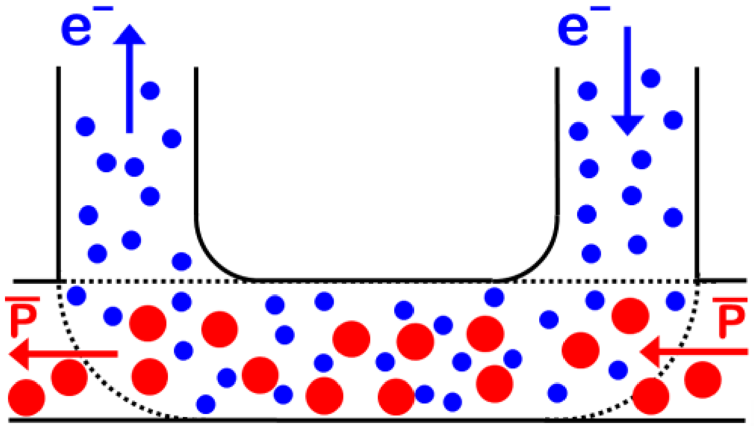
EIC design features enabling high Luminosity and high polarization

- Crossing angle and crab cavities
  - Enables strong focusing at IP, control background



- Hadron beam cooling
  - Combat Intra-Beam Scattering, reduce and preserve emittance

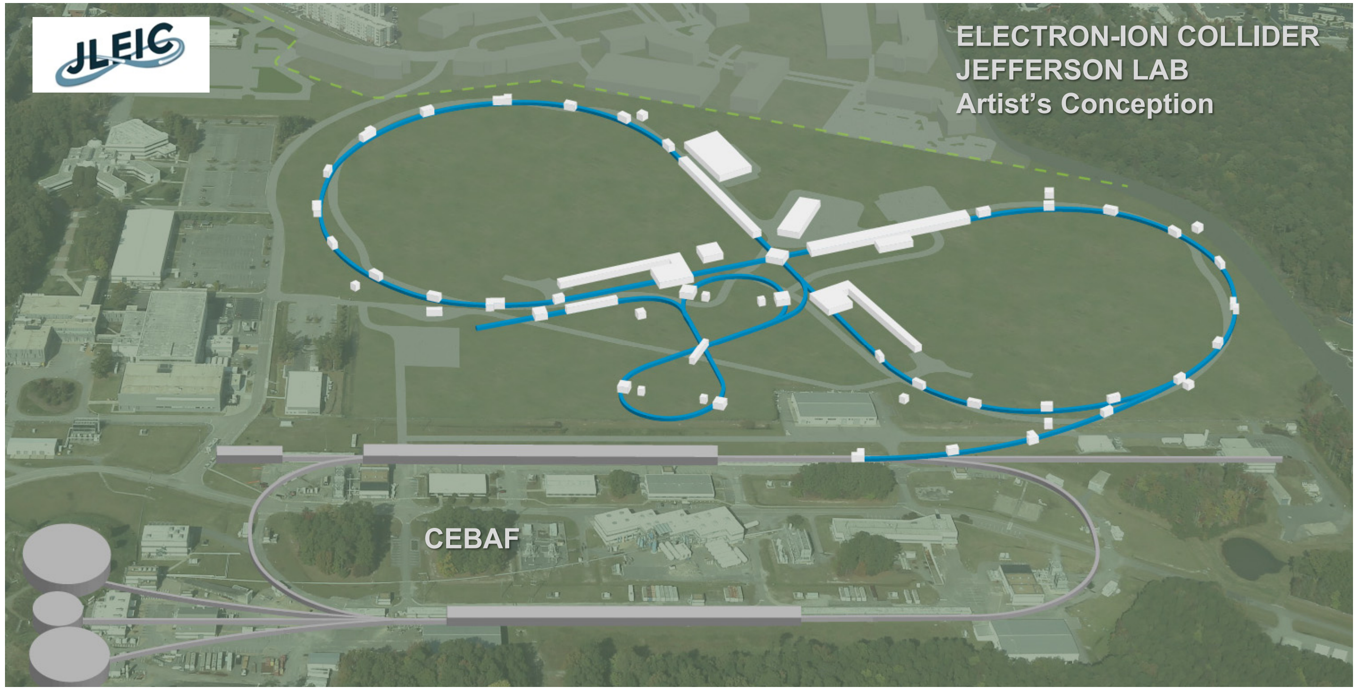


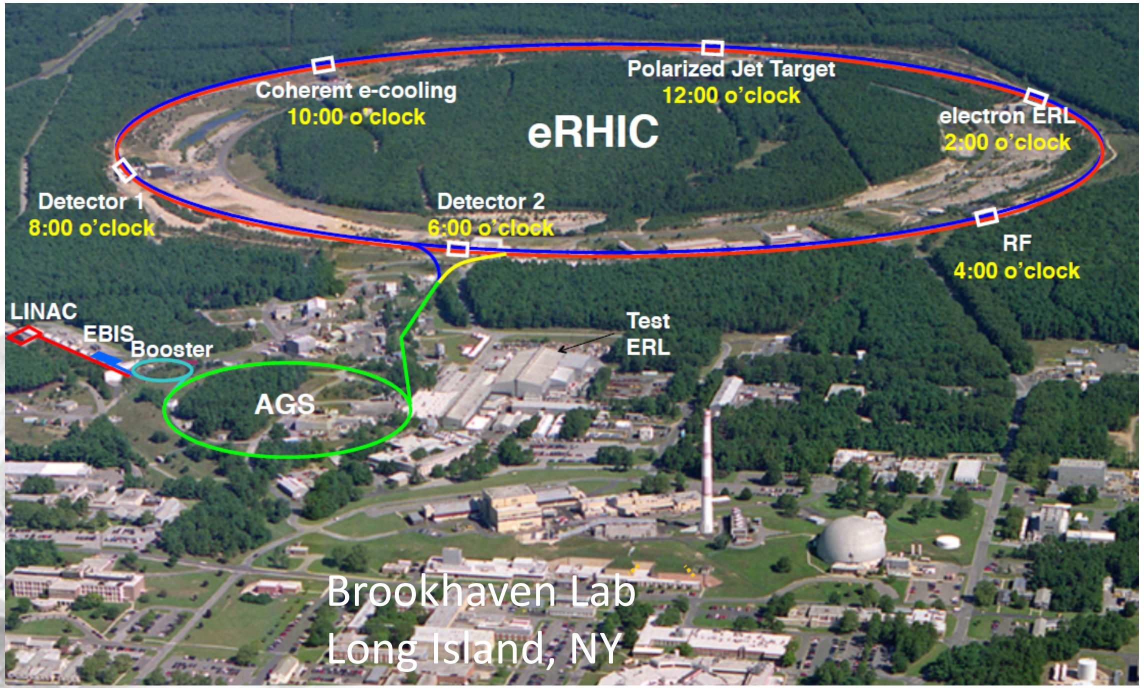


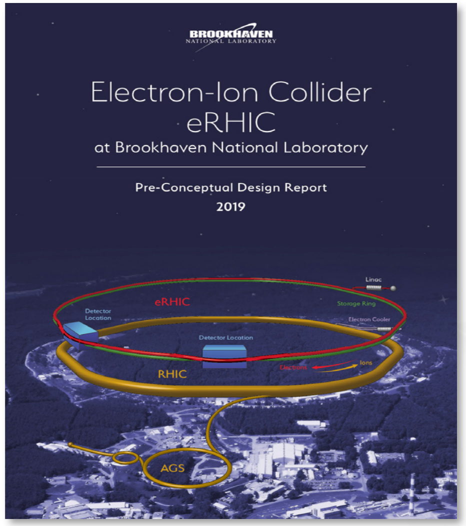
- Use of Siberian snakes or figure-8 topology
  - Preserve high polarization of beams

EIC Designs

Y. Zhang, JLEIC updates, MOYBA3







C. Montag, eRHIC updates, MOYBA4

Accelerator R&D going on with strong cooperation between several DOE labs under DOE NP stewardship

EIC Designs

Both EIC concepts designed to meet the requirements set forth in NSAC Long Range Plan, which was emphasized by the NAS report:

- Highly polarized (~70%) electron and nucleon beams
- Ion beams from deuterons to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ~20 - ~100 GeV, upgradable to ~140 GeV
- High collision luminosity ~10^{33} – 10^{34} $cm^{-2}s^{-1}$
- Possibilities of having more than one interaction region

Both designs based on ring-ring approach, both benefit from existing Nuclear Physics infrastructure and are based on the same accelerator principles:

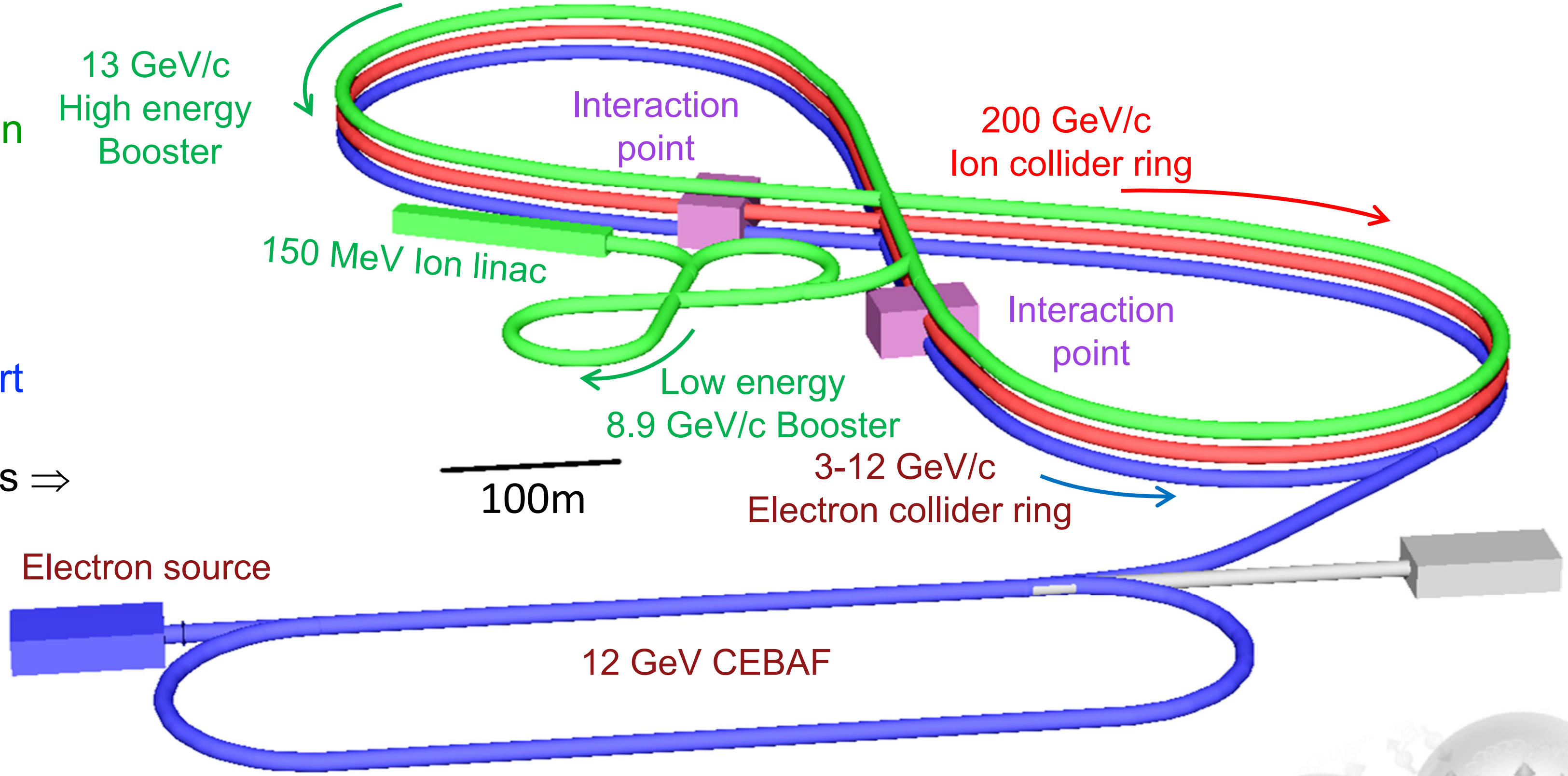
Electron Storage Rings with frequent injection of fresh polarized beams

