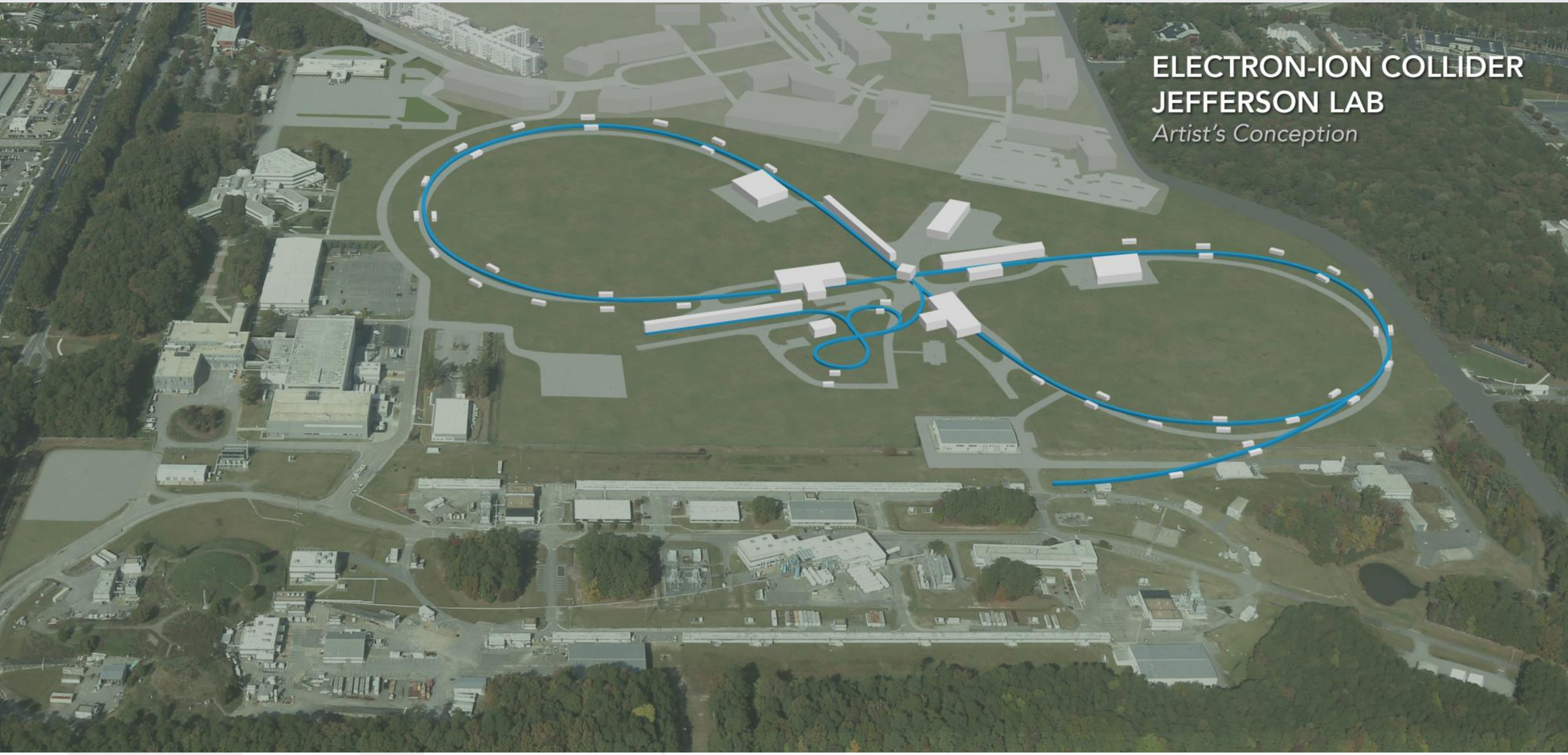
JLEIC Design Update (Oct. 2018)



