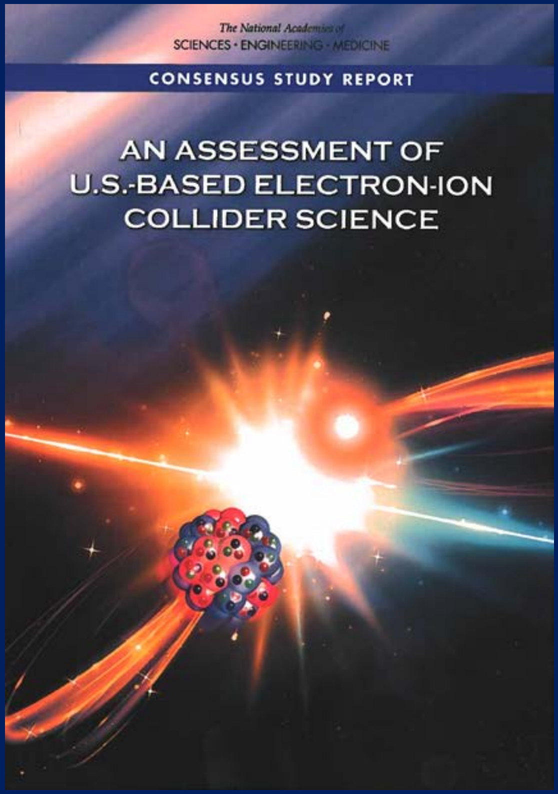
The EIC User Group and Findings of the National Academy of Sciences Assessment of EIC Science

Electron-Ion Collider User Group
The world's most powerful microscope for studying the "glue" that binds the building blocks of visible matter.

Christine A. Aidala
University of Michigan

Inaugural Symposium
Center for Frontiers in Nuclear Science
November 29, 2018



2016: Creation of EIC User Group

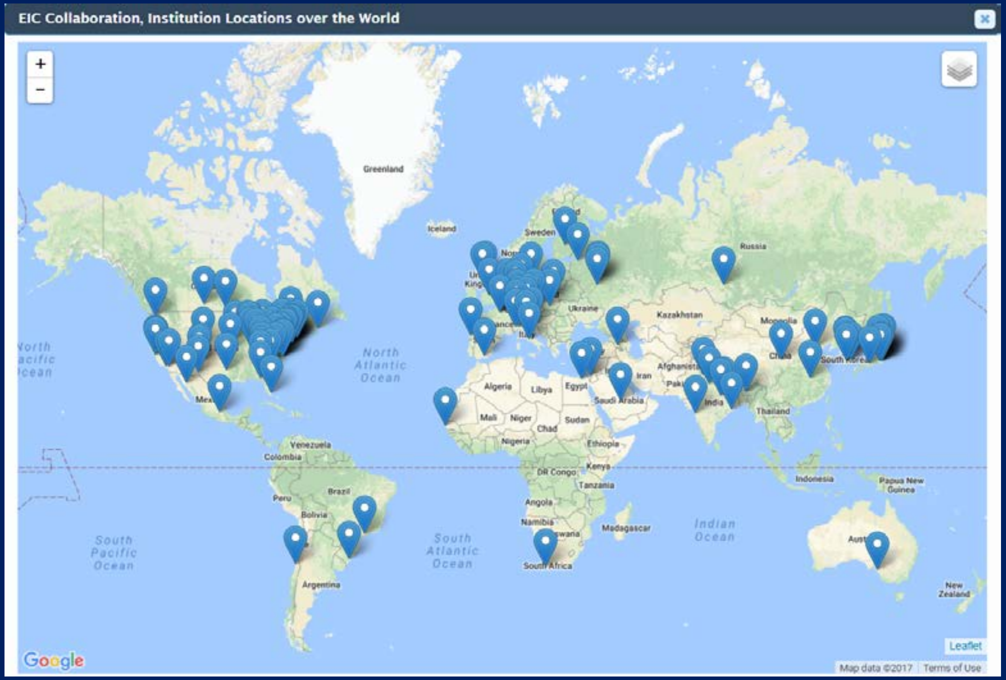
www.eicug.org

- 2015 NSAC Long-Range Plan prompted official formation of EIC User Group, consisting of interested members of the experimental, theoretical, and accelerator communities

