Status and Perspectives of a US-based Electron-Ion Collider (EIC)

Bernd Surrow

Electron-Ion Collider facility concepts
The EIC Physics Pillars
The **EIC Physics** Pillars

The **EIC Accelerator Concepts** (**JLEIC at JLab** / **eRHIC at BNL**): Requirements and Layout
Outline

- The EIC Physics Pillars
- The EIC Accelerator Concepts (JLEIC at JLab / eRHIC at BNL): Requirements and Layout
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- The EIC Detector Concepts: Requirements & Design

(JLab: TOPSiDE / JLEIC / BNL: BEAST / EIC-sPHENIX)
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- The EIC Physics Pillars
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- The EIC Detector Concepts: Requirements & Design (JLab: TOPSiDE / JLEIC / BNL: BEAST / EIC-sPHENIX)
- The EIC Users Group
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- The EIC Users Group
- The US NP Long-Range Plan and EIC Science Assessment by the National Academy of Sciences
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- Summary
The EIC Physics Pillars

- EIC - A QCD lab to explore the structure and dynamics of the visible world
EIC - A QCD lab to explore the structure and dynamics of the visible world

\[ \mathcal{L}_{QCD} = \sum_{j=1}^{n_f} \bar{\psi}_j (i D_\mu \gamma^\mu - m_j) \psi_j - \frac{1}{4} \text{Tr} G^{\mu\nu} G_{\mu\nu} \]
The EIC Physics Pillars

- EIC - A QCD lab to explore the structure and dynamics of the visible world

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- Interactions arise from fundamental symmetry principles: SU(3)_c
The EIC Physics Pillars

- EIC - A QCD lab to explore the structure and dynamics of the visible world

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- Interactions arise from fundamental symmetry principles: SU(3)\(_c\)
- Properties of visible universe such as mass and spin (e.g. proton): Emergent through complex structure of the QCD vacuum

D. Leinweber: Quantum fluctuations in gluon fields
The EIC Physics Pillars

- EIC - A QCD lab to explore the structure and dynamics of the visible world

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D. Leinweber: Quantum fluctuations in gluon fields
EIC - A QCD lab to explore the structure and dynamics of the visible world

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D. Leinweber: Quantum fluctuations in gluon fields
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D. Leinweber: Quantum fluctuations in gluon fields
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1) Tomography of hadrons and nuclear matter in terms of quarks and gluons

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Major goal:
Understanding QCD interactions and emergence of hadronic and nuclear matter in terms of quarks and gluons

Essential elements looking forward:
1) Tomography of hadrons and nuclear matter in terms of quarks and gluons
2) Synergy of experimental progress and theory

D. Leinweber: Quantum fluctuations in gluon fields
The EIC Physics Pillars

- EIC: Study
  structure and
dynamics of matter
at high luminosity,
high energy with
polarized beams and
wide range of nuclei
The EIC Physics Pillars

- **EIC: Study**
  - structure and dynamics of matter at high luminosity,
  - high energy with polarized beams and wide range of nuclei

- **Whitepaper:**
EIC: Study
structure and
dynamics of matter
at high luminosity,
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Whitepaper:
arXiv:1212.1701

The EIC Physics Pillars

Understanding the glue that binds us all!
The EIC Physics Pillars

- **EIC: Study**
  - structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei

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Spin and Flavor Structure of the Nucleon and Nuclei

Parton Distributions in Nuclei

QCD at Extreme Parton Densities - Saturation

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The EIC Physics Pillars

- Luminosity (cm$^{-2}$ sec$^{-1}$)
  - $10^{32}$
  - $10^{33}$
  - $10^{34}$

- Integrated Luminosity (fb$^{-1}$/yr)
  - 1
  - 10
  - 100

- $\sqrt{s}$ (GeV)
  - 40
  - 80
  - 120

- Understanding the glue that binds as all!
- EIC: Study structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei.

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- Understanding the glue that binds us all!
The EIC Physics Pillars

QCD dynamics

$Q^2 (\text{GeV}^2)$

Quarks and Gluons

Resolution

Strongly Correlated Quark-Gluon Dynamics

Linear evolution

Non-linear evolution

Confinement, Chiral Symmetry Breaking

$Q^2(x)$

Hadrons

Non-linear regime

Pomerons? Regge trajectories?

