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

Bernd Surrow

Electron-Ion Collider facility concepts

23rd International Spin Physics Symposium - SPIN 2018
Ferrara, Italy, September 10-14, 2018

DOE NP contract: DE-SC0013405
Outline
The **EIC Physics** Pillars
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- The EIC Physics Pillars
- The EIC Accelerator Concepts (eRHIC at BNL / JLEIC at JLab): Requirements and Layout
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- The **EIC Physics** Pillars
- The **EIC Accelerator Concepts** (eRHIC at BNL / JLEIC at JLab): Requirements and Layout
- The **EIC Detector Concepts**: Requirements & Design
  (BNL: BEAST / EIC-SPHENIX / JLab: TOPSiDE / JLEIC)
The EIC Physics Pillars

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

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The EIC Users Group
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- The EIC Physics Pillars
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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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- Anticipated next steps and plans
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- Summary
EIC - A QCD lab to explore the structure and dynamics of the visible world
The EIC Physics Pillars

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

\[ \mathcal{L}_{QCD} = \sum_{j=1}^{n_f} \bar{\psi}_j \left( iD_\mu \gamma^\mu - m_j \right) \psi_j - \frac{1}{4} \text{Tr} G^{\mu\nu} G_{\mu\nu} \]
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)$_c$
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- 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
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D. Leinweber: Quantum fluctuations in gluon fields
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Understanding QCD interactions and emergence of hadronic and nuclear matter in terms of quarks and gluons

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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
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:**
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:

arXiv:1212.1701
The EIC Physics Pillars

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**Parton Distributions in Nuclei**

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

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Understanding the glue that binds us all!

Electron Ion Collider: The Next QCD Frontier

Understanding the glue that binds us all

QCD at Extreme Parton Densities - Saturation

Parton Distributions in Nuclei

Transverse Momentum Distribution and Spatial Imaging

Spin and Flavor Structure of the Nucleon and Nuclei

Tomography (p/A)
EIC: Study structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei.

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Electronic Ion Collider: The Next QCD Frontier

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

- QCD dynamics

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

Quarks and Gluons

Strongly Correlated Quark-Gluon Dynamics

Confinement, Chiral Symmetry Breaking

Non-linear regime

Pomeron?

Regge trajectories?

Non-linear evolution

High-Density Gluon Matter

Linear evolution

weak coupling

perturbative

non-perturbative

Hadrons

\( Q^2(x) \)

1/x

Parton Density
Non-Linear Dynamics

Figure 13: The development of the internal quark and gluon density is so large that the gluons radiated because of the strong coupling. The parton structure of the proton changes from high values to low values, corresponding to increasing the center-of-mass energy. High luminosities at the EIC, combined with the three dimensional dynamics encoded in the DGLAP equations for the one dimension parton density, are no longer weakly coupled but become increasingly strongly coupled generating the phenomena of chiral symmetry breaking and confinement.

The nonperturbative quantities that encode such spatial tomographic information are often referred to as Generalized Parton Distributions (GPDs) and are defined at a nonperturbative factorization scale that separates the nonperturbative phenomena of chiral symmetry breaking and confinement dynamics at short distances. Powerful renormalization group arguments, analogous to those of the theory group arguments, are employed to constrain experimental systematic uncertainties. Figure 12 uses simulated data to clearly demonstrate the EIC's impact on the knowledge of exclusive processes, such as deeply virtual Compton scattering (DVCS) and the exclusive production of exclusive processes, as well as the understanding of the confining dynamics of quarks and gluons in the small resolution scale.

The EIC Physics Pillars

QCD dynamics

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

- Quarks and Gluons
- Hadrons
- Non-linear regime
- Strongly Correlated Quark-Gluon Dynamics
- Confinement, Chiral Symmetry Breaking
- Linear evolution
- Non-linear evolution
- High-Density Gluon Matter
- Pomerons? Regge trajectories?

\[ Q^2 (x) \]

1/x

non-perturbative

perturbative

weak coupling

strong coupling

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arXiv:1708.01527
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!
The EIC Physics Pillars

- QCD dynamics / Parton distributions in nuclei

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QCD dynamics / Parton distributions in nuclei

Q²(GeV²)

Quarks and Gluons

Strongly Correlated Quark-Gluon Dynamics

Confinement, Chiral Symmetry Breaking

Non-perturbative

perturbative

High-Density Gluon Matter

Non-linear regime

Linear evolution

Q²(x)

Strong coupling

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Parton Density

1/x

Explore QCD landscape in various aspects over a wide range in x and Q² - Heavy nuclei at high energy critical to explore high-density gluon matter!