Hadron storage rings with strong cooling or alternatively frequent injections

JLEIC Layout

Y. Zhang, JLEIC updates, MOYBA3

- Full-energy top-up injection of highly polarized electrons from CEBAF ⇒ High stored electron current and polarization
- Full-size high-energy booster ⇒ Quick replacement of colliding ion beam ⇒ High average luminosity
- High-rate collisions of strongly-focused short low-charge low-emittance bunches similarly to record-luminosity lepton colliders ⇒ High luminosity
- Multi-stage electron cooling using demonstrated magnetized cooling mechanism ⇒ Small ion emittance ⇒ High luminosity

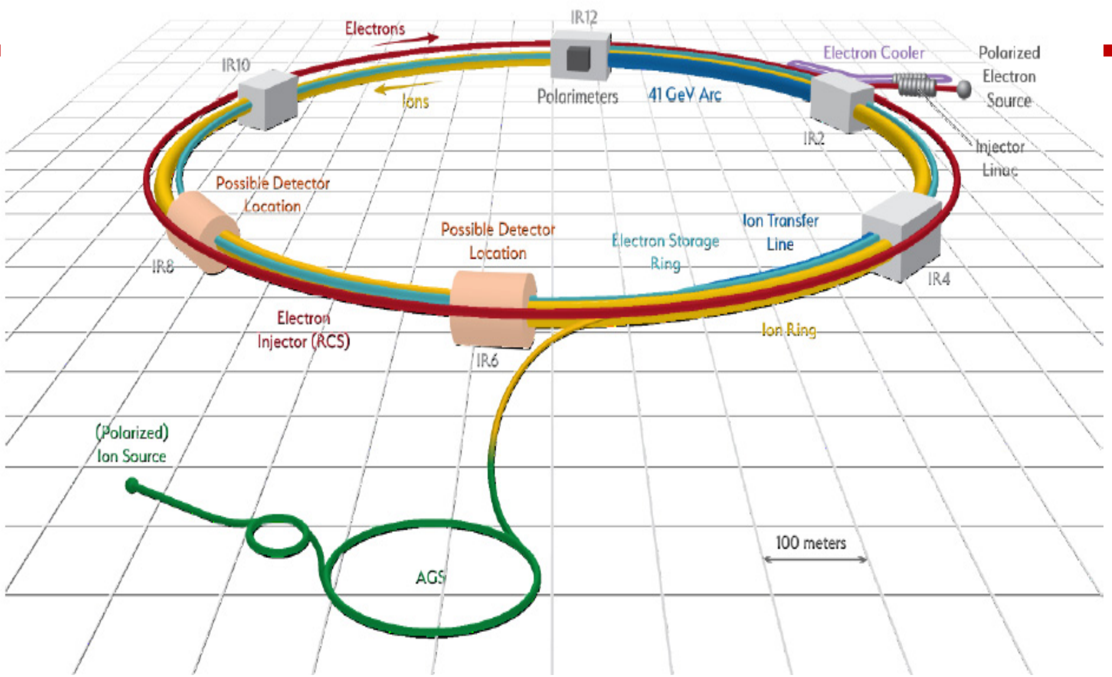


- Figure-8 ring design ⇒ High electron and ion polarizations, polarization manipulation and spin flip
- Integrated full acceptance detector with far-forward detection sections being parts of both machine and detector
- Upgradable to 140 GeV CM by replacing the ion collider 6T NbTi cosΘ bending dipoles only with 12 T Nb3Sn magnets
- Design meets the high luminosity goal of **$L = 10^{34} cm^{-2} s^{-1}$**

eRHIC layout

- **Hadrons up to 275 GeV**

  eRHIC is using the existing RHIC complex: Storage ring (Yellow Ring), injectors, ion sources, infrastructure
- Need only few modifications for eRHIC
- Todays RHIC beam parameters are close to what is required for eRHIC



- **Electrons up to 18 GeV**

- Electron storage ring with up to 18GeV ➔ E_{cm} = 20 GeV -141 GeV installed in RHIC tunnel. Beam current are limited by the choice of installed RF power 10 MW
- Electron beams with a variable spin pattern accelerated in the on-energy, spin transparent injector: Rapid Cycling Synchrotron with 1-2 Hz cycle frequency in the RHIC tunnel
- Polarized electron source and 400 MeV s-band injector linac in existing tunnel
- Design meets the high luminosity goal of **$L = 10^{34} cm^{-2} s^{-1}$**

High Luminosity Implementation

As both designs, JLEIC and eRHIC are storage ring designs, the same ingredients are required for large luminosity

- **Large bunch charge** (yet small in comparison with hadron colliders)
- **Many bunches** ➔ large total beam currents

  ➔ crossing angle collision geometry
- **Small beam size** at collision point achieved by

  * **small emittance**

    ➔ small hadron emittance

  * **and strong focusing at IR** (small β)

    ➔ required short bunches

➔ requires strong hadron cooling **or** frequent injection of pre-cooled beam

- Luminosity limits vs E: **Space Charge, Beam-Beam Limits, Synchrotron Radiation**

EIC Luminosity

EIC designs baselines

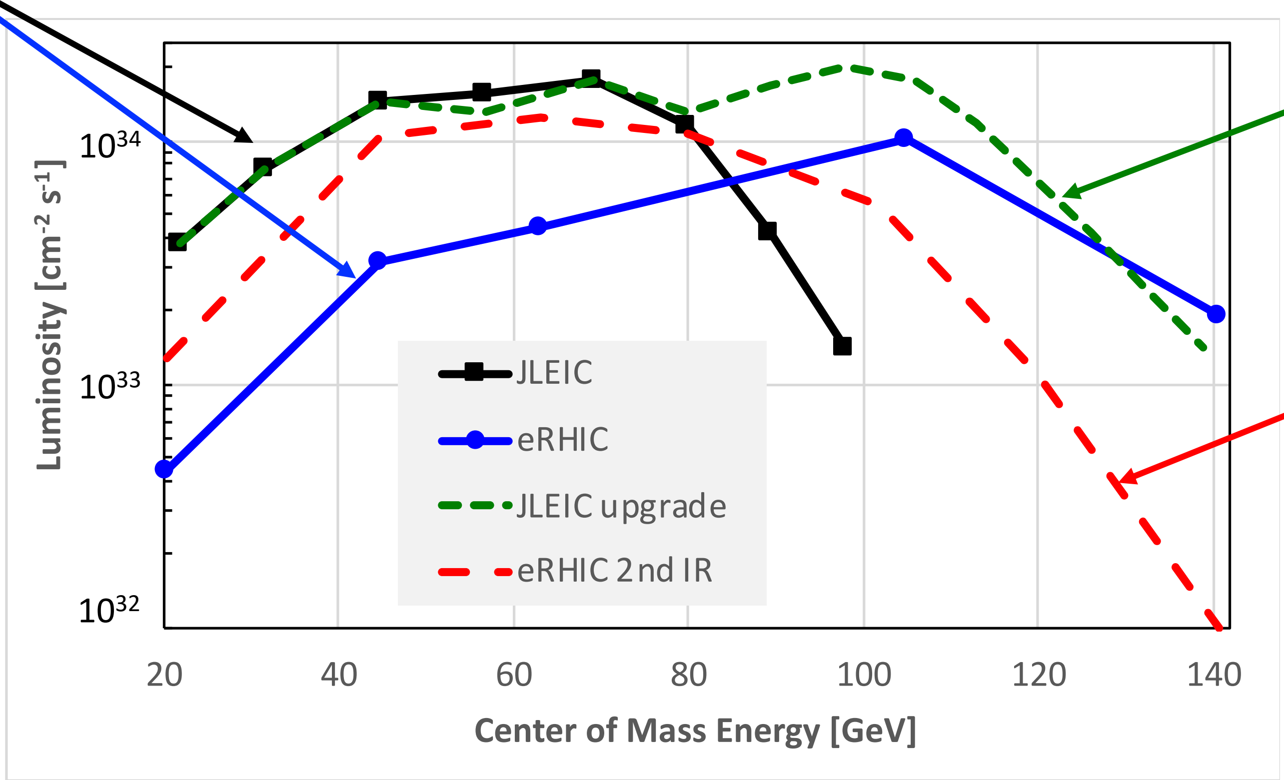
Luminosity limits:

Beam-beam

Space-charge

Synch. Rad.

