Electron-Ion Collider in the US

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Hard Probes, Aix-les-Bains, Oct 4, 2018

Center for Frontiers in Nuclear Science

EIC Center at Jefferson Lab

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

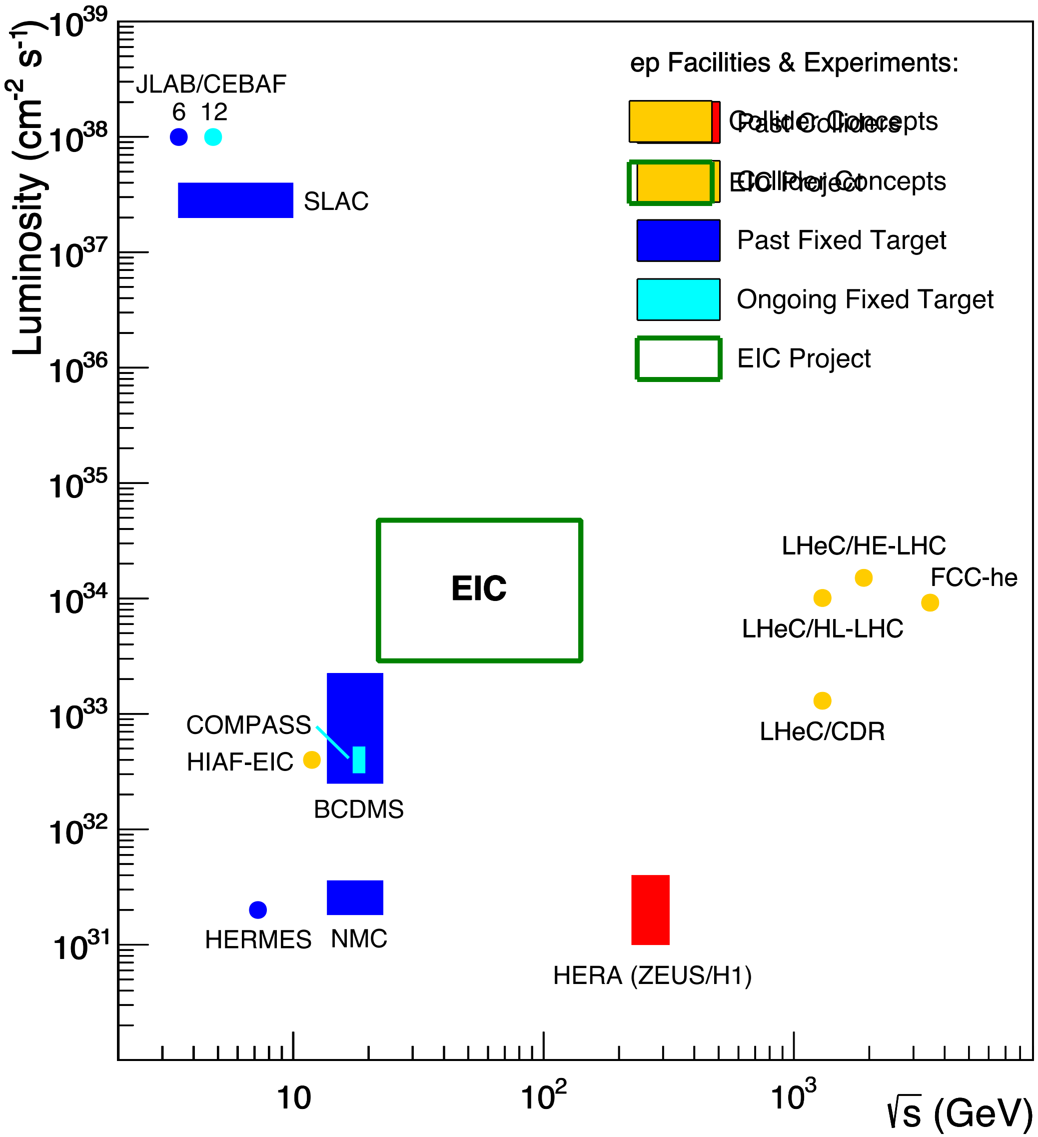
Electron-Ion Colliders around the world

	HERA @DESY	LHeC	VLHEeP	eRHIC@BNL	JLEIC@JLAB	HIAF@CAS	ENC@GSI
E_{CM} (GeV)	320	800-1300	1000-9000	30-140	20-100 → 140	12-65	14
Proton x_{min}	10^{-5}	5×10^{-7}	10^{-7-8}	2×10^{-5}	5×10^{-5}	3×10^{-4}	5×10^{-3}
ion	p	p to HI	p to HI	p to HI	p to HI	p to HI	p to ^{40}Ca
ion polarization	-	-	-	p, d, ^{3}He,(^{6}Li)	p,d,^{3}He,(^{6}Li)	p,d,^{3}He	p,d
L (/cm²/s)	2×10^{31}	10^{34}	10^{28-29}	10^{33-34}	10^{33-34}	10^{33-35}	10^{32}
IP	2	1	1	2	2	1	1
When	1992 -2007					Upgrade to HIAF	Upgrade to FAIR

+FCCeh

US Based EIC
at most 1 will be built

Uniqueness of US EIC among all DIS Facilities



All DIS facilities in the world.

However,
if we ask for:

- high luminosity & wide reach in √s
- polarized lepton & hadron beams