- Goal to give community a stronger and more visible role in the process leading to the realization of an EIC

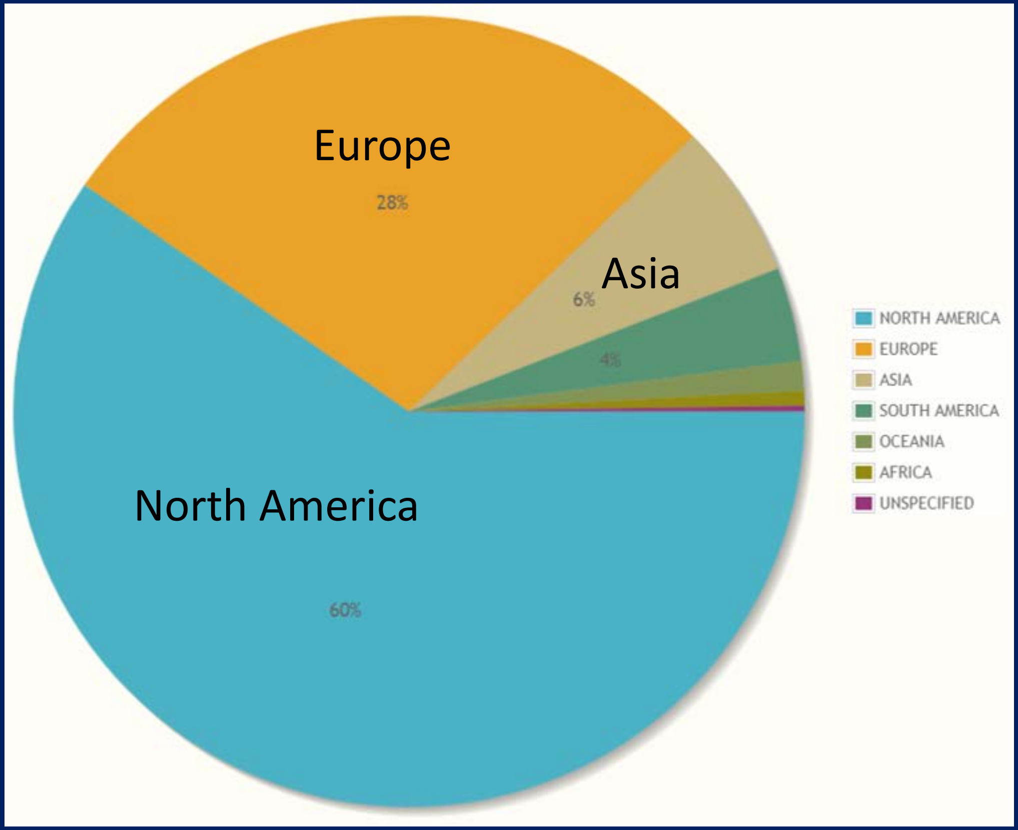
- Currently 834 members from 177 institutions in 30 countries
- To join:

  http://www.eicug.org/web/newmembers



Strong EIC User Group international participation

354 EICUG members (42%) from outside the U.S., from 71 institutions



EIC User Group

- Organization laid out in EICUG Charter
- Charter anticipates several phases of the EIC project (U.S. Dept. of Energy Critical Decision steps)
  - Phase 1 (current) – The period until CD-0, formal recognition of scientific mission need
  - Phase 2 – From CD-0 to CD-1
  - Phase 3 – From CD-1 to CD-4, end of construction
  - Phase 4 – EIC operation
- Expect real experimental collaborations to form in phases 2-3

EICUG mission in Phase 1

- Enhance and refine the science case beyond the White Paper written for the 2015 Long-Range Plan
- Provide a forum for discussion and promote collaboration among the accelerator, experimental, and theoretical communities to enhance progress
- Represent the interests of the EIC community in discussions with the laboratories and funding agencies
- Ensure that the EIC and EIC science are visible at national and international conferences and meetings