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Q² = 1.69 GeV²

EPPS16

Q² = 10 GeV²

EPPS16

LHC- AA

RHIC- AA

R²p(x,Q²)

R²p(x,Q²)

V_s=39 GeV

V_s=40 GeV

V_s=39 GeV

V_s=40 GeV
QCD dynamics / Parton distributions in nuclei

- Study modifications of gluons in nuclear environment complementing LHC-AA and RHIC-AA programs.
- 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!

The EIC Physics Pillars

- QCD dynamics / Parton distributions in nuclei
- Non-Linear Dynamics
- Parton "femtoscopy" by correlating information
- Gluon structure of the proton going from high to low
- Contribution to the orbital angular momentum for
- EIC's impact on the knowledge

Q^2 (GeV^2)

- Quarks and Gluons
- Q^2(x)
- Strongly Correlated Quark-Gluon Dynamics
- Linear evolution
- Non-linear evolution
- High-Density Gluon Matter
- Confinement, chiral symmetry breaking
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- Pomerons?
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- Weak coupling
- Strong coupling
- Parton Density
- 1/x

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arXiv:1708.01527
Spin and Flavor Structure of the Nucleon

- $g_1$ stat. uncertainty projections for 10 fb$^{-1}$ 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

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The EIC Physics Pillars

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

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

\[ \int d^2 b_T \ W(x, b_T, k_T) \quad \text{Wigner Distribution} \]

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

Transverse Momentum Distribution (TMD)

Impact Parameter Distribution

psi

deltapsi

\[ k_T \]

\[ x, p \]

\[ b_T \]
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Transverse Momentum Distribution and Spatial Imaging

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

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Transverse Momentum Distribution (TMD)

Wigner Distribution

Impact Parameter Distribution

Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering
Transverse Momentum Distribution and Spatial Imaging

\[ f(x, k_T) \] 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

Impact Parameter Distribution

Generalized Parton Distribution (GPD)
The EIC Facility Concepts
The EIC Facility Concepts

Requirements
The EIC Facility Concepts

- Requirements
  - Machine:
    - High luminosity: $10^{33}\text{cm}^{-2}\text{s}^{-1} - 10^{34}\text{cm}^{-2}\text{s}^{-1}$
    - Flexible center-of-mass energy: Wide kinematic range
    - Highly polarized electron (0.8) and proton / light ion (0.7) beams: Spin structure studies
    - Wide range of nuclear beams (d to Pb/U): High gluon density
The EIC Facility Concepts

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Detector:
- Wide acceptance detector system including particle ID (e/h separation & π, K, p ID - flavor tagging)
- Instrumentation for tagging of protons from elastic reactions and neutrons from nuclear breakup: Target / nuclear fragments in addition to low $Q^2$ tagger / polarimetry and luminosity (abs. and rel.) measurement
**The EIC Facility Concepts**

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- **non-perturbative**

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Non-perturbative

**Q^2 (GeV^2)**

- **EIC**

10^{-1} 1 10 10^2 10^3 10^4 10^5
The EIC Facility Concepts

Requirements

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**Figure:**

- HERMES, COMPASS, JLab6, JLAB12
- HERA
- EIC
- $Q^2(\text{GeV}^2)$

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The Spin and Flavor Structure of the Nucleon

The EIC should also illuminate the role of gluons, which are non-linearly polarized. The gluons have a substantial contribution to the nucleon's spin, and their contribution is only approximated by fitting the empirically observed nucleon spin. Despite the large contribution of gluons, their helicity contribution is not yet accurately constrained. The EIC's high-energy capability to reach two orders of magnitude lower in the parton momentum fraction compared to existing data will help to access the non-perturbative kinematic region.

Figure 1.2 (Right) shows the reduction in the parton momentum fraction from the region of parton momentum fractions that would be achievable by the EIC in its early operations. In future, the hadron structure and properties can be explored down to the lowest parton momentum fractions.

