Major Nuclear Science Issues to be Studied by a Future Electron-Ion-Ion Collider

Jianwei Qiu
Theory Center, Jefferson Lab

Acknowledgement: Much of the physics presented here are based on the work of EIC White Paper Writing Committee put together by BNL and JLab managements, …
Probing nuclear matter in all its forms & Exploring their potential for applications
Outline of the rest talk

- Great intellectual challenges for the Nuclear Science
  - Probing quarks and gluons & exploring their interactions without being able to “see” them!

- What is an Electron-Ion Collider (EIC)?
  - US EIC – two options of realization

- What an EIC can do and why other machine cannot do?
  - Major Nuclear Science issues to be studied at an EIC
  - EIC is an international effort

- Summary and outlook
Great Challenges for Nuclear Science

- How to make up the hadrons and nuclei from quarks and gluons?

- How does the role of quarks and gluons evolve, along with the evolution of the universe?

Quarks and gluons have played a critical role in every stage of the evolution of the universe. Can we verify and quantify what happened in the past, and predict the future?
The “Little Bang”

- A virtual journey of quarks and gluons:
  - Lorentz contraction
  - Near collision
  - Quark-gluon plasma
  - Hadronization
  - Freeze-out
  - Seen in the detector

Visible!

Need to “See” the unseen

Visible!
The “Little Bang”

- A virtual journey of quarks and gluons:

Lorentz contraction  Near collision  Quark-gluon plasma  Hadronization  Freeze-out

Visible!  Seen in the detector

Discovery:
A nearly perfect quantum fluid (NOT a gas!) at 4 trillion degrees Celsius,
Not, at $10^{-5}$ K like $^6$Li

Visible!

Where we are now
The “Little Bang”

- A virtual journey of quarks and gluons:
  - Lorentz contraction
  - Near collision
  - Quark-gluon plasma
  - Hadronization
  - Freeze-out

Visible!

Visible!

Structure of hadrons?
= initial conditions of HIC?

QCD phase Diagram!

Emergence of hadronic particles?

Where we are now
Overarching Questions for Hadronic Matter

- How does quark-gluon plasma evolve along with temperature?
- How hadrons are emerged from quarks and gluons?
- How does QCD make up the properties of hadrons? 
  Their mass, spin, magnetic moment, ...
- What is the QCD landscape of nucleon and nuclei?
- How do the nuclear force arise from QCD?
- ...
Unprecedented Intellectual Challenge!

Facts:
- Gluons are dark!
  - No modern detector has been able to see quarks and gluons in isolation!

The challenge:
- How to probe the quark-gluon dynamics, quantify the hadron structure, study the emergence of hadrons, …, if we cannot see quarks and gluons?

Answer to the challenge:
- Theory advances:
  - QCD factorization – matching the quarks/gluons to hadrons with controllable approximations!
- Experimental breakthroughs:
  - Jets – Footprints of energetic quarks and gluons
  - Quarks – Need an EM probe to “see” their existence, …
  - Gluons – Varying the probe’s resolution to “see” their effect, …

Energy, luminosity and measurement – Unprecedented resolution, event rates, and precision probes, especially EM probes, …
High-Energy Collisions

- Lepton-lepton collisions:

  - No hadron in the initial-state
  - Hadrons are emerged from energy
  - Not ideal for studying hadron structure

- Hadron-hadron collisions:

  - Hadron structure – motion of quarks, …
  - Emergence of hadrons, …
  - Initial hadrons broken – collision effect, …

- Lepton-hadron collisions:

  Hard collision without breaking the initial-state hadron – spatial imaging, …
Electron-Ion Collider (EIC)

- **A giant “Microscope”** – “see” quarks and gluons by breaking the hadron

  - \[ e \rightarrow p \]

  - \[ \gamma^*, Z^0, .. \]

  - \[ 1/Q < 1/10 \text{ fm} \]

  - *To see the non-linear dynamics of the glue!*

- **A sharpest “CT”** – “imagine” quark/gluon structure without breaking the hadron

  - “cat-scan” the nucleon and nuclei

  - with a better than 1/10 fm resolution

  - “see” proton “radius” of quark/gluon density comparing with the radius of EM charge density

  - *To discover color confining radius, hints on confining mechanism!*
Many Complementary Probes at One Facility

- **High energy and luminosity Lepton-hadron facility:**

  \[ Q^2 \rightarrow \text{Measures of resolution} \]
  \[ y \rightarrow \text{Measure of inelasticity} \]
  \[ x \rightarrow \text{Measure of momentum fraction of the struck quark in a proton} \]
  \[ Q^2 = S \times y \]

  **Inclusive events:** \( e+p/A \rightarrow e'+X \)
  
  Detect only the scattered lepton in the detector
  
  (Modern Rutherford experiment!)