Parton Density

1/x

1/x

strong coupling

weak coupling

perturbative

non-perturbative

$Q^2(x)$

High-Density Gluon Matter

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Non-Linear Dynamics

The three dimensional parton structure of the proton changes from the valence quark dominated regime to an intrinsically nonlinear regime where the proton's constituents are gluons and sea quark-antiquark pairs generated through QCD radiation, and finally at a large kinematic reach, open up a unique opportunity to probe how hadrons are made and broken. Figure 13 uses simulated data to clearly reveal the com-plex many-body structure of quarks and gluons in QCD. This is because one will be able to probe, with fine resolution, the spatial and transverse position of the scattered quark or gluon in the small $x$ region constrain this behavior. The statistical precision of the integral of the proton's quark and gluon GPDs, changes as this factorization scale is varied significantly across the QCD landscape sketched in Fig. 1 of Section 2.2. We illustrate schemati-cally how the parton structure of the proton changes when the center-of-mass energy.

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The EIC Physics Pillars

- QCD dynamics

$Q^2 (\text{GeV}^2)$

- Strongly Correlated Quark-Gluon Dynamics
- Linear evolution
- Non-linear evolution
- High-Density Gluon Matter
- Q$^2(x)$
- Confinement, Chiral Symmetry Breaking
- Non-linear regime

Parton Density

- Pomerons? Regge trajectories?
- Confinement, Chiral Symmetry Breaking
- Non-linear regime

Resolution

- Quarks and Gluons
- Hadrons

Q$^2(x)$

- Strong coupling
- Weak coupling

- $1/x$

- Explore QCD landscape in various aspects over a wide range in $x$ and $Q^2$ - Heavy nuclei at high energy critical to explore high-density gluon matter!
Non-Linear Dynamics

The EIC Physics Pillars

QCD dynamics / Parton distributions in nuclei

\( Q^2 (\text{GeV}^2) \)

\( Q^2(x) \)

Strongly Correlated Quark-Gluon Dynamics

Confinement, Chiral Symmetry Breaking

High-Density Gluon Matter

Parton Density

Sea

Gluon

\[ R_i(x,Q^2) \]

\( Q^2 = 1.69 \text{ GeV}^2 \)

EIC Physics Pillars

1. Ratio \( R_i(x,Q^2) \) of PDF’s of Pb/p - Significant reduction of uncertainties of nuclear sea quarks / gluons with EIC

2. Explore QCD landscape in various aspects over a wide range in \( x \) and \( Q^2 \) - Heavy nuclei at high energy critical to explore high-density gluon matter!
Spin and Flavor Structure of the Nucleon

- $g_1$ stat. uncertainty projections for 10fb$^{-1}$ for range of CME in comparison to DSSV+ predictions incl. uncertainties
- EIC impact on helicity distributions of anti-u, anti-d and s quarks together with gluons

The EIC Physics Pillars
The EIC Physics Pillars

- Transverse Momentum Distribution and Spatial Imaging
Transverse Momentum Distribution and Spatial Imaging

\[ f(x, k_T) \quad 1+2D \]

\[ \int d^2 b_T W(x, b_T, k_T) \int d^2 k_T f(x, b_T) \quad 1+2D \]

Transverse Momentum Distribution (TMD)

Wigner Distribution

Impact Parameter Distribution
The EIC Physics Pillars

Transverse Momentum Distribution and Spatial Imaging

\[ f(x, k_T) \text{ 1+2D} \]

Transverse Momentum Distribution (TMD)

\[ \int d^2b_T W(x, b_T, k_T) \int d^2k_T f(x, b_T) \text{ 1+2D} \]

Impact Parameter Distribution

Wigner Distribution

Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering
The EIC Physics Pillars

- Transverse Momentum Distribution and Spatial Imaging

\[ f(x, k_T) \quad 1+2D \]

\[ \int d^2 b_T \quad W(x, b_T, k_T) \quad \int d^2 k_T \quad f(x, b_T) \quad 1+2D \]

Transverse Momentum Distribution (TMD)

- Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering

- Spin-dependent 1+2D impact parameter (transverse) images from exclusive scattering

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The EIC Facility Concepts

- **Luminosity** / $\sqrt{s}$ / Kinematic coverage

![Graph showing luminosity vs. $\sqrt{s}$](image)

- **EIC**
  - LHeC/HE-LHC
  - FCC-he
  - LHeC/HL-LHC
  - LHeC/CDR

![Graph showing $Q^2$ vs. $x$](image)