The EIC will allow for the precise quantification of how the spin of gluons contributes to the nucleon spin. This will resolve crucial questions, such as whether the spin of quarks and antiquarks is the main contributor to nucleon spin or if a substantial “missing” portion of nucleon spin resides in the gluons. By providing high-energy probes of partons’ transverse momenta, the EIC should also illuminate the role of gluons in the hadron structure and properties.
The EIC Facility Concepts

- **eRHIC layout and parameters**
  - **eRHIC design concept:**
    - Added electron storage ring (5-18GeV) (~80% pol.) with up to 2.1A e-current and 10MW max. RF power
    - Proton beams up to 275GeV (~70% pol.) and ion beams up to 100GeV/n - existing RHIC facility
    - $^3$He and possibly d / A up to U
    - Repetition rate: 112.6MHz (With cooling)
    - Flat proton beam formed by cooling
    - Polarized electron source and 400MeV injector linac
    - On-energy polarized electron injector
    - Alternative approach of e-ERL accelerator considered in past / Technology risks addressed by R&D
- **JLEIC layout and parameters**
  - **JLEIC design concept:**
    - Polarized electrons 3 to 12GeV and polarized protons 40 to 100-400GeV and ions 40 to 160GeV/u - Polarization > 70%
    - Polarized light ions $^1$d, $^3$He and possibly Li / $^A$A above 200 (Au,Pb)
    - Electron complex with CEBAF as full energy injector and collider ring up to 12GeV
    - Ion complex with source and linac, booster and collider ring
    - Polarization - Figure-8 topology for ions rings / Spin precessions in left/right section of Figure-8 arrangement cancel
    - Repetition rate: 476MHz - High lumi. concept!
The EIC Detector Concepts

- Overview of processes and final states

arXiv:1212.1701
Overview of processes and final states

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.
The EIC Detector Concepts

Overview of processes and final states

Inclusive DIS

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

Semi-Inclusive DIS (SDIS)

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

- **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
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
- **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)

The EIC Detector Concepts

arXiv:1212.1701
EIC kinematic considerations: $E_e=10\text{GeV} \times E_p=250\text{GeV}$ ($\sqrt{s}=100\text{GeV}$)
The EIC Detector Concepts

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**The EIC Detector Concepts**

- **EIC kinematic considerations**: $E_e=10\text{GeV}$ $\times$ $E_p=250\text{GeV}$ ($\sqrt{s}=100\text{GeV}$)

![Diagram showing EIC kinematics with $E_e=10\text{GeV}$ and $E_p=250\text{GeV}$]
The EIC Detector Concepts

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![EIC Detector Diagram](image)
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Kinematic peak location!
The EIC Detector Concepts

- Overview of general requirements

Central Detector with Solenoid Magnet

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

Dipole Magnet (1 of 4)

arXiv:1212.1701
The EIC Detector Concepts

Overview of general requirements
Overview of general requirements

1: Scattered electron

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

1: Scattered electron

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3: Nuclear and nucleonic fragments / scattered proton

Bernd Surrow

The EIC Detector Concepts

arXiv:1212.1701
The EIC Detector Concepts

Overview of general requirements

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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

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% $X/X_0$)

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Overview of general requirements

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The EIC Detector Concepts

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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 $-2 < \eta < 1$.

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23rd International Spin Physics Symposium - SPIN 2018
Ferrara, Italy, September 10-14, 2018

Bernd Surrow

arXiv:1212.1701
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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)

arXiv:1212.1701
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- Good momentum resolution Δp/p ~ few %
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- High spatial vertex resolution ~ 10-20μm for vertex reconstruction

The EIC Detector Concepts

1: Scattered electron

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- Low-angel taggers:
  - Recoil proton
  - Low $Q^2$ electron
  - Neutrons on hadron direction

3: Nuclear and nucleonic fragments / scattered proton

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Bernd Surrow
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The EIC Detector Concepts

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

- **Particle ID** for π/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.
- **Low-angel taggers**:
  - Recoil proton
  - Low $Q^2$ electron
  - Neutrons on hadron direction
- **Luminosity** (Absolute and relative) and local polarization direction measurement.
The EIC Detector Concepts

- **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 /

The EIC Detector Concepts

Detector design: BEAST (1) - BNL

hadronic calorimeters  e/m calorimeters  RICH detectors

hadrons  electrons

Silicon trackers  TPC  GEM tracker  MicroMegas Tracker  3T solenoid cryostat  magnet yoke

up to 9.0m
The EIC Detector Concepts

Detector design: BEAST (2) - BNL

Highly redundant tracker
(TPC / endcap GEM disks and MAPS vertex detector)