  **Semi-Inclusive events:** \( e+p/A \rightarrow e'+h(\pi,K,p,\text{jet})+X \)
  
  Detect the scattered lepton in coincidence with identified hadrons/jets
  
  (Initial hadron is broken – confined motion! – cleaner than h-h collisions)

  **Exclusive events:** \( e+p/A \rightarrow e'+ p'/A' + h(\pi,K,p,\text{jet}) \)
  
  Detect every things including scattered proton/nucleus (or its fragments)
  
  (Initial hadron is NOT broken – tomography! – almost impossible for h-h collisions)
## EIC: the World Wide Interest

<table>
<thead>
<tr>
<th></th>
<th>HERA@DESY</th>
<th>LHeC@CERN</th>
<th>eRHIC@BNL</th>
<th>JLEIC@JLab</th>
<th>HIAF@CAS</th>
<th>ENC@GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{CM}}$ (GeV)</td>
<td>320</td>
<td>800-1300</td>
<td>45-175</td>
<td>12-140</td>
<td>12 $\rightarrow$ 65</td>
<td>14</td>
</tr>
<tr>
<td>proton $x_{\text{min}}$</td>
<td>$1 \times 10^{-5}$</td>
<td>$5 \times 10^{-7}$</td>
<td>$3 \times 10^{-5}$</td>
<td>$5 \times 10^{-5}$</td>
<td>$7 \times 10^{-3} \rightarrow 3 \times 10^{-4}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>ion</td>
<td>p</td>
<td>p to Pb</td>
<td>p to U</td>
<td>p to Pb</td>
<td>p to U</td>
<td>p to $^{40}\text{Ca}$</td>
</tr>
<tr>
<td>polarization</td>
<td>-</td>
<td>-</td>
<td>p, $^3\text{He}$</td>
<td>p, d, $^3\text{He}$ ($^6\text{Li}$)</td>
<td>p, d, $^3\text{He}$</td>
<td>p, d</td>
</tr>
<tr>
<td>$L$ [cm$^2$ s$^{-1}$]</td>
<td>$2 \times 10^{31}$</td>
<td>$10^{33}$</td>
<td>$10^{33-34}$</td>
<td>$10^{33-34}$</td>
<td>$10^{32-33} \rightarrow 10^{35}$</td>
<td>$10^{32}$</td>
</tr>
<tr>
<td>IP</td>
<td>2</td>
<td>1</td>
<td>2+</td>
<td>2+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Year</td>
<td>1992-2007</td>
<td>2022 (?)</td>
<td>2022</td>
<td>Post-12 GeV</td>
<td>2019 $\rightarrow$ 2030</td>
<td>upgrade to FAIR</td>
</tr>
</tbody>
</table>

The past

Possible future
US EIC – Two Options of Realization

The White Paper
A. Accardi et al

Electron Ion Collider: The Next QCD Frontier
Understanding the glue that binds us all
Edited by A. Deshpande
Z.-E. Meziani
J.-W. Qiu
SECOND EDITION
U.S. - based Electron-Ion Collider

- **NSAC 2007 Long-Range Plan:**
  
  “An Electron-Ion Collider (EIC) with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier.”

- **NSAC Facilities Subcommittee (2013):**
  
  “The Subcommittee ranks an EIC as Absolutely Central in its ability to contribute to world-leading science in the next decade.”

- **NSAC 2015 Long-Range Plan:**
  
  “We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.”

- **Under review of National Academy of Science:**
  
  Expect to have the committee report early next year!
Why US-EIC can do what HERA was not able to do?