Rik Yoshida for the JLEIC Collaboration

Oct 22, 2018, INT, Seattle

Jefferson Lab

EIC² EIC Center at Jefferson Lab

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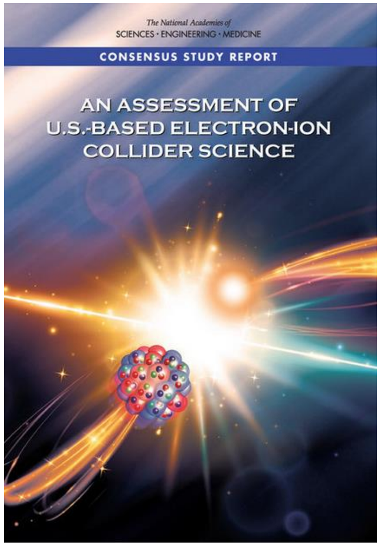
JSA

EIC Performance Requirements: NAS report



- Extensive center-of-mass energy range, from ~20-100 GeV, upgradable to ~140 GeV, to map the transition in nuclear properties from a dilute gas of quarks and gluons to saturated gluonic matter.
- Ion beams from deuterons to the heaviest stable nuclei.
- Luminosity on the order of 100 to 1,000 times higher than the earlier electron-proton collider Hadron-Electron Ring Accelerator (HERA) at Deutsches Elektronen-Synchrotron (DESY), to allow unprecedented three-dimensional (3D) imaging of the gluon and sea quark distributions in nucleons and nuclei.
- Spin-polarized (~70 percent at a minimum) electron and proton/light-ion beams to explore the correlations of gluon and sea quark distributions with the overall nucleon spin. Polarized colliding beams have been achieved before only at HERA (with electrons and positrons only) and Relativistic Heavy Ion Collider (RHIC; with protons only).
- One or more interaction regions, which integrate the detectors into the collider and preserve the extensive kinematic coverage for measurements.

- $\sqrt{s_{ep}}$ range ~20 to ~100 GeV upgradable to ~140 GeV
- Ion beams from D to heaviest stable nuclei
- 100 to 1000 times HERA luminosity—will discuss what this means
- At least ~70% polarization for electrons, protons and light ions
- One or more IR with integrated detector with high acceptance

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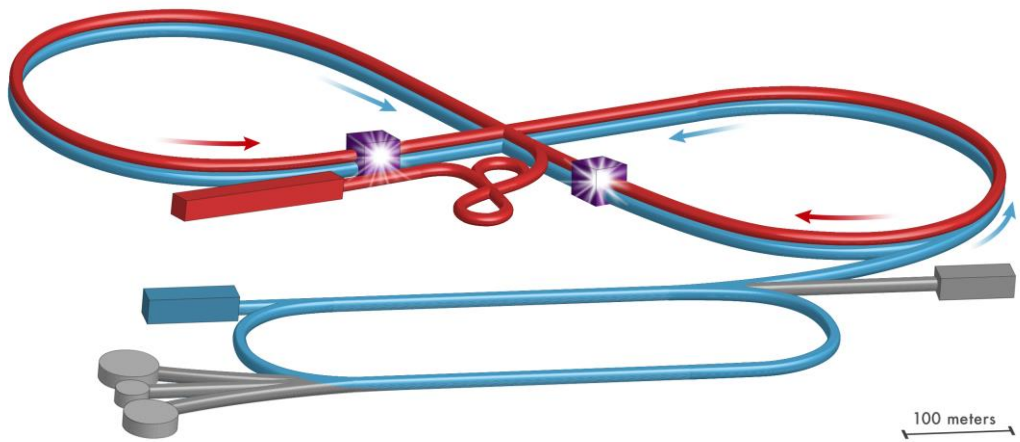
Fundamental concept unchanged



Update History

This Update

arXiv:1504.07961

Document
Under development

This update:

- Increase √s range by increasing ion ring dipoles from 3T→6T.
- Keep the land footprint of the design the same.
- The luminosity performance satisfies the requirements.
- IR design retains high acceptance.
- Polarization remains high.
- Relatively small design changes

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beam energy range:

E_e: 3 to 12 GeV (same as before)