2 barrel layers of MAPS sensors (20X20µm²) with ~0.3% X/X₀ per layer / Similar technology for forward and rear disks
The EIC Detector Concepts

Detector design: EIC-SPHENIX (1) - BNL

- Solenoid
- EM Calorimeter
- Hadron Calorimeter
- Flux return
- Central Tracker
Detector design: EIC-SPHENIX (1) - BNL

- Solenoid
- EM Calorimeter
- Hadron Calorimeter
- Flux return
- Central Tracker
- Forward Tracker
- Particle ID

The EIC Detector Concepts
The EIC Detector Concepts

- Detector design: EIC-SPHENIX (2) - BNL

<table>
<thead>
<tr>
<th>η range</th>
<th>Material</th>
<th>Dimensions</th>
<th>Attenuation @ E</th>
<th>Energy Resolution @ E</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4 &lt; η &lt; -1.55</td>
<td>PbWO₄</td>
<td>2 cm x 2 cm</td>
<td>2.5% / √E ⊕ 1%</td>
<td></td>
</tr>
<tr>
<td>-1.55 &lt; η &lt; 1.24</td>
<td>W-SciFi</td>
<td>0.025 x 0.025</td>
<td>16% / √E ⊕ 5%</td>
<td></td>
</tr>
<tr>
<td>1.24 &lt; η &lt; 3.3</td>
<td>PbScint</td>
<td>5.5 cm x 5.5 cm</td>
<td>8% / √E ⊕ 2%</td>
<td></td>
</tr>
<tr>
<td>3.3 &lt; η &lt; 4</td>
<td>PbWO₄</td>
<td>2.2 cm x 2.2 cm</td>
<td>12% / √E</td>
<td></td>
</tr>
<tr>
<td>-1.1 &lt; η &lt; 1.1</td>
<td>Fe Scint + Steel Scint</td>
<td>0.1 x 0.1</td>
<td>81% / √E ⊕ 12%</td>
<td></td>
</tr>
<tr>
<td>-1.24 &lt; η &lt; 5</td>
<td>Fe Scint</td>
<td>10 cm x 10 cm</td>
<td>70% / √E</td>
<td></td>
</tr>
</tbody>
</table>
The EIC Detector Concepts

Detector design: TOPSiDE - JLab

TOPSiDE: Timing Optimized PID Silicon Detector for the EIC

Features:

- Ultra-fast Si detectors (UFSD TOF) (PID π/K/p separation)
- Highly granular imaging calorimeters and particle flow algorithms (PID of hadrons/neutrals and background rejection)
- Full particle-ID over entire central and rear regions (-5 < η < 3)
- Forward detectors (3 < η < 5): UFSD TOF and RICH PID (π/K/p separation for SIDIS) / Dipole or Toroid for p measurement
- Rear detectors (-5 < η < -3): UFSD TOF for full PID (No RICH needed!) / Crystal calorimeter for optimal energy resolution
The EIC Detector Concepts

Detector design: JLEIC (1) - JLab

M. Diefenthaler
Detector design: JLEIC (1) - JLab

The EIC Detector Concepts

M. Diefenthaler
The EIC Detector Concepts

Detector design: JLEIC (1) - JLab

M. Diefenthaler
The EIC Detector Concepts

Detector design: JLEIC (1) - JLab

M. Diefenthaler
Detector design: JLEIC (2) - JLab

- Detector view
- Central Detector
- Forward hadron spectrometer
- ZDC
- low-\(Q^2\) electron detection and Compton polarimeter
- p
- e

The EIC Detector Concepts

M. Diefenthaler
Detector design: JLEIC (2) - JLab

Extended detector: 80m
30m for multi-purpose chicane, 10m for central detector, 40m for the forward hadron spectrometer
fully integrated with accelerator lattice

low-Q^2 electron detection and Compton polarimeter

M. Diefenthaler
The EIC Detector Concepts

arXiv:1212.1701
Auxiliary detector systems: Luminosity (Abs. / Rel.) and Polarimetry

arXiv:1212.1701
The EIC Detector Concepts

Auxiliary detector systems: Luminosity (Abs. / Rel.) and Polarimetry

- Luminosity (Absolute / Relative)
  - Bethe-Heitler process \((e+p \rightarrow e+\gamma+p)\) successfully used at HERA I/II (QED theory precision \(\sim 0.2\%\)) / Systematic uncertainty achieved \(\sim 1-2\%\). For polarized beam-mode, polarization dependence. Systematic uncertainty of e/p polarization and theory uncertainty will limit abs./rel. luminosity - Critical for asymmetry measurements in particular at low \(x\).
The EIC Detector Concepts