EIC designs peak luminosity



JLEIC upgrade with 12T Nb3Sn dipoles

eRHIC 2nd IR optimized for high luminosity at 63 GeV CM

Relation of the peak luminosity to the average one varies with CM energy and operational assumptions

EIC parameters *for one selected energy for each case shown in the Luminosity plot*

design parameter	eRHIC proton	eRHIC electron	JLEIC proton	JLEIC electron	eRHIC-opt. proton	eRHIC-opt. electron	JLEIC-upgrade proton	JLEIC-upgrade electron
center-of-mass energy [GeV]	104.9		44.7		63.3		105.8	
energy [GeV]	275	10	100	5	100	10	400	7
number of bunches	1160		3456		2320		864	
particles per bunch [10^{10}]	6.9	17.2	1.06	4.72	3.4	8.6	4.2	19.3
beam current [A]	1.0	2.5	0.75	3.35	1.0	2.5	0.75	3.4
beam polarization [%]	80	80	85	85	80	80	85	85
total crossing angle [mrad]	25		50		50		50	
ion forward acceptances [mrad]	±20/±4.5		±50/±10		±35/±8		±50/±5.6	
h./v. norm. emittance [μm]	2.8/0.45	391/24	0.65/0.13	83/16.6	1.5/0.15	391/24	3/0.5	228/45.6
bunch length [cm]	6	2	2.5	1	4	2	3.5	1
β_x^* / β_y^* [cm]	90 / 4.0	43 / 5.0	8 / 1.3	5.72 / 0.93	18 / 2	13 / 2.4	40 / 2.25	16.9 / 0.8
hor./vert. beam-beam param.	.014/.007	.073/.1	.015/.0135	.049/.044	.012/.013	.036/.062	.014/.008	.076/.037
peak lumi. [$10^{34}cm^{-2}s^{-1}$]	1.01		1.46		1.24		1.78	
average lumi. [$10^{34}cm^{-2}s^{-1}$]	0.93*		1.4		0.95*		1.47*	

L_{ave} numbers with * are without strong cooling

Strong Hadron Cooling and High Luminosity

For high luminosity operation of the EIC strong hadron cooling is desirable if not necessary to avoid rapid decay of the luminosity caused by emittance blow-up due to intrabeam scattering

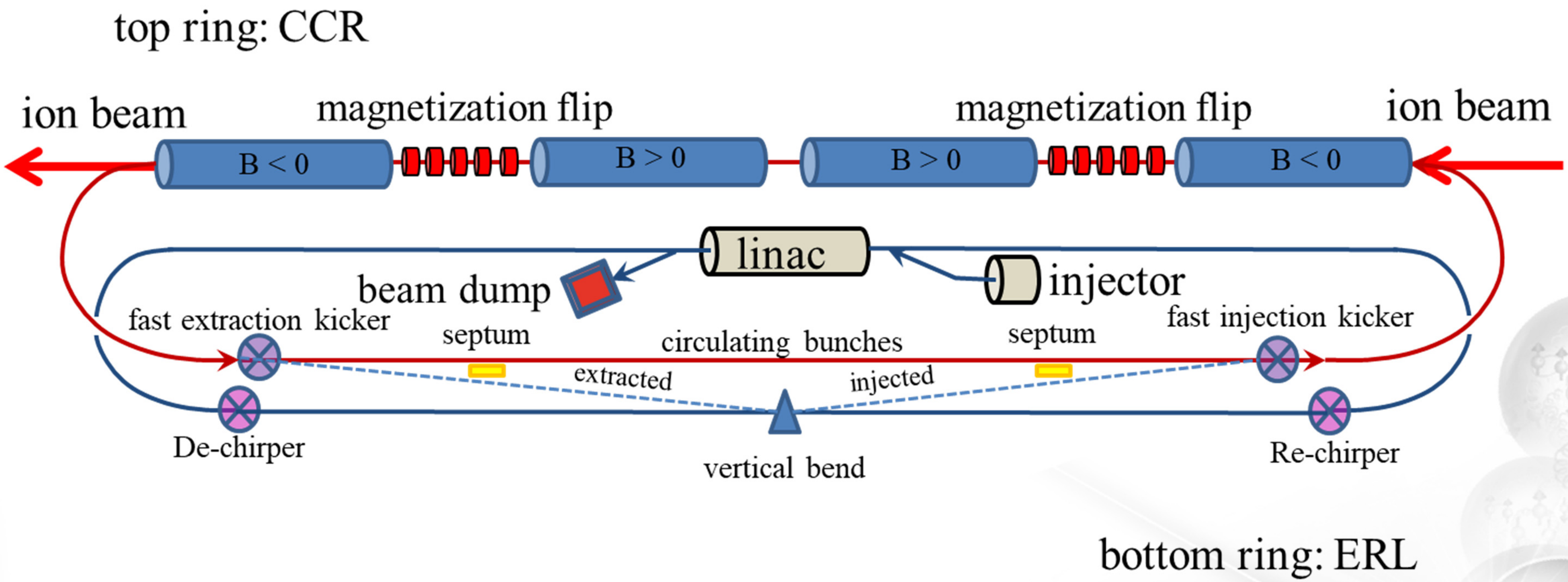
The two designs aimed to optimize luminosity at different ranges of hadron energy and the cooling systems are optimized accordingly

- JLEIC uses a multi-turn incoherent magnetized bunched electron beam cooling ring fed by an energy recovery linac to balance IBS growth time between ~5 and ~40 minutes. This cooling increases the luminosity at lower energies, however JLEIC is not relying on this cooling for reaching NSAC goals, as it can use short fills with rapid turn arounds for achieving high average luminosity of $1\cdot10^{34}$ $cm^{-2}s^{-1}$

- eRHIC has IBS growth rates of ~25min to ~2h for highest luminosity. It uses micro-bunched coherent electron cooling as an option but does not rely on cooling to operate at highest luminosity as there is an on-energy frequent injections available which results in an average luminosity which is still 90% of the peak luminosity

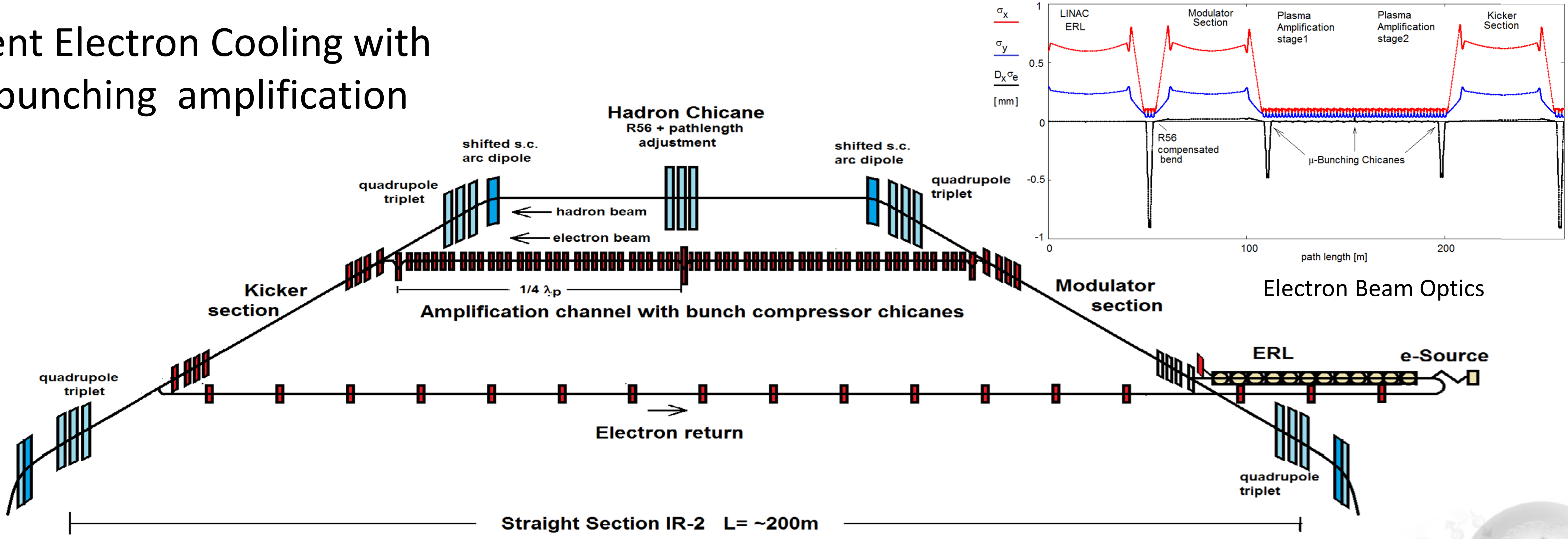
Strong Incoherent Hadron Cooling Scheme for JLEIC

- Magnetized electron beam for higher cooling efficiency
- Cooling electron beam is energy-recovered to minimize power consumption
- 11-turn circulator ring with ~1 amp of beam current relaxes electron source requirements
- Fast harmonic kicker to kick electrons in and out of the circulator ring
- Pre-cooling at low energy is essential to achieve the anticipated performance



Strong Coherent Hadron Cooling Scheme for eRHIC

Coherent Electron Cooling with micro-bunching amplification

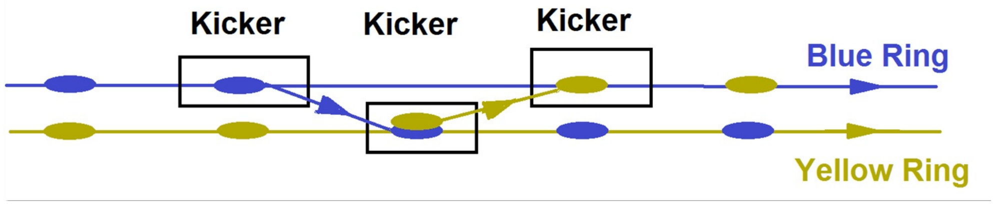


Electron Beam Optics

- Micro-bunched cooling is a novel scheme based on available technology
- Strong cooling as desirable but not necessary for high luminosity (especially high average luminosity)
- Similarly as for the JLEIC scheme, this option requires electron cooling at low energy
- Strong cooling is not necessary as the hadron beam could be replaced frequently on-energy using the existing second ring of present RHIC

Alternative to Strong Hadron Cooling in eRHIC and JLEIC

- eRHIC maximum luminosity of $1 \cdot 10^{34}$ $cm^{-2}s^{-1}$ does not depend on the feasibility of strong hadron cooling
  - Since RHIC has a second superconducting ring, the Blue Ring, on-energy injections into the collider ring, the Yellow Ring will replace the hadron bunches after one hour of storage
  - Transfer takes 13 μs and will preserve the total charge in both machines, no transient injection effect