- nuclear beams

EIC is a unique facility …

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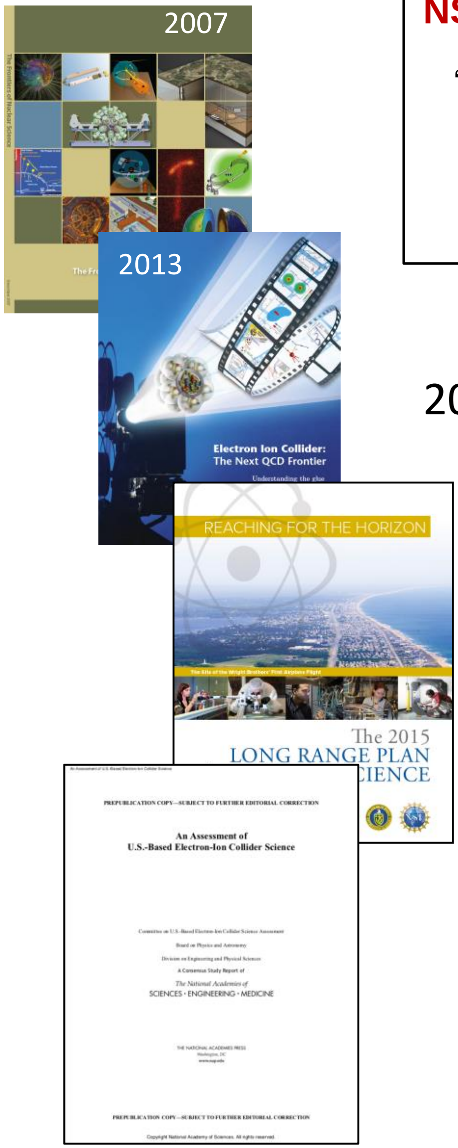
History of US EIC



NSAC 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**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia."

2013 EIC White Paper

NSAC 2015 Long-Range Plan: RECOMMENDATION III

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

National of Academy of Sciences : 2018 Assessment of US EIC

In summary, 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. In addition, the development of an EIC would advance accelerator science and technology in nuclear science; it would as well **benefit other fields** of accelerator- based science and society, from medicine through materials science to elementary particle physics.

Findings of the NAS committee

Main Findings

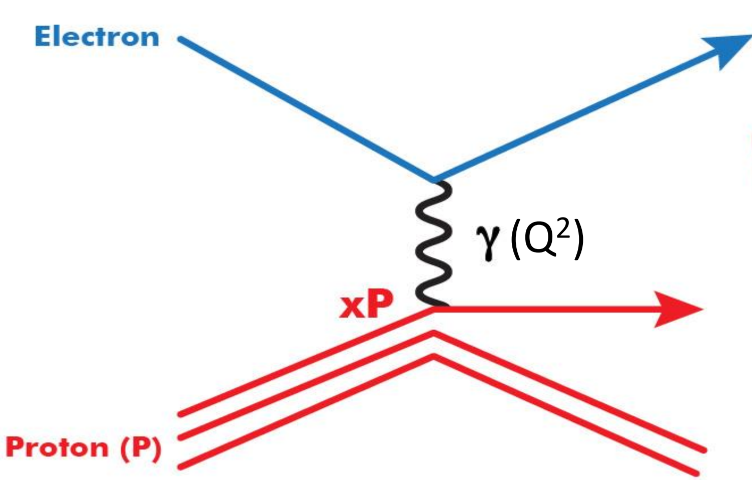
- **Finding 1:** An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
- **Finding 2:** 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**.