- **Quantum Imaging:**
  - HERA discovered: 15% of e-p events is diffractive – Proton not broken!
  - US-EIC: 100-1000 times luminosity – **Critical for 3D tomography!**

- **Quantum Interference:**
  - US-EIC: Highly polarized beams – *Origin of hadron property: Spin, … Direct access to chromo-quantum interference!*

\[
\sigma(Q, \bar{s}) \propto \begin{array}{c}
p, \bar{s} \\
\rightarrow t \sim 1/Q \\
\end{array}
\]

\[
\sigma(s) - \sigma(-s) \rightarrow \text{Quantum interference} \rightarrow T^{(3)}(x, \bar{x}) \propto
\]

- **Nonlinear Quantum Dynamics:**
  - US-EIC: Light-to-heavy nuclear beams – *Origin of nuclear force, … Enhanced access to the transition from chromo-quantum fluctuation to chromo-condensate of gluons – “a controllable knob” – Atomic weight of nuclei*
What a US EIC can Do?

Major Nuclear Science issues to be studied at an EIC or “Big” questions/puzzles about QCD, ...

The key Deliverables & Opportunities

*Why existing facilities, even with upgrades, cannot do the same?*
The Proton Mass?

- How does QCD generate the nucleon mass?
  
  “… The vast majority of the nucleon’s mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. …”  
  
  The 2015 Long Range Plan for Nuclear Science

- Higgs mechanism is not relevant to hadron mass!

```
Higgs mechanism

Quarks
Mass ≈ 1.78x10^{-26} g

~ 1% of proton mass

Dynamics of gluons

Proton
Mass ≈ 168x10^{-26} g

~ 99% of proton mass
```

“Mass without mass!”
How does QCD generate the nucleon mass?

“... The vast majority of the nucleon’s mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. ...”  

The 2015 Long Range Plan for Nuclear Science

Hadron mass from Lattice QCD calculation:

How does QCD generate this? The role of quarks vs that of gluons?

If we do not understand proton mass, we do not understand QCD
How to answer the “Big” questions?

- Three-pronged approach to explore the origin of hadron mass
  - Lattice QCD
  - Mass decomposition – roles of the constituents
  - Model calculation – approximated analytical approach

The Proton Mass
At the heart of most visible matter.
Temple University, March 28-29, 2016

https://phys.cst.temple.edu/meziani/proton-mass-workshop-2016/

http://www.ectstar.eu/node/2218
How to answer the “Big” questions?

- **How does QCD generate the nucleon mass?**
  “... The vast majority of the nucleon’s mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. ...” — The 2015 Long Range Plan for Nuclear Science

- **Role of quarks and gluons?**
  - **QCD energy-momentum tensor:**
    \[ T^{\mu\nu} = \frac{1}{2} \bar{\psi} i \slashed{D}^{(\mu} \gamma^{\nu)} \psi + \frac{1}{4} g^{\mu\nu} F^2 - F^{\mu\alpha} F_{\nu}^{\alpha} \]
  - **Trace of the QCD energy-momentum tensor:**
    \[ T_{\alpha}^{\alpha} = \frac{\beta(g)}{2g} F_{\mu
u,a}^{\mu\nu} F_{\alpha}^{\alpha} + \sum_{q=u,d,s} m_q (1 + \gamma_m) \bar{\psi}_q \psi_q \]
    QCD trace anomaly \[ \beta(g) = -(11 - 2n_f/3) g^3/(4\pi^2) + ... \]
  - **Mass, trace anomaly, chiral symmetry break, and ...**
    \[ m^2 \propto \langle p | T_{\alpha}^{\alpha} | p \rangle \quad \Rightarrow \quad \frac{\beta(g)}{2g} \langle p | F^2 | p \rangle \]
    at the chiral limit!

- Heavy quarkonium production near the threshold, from JLab12 to EIC
How to answer the “Big” questions?

How does QCD generate the nucleon mass?

“... The vast majority of the nucleon’s mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. ...”  

The 2015 Long Range Plan for Nuclear Science

Role of quarks and gluons?