- **Current polarized DIS data**
  - CERN, DESY, JLab, SLAC

- **Current polarized BNL-RHIC pp data**
  - PHENIX, STAR 1-jet

- **Measurements with $A > 56$ (Fe):**
  - eA ep DIS (E-139, E-665, EMC, NMC)
  - A DIS (CCFR, CDHSW, CHORUS, NuTeV)
  - DY (E772, E866)

- **Ranges:**
  - Perturbative
  - Non-perturbative

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The EIC Facility Concepts

Luminosity / $\sqrt{s}$ / Kinematic coverage

- **Luminosity (cm$^{-2}$ s$^{-1}$)**
  - JLAB/CEBAF: $10^{38}$
  - SLAC: $10^{36}$
  - COMPASS, HIAF-EIC, BCDMS, HERMES, NMC

- **Kinematic coverage**
  - $\sqrt{s}$ (GeV): $10^2 - 10^4$
  - Increase in luminosity: HERA to EIC

- **Facilities & Experiments**
  - Past Colliders
  - Collider Concepts
  - Past Fixed Target
  - Ongoing Fixed Target
  - EIC Project

- **Measurements with $A \geq 56$ (Fe):**
  - $eA\mu$ DIS (E-139, E-665, EMC, NMC)
  - $eA$ DIS (CCFR, CDHSW, CHORUS, NuTeV)
  - DY (E772, E866)

- **Current polarized DIS data:**
  - CERN, DESY, JLab, SLAC

- **Current polarized BNL-RHIC pp data:**
  - PHENIX, STAR 1-jet

- **EIC**
  - $eA$ vs. the quark helicity contribution
  - $e\mu$ vs. the square of the momentum transfer

- **Future prospects:**
  - The range in parton momentum fraction $x$ can be further extended from 0.001 to 1.0. This would be achieved by realizing this by colliding longitudinally polarized electrons and nucleons, with both inclining their orbital motion contributing to nucleon spin. Recent RHIC results indicate that a substantial "missing" portion of nucleon spin resides in the gluons. By providing high-precision energy probes of partons' transverse momenta, the EIC should also illuminate the role of the gluons and sea quarks in determining the hadron structure and properties. This will resolve crucial questions, such as whether the spin of quarks and antiquarks, evaluated in the predominantly valence quark region. However, these programs will be dramatically extended at the EIC to explore the role of the gluons and sea quarks in determining the nucleon spin.

- **Kinematic range**
  - $s = 45$ GeV, $0.01 \leq y \leq 0.95$
  - $s = 90$ GeV, $0.01 \leq y \leq 0.95$
  - $s = 45$ GeV, $0.01 \leq y \leq 0.95$

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The EIC Facility Concepts

- **EIC accelerator design at JLab and BNL**

  Highly polarized electron / Highly polarized proton and lights ions / Unpolarized heavy ion colliding beams

  - CME: ~20-100GeV, upgradable to 140GeV
  - Luminosity: \(\sim 10^{33-34}\text{cm}^{-2}\text{s}^{-1}\)

*JLEIC Collaboration*

- Electron complex with CEBAF as full energy injector and collider ring up to 12GeV
- Ion complex with source and linac, booster and collider ring
- 2 detector IP’s integrated into IR design

*JLEIC Collaboration*

*eRHIC Collaboration*

- Polarized electron source and 400MeV injector linac
- Polarized proton beams and ion beams based on existing RHIC facility
- 2 detector IP’s integrated into IR design

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The EIC Detector Concepts

- Overview of processes and final states
The EIC Detector Concepts

- **Overview of processes and final states**

  \[ e + p/A \rightarrow e' + X \]

  - **Inclusive DIS**
    - **Inclusive**: Unpolarized \( f_i(x,Q^2) \) and helicity distribution \( \Delta f_i(x,Q^2) \) functions through unpolarized and polarized structure function measurements (\( F_2, F_L, g_1 \)).
    - Define kinematics \((x, y, Q^2)\) through electron (e-ID and energy+angular measurement critical) / hadron final state or combination of both depending on kinematic \( x-Q^2 \) region.
Overview of processes and final states

**Inclusive DIS**

- Unpolarized $f_i(x,Q^2)$ and helicity distribution $\Delta f_i(x,Q^2)$ functions through unpolarized and polarized structure function measurements ($F_2, F_L, g_1$)
- Define kinematics ($x, y, Q^2$) through electron (e-ID and energy+angular measurement critical) / hadron final state or combination of both depending on kinematic $x$-$Q^2$ region