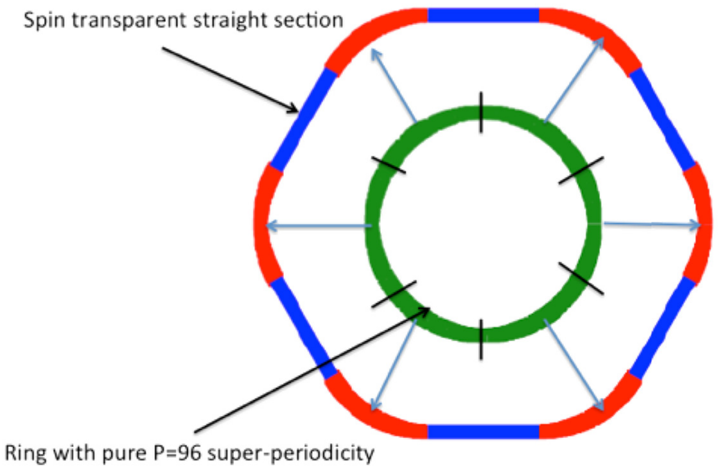
  - The emittance growth between injections is small, allowing L_{ave} of **$0.93 \cdot 10^{34}$ $cm^{-2}s^{-1}$** to be achieved
  - The required small vertical $\varepsilon_{Ny} = 0.5$ μm will be achieved with standard DC electron beam cooling in the AGS
  - No new hardware for spin transparency is required
- JLEIC maximum and ave. luminosity of $1 \cdot 10^{34}$ $cm^{-2}s^{-1}$ does not depend on the feasibility of strong hadron cooling
  - The full size booster of JLEIC can be used for hourly injection of beam pre-cooled by a conventional DC electron cooler

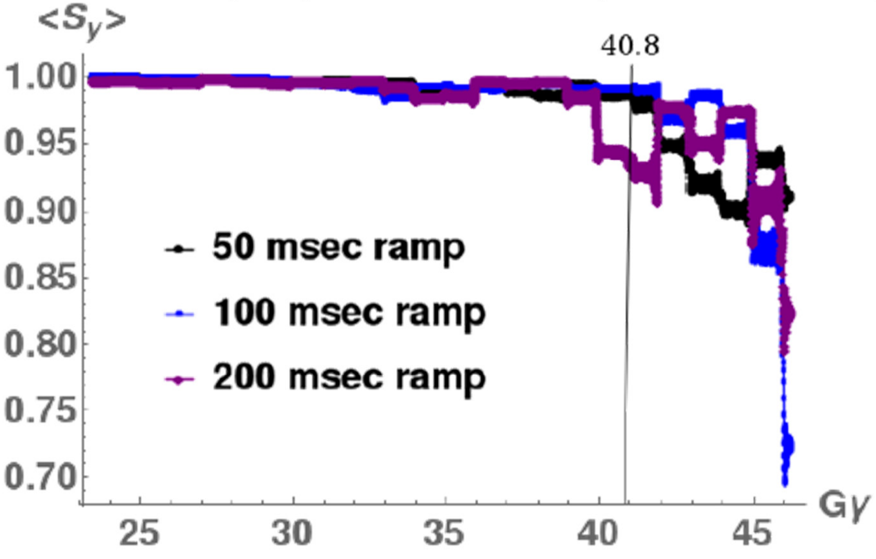
Polarized e- : eRHIC Rapid Cycling Synchrotron & CEBAF full-E injector

RCS optical design approach: high periodicity arcs and unity transformation in the straights suppresses all systematic depolarizing resonances up to $G\gamma$ =45

➔ **resonance free acceleration up >18 GeV**

➔ **no loss of polarization on the entire ramp up to 18 GeV (100 ms ramp time)**



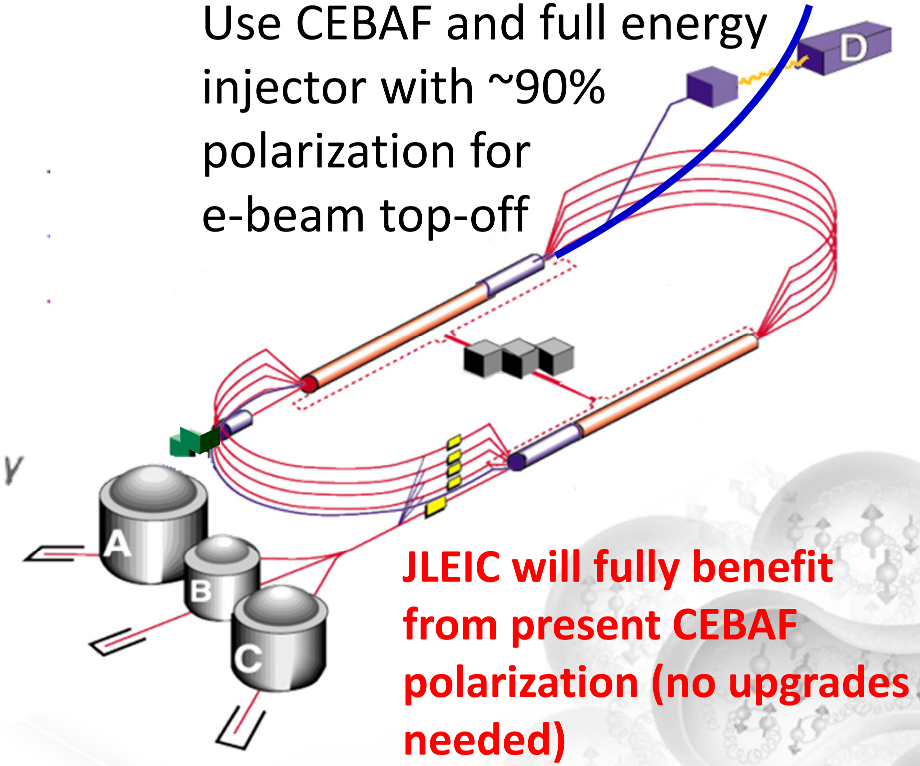


Need well aligned quadrupoles and rms orbit ≤ 0.5 mm and good reproducibility

➔ Well within the present state of the art of orbit control and achieved today by NSLS-II Booster synchrotron

Up to 12 GeV to JLEIC

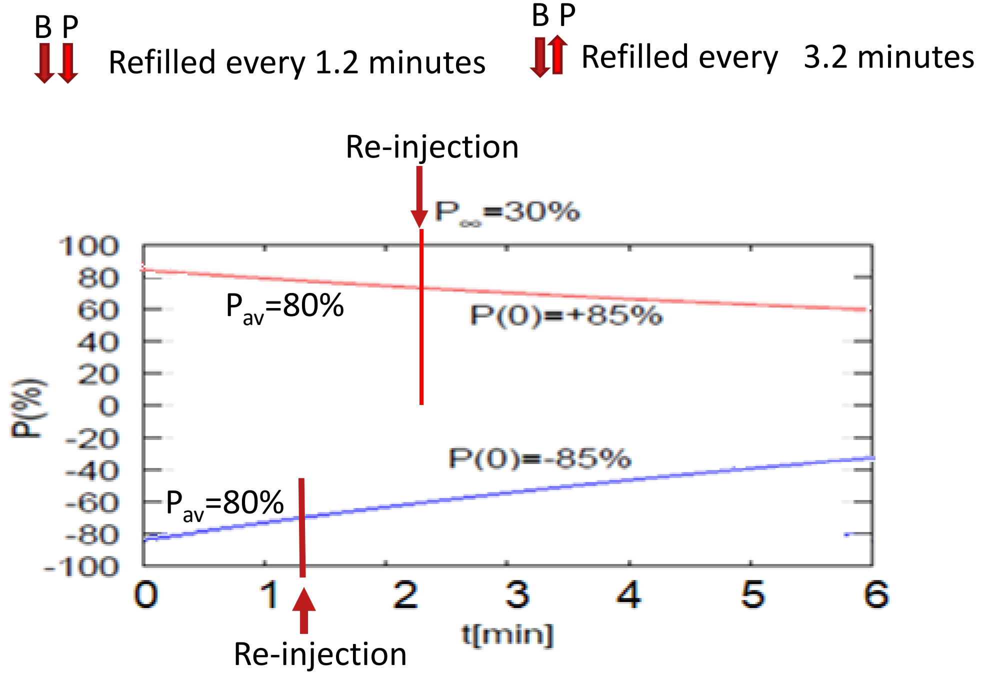
Use CEBAF and full energy injector with ~90% polarization for e-beam top-off



JLEIC will fully benefit from present CEBAF polarization (no upgrades needed)

Polarization in the eRHIC electron storage ring

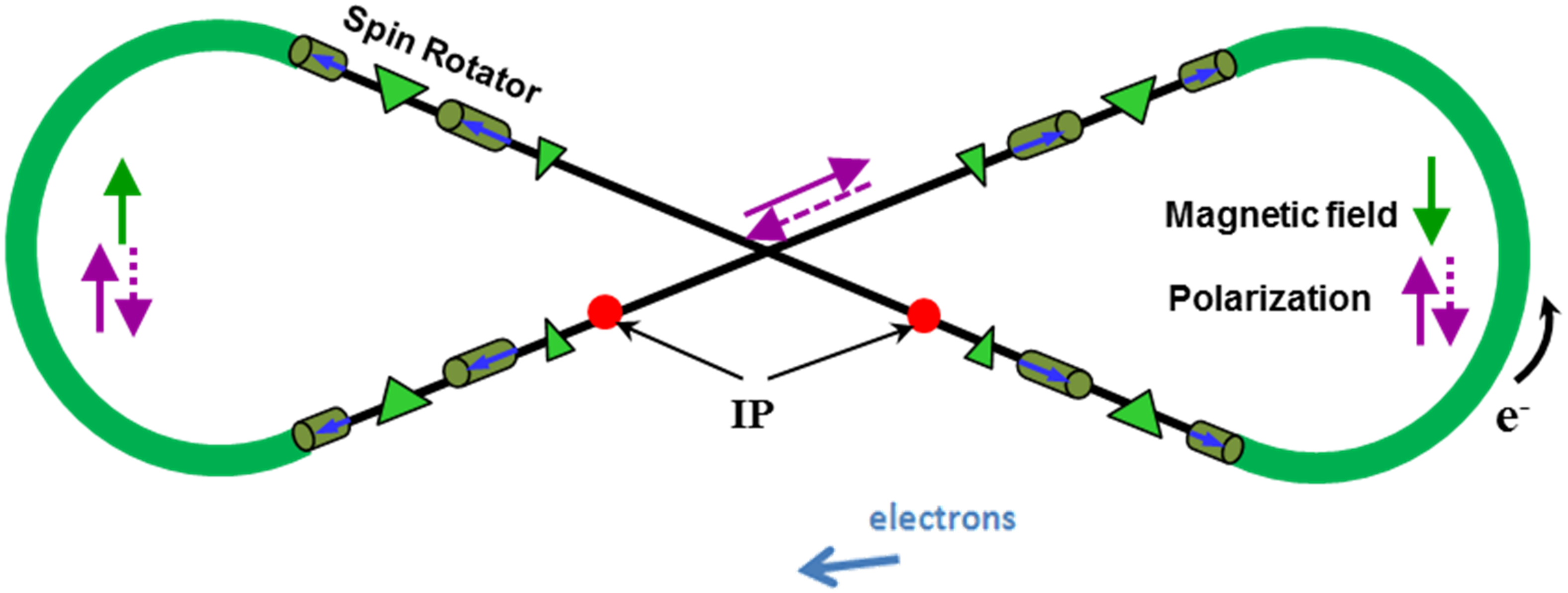
- Solenoid based Spin rotators ➔ longitudinal spin in collisions (arcs: vertical polarization)
- High initial polarization of 85% will decay towards equilibrium polarization $\mathbf{P_\infty}$ due to Sokolov-Ternov effect
- P_∞ of 40-50% achievable (HERA experience and eRHIC simulations)
- Time evolution of high polarization of bunches injected into the electron storage ring at 18 GeV (worst case) RCS cycling rate = 2Hz ➔ on average, every bunch refilled in 2.2 min