✧ QCD energy-momentum tensor:

\[ T^{\mu\nu} = \frac{1}{2} \bar{\psi} i \gamma^{\mu\nu} \gamma_5 \psi + \frac{1}{4} g^{\mu\nu} F_2^2 - F_{\mu\alpha} F_{\nu}^{\alpha} \]

✧ Mass = energy of the hadron when it is at the rest

\[ m = \frac{\langle p \rangle}{\langle p | p \rangle} \int d^3 x T^{00} |p\rangle \sim \text{GeV} \quad \text{when proton is at rest!} \]

\[ m = E_q + E_g + \chi m_q + T_g \]

Decomposition is not unique!
How does QCD generate the nucleon’s spin?

\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + (L_q + L_g) = \sum \langle P, S | \mathbf{j}^z_f(\mu) | P, S \rangle
\]

If we do not understand proton spin, we do not understand QCD.
How to answer the “Big” questions?

- How does QCD generate the nucleon’s spin?

\[ \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + (L_q + L_g) \]

- What can JLab12 and EIC do?

Plus many more JLab12 experiments – flavor
How to answer the “Big” questions?

How does QCD generate the nucleon’s spin?

\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + (L_q + L_g)
\]

To understand the proton spin, fully, we need to understand the distribution and confined motion of quarks and gluons inside the proton in QCD, encoded in GPDs, TMDs, GTMDs, …

Need new “probes” with two distinctive momentum scales!

Hard scale – to “see” the particle nature of quarks and gluons
Soft scale – to “be” sensitive to the QCD confinement ~ 1/fm ~ 200 MeV
Diffraction sensitive to gluon momentum:

$g(x, Q^2) \propto V = J/\psi, \phi, \rho_p - p' \, z_1 - z \, r \, (1 - z) \, b (1 - z) \, r \, x \, x'$

How does the gluon distribution saturate at small $x$?

Which "glue" the quarks together. But experiments probing proton structure at the HERA collider at Germany's DESY laboratory, and the increasing body of evidence from RHIC and LHC, suggest that this picture is far too simple. Countless other gluons and a "sea" of quarks and anti-quarks pop in and out of existence within each hadron. These fluctuations can be probed in high energy scattering experiments: due to Lorentz time dilation, the more we accelerate a proton and the closer it gets to the speed of light, the longer are the lifetimes of the gluons that arise from the quantum fluctuations. An outside "observer" viewing a fast moving proton would see the cascading of gluon slas long and longer the larger the velocity of the proton. So, in effect, by speeding the proton up, one can slow down the gluon fluctuations enough to "take snapshots" of the particles that interact with the high-energy proton.

In DIS experiments one probes the proton wave function with a lepton, which interacts with the proton by exchanging a (virtual) photon with it (see the Sidebar on page ... ). The virtuality of the photon $Q^2$ determines the size of the region in the plane transverse to the beam axis probed by the photon: by uncertainty principle the region's width is $\Delta r_\perp \sim 1/Q$. Another relevant variable is Bjorken $x$, which is the fraction of the proton's momentum carried by the struck quark. At high energy $x \approx Q^2/W^2$ is small ($W^2$ is the center-of-mass energy squared of the photon-proton system): therefore, small $x$ corresponds to high energy scattering.

$\begin{align*}
\text{Experimental uncertainty} \\
\text{Model uncertainty} \\
\text{Parametrization uncertainty}
\end{align*}$

Figure 1.1: Proton parton distribution functions plotted as functions of Bjorken $x$. Note that the gluon and sea quark distributions are scaled down by a factor of 20. Clearly gluons dominate at small-$x$.

The proton wave function depends on both $x$ and $Q^2$. An example of such dependence is shown in Fig. 1.1, representing some of the data reported by HERA for D1S on proton. Here we plot the $x$-dependence of the parton (quark or gluon) distribution functions (PDFs). At the leading order PDFs can be interpreted as providing the number of quarks and gluons with a certain fraction $x$ of the proton's momentum. In Fig. 1.1 one can see the PDFs of $f(x,k_T)$ and $f(x,b_T)$, representing two different observables.
How to answer the “Big” questions?

- **3D boosted partonic structure:**

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

  \( f(x, k_T) \) \quad EIC white paper: EPJ A52 (2016) 268

  \( f(x, b_T) \) \quad Imaging

  **Sivers Function**

- **Density distribution of an unpolarized quark in a proton moving in z direction and polarized in y-direction**

- **Momentum Space**

- **Coordinate Space**

- **TMDs**

- **GPDs**

- **Imaging**

  Spatial density distributions – “radius”
How to answer the “Big” questions?