- Auxiliary detector systems: Luminosity (Abs. / Rel.) and Polarimetry

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  - Polarimetry: Lepton
    - Compton back-scattering / HERA used two setups of measuring trans. (TPOL) and long. (LPOL) polarization and achieved for sys. uncertainties 3.5\% (TPOL) and 1.6\% (LPOL) at HERA I / 1.9\% (TPOL) and 2.0\% (LPOL) at HERA II. Prospect to improve precision to \(~1\%).

arXiv:1212.1701
The EIC Detector Concepts

Auxiliary detector systems: Luminosity (Abs. / Rel.) and Polarimetry

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- **Polarimetry: Hadron**
  - Extensive experience at RHIC from polarized p program. Two aspects are relevant: Absolute and relative polarization measurement.
    - Absolute: Elastic scattering of polarized p on polarized hydrogen jet target
    - Relative: High statistics bunch-by-bunch polarized proton on carbon fiber target
    - Achieved precision: 3.3% (Run 13 - 255GeV polarized p beam) for single-spin asymmetry
    - Further improvements from stability control of hydrogen jet target / carbon-fiber target and energy calibration of recoil silicon detectors.
EIC User Group and R&D activities

EIC User Group:
- EICUG organization established in summer 2016
- In numbers: **817 members** (470: Experimentalists / 163: Theorists / Accelerator Scientists: 142 / Support: 3 / Other: 39), 173 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
EIC User Group and R&D activities

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Internationalization is critical!
The EIC Users Group

- EIC community activities / Conferences and Workshops
The EIC Users Group

- EIC community activities / Conferences and Workshops

EICUG2019, Paris, France
July 22-26, 2019

EICUG2018

EICUG 2017
Electron Ion Collider User Group Meeting 2017
Trento, Italy
May 15-22, 2017

EICUG 2018
Electron Ion Collider User Group Meeting 2018
July 10-14, 2018
University of Trieste
Department of Physics

EICUG 2019
Electron Ion Collider User Group Meeting 2019
July 22-26, 2019
Paris, France
The EIC Users Group

- EIC community activities / Conferences and Workshops

POETIC VI
4th International Conference on Physics Opportunities at an Electron-Ion Collider
7-9 September 2015
École Polytechnique, Palaiseau, France
http://poetic6.sciencecord.org/

Joint CTEQ Meeting and POETIC 7
(7th International Conference on Physics Opportunities at an Electron-Ion-Collider)
Temple University
November 14-18, 2016

POETIC 8
8th International Conference on Physics Opportunities at an Electron-Ion-Collider
19-23 March 2018, University of Regensburg

EICUG 2018
Electron Ion Collider User Group Meeting 2018
July 9-13, 2018
University of Liverpool, UK

EICUG 2019, Paris, France
July 22-26, 2019

23rd International Spin Physics Symposium - SPIN 2018
Ferrara, Italy, September 10-14, 2018
Bernd Surrow
The EIC Users Group

EIC community activities / Conferences and Workshops
The EIC Users Group

- EIC community activities / Conferences and Workshops

Programs & Workshops

- 2017 Programs
  - Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (NT-17-1a)
  - D. Lee
  - Properties of Jets and Heavy Quarks (NT-17-1b)
  - L. Ru

- 2017 Workshop
  - Probing QCD in Photon-Nucleon Interactions at RHIC & LHC: the Path to EIC (NT-17-001)
  - J. Tafula, C. J. Bergsven, B. M. Klein, T. Lapp, M. Strikman

- 2017 Workshop
  - Light-Quark Lepton Pair (μν) Production Double-β Decay (NT-17-676)
  - July 5 - 7, 2017
  - E. Donnelli, R. N. David, A. Shaposhnikov, M. J. Savage

- The Flavor Structure of Nucleon Baryons (NT-17-684)
  - October 2 - 6, 2017
  - C. Agashe, W. David, J. Qiu, W. Vogl