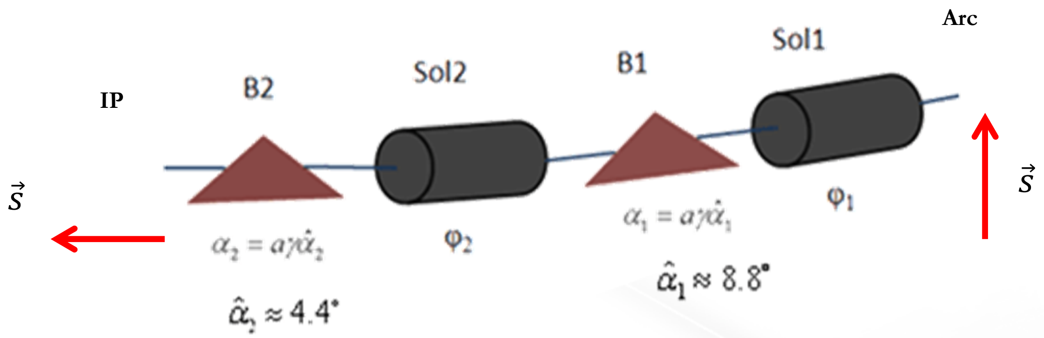


Note: Calculation with P_∞=30% is conservative as P_∞= 50% was shown feasible

Polarization in the JLEIC electron storage ring

- Two highly polarized bunch trains maintained by top-off
- Universal spin rotator
  - Minimizes spin diffusion by switching polarization between vertical in arcs and longitudinal in straights
  - Sequence of solenoid and dipole sections
  - Geometry independent of energy
  - Two polarization states with equal lifetimes
  - Basic spin match



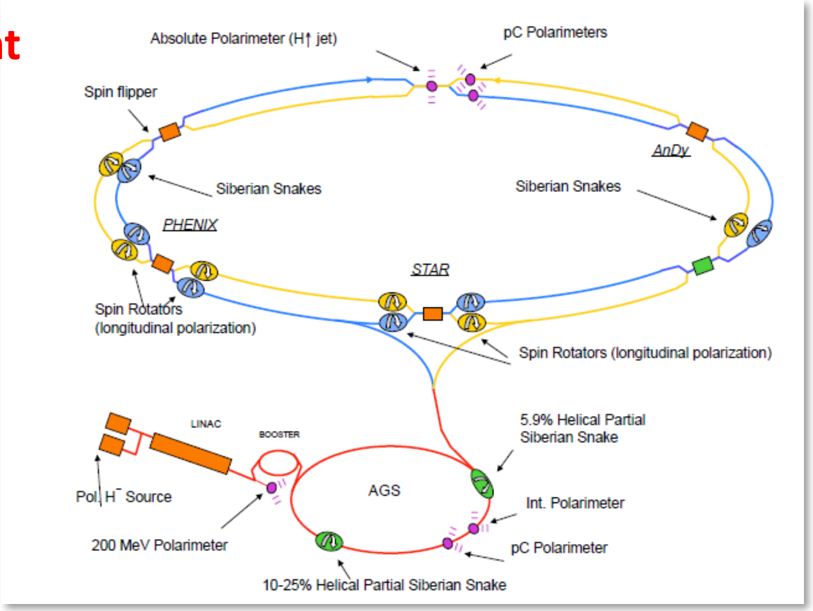


- Advantage of figure-8 geometry: negligible depolarization demonstrated by spin tracking

Ion Polarization in eRHIC

Measured RHIC Results:
- Proton Source Polarization 83 %
- Polarization at extraction from AGS 70%
- Polarization at RHIC collision energy 60%

eRHIC will fully benefit from present RHIC polarization and near future upgrades



Planned near term improvements:

AGS: Stronger snake, skew quadrupoles, increased injection energy

➔expect 80% at extraction of AGS

RHIC: Add 2 snakes to 4 existing no polarization loss

➔ expect 80% in Polarization in RHIC and eRHIC

Expected results obtained from simulations which are benchmarked by RHIC operations

^{3}He in eRHIC with six snakes

Achieved 85% polarization in 3He ion source

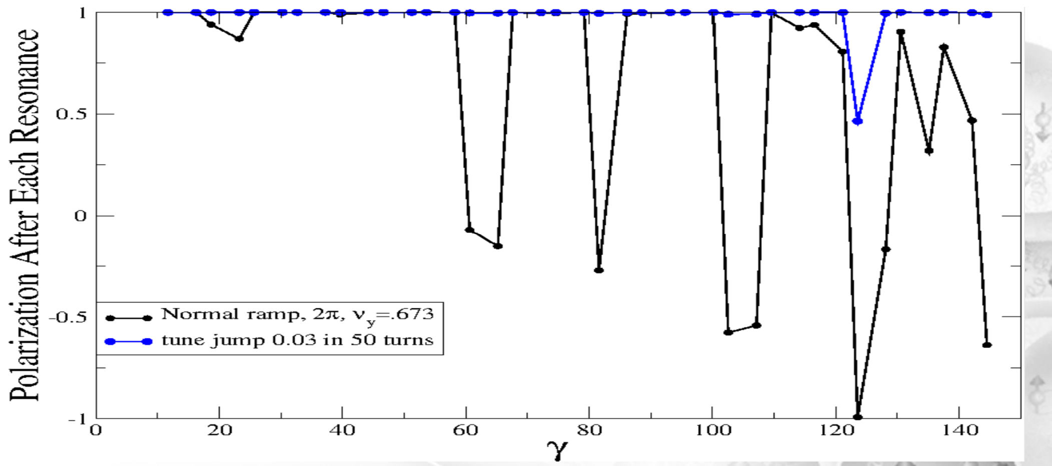
Polarization preserved with 6 snakes for up to twice the design emittance

Deuterons in eRHIC:

Requires tune jumps in the AGS, then

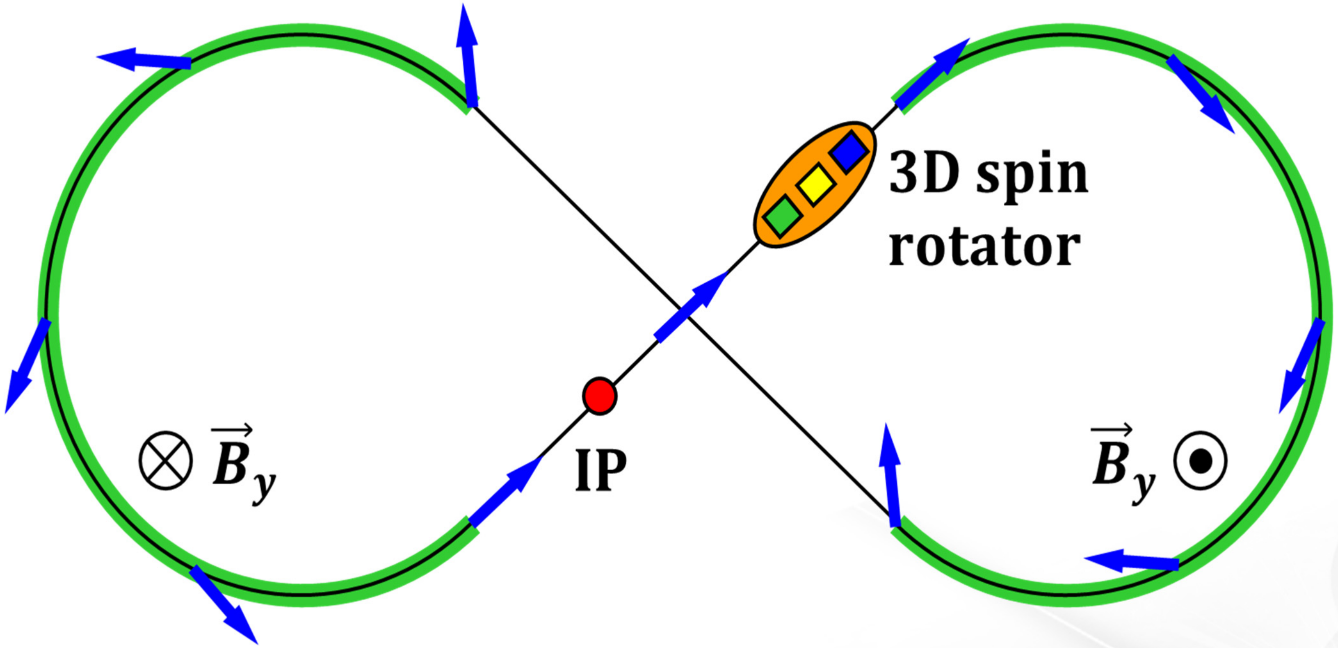
benchmarked simulation show 100% Spin transparency

No polarization **loss** expected in the eRHIC hadron ring



Ion Polarization in JLEIC

- Figure-8 concept: Spin precession in one arc is exactly cancelled in the other
- Spin stabilization by small fields: ~3 Tm vs. < 400 Tm for deuterons at 100 GeV
  - —Criterion: induced spin rotation >> spin rotation due to orbit errors
- 3D spin rotator: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring
- No effect on the orbit
- Polarized deuterons
- Frequent adiabatic spin flips