- 3D boosted partonic structure:
  - Momentum Space
  - Coordinate Space
  - TMDs
  - GPDs

\[ \int d^2 b_T \quad \text{and} \quad \int d^2 k_T \]

\[ f(x,k_T) \quad \text{EIC white paper: EPJ A52 (2016) 268} \quad f(x,b_T) \]

Sivers Function

Position \( r \times \) Momentum \( p \) → Orbital Motion of Partons
How to answer the “Big” questions?

- 3D boosted partonic structure:
  - Momentum Space
  - Coordinate Space
  - TMDs
    \[ \int d^2b_T \]
  - GPDs
    \[ \int d^2k_T \]

\[ f(x,k_T) \quad \text{EIC white paper: EPJ A52 (2016) 268} \]

Quarks

Gluons

Role of momentum fraction - “x”, and nature of pion cloud?
Rutherford’s experiment – atomic structure (100 years ago):

J.J. Thomson’s plum-pudding model → Rutherford’s planetary model → Modern model

Atom:

1911

Discovery of nucleus
A localized charge/force center
A vast “open” space

Why 3D Nucleon Structure?

Completely changed our “view” of the visible world:

- Mass by “tiny” nuclei – less than 1 trillionth in volume of an atom
- Motion by quantum probability – the quantum world!

Provided infinite opportunities to improve things around us:

- Gas, Liquid, Solid, Nano materials, Quantum computing, …
Why 3D Nucleon Structure?

Spatial distributions of quarks and gluons:

Bag Model:
Gluon field distribution is wider than the fast moving quarks.
Gluon radius $> \text{Charge Radius}$

Constituent Quark Model:
Gluons and sea quarks hide inside massive quarks.
Gluon radius $\sim \text{Charge Radius}$

Lattice Gauge theory (with slow moving quarks):
Gluons more concentrated inside the quarks
Gluon radius $< \text{Charge Radius}$

3D Confined Motion (TMDs) + Spatial Distribution (GPDs)

Hints on the color confining mechanism
Relation between charge radius, quark radius ($x$), and gluon radius ($x$)?
Why 3D Nucleon Structure?

- **Nature of nuclear force:**
  If we only see quarks and gluons, ...
  What does the nucleus look like?

- **Range of color force:**
  *Does the color of nucleon “A” correlated with the color of nucleon “B”?*
  If it does, what is the strength of such correlation?
  *Can a large nucleus look like a big proton at small-x? the range of color correlation?*
  How far does glue density spread?
  How fast does glue density fall?
  Imaging gluon density
  Only possible at EIC
Emergence of Hadrons/Jets – A puzzle?

- Emergence of hadrons:
  How do hadrons emerge from a created quark or gluon?
  How is the color of quark or gluon neutralized?

- Need a femtometer detector or “scope”:
  Nucleus, a laboratory for QCD
  A “vertex” detector: Evolution of hadronization

- Strong suppression of heavy flavors in AA collisions:
How to answer the “Big” questions?

- Emergence of a hadron?

- Heavy quark energy loss:
  - Mass dependence of fragmentation

\[ \nu = \frac{Q^2}{2mx} \]

Control of \( \nu \) and medium length!

Need the collider energy of EIC and its control on parton kinematics.
Another HERA Discovery

- Run away gluon density at small x?

  What causes the low-x rise?
  - gluon radiation
  - non-linear gluon interaction

  What could tame the low-x rise?
  - gluon recombination
  - non-linear gluon interaction

- QCD vs. QED:

  **QCD – gluon in a proton:**
  \[ Q^2 \frac{d}{dQ^2} xG(x, Q^2) \approx \frac{\alpha_s N_c}{\pi} \int_x^1 \frac{dx'}{x'} x'G(x', Q^2) \]

  **QED – photon in a positron:**
  \[ Q^2 \frac{d}{dQ^2} x\phi_\gamma(x, Q^2) \approx \frac{\alpha_{em}}{\pi} \left[ -\frac{2}{3} x\phi_\gamma(x, Q^2) \\
  + \int_x^1 \frac{dx'}{x'} x'\left[ \phi_{e^+}(x', Q^2) + \phi_{e^-}(x', Q^2) \right] \right] \]

  - At very small-x, proton is “black”, positronium is still transparent!
  - Recombination of large numbers of glue could lead to saturation phenomena
How to answer the “Big” questions?