EIC User Group - Leadership

- **Steering Committee**
  - Bernd Surrow, Temple U. – Chair
  - Charles Hyde, Old Dominion U. – Vice-Chair
  - John Arrington, ANL
  - Marco Radici, INFN Pavia
  - Ernst Sichtermann, LBL
  - Daniel Boer, Groningen – European representative
  - Yuji Goto – International representative
  - Thomas Ullrich – BNL representative
  - Rik Yoshida – JLab representative

- **Institutional Board**
  - Christine Aidala, U. of Michigan – Chair (and ex-officio member of Steering Committee)

- **Election & Nominating Committee**
  - Richard Milner, MIT - Chair
  - Kawtar Hafidi, ANL
  - Paul Newman, Birmingham
  - Raju Venugopalan, BNL
  - Christian Weiss, JLab

- **Talks & Conferences Committee**
  - Ralf Seidl, RIKEN – Chair
  - Carlos Munoz Camacho, Orsay
  - Barbara Pasquini, U. of Pavia
  - Yulia Furletova, JLab
  - Lijuan Ruan, BNL

EIC User Group meetings

- UC Berkeley, January 2016
- Argonne National Lab, July 2016
- Trieste, July 2017
- Catholic University of America in Washington, DC, July - August 2018
- Next: Paris, July 2019

Trieste, 2017

Impact of the EIC User Group

- Goal to give community a stronger and more visible role in the process leading to the realization of an EIC
  - With more than 800 members from 177 institutions in 30 countries, the EIC User Group makes it clear that there's significant worldwide interest!

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- Verbal comment by Paul Dabbar, DOE Undersecretary for Science, at NSAC meeting earlier this month:
  "We understand there's a lot of interest. I think one of the wonderful things about the NP community is that user groups get formed before there's a user facility. . . . So the importance of this community on actually providing support on something which isn't even built in terms of how it is going to be used has great value."

U.S. National Academy of Sciences review of EIC science

- National Academy of Sciences: Established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology.

- The National Academies of Sciences, Engineering and Medicine produce reports that shape policies, inform public opinion, and advance the pursuit of science, engineering, and medicine.

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Committee on Assessment of U.S.-Based Electron-Ion Collider Science

In 2016, the U.S. Dept. of Energy charged the National Academy of Sciences Board on Physics and Astronomy to assess the scientific justification for building an Electron-Ion Collider (EIC) facility. The unanimous conclusion of the Committee is that an EIC, as envisioned in this report, would be…

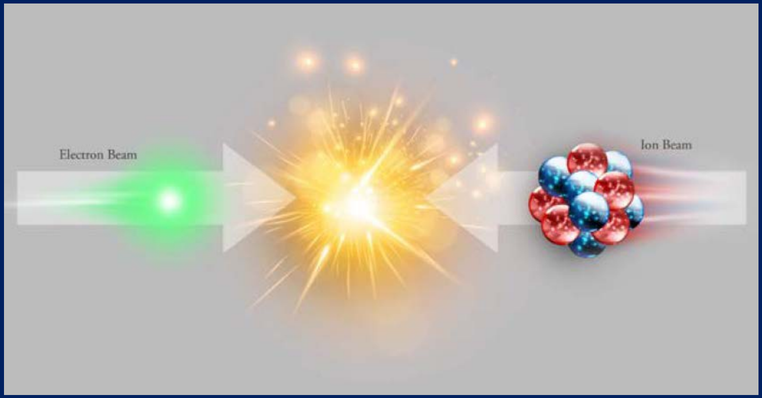
… a unique facility in the world that would answer science questions that are compelling, fundamental, and timely, and help maintain U.S. scientific leadership in nuclear physics.