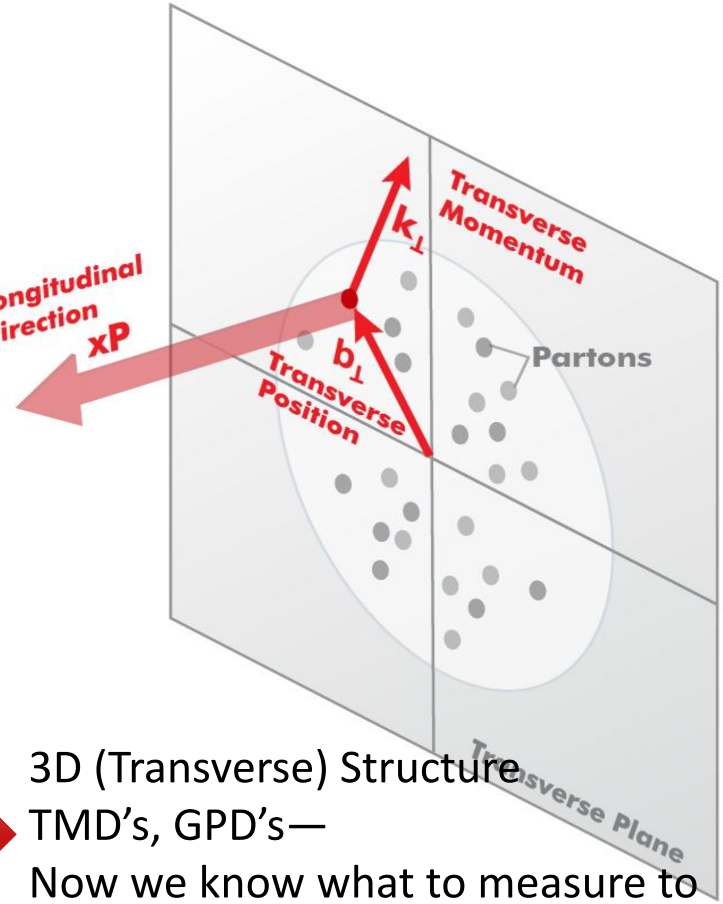
Further findings

- **Finding 3:** An EIC would be a 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 6:** The current accelerator R&D program supported by DOE is crucial to addressing outstanding design challenges.
- +3 more

Progress in pQCD Theory (~1980-~2010)

Factorization II



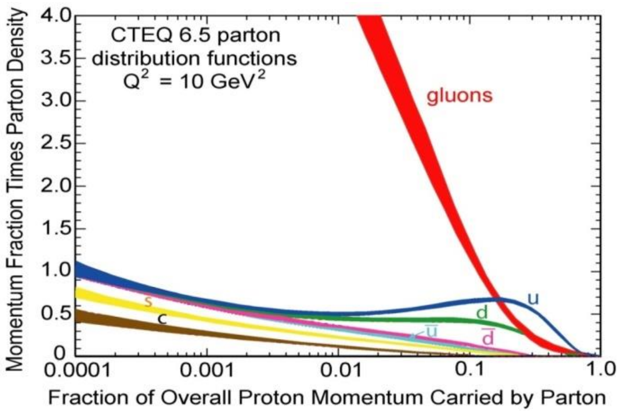


Parton Distribution Functions:
Longitudinal only—
No way to interpret nucleon partonic structure in rest frame