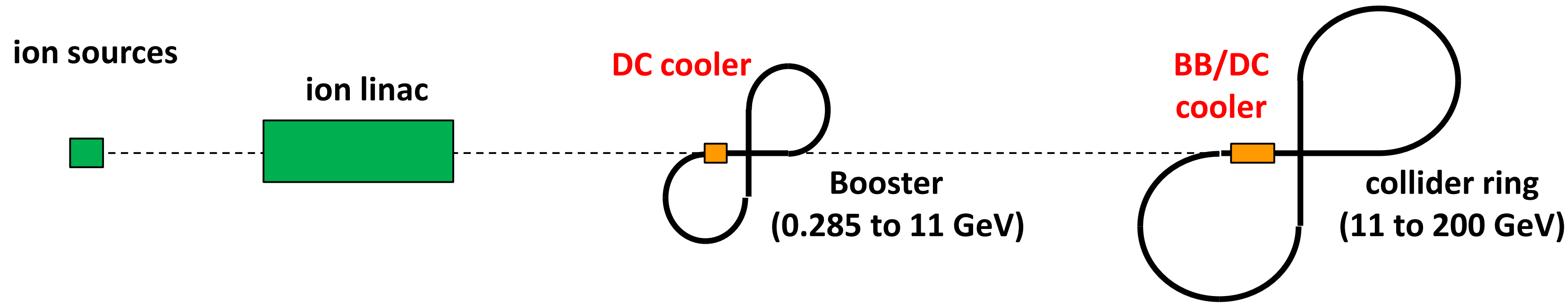
E_p: 30 to 200 GeV (enabled by 3T→6T dipoles) upgradable to 400 GeV (use HE-LHC/FCC development—12T dipoles)

JLEIC Energy: √s = 20 to 100 GeV upgradable to 140 GeV ✓

Most of the design remains the same

- **Electron complex** (unchanged)
  - CEBAF
  - Electron collider ring
- **Ion complex** (mainly incremental changes)
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring (3T→6T dipoles)
- Fully integrated high-acceptance IR (being re-optimized for higher energies) ✓ and **detector**
  - 2 IRs with same acceptance
- DC and bunched beam **coolers** (incremental changes + no BBC concept)

High luminosity: multi-phased cooling



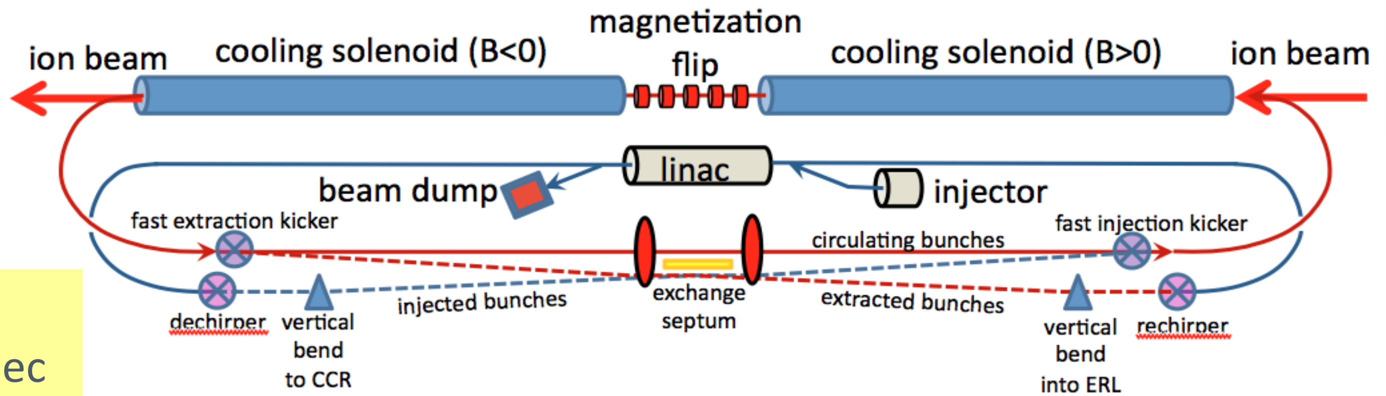
Ring	Functions	Kinetic energy (GeV / MeV)			Cooler type
		Proton	Lead ion	Electron	
booster ring	Accumulation of positive ions		0.1 (injection)	0.054	DC
collider ring	Maintain emitt. during stacking	11 (injection)	3 (injection)	6.0 (proton) 1.6 (lead)	DC
	Pre-cooling for emitt. reduction	11 (injection)	11 (ramp to)	6.0	DC
	Maintain emitt. during collision	Up to 200	Up to 78.3	Up to 109	BBC/ERL