**Semi-Inclusive DIS (SDIS)**

- Flavor tagging through hadron identification studying FF / TMD's (Transverse momentum, $k_T$, dependence) requiring azimuthal asymmetry measurement - Full azimuthal acceptance
- Heavy flavor (charm / bottom): Excellent secondary vertex reconstruction
The EIC Detector Concepts

Overview of processes and final states

- **Inclusive**: Unpolarized $f_i(x,Q^2)$ and helicity distribution $\Delta f_i(x,Q^2)$ functions through unpolarized and polarized structure function measurements ($F_2$, $F_L$, $g_1$)
- **Define kinematics ($x$, $y$, $Q^2$) through electron (e-ID and energy+angular measurement critical) / hadron final state or combination of both depending on kinematic x-$Q^2$ region**
- **SDIS**: Flavor tagging through hadron identification studying FF / TMD's (Transverse momentum, $k_T$, dependence) requiring azimuthal asymmetry measurement - Full azimuthal acceptance
- **Heavy flavor (charm / bottom)**: Excellent secondary vertex reconstruction
- **Exclusive**: Tagging of final state proton using Roman pot system studying GPD's (Impact parameter, $b_T$, dependence) using DVCS and VM production
- **$eA$**: Impact parameter determination / Neutron tagging using Zero-Degree Calorimeter (ZDC)

Inclusive DIS:
\[
e + p/A \rightarrow e' + X
\]

Semi-Inclusive DIS (SDIS):
\[
e + p/A \rightarrow e' + h + X
\]

Deeply-Virtual Compton Scattering (DVCS):
\[
e + p/A \rightarrow e' + N'/A' + \gamma/m
\]
The EIC Detector Concepts

Overview of general requirements

Central Detector with Solenoid Magnet

1. Ion Beamline
2. Dipole Magnet (1 of 4)
3. Electron Beamline

Dipole Magnet (1 of 3)

arXiv:1212.1701
The EIC Detector Concepts

Overview of general requirements

1: Scattered electron

Central Detector with Solenoid Magnet

Dipole Magnet (1 of 4)

Electron Beamline

Dipole Magnet (1 of 3)

1

2

3

Ion Beamline

arXiv:1212.1701
Overview of general requirements

1: Scattered electron

2: Fragmented particles (e.g. $\pi$, K, p) of struck quark
Overview of general requirements

1: Scattered electron

2: Fragmented particles (e.g. π, K, p) of struck quark

3: Nuclear and nucleonic fragments / scattered proton
Overview of general requirements

- 3: Nuclear and nucleonic fragments / scattered proton

- 1: Scattered electron

- 2: Fragmented particles (e.g. π, K, p) of struck quark

- Acceptance: Close to 4π coverage with a η-coverage
  
  \[ \eta = -\ln(\tan(\theta/2)) \]
  
  of approximately \( |\eta| < 3.5 \) combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage

arXiv:1212.1701
The EIC Detector Concepts

Overview of general requirements

3: Nuclear and nucleonic fragments / scattered proton

Acceptance: Close to 4π coverage with a η-coverage

(η = -ln(tan(θ/2)) of approximately η < |3.5| combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage

Low dead material budget in particular in rear direction (~5% X/X₀)

1: Scattered electron

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arXiv:1212.1701
Overview of general requirements

1: Scattered electron

2: Fragmented particles (e.g. $\pi$, K, p) of struck quark

3: Nuclear and nucleonic fragments / scattered proton

- **Acceptance**: Close to $4\pi$ coverage with a $\eta$-coverage ($\eta = -\ln(\tan(\theta/2))$) of approximately $\eta < |3.5|$ combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage
- **Low dead material** budget in particular in rear direction (~5% $X/X_0$)
- **Good momentum resolution** $\Delta p/p \sim$ few %
Overview of general requirements

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2: Fragmented particles (e.g. π, K, p) of struck quark

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- **Low dead material** budget in particular in rear direction ($\sim 5\% X/X_0$)
- **Good momentum resolution** $\Delta p/p \sim$ few %
- **Electron ID** for e/h separation varies with $\theta / \eta$ at the level of $1:10^4 / \sim 2-3\%/\sqrt{E}$ for $\eta<-2$ and $\sim 7\%/\sqrt{E}$ for $-2<\eta<1$
Overview of general requirements

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- Low dead material budget in particular in rear direction (~5% X/X₀)
- Good momentum resolution Δp/p ~ few %
- Electron ID for e/h separation varies with θ / η at the level of 1:10⁴ / ~2-3%/√E for η<2 and ~7%/√E for -2<η<1