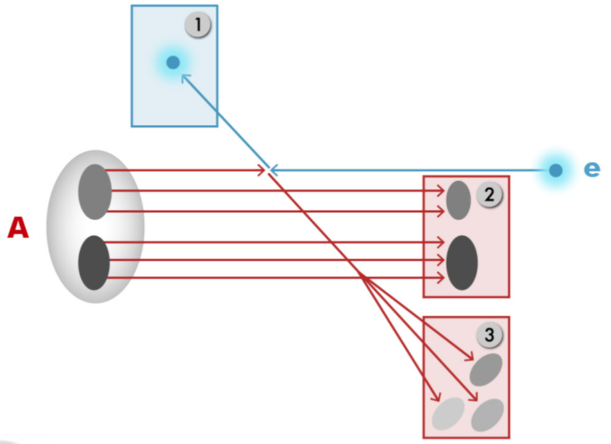
Interaction Region Design

- The interaction regions are the most challenging parts of a EIC design
- The EIC physics requires nearly 100% acceptance, including stringent requirements on the detection of final state particles in the directions along the beamline
  - Both designs use a crossing angle, compensated by crab cavities, and arrange the magnet apertures and locations of detectors to allow large forward coverage
- IRs need to fit several essential components into a relatively small area
  - Strong focusing, auxiliary detectors, masks and collimators, diagnostics
  - The accelerator components should not compromise the detector acceptance
- Design has to take into account that there are beam dynamics constraints:
  - IR chromaticity and related dynamic aperture issues, beam-beam tune shift, tight tolerances for magnet errors, residual crab cavity effects, …

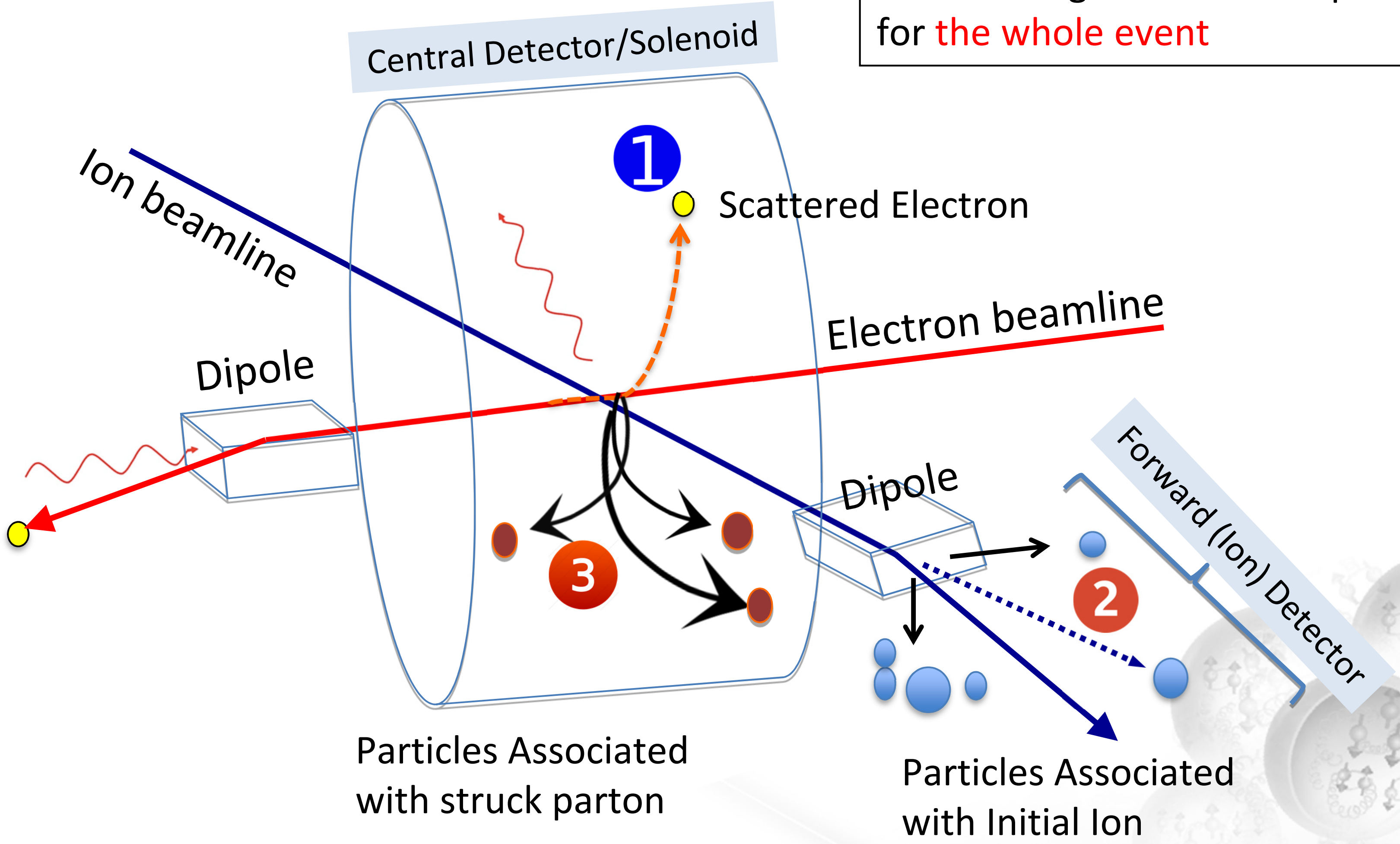
Interaction Region Concept

B. Parker, EIC MDI, TUZBA2

EIC detector must accept and measure *all* particles from the interaction. (Unlike existing collider detectors!)



Possible to get ~100% acceptance for the whole event



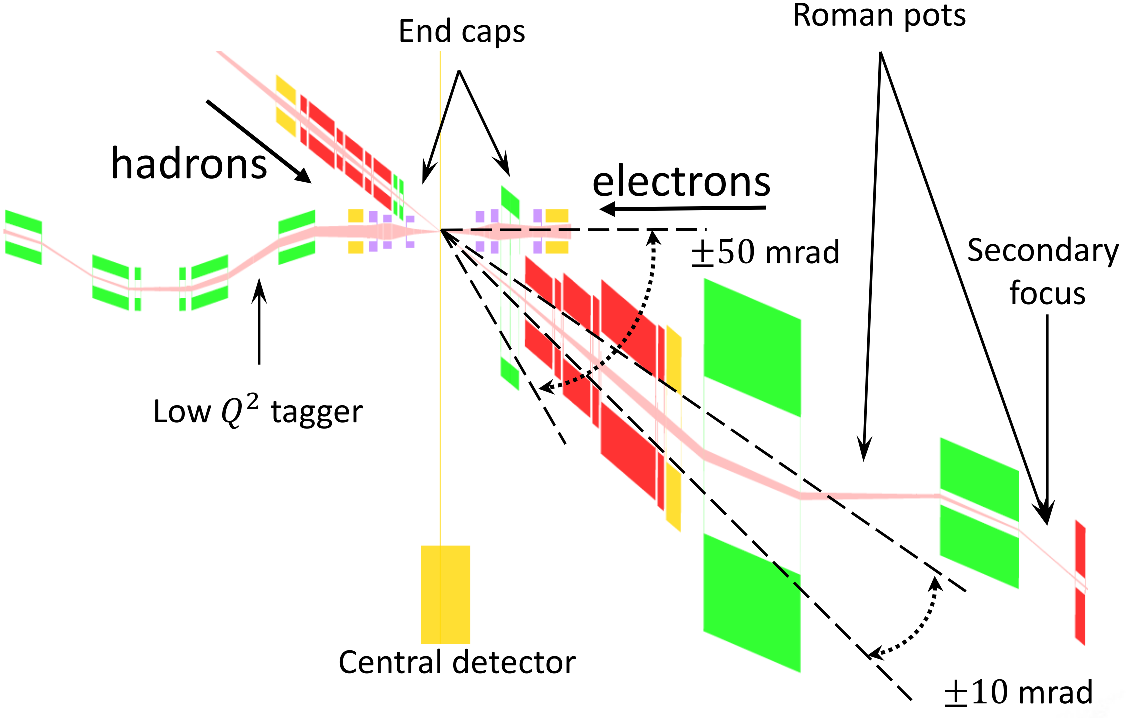
EIC parameters in detail & Interaction Region

design	eRHIC		JLEIC		eRHIC-opt.		JLEIC-upgrade	
parameter	proton	electron	proton	electron	proton	electron	proton	electron
center-of-mass energy [GeV]	104.9		44.7		63.3		105.8	
energy [GeV]	275	10	100	5	100	10	400	7
number of bunches	1160		3456		2320		864	
particles per bunch [10^{10}]	6.9	17.2	1.06	4.72	3.4	8.6	4.2	19.3
beam current [A]	1.0	2.5	0.75	3.35	1.0	2.5	0.75	3.4
beam polarization [%]	80	80	85	85	80	80	85	85
total crossing angle [mrad]	25		50		50		50	
ion forward acceptances [mrad]	±20/±4.5		±50/±10		±35/±8		±50/±5.6	
h./v. norm. emittance [μm]	2.8/0.45	391/24	0.65/0.13	83/16.6	1.5/0.15	391/24	3/0.5	228/45.6
bunch length [cm]	6	2	2.5	1	4	2	3.5	1
β_x^* / β_y^* [cm]	90 / 4.0	43 / 5.0	8 / 1.3	5.72 / 0.93	18 / 2	13 / 2.4	40 / 2.25	16.9 / 0.8
hor./vert. beam-beam param.	.014/.007	.073/.1	.015/.0135	.049/.044	.012/.013	.036/.062	.014/.008	.076/.037
peak lumi. [$10^{34}cm^{-2}s^{-1}$]	1.01		1.46		1.24		1.78	
average lumi. [$10^{34}cm^{-2}s^{-1}$]	0.93*		1.4		0.95*		1.47*	

EIC parameters for selected E of cases shown in the Lumi plot. L_{ave} numbers with * are without strong cooling.