An EIC as envisioned in the NAS report

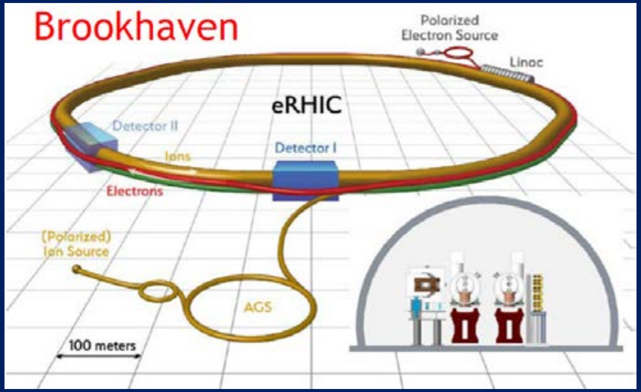
An advanced accelerator that collides beams of electrons with beams of protons or heavier ions (atomic nuclei).

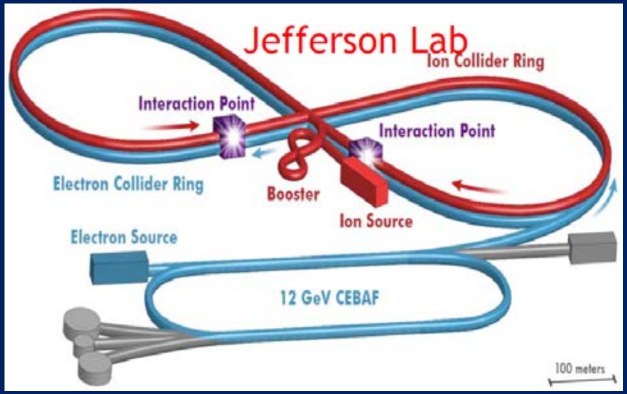
Electron-ion center of mass energy ~10-100 GeV, upgradable to ~140 GeV.

High luminosity and polarization!



1) Highly polarized electrons, E ~ 4 GeV to possibly 20 GeV
2) Highly polarized protons, E ~ 30 GeV to some 300 GeV, and heavier ions





Two possible configurations: Brookhaven National Lab and Jefferson Lab

U.S. National Academy of Sciences review of EIC science

- Committee formed late 2016—mix of physicists from within and outside of the EIC community
- Collected input from EICUG and various experts via solicited presentations at three in-person meetings
- Fourth in-person meeting focused on writing
- Final report released July 2018: https://www.nap.edu/catalog/25171/

Committee Statement of Task – from DOE to the Board on Physics and Astronomy:

The committee will assess the scientific justification for a U.S. domestic electron ion collider facility, taking into account current international plans and existing domestic facility infrastructure. In preparing its report, the committee will address the role that such a facility could play in the future of nuclear physics, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics.

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U.S. National Academy of Sciences review of EIC science: Charge questions

- What is the merit and significance of the science that could be addressed by an electron ion collider facility and what is its importance in the overall context of research in nuclear physics and the physical sciences in general?

- What are the capabilities of other facilities, existing and planned, domestic and abroad, to address the science opportunities afforded by an electron-ion collider? What unique scientific role could be played by a domestic electron ion collider facility that is complementary to existing and planned facilities at home and elsewhere?

- What are the benefits to U.S. leadership in nuclear physics if a domestic electron ion collider were constructed?

- What are the benefits to other fields of science and to society of establishing such a facility in the United States?

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National Academy committee members

- Gordon Baym, U. of Illinois Urbana-Champaign – Co-Chair
- Christine Aidala, Michigan
- Peter Braun-Munzinger, GSI
- Haiyan Gao, Duke
- Kawtar Hafidi, ANL
- Wick Haxton, UC Berkeley
- John Jowett, CERN
- Larry McLerran, INT, U. of Washington
- Ani Aprahamian, Notre Dame – Co-Chair
- Lia Merminga, Fermilab
- Zein-Eddine Meziani, Temple
- Richard Milner, MIT
- Thomas Schaefer, North Carolina State U.
- Ernst Sichtermann, LBL
- Michael Turner, U. of Chicago

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National Academy committee members

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Bottom line

- 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 nuclear physics community.
- The technological benefits of meeting the accelerator challenges are enormous, both for basic science and for applied areas that use accelerators, including material science and medicine.