Particle ID for π/K/p separation over wide momentum range
(Forward η up to ~50GeV/c / Barrel η up to ~4GeV/c / Rear η up to ~6 GeV/c)
The EIC Detector Concepts

Overview of general requirements

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- **Particle ID** for $\pi/K/p$ separation over wide momentum range
  (Forward $\eta$ up to $\sim 50$ GeV/c / Barrel $\eta$ up to $\sim 4$ GeV/c / Rear $\eta$ up to $\sim 6$ GeV/c)

- **High spatial vertex resolution** $\sim 10-20\mu m$ for vertex reconstruction

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The EIC Detector Concepts

Overview of general requirements

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- High spatial vertex resolution ~ 10-20μm for vertex reconstruction
- Low-angel taggers:
  - Forward proton / A fragment spectrometer (Roman pots)
  - Low Q² tagger
  - Neutrons on hadron direction

arXiv:1212.1701
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- **Acceptance**: Close to $4\pi$ coverage with a $\eta$-coverage ($\eta = -\ln(\tan(\theta/2))$) of approximately $\eta < |3.5|$ combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage.

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- **Luminosity** (Absolute and relative) and local polarization direction measurement

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Generic Detector R&D program for an EIC

- In January 2011, BNL, in association with JLab and the DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC facility.

- Goals:
  - Enable successful design and timely implementation of an EIC experimental program
  - Develop instrumentation solutions that meet realistic cost expectations
  - Stimulate the formation of user collaborations to design and build experiments

- Peer-reviewed program funded by DOE and managed by BNL with $1M/year to $1.5M/year. Initiated and coordinated by Tom Ludlam (BNL) until 2014 / Since 2014 coordinated by Thomas Ullrich (BNL)

- Key to success: Standing EIC Detector Advisory Committee
  - Current members: Marcel Demarteau (ANL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick van Berg (UPenn), Jerry Va’vra (SLAC) and Glenn Young (JLab)
  - Past members: Robert Klanner (Hamburg) and Howard Wieman (LBL)

- Wide range of R&D programs: Calorimetry / Tracking (GEM, MicroMegas, TPC) incl. silicon / Particle ID (TRD, Dual-RICH, Aerogel RICH, DIRC, TOF) / Polarimetry / Background / Simulation Tools /

https://wiki.bnl.gov/conferences/index.php/EIC_R%2520D

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The EIC Detector Concepts

- EIC detector design at JLab and BNL
  - (a) TOPSiDE at JLab:
    - Jose Repond (ANL): DIS 2019 / WG7
  - (b) JLEIC detector design at JLab:
  - (c) BEAST detector design at BNL:
    - Alexander Kiselev (BNL): DIS2019 / WG7
  - (d) sPHENIX-EIC detector design at BNL:

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EIC User Group and R&D activities

- **EIC User Group:**
  - EICUG organization established in summer 2016
  - In numbers: 859 members (496: Experimentalists / 179: Theorists / Accelerator Scientists: 142 / Support: 3 / Other: 39), 181 institutions, 30 countries, 7 world regions

- **World map:**

- **R&D activities:**
  - EIC Detector R&D program operated by BNL with ~$1M / year
  - EIC Accelerator R&D with ~$7M / year

WWW-page: www.eicug.org
EIC User Group and R&D activities

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Internationalization is critical!

The EIC Users Group

WWW-page: www.eicug.org

Institutions by region

33%

17%

45%
EIC Users’ Group: Lab News

- EIC Science Centers at JLab and BNL/Stony Brook University
  - Dedicated EIC Science Centers at both JLab and BNL/Stony Brook University

- JLab: EIC2@JLab
  - Director: Rik Yoshida
  - WWW-page: https://www.eiccenter.org

- BNL/Stony Brook University: Center for Frontiers in Nuclear Science
  - Director: Abhay Deshpande
  - WWW-page: https://www.stonybrook.edu/cfns/

The Electron-Ion Collider Center at Jefferson Lab (EIC2@JLab) is an organization to advance and promote the science program at a future electron-ion collider (EIC) facility. Particular emphasis is on the close connection of EIC science to the current Jefferson Lab 12 GeV CEBAF science program.