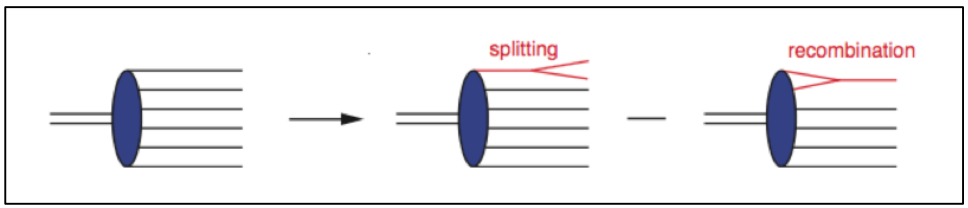
3D (Transverse) Structure
TMD's, GPD's—
Now we know what to measure to understand the 3D structure of nucleons

Transverse Momentum Dependent Distributions (TMD): k_t
Generalized Parton Distributions (GPD): b_t

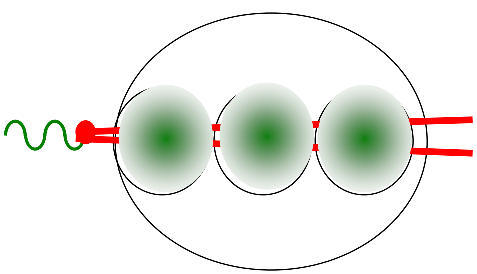
QCD at Extremes: Parton Saturation



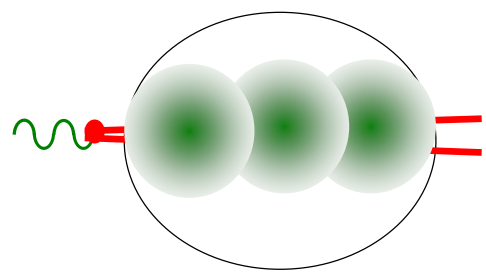
HERA discovered a dramatic rise in the number of gluons carrying a small fractional longitudinal momentum of the proton (i.e. small-x).



This cannot go on forever as x becomes smaller and smaller: parton recombination must balance parton splitting.
i.e. Saturation—unobserved at HERA for a proton. (expected at extreme low x and high Q^2)