4.3 MeV DC Cooler @Fermilab

- DC cooling for emittance reduction
- BBC cooling for emittance preservation against intra-beam scattering

Bunched Beam Cooling

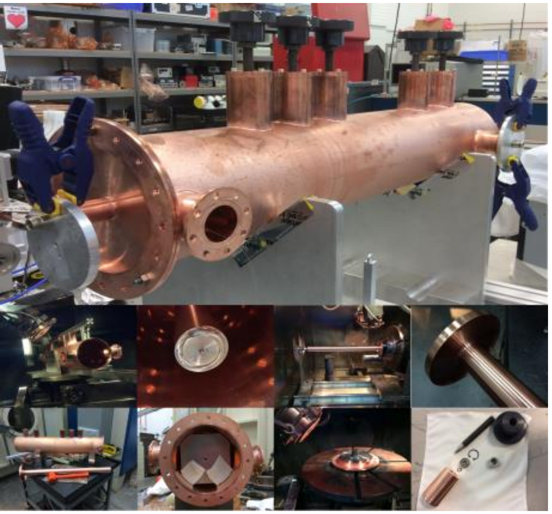
ERL cooler + Multi-turn circulator ring



Enabling technologies :

Fast kickers, risetime <1 nsec

Magnetized source ~75mA

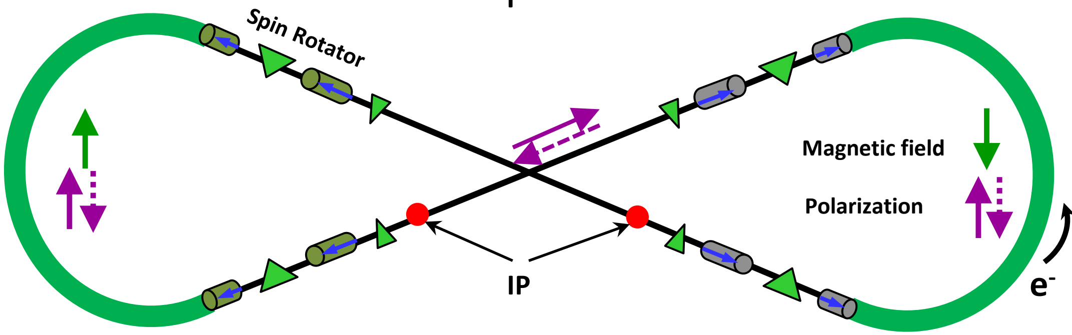


Parameter	Units	Value
Energy	[MeV]	20–110
Charge	[nC]	3.2
CCR pulse frequency	[MHz]	476.3
Gun frequency	[MHz]	43.3
Bunch length (tophat)	[cm,o]	3 / 23
Thermal (Larmor) emittance	[mm-mrad]	<19
Cathode spot radius	[mm]	3.1
Cathode field	[T]	0.05
Normalized hor. drift emittance	[mm-mrad]	36
rms Energy spread (uncorr.)*		3×10^{-4}
Energy spread (p-p corr.)*		$<6\times10^{-4}$
Solenoid field	[T]	2
Electron beta in cooler	[cm]	37.6
Solenoid length	[m]	4× 15
Bunch shape		beer can