The mission of this Center is to promote and facilitate the realization of the U.S. based EIC by enhancing the science case and collaborations amongst the scientists around the world interested in the EIC.
EIC community activities / Conferences and Workshops
The EIC Users Group

- EIC community activities / Conferences and Workshops

EICUG 2017
Electron Ion Collider User Group Meeting 2017
Trieste, Italy May 16-22, 2017

EICUG 2018
Electron Ion Collider User Group Meeting 2018
July 30 - August 3, 2018
University of Trieste, Italy

EICUG 2019
Electron Ion Collider User Group Meeting 2019
July 15-19
University of Trieste, Italy

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The EIC Users Group

- EIC community activities / Conferences and Workshops

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- EIC community activities / Conferences and Workshops

- **POETIC VI**
  6th International Conference on Physics Opportunities at an Electron-Ion-Collider
  7-9 September 2016
  École Polytechnique, Palaiseau

- **EICUG 2017**
  Electron Ion Collider User Group Meeting 2017
  October 16-18, 2017
  Temple University
  Conference Hotel: DoubleTree Hotel, Center City, Philadelphia
  Venue: Howard Gittis Student Center at Temple University
  Nov. 14 - 16, 2016: POETIC 7 Conference
  Nov. 17, 2016: Joint CTEQ Meeting and POETIC 7 Conference
  Nov. 18, 2016: CTEQ Business Meeting

- **CTEQ Organizing Committee**
  Cynthia Keppel (Jefferson Lab, USA)
  Pavel Nadolsky (Southern Methodist University, USA)
  Fred Olness (Southern Methodist University, USA)
  Jeff Owens (Florida State University, USA)

- **International Advisory Committee**
  Nestor Armesto (Universidade de Santiago de Compostela, Spain)
  Elke Aschenauer (BNL, USA)
  Daniel Boer (University of Groningen, Netherlands)
  Marco Contalbrigo (INFN Ferrara, Italy)
  Markus Diehl (DESY, Germany)
  Rolf Ent (JLab, USA)
  Max Klein (University of Liverpool, UK)
  Andrzej Sandacz (Soltan Institute for Nuclear Studies, Poland)
  Marco Stratmann (University of Tubingen, Germany)
  Lech Szymanowski (Soltan Institute for Nuclear Studies, Poland)
  Tony Thomas (University of Adelaide, Australia)
  Thomas Ullrich (BNL, USA)
  Raju Venugopalan (BNL, USA)

- **Local Organizing Committee**
  Franco Bradamante, Andrea Bressan, Michela Chiosso, Marco Contalbrigo, Silvia Dalla Torre, Raffaella De Vita, Stefano Levorato, Anna Martin, Marco Miraziti, Roberto Preghenella, Marta Ruspa, Fulvio Tessarotto

- **Sponsors**
  Martha Constantinou, Andreas Metz (Co-Chair), Zein-Eddine Meziani, Jim Napolitano, Nikos Spaveris, Bernd Surrow (Co-Chair)

- **Scientific Advisory Committee**
  Christine Aidala, Mauro Anselmino, Nestor Armesto, Andrea Bressan, Silvia Dalla Torre, Abhay Deshpande, Nicole D'Hose, Rolf Ent, Kawtar Hafidi, Charles Hyde, Barbara Jacak, Richard Milner, Fulvia Pilat, Thomas Roser, Patrizia Rossi, Bjoern Seitz, Thomas Ullrich, Werner Vogelsang, Rikutaro Yoshida

- **EICUG 2017**
  Electron Ion Collider User Group Meeting 2017
  July 18-22, 2017
  Trieste (Italy)
  Secretariat and contact: Erica Novacco: tel.+39 040 558 3367, e-mail: eicug2017@ts.infn.it
  Web Site: http://eicug2017.ts.infn.it
  Venue: University of Trieste, USSL MIT Building Aula Magna via Filzi, 14

- **Physics Opportunities at an Electron-Ion Collider IX**
  Structure of hadrons
  QCD at high parton densities
  Hadronization and jet properties
  Complementarity and connections with topics in Nuclear and High-Energy Physics
  Future DIS facilities and developments

- **POETIC IX, LBNL, Sept. 16 - 21, 2019**

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Bernd Surrow
The EIC Users Group

EIC community activities / Conferences and Workshops
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- EIC community activities / Conferences and Workshops

POETIC IX, LBNL, Sept. 16 - 21, 2019

Programs related to EIC
The EIC Users Group

- EIC community activities / Conferences and Workshops

Programs & Workshops

- Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (NT-17-1a)
- Structure of quark-hadron interactions at RHIC and LHC: the Path to EIC (NT-17-1b)
- The Flavor Structure of Nucleon Sea (NT-17-1c)
- Neutron-Photon Interactions: Appearance, Disappearance, and Baryogenesis (NT-17-1d)

2017 Workshop

- Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: the Path to EIC (NT-17-1a)
- The Flavor Structure of Nucleon Sea (NT-17-1c)

2017 Programs

- Structure of quark-hadron interactions at RHIC and LHC: the Path to EIC (NT-17-1b)
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2018 Programs

- Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: the Path to EIC (NT-17-1a)
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Highly Active EIC Community!