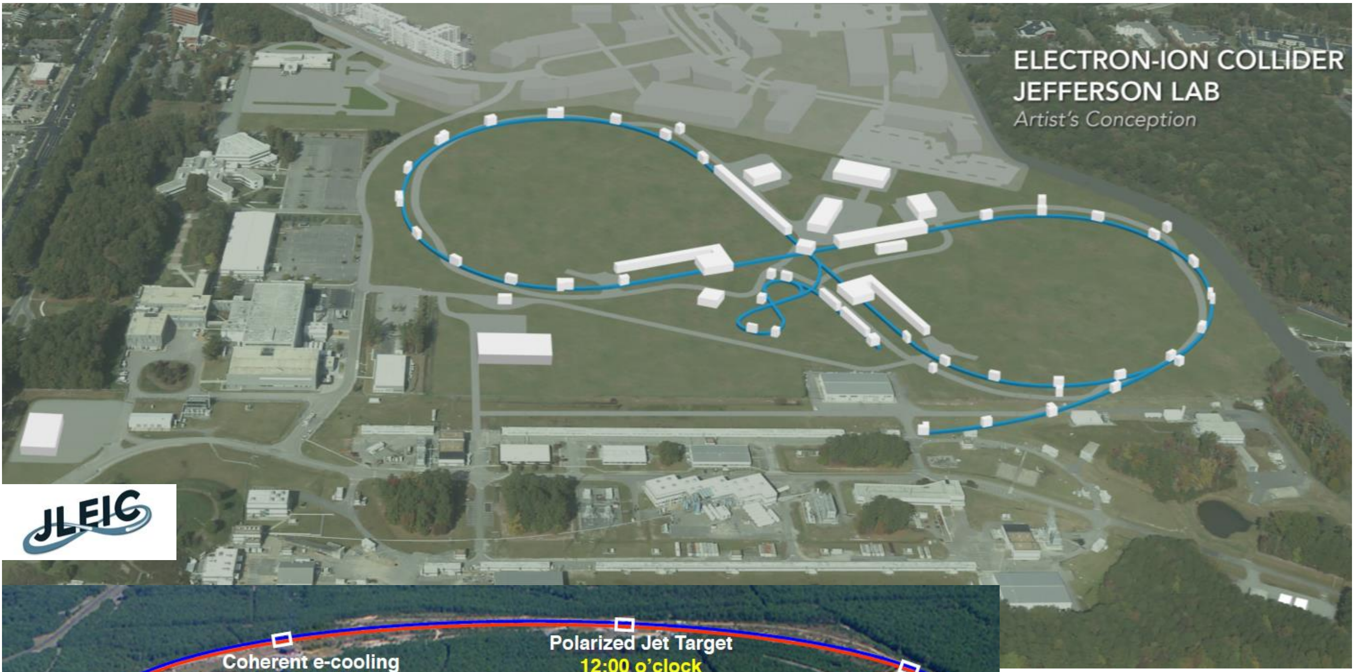


In nuclei, the interaction probability geometrically enhanced by $A^{1/3}$?



Will nuclei saturate faster as color leaks out of nucleons?

US-Based EIC Proposals



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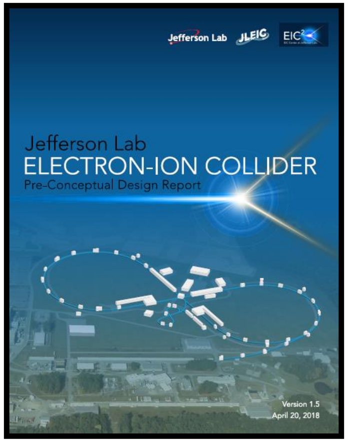
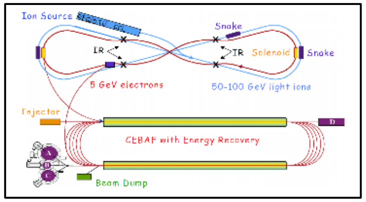
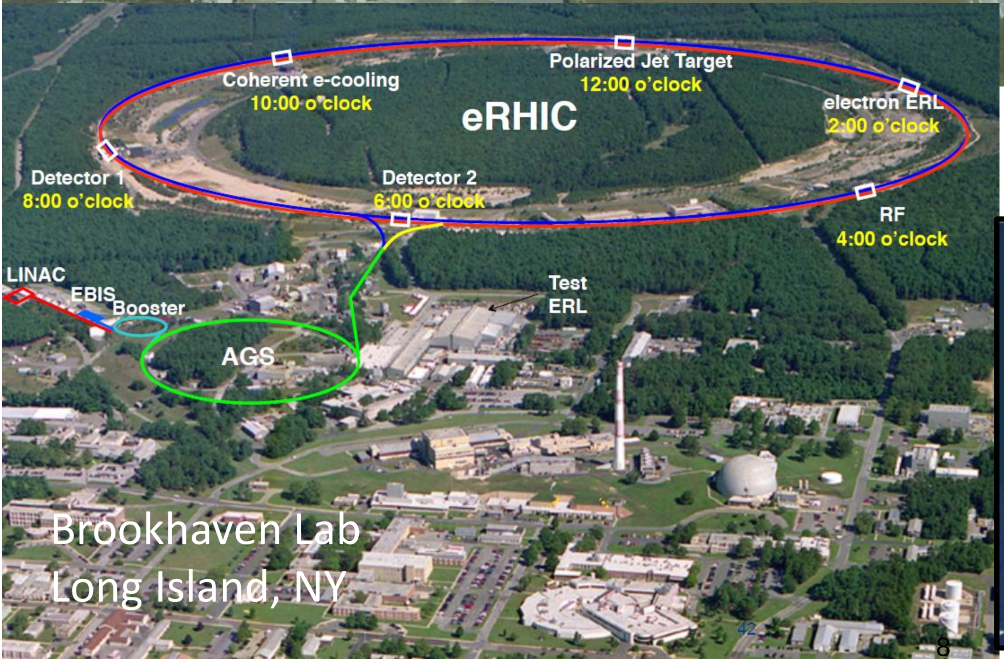
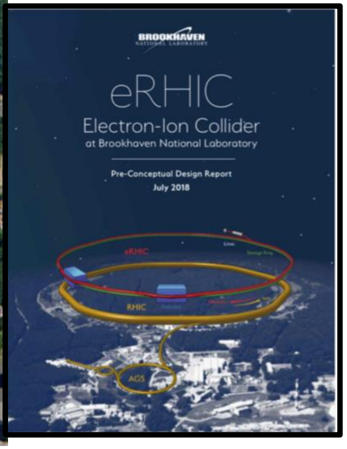