High polarization: Figure-8

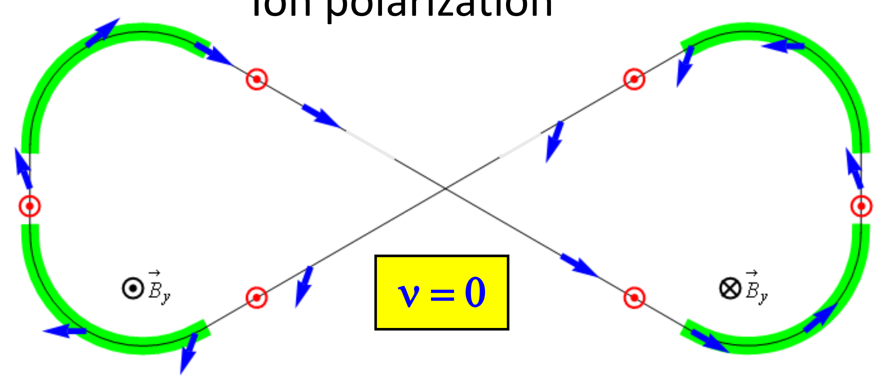
- **Figure-8** concept: <u>spin precession in one arc is exactly cancelled in the other</u>
- **Spin stabilization by small fields**: ~3 Tm vs. ~ 400 Tm for **deuterons** at 100 GeV
  - Criterion: induced spin rotation >> spin rotation due to orbit errors
- **Highly polarized deuteron beams will run in JLEIC**
- **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
- Adiabatic spin flips
- **Spin tracking** in progress

Electron polarization



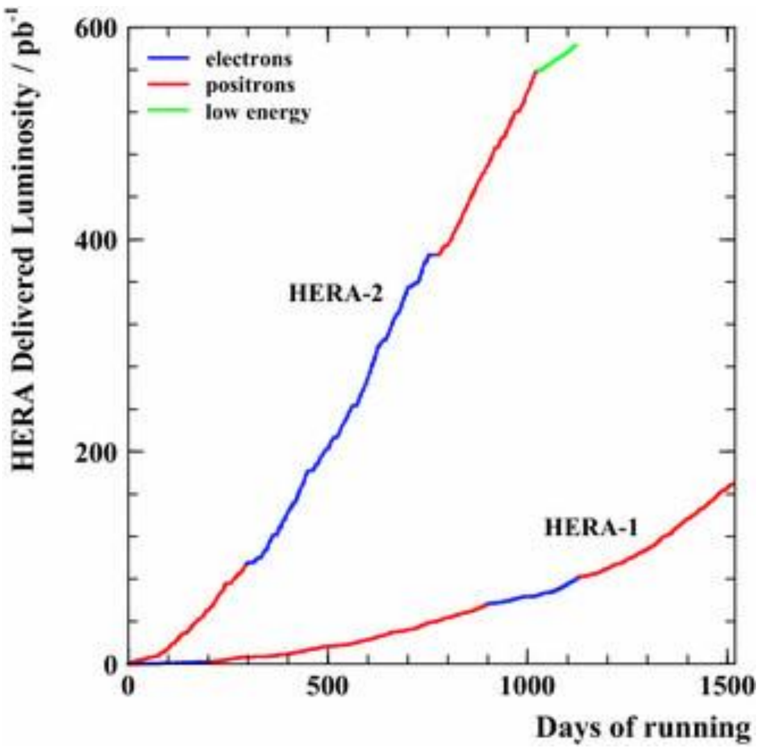
E- energy (GeV)	3	5	7	9	10
Estimated Pol. Lifetime (hours)	66	5.2	2.2	1.3	0.8

Ion polarization



Polarization for proton, light ions (incl. deuterons), electrons >80%. ✓

Luminosity Discussion



In HERA-2, ~600 pb^{-1} of integrated luminosity was delivered (to ZEUS) over ~1000 days of running.

The means that HERA-2 delivered ~0.6 pb^{-1}/day or ~4 pb^{-1}/week of integrated luminosity during "running". There were two collider experiments, so inflate this a little to 6 pb^{-1}/week

6 pb^{-1}/(one week in seconds) = 10^{31} cm^{-2}s^{-1}
This is the average luminosity of HERA while running

We would like to have 100 – 1000 times HERA luminosity:
So the aim for the EIC is 0.6 fb^{-1} to 6 fb^{-1}/week of running.
Or average luminosity (while running) of 10^{33} to 10^{34} cm^{-2} s^{-1}

average while running (not instant, not peak, etc.)