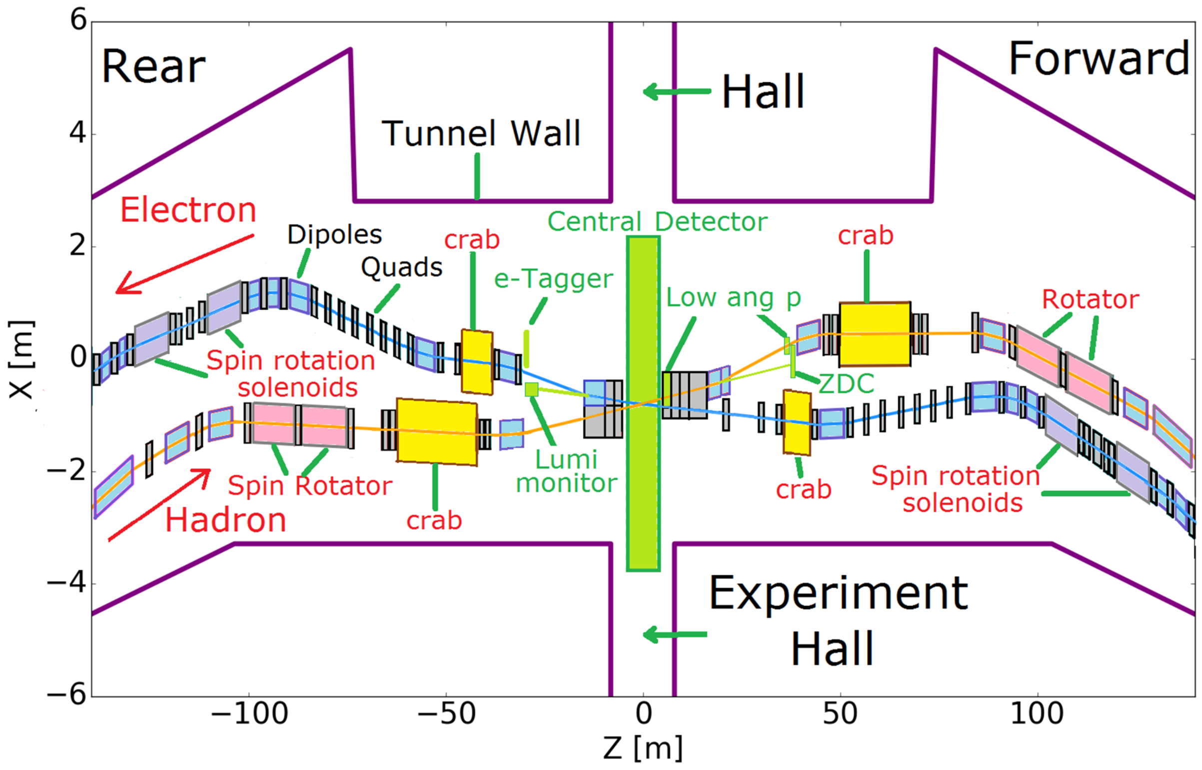
Full Acceptance JLEIC IR Layout

- 50 mrad crossing angle
- Forward hadron detection in three stages
  - Endcap
  - Small dipole covering angles up to ~3°
  - Far forward, ~10 mrad, for particles passing through accelerator quads
- Low-Q2 tagger
  - Small-angle electron detection
- Large beta functions in the IR up to 4 km but manageable chromatics and dynamic aperture



B. Parker, EIC MDI, TUZBA2

Full Acceptance eRHIC IR Layout



Design

- All superconducting magnets
- Only 5 magnets need collared Nb-Ti coils
- All other magnets can be built with **direct wind** of Nb-Ti wire
- Full acceptance e.g.
  P_t =200 MeV/c-1.3 GeV/c
  Neutrons 4 mrad
- Large Aperture Dipole with instrumented gap
- Modest IR chromaticity
  Hadrons up to β<200m

➔ Manageable dynamic aperture optimization

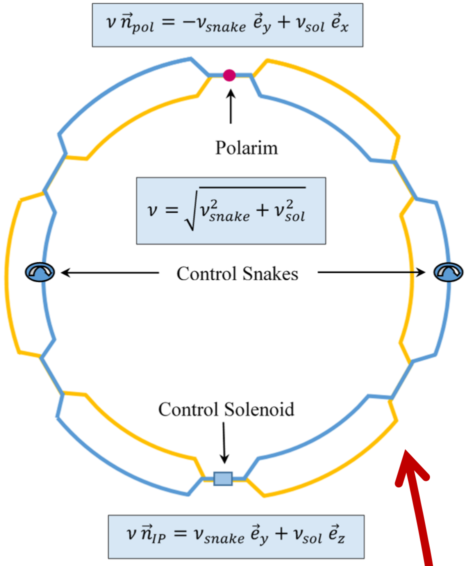
B. Parker, EIC MDI, TUZBA2

EIC Beam Dynamics Challenges

- Proton Beam Stability (emittance growth, halo forming) in presence of strong, crab-enhanced beam-beam effects, strong chromatics
- Electron cloud in the hadron vacuum, suppression of secondary emission yield
- Fast Ion instability for the electron beam
- Multi-bunch stability and feedback: feedback noise and hadron emittance growth
- Impedance optimization in the IR
- Dynamic aperture with extreme beta in the IR

Multi-lab Joint EIC R&D – Examples

- High-Priority EIC R&D topics defined by the Jones review panel
- A number of joint R&D funded by NP – FY17, significant progress achieved in:
  - Crab system design and experimental test
  - Electron cooler design
  - IR magnet design
  - Simulation software development
- Example of awarded FY18-19 proposals:
  - Crab cavity operation in a hadron ring (Lead: ODU, collaborators: JLab, BNL)
  - Strong hadron cooling
    - Development of innovative high-energy magnetized electron cooling for an EIC (Lead: JLab, collab.: BNL, FNAL, ODU)
    - Strong hadron cooling with micro-bunched electron beams (Lead: BNL, collaborators: JLab, SLAC, ANL)
  - Magnet design
    - High Gradient Actively Shielded Quadrupole (Lead: BNL, collaborators: JLab, LBNL)
    - Validation of EIC IR magnet parameters and requirements using existing magnet results (Lead: JLAB, collab.: SLAC, LBNL)
  - Benchmarking of EIC simulations
    - Development & test of simulation tools for EIC beam-beam interaction (Lead: BNL, collaborators: JLab, MSU, LBNL)
    - Experimental verification of spin transparency mode in an EIC (Lead: JLab, collaborator: BNL)
  - Electron complex
    - High Bandwidth Beam Feedback Systems for a High Luminosity EIC (Lead: ANL, collaborator: JLab)



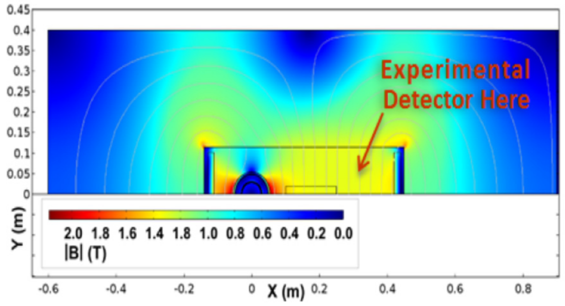
On-Going EIC R&D Effort

Component Development

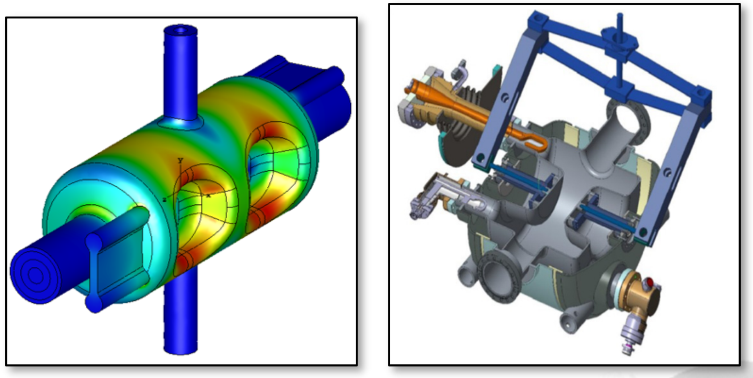
- Crab Cavity design development and prototyping
- IR magnet development and prototyping
- HOM damping for RF structure development
- Variable coupling high power forward power couplers development
- Effective in situ Cu coating of the beam pipe (BNL hadron only)
- High average current electron gun development
- Polarized ^{3}He source
- Bunch by bunch polarimetry

Accelerator Physics R&D

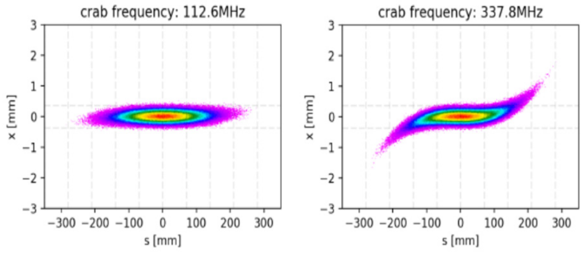
- Strong hadron cooling CeC, cooling development (simulation and experimental)
- Strong hadron cooling bunches electron beam cooling (simulation and experimental)
- ERL development for strong hadron cooling
- Test of suppression of intrinsic depolarizing resonances
- Experimental verification of figure-8 spin transparency
- Study of residual crab cavity effect on beam emittance



Instrumented accelerator magnet



Crab cavity prototypes developed for CERN SpS tests



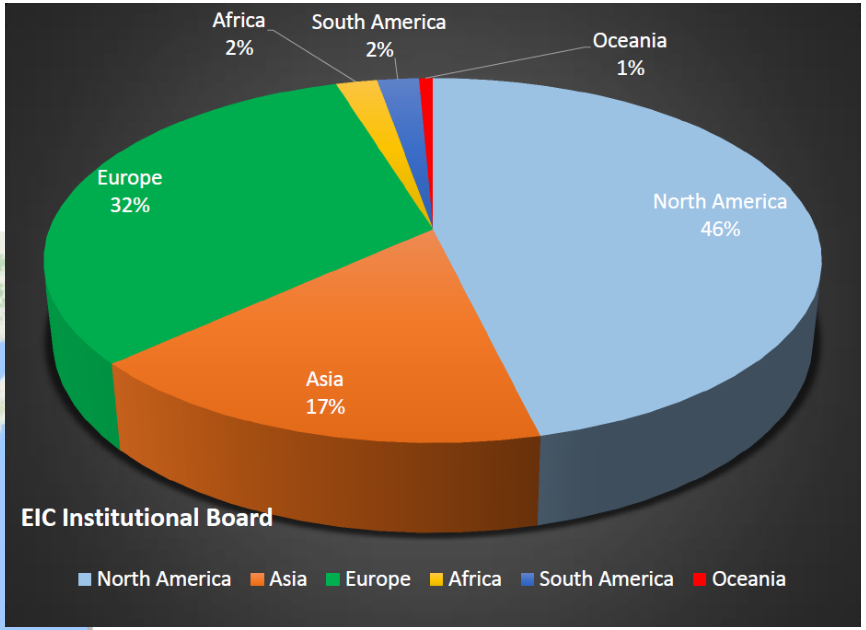
Crabbed beam dynamics

Joint EIC R&D - perspectives

- R&D partnership is expected to grow further, once CD-0 is awarded, to play a significant role in the realization of the EIC
- Through design optimizations and alternate technology choices, selected technology elements from the Jones Report:
  - JLEIC: strong incoherent electron cooling, gear change
  - eRHIC: high current polarized electron sources, high peak current injector linac
- are no longer required for achieving specified EIC performance.
  - The strong incoherent electron cooling effort for the JLEIC is continued, as it further increases the luminosity between 20 and 55 GeV CM reducing the time for dataset accumulation
  - Micro-bunched electron cooling is under active study as a FOA and is the baseline technique for achieving an eRHIC average luminosity of 1.0×10^{34}. Using the Blue ring as an on energy injector, with no cooling, reduces this by 5%, while no mitigation yields 0.33×10^{34}
- R&D plans of both EIC concepts focus on efforts towards cost and/or schedule risk reduction as well as remaining activities for strong electron cooling

Very Strong International Interest through EIC Users Group

Formed 2016, currently: 881 members
186 institutions, 30 countries



http://www.eicug.org

EIC will boost accelerator technology impact on other areas

NAS report: “development of an EIC would advance accelerator science and technology in nuclear science; it would also benefit other fields of accelerator-based science and society, from medicine through materials science to elementary particle physics.”