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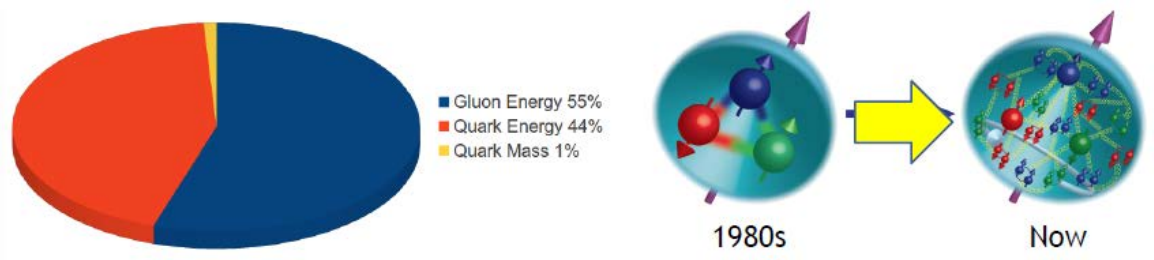
Outline of the report

- Front Mattter
- Preface
- Summary
- Ch. 1: Introduction (overview)
- Ch. 2: The scientific case for an electron-ion collider (and how an EIC would do the science)
- Ch. 3: The role of an EIC within the context of nuclear physics in the U.S. and internationally
- Ch. 4: Accelerator science, technology, and detectors needed for a U.S.-based EIC
- Ch. 5: Comparison of a U.S.-based EIC to current and future facilities
- Ch. 6: Impact of an EIC on other fields
- Ch. 7: Conclusion and findings
- Appendices: Statement of Task; Bios; Acronyms

Ch. 2: Basic science to be explored

- *How does a nucleon acquire mass?* --almost 100 times greater than the sum of its valence quark masses. Cannot be understood via Higgs mechanism



- *How does the spin (internal angular momentum) of the nucleon arise from its elementary quark and gluon constituents?* Proton spin is the basis of magnetic resonance imaging (MRI).

- *What are the emergent properties of dense systems of gluons?* How are they distributed in both position and momentum in nucleons and nuclei and how are they correlated among themselves and with the quarks and antiquarks present? *What are their quantum states?* Are there new forms of matter made of dense gluons?

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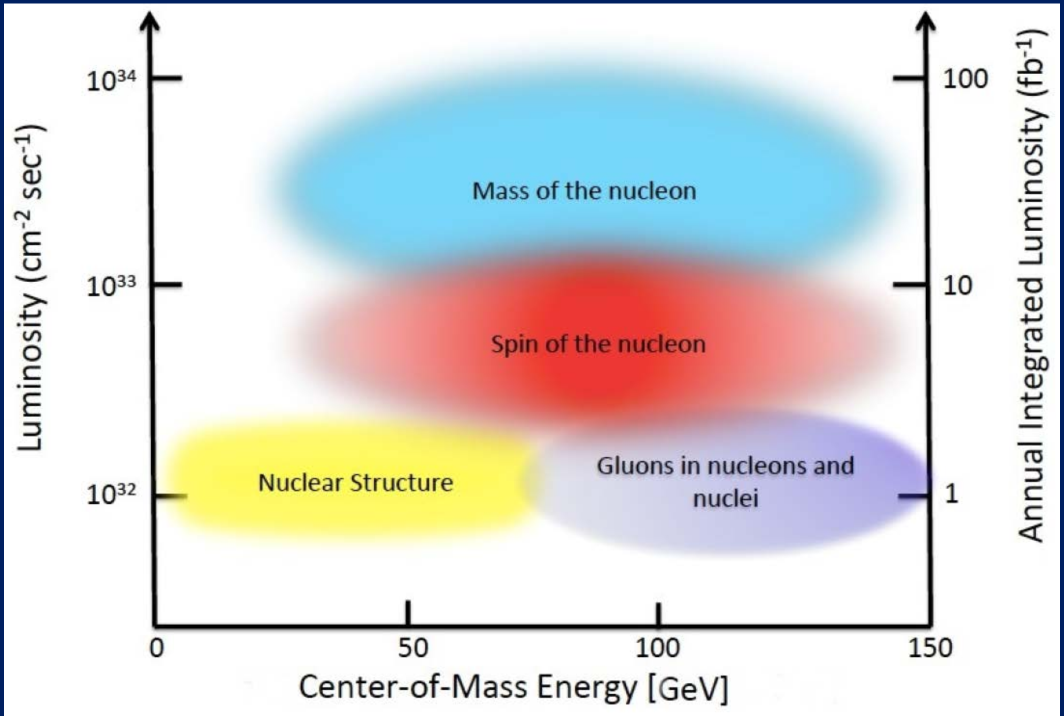
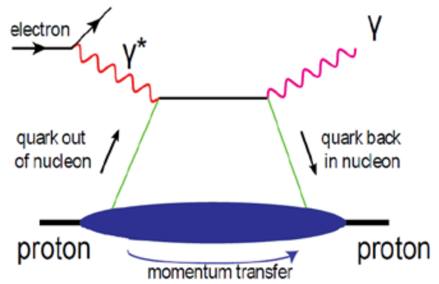
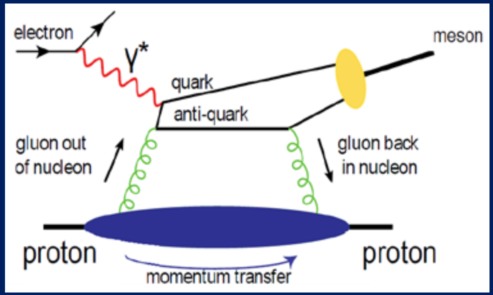
Basic experiments in c.m. energy – luminosity landscape