- Run away gluon density at small x?
  - What causes the low-x rise?
    - gluon radiation
    - non-linear gluon interaction
  - What could tame the low-x rise?
    - gluon recombination
    - non-linear gluon interaction

- Particle vs. wave feature:
  - Gluon saturation – Color Glass Condensate
    - Radiation = Recombination
    - Leading to a collective gluonic system? with a universal property of QCD?
      - new effective theory QCD – CGC?
  - Expectation: \( x = 10^{-5} \) in a proton at \( Q^2 = 5 \text{ GeV}^2 \)
Separation of the Collision Effect?

A simple question:

Will the suppression/shadowing continue to fall as $x$ decreases?

*Saturation in $RF_2^A$*

*No saturation in $F_2^A$*

*Color localized inside nucleons*

*Fermi motion*

*original EMC finding*

*collision effects*
If the color is localized inside nucleon, …

\[ \xi^2 = 0.09 - 0.12 \text{ GeV}^2 \]

One number for all \( x_B, Q, \) and \( A \) dependence!
A simple question: Will the suppression/shadowing continue to fall as $x$ decreases?

Saturation in nucleon

Color localized inside nucleons

Saturation in $RF_2$

No saturation in $F_2^A$

Collision effects

Color leaks outside nucleons

Soft gluon radius is larger
Best Signature for Gluon Saturation

Diffractive cross section:

\[ \frac{1}{\sigma_{\text{tot}}^e} \frac{d\sigma_{\text{diff}}^{eA}}{dM_x^2} \bigg/ \frac{1}{\sigma_{\text{tot}}^{ep}} \frac{d\sigma_{\text{diff}}^{ep}}{dM_x^2} \approx \frac{25 - 30\%}{10 - 15\%} > 1 \]

\[ \sigma_{\text{diff}} \propto [g(x, Q^2)]^2 \]

- off a single hard, local interaction

At HERA

ep: 10-15% diffractive

At EIC eA, if Saturation/CGC

eA: 25-30% diffractive

Early work – E665 @ FNAL:

Nuclear shadowing, diffractive scattering and low momentum protons in \( \mu \) Xe interactions at 490 GeV

\[ f \Delta t = 1 \text{ fb}^{-1} / \text{A} \]

\[ Q^2 = 5 \text{ GeV}^2 \]

\[ x = 1 \times 10^{-3} \]

\[ M_x^2 (\text{GeV}^2) \]
EIC – An International Effort

- **EIC Users Group – EICUG.ORG:**
  - 705 collaborators, 29 countries, 162 institutions... (August, 2017)
  - Map of institution’s locations

The EIC Users Meeting at Stony Brook, June 2014:
→ [http://skipper.physics.sunysb.edu/~eicug/meeting1/SBU.html](http://skipper.physics.sunysb.edu/~eicug/meeting1/SBU.html)

The EIC UG Meeting at University of Berkeley, January 6-9, 2016

Recent EICUG Argonne National Laboratory July 7-10, 2016

Remote/Internet: meeting: March 16th: For NAS Review preparation

Most recent meeting: July 18-22, 2017: Universita, Degli Studi Di Trieste, INFN, Trieste, Italy
Summary and outlook

- EIC is a ultimate QCD machine:
  1) to discover and explore the quark/gluon structure and properties of hadrons and nuclei,
  2) to search for hints and clues of color confinement, and
  3) to measure the color fluctuation and color neutralization

- EIC is a tomographic machine for nucleons and nuclei with a resolution better than 1/10 fm

- EIC could study major Nuclear Science issues that other existing facilities, even with upgrades, cannot do

- US-EIC designs explore the polarization and intensity frontier, as well as the frontier of new accelerator/detector technology

- US-EIC is sitting at a sweet spot for rich QCD dynamics – capable of taking us to the next QCD frontier

Thanks!
Electroweak physics at EIC

Running of weak interaction – high luminosity:

- Fills in the region that has never been measured
- have a real impact on testing the running of weak interaction