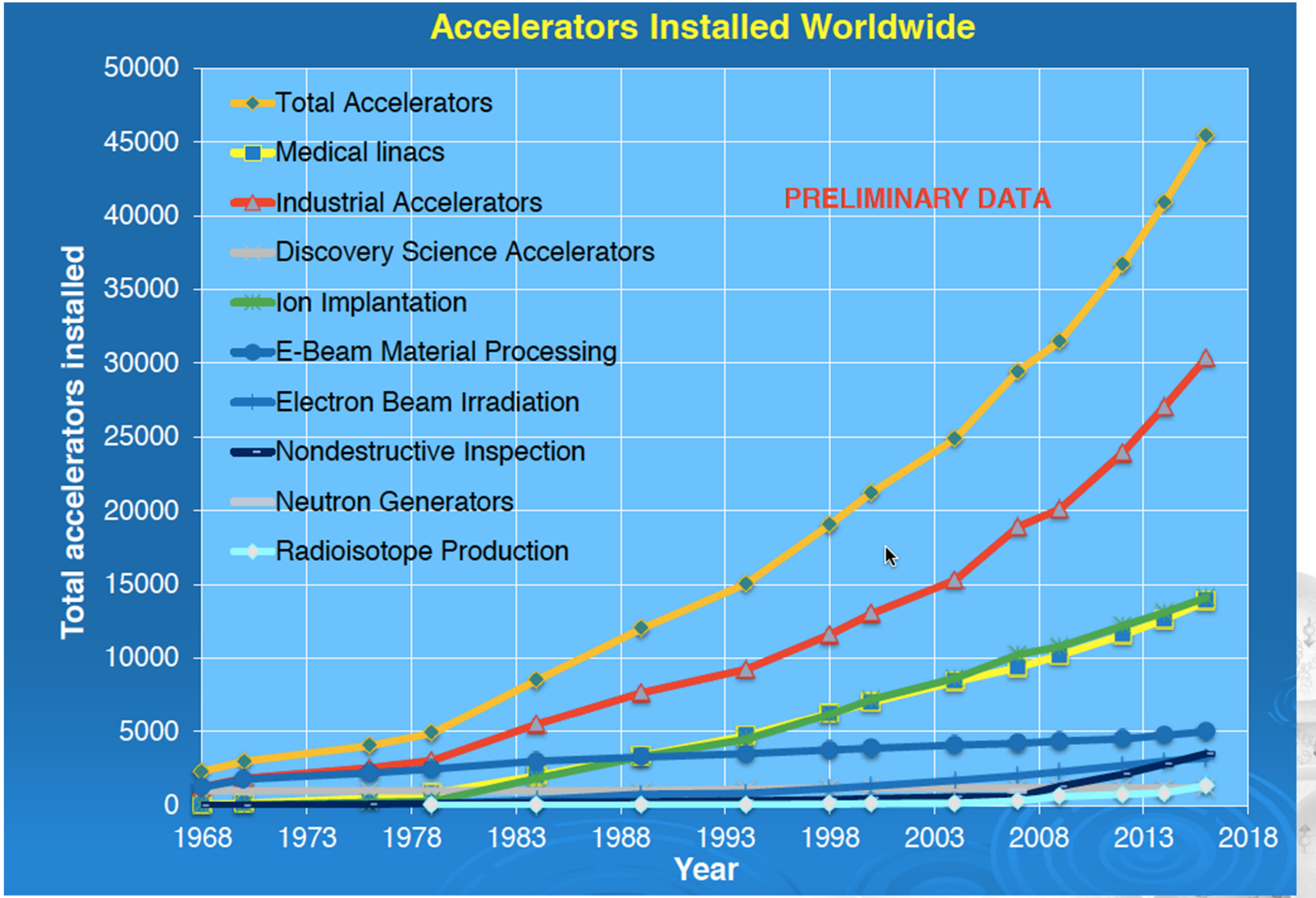


Chart from Robert W. Hamm, Accelerator Industrial Stewardship event, JLAB, December, 2018

Summary

- The future EIC will be much more capable and much more challenging to build than earlier electron or polarized proton machines
- It will be the most sophisticated and challenging accelerator currently proposed for construction in the United States and will significantly advance accelerator science and technology in the US and around the world
- The EIC design team is working on optimization and analyzing the performance of both design concepts and is looking forward for collaborative efforts for making the EIC a reality

Thanks to all co-authors – the EIC design team

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D.Barber - DESY, D.Teytelman - Dimtel Inc., Z.Zhao, - Duke Univ.,
S.Benson, A.Bogacz, P.Brindza, M.Bruker, A.Camsonne, P.Degtyarenko, E.Daly, Ya.Derbenev, M.Diefenthaler, J.Dolbeck, D.Douglas, R.Ent, R.Fair, D.Fazenbaker, Y.Furletova, R.Gamage, D.Gaskell, R.Geng, P.Ghoshal, J.Grames, J. Guo, F.Hannon, L.Harwood, S.Henderson, H.Huang, A.Hutton, K.Jordan, A.Kimber, D.Kashy, G.Krafft, R.Lassiter, R.Li, F.Lin, M.Mamun, F.Marhauser, R.McKeown, T.Michalski, V. Morozov, E. Nissen, G.Park, H.Park, M.Poelker, T.Powers, R.Rajput-Ghoshal, R.Rimmer, Y.Roblin, D.Romanov, P.Rossi, T.Satogata, A.Seryi, M.Spata, R.Suleiman, A.Sy, C.Tennant, H.Wang, S.Wang, C.Weiss, M.Wiseman, W.Wittmer, R.Yoshida, H.Zhang, S.Zhang, Y.Zhang - JLab,
E.Gianfelice-Wendt, S.Nagaitsev - FNAL, J.Qiang, G.Sabbi - LBNL,
M.Musgrave, J.Maxwell, R.Milner - MIT, Y.Hao, P.Ostroumov, A.Plastun, R.York - Michigan State Univ.,
V.Dudnikov, R.Johnson - Muons, Inc., B.Erdelyi, P.Piot - Northern Illinois Univ.,
J.Delayen, C.Hyde, S.De Silva, S.Sosa, B.Terzic - Old Dominion Univ.,
D.Abell, D.Bruhwiler, I.Pogorelov - Radiasoft LLC,
Y.Cai, Y.Nosochkov, A.Novokhatski, G.Stupakov, M.Sullivan, C.Tsai - SLAC, J.Fox - Stanford Univ.,
P.Nadel-Turonski - Stony Brook Univ., G.Bell, J.Cary - Tech-X Corp.,
J.Gerity, T.Mann, P.McIntyre, N.Pogue, A.Sattarov - Texas A&M Univ.

NAPAC EIC presentations

MOYBA3 "JLEIC: A High Luminosity Polarized Electron-Ion Collider at Jefferson Lab", by Yuhong Zhang (JLab)
MOYBA4 "eRHIC Design Update", by C. Montag (BNL)
MOZBB5 "Magnetized Electron Source for JLEIC Electron Cooler", by Riad Suleiman (JLAB)
TUZBA2 "EIC Machine Detector Interface", by Brett Parker (BNL)
TUZBA3 "A High-Energy Design for JLEIC Ion Complex", by Brahim Mustapha (ANL)
TUZBA4 "Interaction Region Magnets for Future Electron-Ion Collider at Jefferson Lab", by Tim Michalski (JLab)
TUYBA6 "Computation of Magnetized Dynamic Friction Force Based on a Reduced Binary Interaction Model", by Ilya Pogorelov (RadiaSoft)
TUZBB4 "Space Charge Study of the Jefferson Lab Magnetized Electron Beam", by S. Wijethunga (ODU)

and posters

MOPLM06 "High Voltage Design of a 350 kV DC Photogun at BNL" by Wei Liu (BNL)
MOPLO13 "Field Quality Analysis of Interaction Region Quadrupoles for JLEIC" by Tim Michalski (JLab)
TUPLM11 "Beam-Beam Damping of the Ion Instability" by Mike Blaskiewicz (BNL)
TUPLM13, SUPLM07 "Two-Energy Storage-Ring Electron Cooler for Relativistic Ion Beams" by Bhawin Dhital (ODU)
TUPLM17 "Optimization of JLEIC Luminosity Performance Without On-Energy Cooling" by Yuhong Zhang (JLab)
TUPLM24 "Electron Heating by Ions in Cooling Rings" by He Zhao (BNL)
TUPLM25 "Connecting Gas-Scattering Lifetime and Fast Ion Instability" by Boris Podobedov (BNL)
TUPLM20 "Generation of High-Charge Magnetized Electron Beams Consistent With JLEIC Electron Cooling Requirement" by Aaron Fetterman (NIU)
TUPLO01, SUPLH10 "Dual-Function Electron-Ion Booster Design for JLEIC High-Energy Option" by Jose Luis Marin (ANL)
TUPLO02, SUPLH11 "Spin Dynamics in the JLEIC Ion Injector Linac" by Jose Luis Marin (ANL)
TUPLO03 "RHIC Beam Abort System Upgrade Options" by Wolfram Fischer (BNL)
TUPLO04 "The Latest Code Development Progress of JSPEC" by He Zhang (JLab)
TUPLO06 "Weak-Strong Beam-Beam Simulation for eRHIC" by Yun Luo (BNL)
TUPLO07 "Calculation of Action Diffusion with Crabbed Collision in eRHIC" by Yun Luo (BNL)
TUPLO08 "JLEIC Electron Collider Ring Design and Nonlinear Dynamics Study" by Fanglei Lin (JLab)
TUPLO09, SUPLH13 "Electron-Ion Collider Performance Studies With Beam Synchronization via Gear-Change" by Isurumali Neththikumara (ODU)
TUPLO12 "Off-momentum Optics Correction in RHIC" by Guillaume Robert-Demolaize (BNL)
TUPLO13 "Interaction Region Magnets for Future Electron-Ion Collider at Jefferson Lab", by Tim Michalski (JLab)
TUPLO15 "Multipole Effects on Dynamic Aperture in JLEIC Ion Collider Ring" by Randy Gamage (JLab)
WEPLH13 "Experimental Demonstration of Cooling of Ions By a Bunched Electron Beam", by Yuhong Zhang (JLab)
WEPLS11 "Simulation of Transparent Spin Experiment in RHIC" by River Huang (JLab)