Deeply virtual Compton scattering



Deeply virtual meson production

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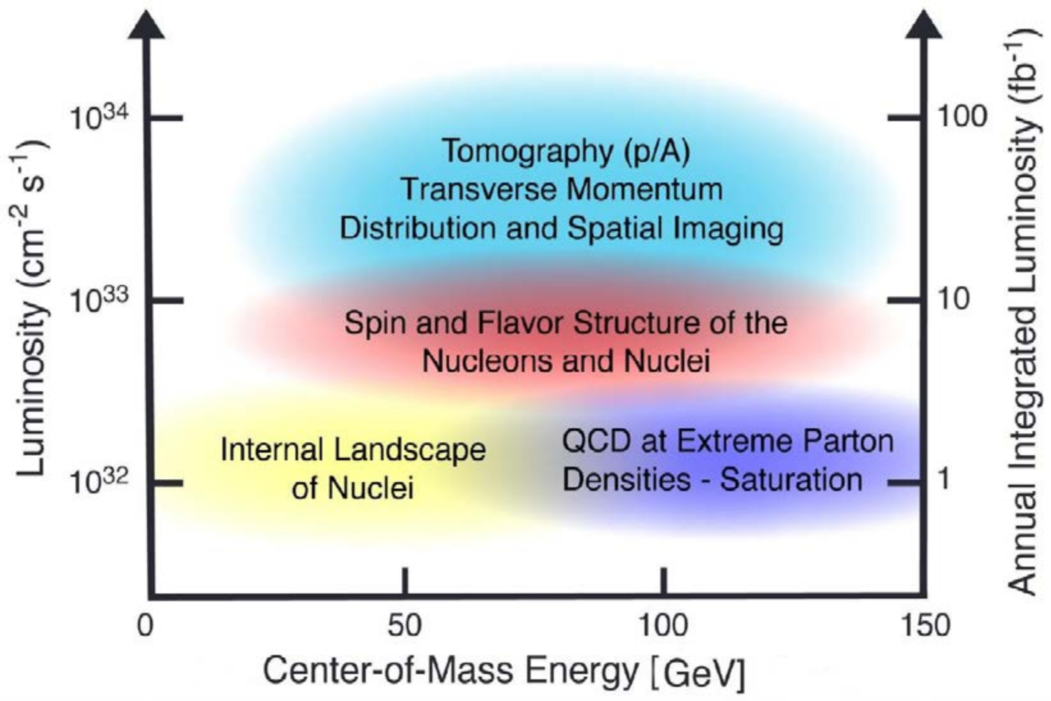
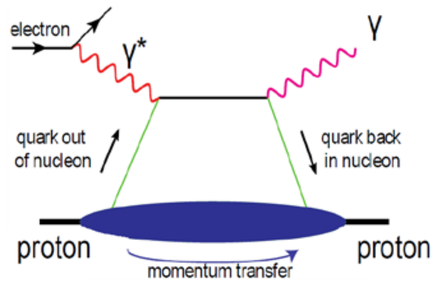
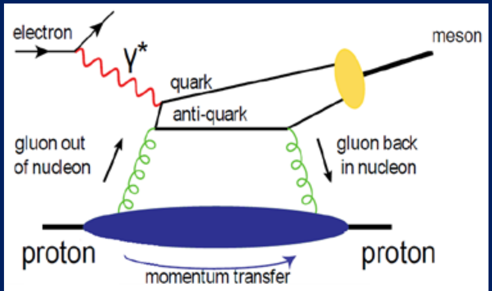