- Neutron-Neutron Oscillations: Appearance, Disappearance, and Baryogenesis (NT-17-679)
  - October 23 - 27, 2017
  - K. Bulu, Z. Benkovi, Y. Komats, B. Kotikov

- 2018 Programs
  - Nuclear Physics at the Electron-Ion Collider (NT-18-018)
    - February 19 - March 23, 2018
    - C. Bartolero, O. Benhar, A. Gelindo-Uban, A. Lovato, J. Menendez

- Multi-Scale Problems Using Effective Field Theories (NT-18-012)
  - May 7 - June 1, 2018
  - E. Bouda, S. Brubacker, T. Schaller, A. Vain

- Fundamental Physics with Electroweak Probes of Light Nuclei (NT-18-02a)
  - June 12 - July 15, 2018
  - S. Bocci, R. J. Hill, S. Pastore, D. Phillips

- Advances in Monte Carlo Techniques for Many-Body Quantum Systems (NT-18-03b)
  - July 30 - September 7, 2018
  - J. Pivetta, S. Clark, S. Gandolfi, M. J. Savage

- Probing Nucleons and Nuclei in High Energy Collisions (NT-18-05)
  - October 1 - November 16, 2018
  - V. Hatta, V. Kostoglu, C. Miquel, A. Protopop

- How to participate
- Info for Organizers
- Program archive

Programs related to EIC

EICUG2019, Paris, France
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- EIC community activities / Conferences and Workshops

Highly Active EIC Community!

Programs related to EIC

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Bernd Surrow
The US Long-Range Plan

NSAC Long-Range Plane 2015

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.
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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.
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The EIC Science Assessment by the US NAS

- **NAS charge and status**
  

- **Charge:** Focus on scientific justification besides impact to other fields in science and society

- **Status:** NAS report released 07/24/2018!
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

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

http://www8.nationalacademies.org/onpinews/newsitem.aspx?
RecordID=25171&
ga=2.209086742.50427317.1532451645-1385917444.1532451645
NAS Webinar and NAS report release: 07/24/2018

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Webinar on Tuesday, July 24, 2018 - Public presentation and report release
The EIC Science Assessment by the US NAS

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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

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


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- 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!
The EIC Science Assessment by the US NAS

NAS report main findings: Webinar on July 24, 2018 (1)

Committee Membership

Gordon Baym, Co-Chair (Illinois): theoretical many-particle physics
Ani Aprahamian, Co-Chair (Notre Dame): nuclear experiment

Christine Aidala (Michigan): heavy ion experiment
Richard Milner (MIT): high energy electron experiment
Ernst Sichtermann (BNL): heavy ion experiment
Zein-Eddine Meziani (Temple): high energy electron experiment
Michael Turner (Chicago): theoretical nuclear physics
Thomas Schaefer (NC State U): theoretical nuclear physics
Wick Haxton (UC Berkeley): high energy electron experiment
Kawtar Hafidi (Argonne): heavy ion experiment
Larry McLerran (Washington): theoretical nuclear physics
Haiyan Gao (Duke): high energy electron experiment
John Jowett (CERN): accelerator physics
Lia Merminga (Fermilab): accelerator physics

Committee Statement of Task -- from DOE to the BPA

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.

In particular, the committee will address the following 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?
The EIC Science Assessment by the US NAS

NAS report main findings: Webinar on July 24, 2018 (2)

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.
The EIC Science Assessment by the US NAS

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
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- Towards a future EIC facility
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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 ~2018/2019
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  - **Best guess for completion of EIC facility construction** would be after 2025, around 2025-2030 - in roughly a decade from now!
Summary
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
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EIC Facility Concepts:

- eRHIC: Added electron storage ring to existing RHIC facility
  - Energies (Polarization): 5-18GeV electrons (~80%) / Up to 275GeV protons (~70%) / Polarized $^3$He possibly d / 100GeV/n nuclei - A up to U
  - Luminosity: $\sim 10^{33}$cm$^{-2}$s$^{-1}$ (Without cooling) - $\sim 10^{34}$cm$^{-2}$s$^{-1}$ (With cooling)
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- **JLEIC**: Added ion complex with source and linac, booster and collider ring to existing CEBAF facility
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- Site selection as early as 2019/2020
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