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- US Capitol Hill visit - December 4, 2018 / EIC delegation
The 2015 Long Range Plan for Nuclear Science

Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.

2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.

3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.

4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

The FY 2018 Request supports progress in important aspects of the 2015 LRP Vision.
Recommendations:

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The FY 2018 Request supports progress in important aspects of the 2015 LRP Vision.
Next Formal Step on the EIC Science Case is Continuing

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE
Division on Engineering and Physical Science
Board on Physics and Astronomy
U.S.-Based Electron Ion Collider Science Assessment

Summary
The National Academies of Sciences, Engineering, and Medicine (“National Academies”) will form a committee to carry out a thorough, independent assessment of the scientific justification for a U.S. domestic electron ion collider facility. In preparing its report, the committee will address the role that such a facility would play in the future of nuclear science, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics. The need for such an accelerator will be addressed in the context of international efforts in this area. Support for the 18-month project in the amount of $540,000 is requested from the Department of Energy.

“U.S.-Based Electron Ion Collider Science Assessment” is now getting underway. The Chair will be Gordon Baym. The rest of the committee, including a co-chair, will be appointed in the next couple of weeks. The first meeting is being planned for January, 2017
The US Long-Range Plan and US NAS review

NAS review request by DOE: US-based EIC Science Assessment

Next Formal Step on the EIC Science Case is Continuing

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Speckle Glue: QCD and Spin

The EIC Science Assessment by the US NAS

NAS Webinar and NAS report release: 07/24/2018
The EIC Science Assessment by the US NAS

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http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=25171\
The EIC Science Assessment by the US NAS

NAS Webinar and NAS report release: 07/24/2018


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The EIC Science Assessment by the US NAS

NAS Webinar and NAS report release: 07/24/2018


FOR IMMEDIATE RELEASE

WASHINGTON – The science questions that could be answered by an electron ion collider (EIC) — a very large-scale particle accelerator — are significant to advancing our understanding of the atomic nuclei that make up all visible matter in the universe, says a new report by the National Academies of Sciences, Engineering, and Medicine. Beyond its impact on nuclear science, the advances made possible by an EIC could have far-reaching benefits to the nation’s science- and technology-driven economy as well as to maintaining U.S. leadership in nuclear physics and in collider and accelerator technologies.

The National Academies were asked by the U.S. Department of Energy (DOE) to examine the scientific importance of an EIC, as well as the international implications of building a domestic EIC facility. The committee that conducted the study and wrote the report concluded that the science that could be addressed by an EIC is compelling and would provide long-elusive answers on the nature of matter. An EIC would allow scientists to investigate where quarks and gluons, the tiny particles that make up protons and neutrons, are located inside protons and neutrons, how they move, and how they interact together. While the famous Higgs mechanism explains the masses of the quarks, the most significant portion of the mass of a proton or neutron comes from its gluons and their interactions. Crucial questions that an EIC would answer include the origin of the mass of atomic nuclei, the origin of spin of neutrons and protons — a fundamental property that makes magnetic resonance imaging (MRI) possible, how gluons hold nuclear together, and whether emergent forms of matter made of dense gluons exist.

The report says a new EIC accelerator facility would have capabilities beyond all previous electron-scattering machines in the U.S., Europe, and Asia. High energies and luminosities — the measure of the rate at which particle collisions occur — are required to achieve the fine resolution needed, and to reach such intensities and energy levels requires a collider where beams of electrons smash into beams of protons or heavier ions. Comparing all existing and proposed accelerator facilities around the world, the committee concluded that an EIC with high energy and luminosity, and highly polarized electron and ion beams, would be unique and in a position to greatly further our understanding of visible matter.

"An EIC would be the most sophisticated and challenging accelerator currently proposed for construction in the U.S. and would significantly advance accelerator science, and more specifically collider science and technologies, here and around the world," said committee co-chair Gordon Baym, Center for Advanced Study Professor Emeritus, George and Ann Fisher Distinguished Professor of Engineering Emeritus, and Research Professor at the University of Illinois at Urbana-Champaign. "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."