Deeply virtual Compton scattering



Deeply virtual meson production

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Ch. 3: The role of an EIC within the context of nuclear physics in the U.S. and internationally

- "Nuclear physics today is a diverse field, encompassing research that spans dimensions from a tiny fraction of the volume of the individual particles (neutrons and protons) in the atomic nucleus to the enormous scales of astrophysical objects in the cosmos."

- FRIB in construction at MSU will keep us at a leadership position in the world in understanding the behavior of hadrons inside the atomic nucleus

- Inside hadrons, the interactions of gluons and quarks address the fundamental questions on the origin of mass, spin, and saturation. Quantum Chromodynamics (QCD) physics

- U.S. Nuclear Science Context for an Electron-Ion Collider
- U.S. Leadership in Nuclear Science

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Ch. 4: Accelerator science, technology, and detectors needed for a U.S.-based EIC

(Choice of design/site for an EIC was not in our statement of task)

- Major challenges in accelerator design:
  - High energy, spin-polarized beams colliding with high luminosity
- BNL eRHIC and JLab JLEIC Conceptual Designs
  - build on existing accelerators in different ways
  - both require extensive R&D to fully address the science
- Enabling Accelerator Technologies
  - Interaction region design, magnet technology
  - Strong hadron beam cooling (innovative concepts)
  - Energy Recovery Linacs
  - Crab cavity operation in hadron ring
  - Polarized *e*, *p*, and ^{3}He sources, preservation in accelerators
  - Simulations of beams in novel EIC operating modes
- Detector Technologies

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Ch. 5: Comparison of a U.S.-based EIC to current and future facilities

- HERA at DESY…A (former) collider of electrons with protons
- CEBAF at JLab…Electron accelerator to 12 GeV
- COMPASS experiment at CERN…muon and hadron beams on fixed targets
- RHIC…Heavy ion and polarized proton collider
- LHC at CERN…Large Hadron Collider: protons and heavy ions
- Other future electron-hadron collider proposals
  - LHeC
  - FCC-he…Future Circular Collider
  - China: possible low energy EIC at HIAF (High Intensity Heavy-Ion Accelerator Facility)

Opportunities for future collaborations!!

Ch. 6: Impact of an EIC on other fields

- EIC will sustain a healthy U.S. accelerator science enterprise
  - Maintain leadership in collider accelerator technology
  - Enable new technology essential for future particle accelerators
  - EIC R&D targeted at developing cutting-edge capabilities
- Workforce
  - Nuclear physicists essential to U.S. security, health & economic vitality
  - About one half of U.S. PhDs in nuclear physics are in QCD
- Advanced scientific computing
  - Maintaining a competitive high performance computing capability is essential to U.S. scientific leadership
  - Lattice QCD uses the world's most advanced computers to provide *ab initio* QCD calculations essential to interpret EIC data
- Connections to:
  - Condensed matter and atomic-molecular physics
  - High-energy physics
  - Astrophysics

Findings

Science

- 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?