2002 JLab Concept





Needed Collision Energy and Luminosity

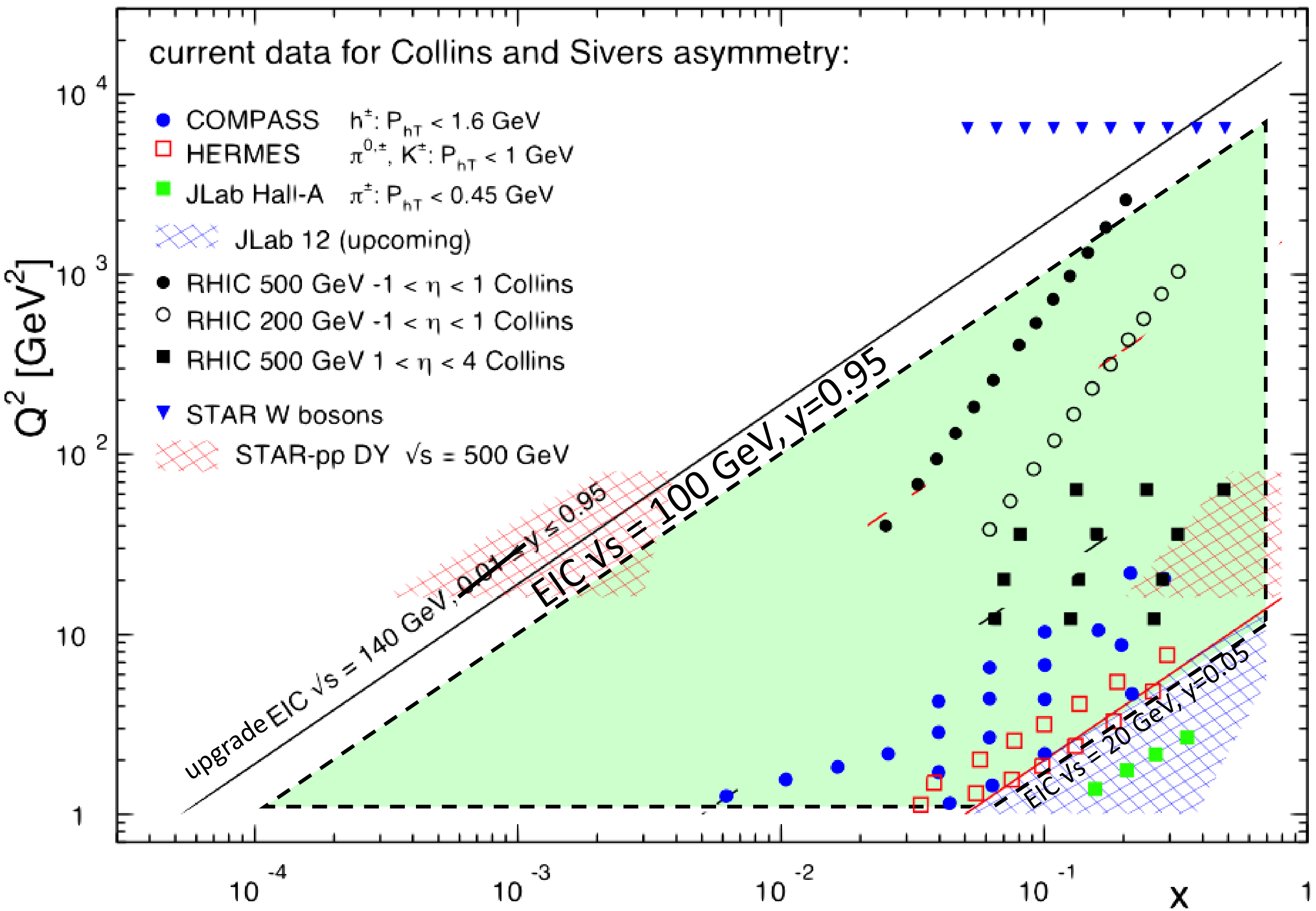
EIC Whitepaper and NAS report

- (Center of mass) Energy Range ~20 to ~100 GeV, upgradable to ~140 GeV.
- Luminosity: $\sim 10^{33\text{-}34}\ cm^{-2}\ s^{-1}$
- Highly polarizable electron and proton/light-ion beams (>70%)

AND

- Ion beams from deuteron to heavy nuclei (e.g. lead)
- Possibility of having more than one interaction point.