Currently, the Brookhaven National Laboratory (BNL) in Long Island, New York, has a heavy ion collider, and the Thomas Jefferson National Accelerator Facility ( Jefferson) in Newport News, Virginia, has very energetic electron beams. Both labs have proposed design concepts for an EIC that would use their already available infrastructure, expertise, and experience. The report, without favoring one over the other, says that taking advantage of the existing facilities would make development of an EIC cost-effective and reduce associated risks that come with building a large accelerator facility. While both labs have well-developed designs for an EIC, both would require considerable R&D to fully deliver on the compelling science questions. The report states DOE R&D investment has been and would continue to be crucial to minimizing design risks in a timely fashion and to addressing outstanding accelerator challenges.

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NAS Webinar and NAS report release: 07/24/2018


Webinar on Tuesday, July 24, 2018 - Public presentation and report release

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The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.

The EIC Science Assessment by the US NAS

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Webinar on Tuesday, July 24, 2018 - Public presentation and report release

Gordon Baym (Co-chair): Webinar presentation

“The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.”

“Glowing” report on a US-based EIC facility!
NAS report main “global” 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.

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 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 furthermore, to glean the fundamental insights into QCD that an EIC can reveal.
Anticipated next steps and plans
Anticipated next steps and plans

Towards a future EIC facility

- **NAS review following NSAC / LRP 2015 recommendation**
  - NAS study started in February 2017 with a series of meetings in 2017 / Report submitted by committee for review
  - Report released on July 24, 2018! - Very positive!
  - CD-0 (US Mission Need Statement) could be awarded after the completion of the NAS study ~FY19
Anticipated next steps and plans

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Anticipated next steps and plans

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Volume 4 - DOE/CF-0154: EIC development part of the most recent DOE FY2020 Congressional Budget Request:

Pg. 10: “Funding is requested in FY 2020 for the start of R&D and conceptual design for a proposed U.S.-based Electron Ion Collider.”
Anticipated next steps and plans

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Volume 4 - DOE/CF-0154: EIC development part of the most recent DOE FY2020 Congressional Budget Request:

Pg. 10: “Funding is requested in FY 2020 for the start of R&D and conceptual design for a proposed U.S.-based Electron Ion Collider.”

Pg. 276: “Other Project Costs (OPC) funding to support high priority, critically needed accelerator R&D to retire high risk technical challenges for the proposed U.S.-based EIC. Subsequent to the FY 2018 National Academy of Science Report confirming the importance of a domestic EIC to sustain U.S. world leadership in nuclear science and accelerator R&D core competencies. Critical Decision-0, Approve Mission Need, is planned for FY 2019.”

https://www.energy.gov/cfo/downloads/fy-2020-budget-justification
Anticipated next steps and plans

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https://www.energy.gov/cfo/downloads/fy-2020-budget-justification

Volume 4 - DOE/CF-0154: EIC development part of the most recent DOE FY2020 Congressional Budget Request:

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Anticipated next steps and plans

Towards a future EIC facility

- **NAS review following NSAC / LRP 2015 recommendation**
  - NAS study started in February 2017 with a series of meetings in 2017 / Report submitted by committee for review
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- Best guess for completion of EIC facility construction later half of next decade - in roughly a decade from now!
EIC Physics Pillars: EIC facility will address fundamental questions on the structure and dynamics of nucleons and nuclei in terms of quarks and gluons using precision measurements including:
- Parton Distributions in Nuclei / QCD at Extreme Parton Densities - Saturation
- Spin and Flavor Structure of the Nucleon and Nuclei
- Tomography (p/A) Transverse Momentum Distribution and Spatial Imaging

EIC Facility Concepts:
- JLEIC: Added ion complex with source and linac, booster and collider ring to existing CEBAF facility
- eRHIC: Added electron storage ring to existing RHIC facility
- Luminosity: \( \sim 10^{33-34}\text{cm}^{-2}\text{s}^{-1} \)
- Polarized e/p and unpolarized heavy ion beams / CME \( \sim 20-100\text{GeV} \)

EIC Status and Plans:
- NAS review completed - Glowing NAS report / Possible CD0 mission statement \( \sim FY19 \)
- EIC facility construction after FRIB completion realistically in FY22/FY23 timeframe
- EIC facility completion in roughly a decade from now!