Accelerator

- 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.

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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 the Department of Energy is crucial to addressing outstanding design challenges.

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Findings

- Finding 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.

- Finding 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 EIC as the highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams (FRIB) at Michigan State University.

- 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.

Briefings to U.S. government

- July 12: Office of Nuclear Physics, DOE
  – Timothy Hallman, Jehanne Gillo, Manouchehr Farkhondeh
- July 18: OMB, OSTP
  – Avital Bar-Shalom
- July 18: Staff on House Science Committee
  – Adam Rosenberg, Emily Domenech, Hillary O'Brien
- August 7: Undersecretary for Science, DOE
  – Paul Dabbar
- October 30: House Appropriations (Energy & Water)
  – Perry Yates

- December 4: Visits to Capitol Hill by EICUG members

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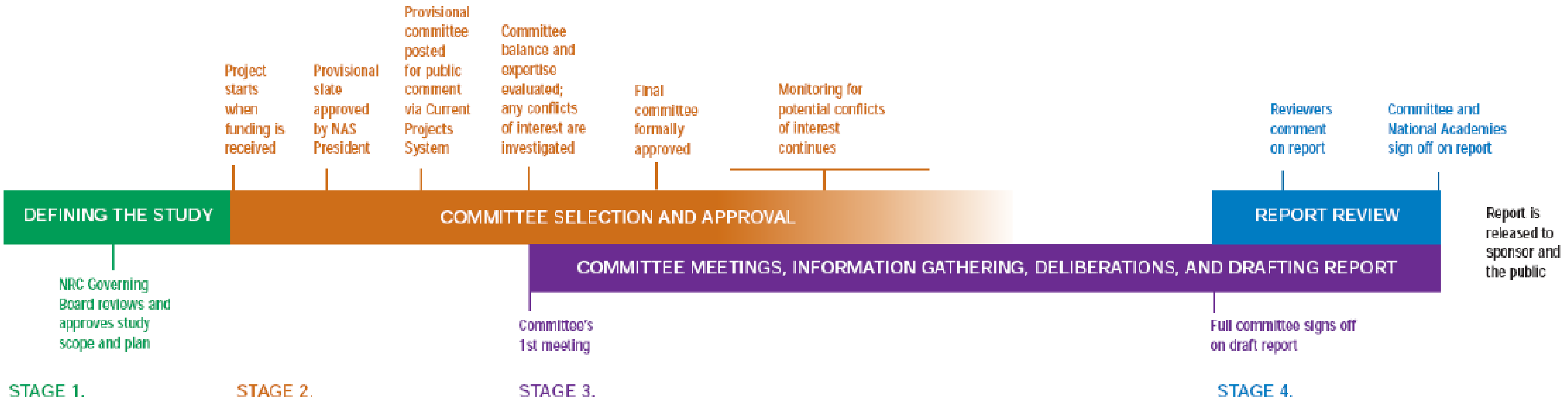
I look forward to the role that the CFNS will play in continued community discussions and planning as we work to realize the EIC

Extra

The report process



Stages:

1) Defining the study.
2) Committee selection and approval
3) Committee meetings, gather information and write the report
4) Report review via Report Review Committee ~30 members
5) Release of report to public (TODAY)

Report process & meeting schedule

Four meetings in 2017, plus three conference calls for entire committee, and many smaller conference calls among working groups

First meeting   Feb. 1-2 Washington
Funding agencies, House Science and Technology Committee, NSAC, EIC collider physics, European perspective, RHIC plans

Second meeting   April 19-20 Irvine
JLab plans, EIC User Group,   EIC in China, CERN, gluon and deep inelastic scattering physics

Third meeting   Sept. 11-12 Woods Hole
EIC accelerator technology, EIC computing, gluon saturation

Fourth and final meeting: Nov. 27-28 Washington

2015 U.S. Nuclear Physics Long-Range Plan

- EIC endorsed by U.S. nuclear community as highest priority facility for new construction after completion of Facility for Rare Isotope Beams (FRIB)