EIC Kinematic Coverage



Luminosity Needs from the EIC whitepaper

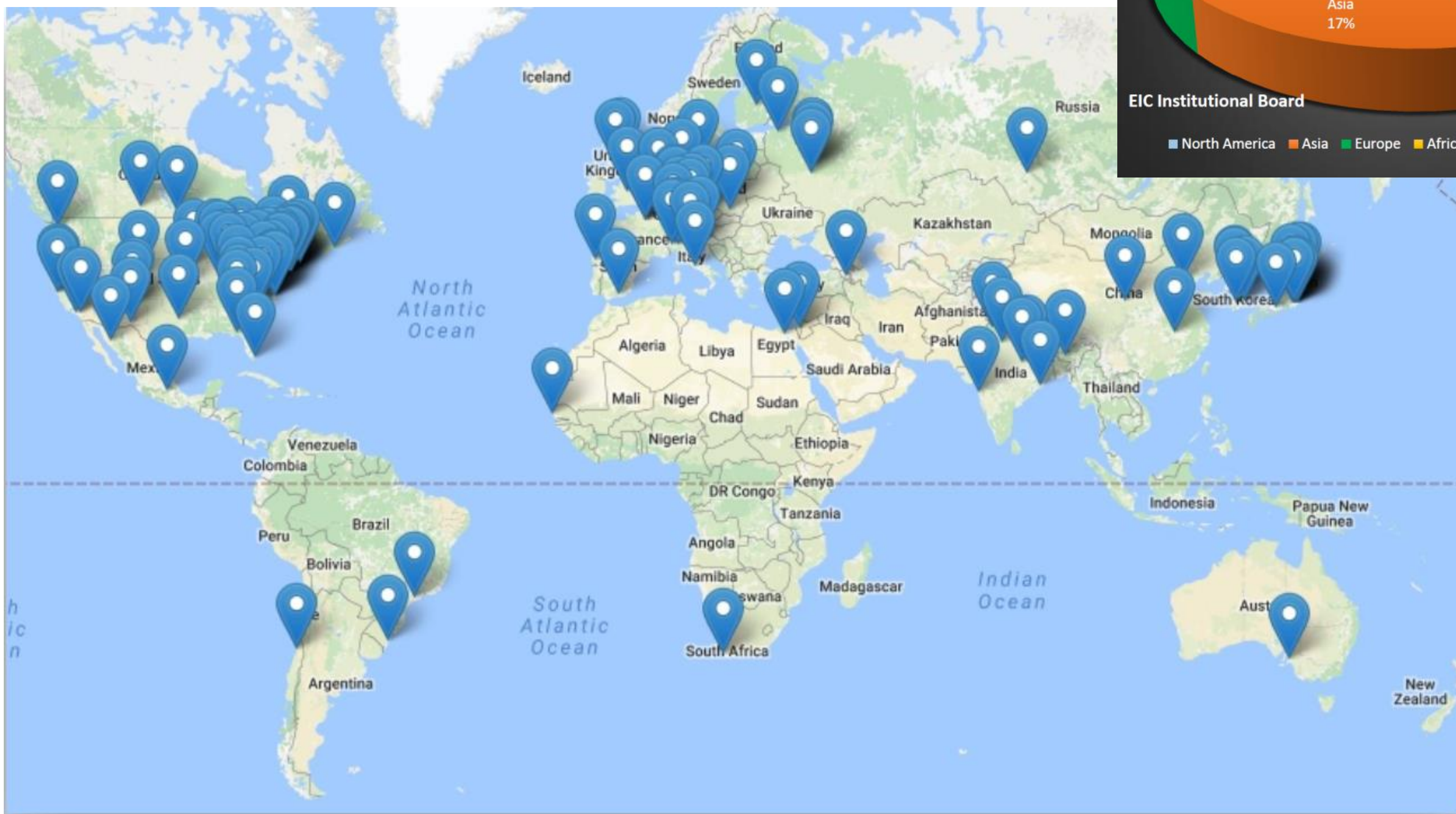
Physics	WP reference	eP low (~20 GeV)	eP medium (~40 GeV)	eP high (~65-100 GeV)	eP Phase II (140 GeV)	eD or e3He	eCa	eAu
Gluon Spin (UL)	Table 2.1			(10)		(10)		
Quark TMD (LL+LT)	Fig 2.15, 2.16	10+10	(10+10)	(10+10)				
Gluon TMD (LL+LT)	Fig 2.17			100+100				
DVCS/VM (LL+LT)	Fig. 2.21, 2.26		100+100	(100+100)				
DVCS eD (LL+LT)	Sec. 2.4.6					100+100		
Saturation(UU)	Fig. 3.16, 3.17,3.18, 3.20 etc.			(10)	10		10	10