6 fb^{-1}/wk ➔ 100 fb^{-1}/yr
assuming 10^7 s in year
(running ~1/3 of the year
or a "snowmass" year)

Average luminosity (while running) is quoted for JLEIC

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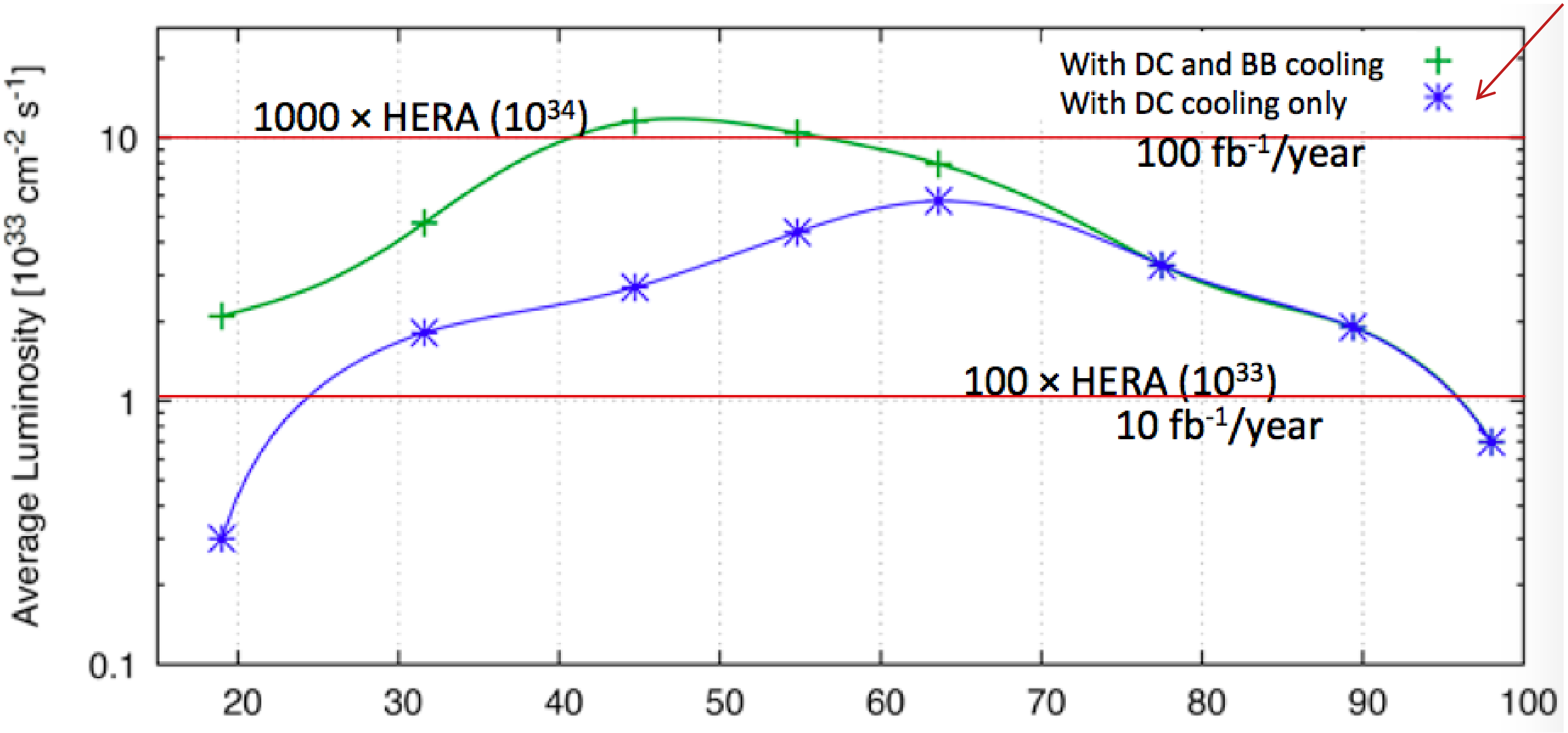
JLEIC Average Luminosity and Energy Reach

Average luminosity during running (operational inefficiency taken into account): i.e.
Integrated luminosity = Av. Lumi × Time of running