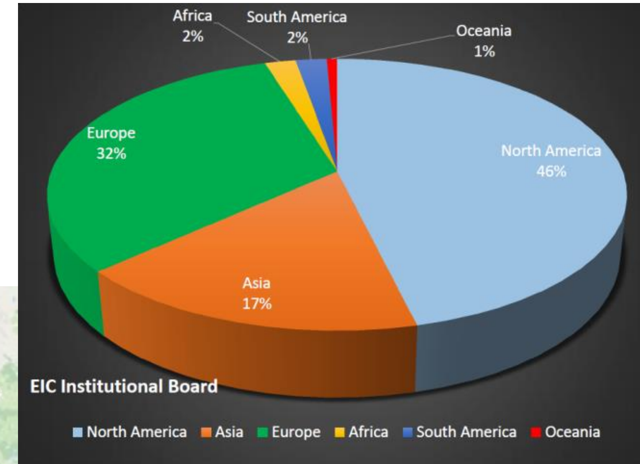
luminosity in \fb. Datasets in () indicates can be concurrently taken with another dataset. Blank entry does not mean there is no interest; merely that WP does not discuss explicitly.

EIC Users Group

Formed 2016, currently: 822 members

173 institutions, 30 countries





EIC write-ups & Lab brochures

- EIC write-ups & Lab brochures
  - Recent EIC write-up in CERN Courier:

    http://iopp.fileburst.com/ccr/archive/CERNCourier2018Oct-digitaledition.pdf

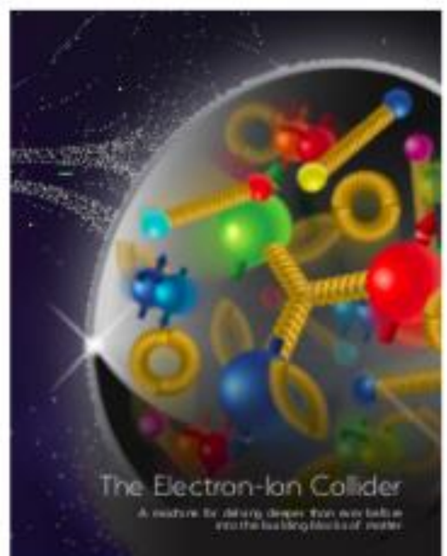
    Article written by Elke Aschenauer (BNL) and Rolf Ent (JLab)

  - EIC fact-sheet:

    http://www.eicug.org/web/sites/default/files/EIC_OnePage_FactSheet.pdf

  - EIC brochure:

    http://www.eicug.org/web/sites/default/files/EIC_Brochure.pdf



EIC Realization Imagined

With a formal NSAC/LRP recommendation, and a very positive NAS committee report what can we speculate about the EIC timeline?

- DOE project “CD0” (Establish Mission Need) will be after the NAS study: 2019.

- EIC construction has to start **after FRIB completion**, with FRIB construction anticipated to start ramping down near or in FY20.

→ Most optimistic scenario would have EIC construction start (CD3) in FY21, perhaps more realistic FY22-23 timeframe

→ Best guess for EIC completion assuming formal NSAC/LRP recommendation would be 2025-2030 timeframe