Note good perf. w DC only



Luminosity 100 to 1000 time that of HERA over the energy range ✓

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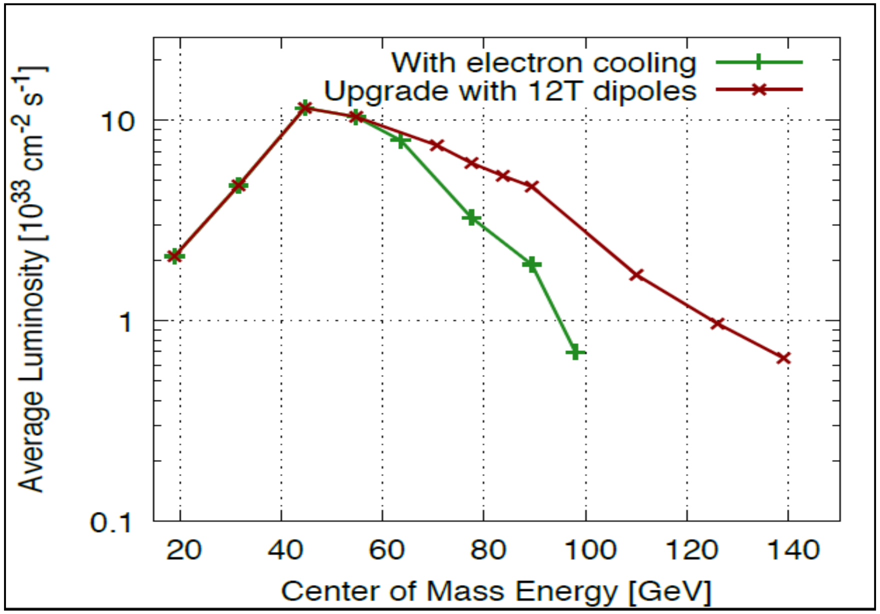
JLEIC Luminosity and Energy Reach with Upgrade



Average luminosity during operation: i.e.
Integrated luminosity = Av. Lumi × Time

Note: Total of ~640 fb^{-1}

- 10^{34} cm^{-2}s^{-1} → 6 fb^{-1}/week, (>100 fb^{-1} /year)
- 10^{33} cm^{-2}s^{-1} → 0.6 fb^{-1}/week, (>10 fb^{-1} /year)

Table 1.1: EIC White Paper Luminosity Needs. Units are integrated luminosity in fb^{-1}. Values in parentheses can be acquired concurrently with other measurements. Blank entry does not mean there is no interest; rather that the White Paper does not discuss these measurements explicitly. Polarizations are indicated as unpolarized (U), transverse (T), and Longitudinal (L).

Physics	White Paper Reference	eP low (~20 GeV)	eP medium (~40 GeV)	eP high (~60–~100 GeV)	eP Phase II (140 GeV)	eD or e^3He	eCa	eAu
Gluon Spin (LL)	Table 2.1	–	–	(10)	–	(10)	–	–
Quark TMD (LL+LT)	Figs. 2.15–2.16	10+10	(10+10)	(10+10)	–	–	–	–
Gluon TMD (LL+LT)	Figs. 2.17	–	–	100+100	–	–	–	–
DVCS (LL+LT)	Fig. 2.21, 2.6	–	100+100	(100+100)	–	–	–	–
DVCS eD (LL+LT)	Sec. 2.4.6	–	–	–	–	100+100	–	–
Saturation (UU)	Figs. 3.16–3.20	–	–	(10)	10	–	10	10

JLEIC SUMMARY

- The basis of the design (ring-ring, high luminosity by high rep-rate, high polarization with Figure-8, full event coverage, and minimization of technical risk) has remained constant since 2005
- The **energy reach** is **$\sqrt{s}$ =20 to 100 GeV** upgradable to **140 GeV,** ✓ using 12 T magnet technology being developed for CERN projects HE-LHC and FCC.
- The design delivers **average** luminosity of **$10^{33\text{-}34}$ cm^{-2} sec^{-1}** in ✓ the almost the entire energy range **with only DC cooling**.
- The figure-8 design achieves **>80%** **polarization** for both light ions (including deuteron) and electrons. ✓
- A **pre-CDR** with a full description is under preparation. There may be a minor update to the parameters upon its release.
- The overall design risk is **low** in most areas.
- Technology demonstration is needed primarily for the **bunched beam electron cooling;** *However*, very good performance can be achieved with only DC cooling.