The EIC Recommendation & a 2 page narrative: A discussion

Hot & Cold QCD Town Meeting

Temple University

September 14, 2014

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+ comments from many others (Ullrich, Aschenaur, Diehl, Mueller, Ent, Venugopalan, Sterman, Rajagopal, Bond, Sichtermann, Jacobs…..)

- The science of EIC has been presented from 30000 ft, and from 10000 meters (yesterday), and various detailed aspects of it were presented from ~micrometers to femptometers distances today:
  - "*Understanding the role of Gluons and Sea Quarks in QCD*"
  - Direct connections & consequences to the science being pursued at JLab, RHIC and at LHC
- The Hot and Cold QCD communities will prepare their list of priorities in form of White Papers with recommendations & narratives
- The conveners (Gao, Heinz, Roberts, Sorensen) plan an identical recommendation & 2 page narrative in the White Papers (Hot and Cold QCD) coming out of this town hall meeting

- They asked us (Meziani, Milner, Qiu & Deshpande) to formulate a draft recommendation bullet for the EIC and also write a 2 page narrative that could be included in the Executive Summaries of the two QCD White Papers.

- A draft was prepared, and sent to a large group of people with a request for comments and suggestions.
  - Many responses. Most/All now incorporated/addressed.

- We present this in this Joint Session: to get more comments and suggestions… through a discussion

Discussion

We will listen to what you have to say & work at a later time on how best to incorporate your input and address any concerns.

Please email me your comments:
Subject: "Comment on EIC Recommendation"
Email: abhay.deshpande@stonybrook.edu

Draft Recommendation

The Electron Ion Collider (EIC) will, for the first time, precisely image the gluons and sea quarks in the proton and nuclei, resolve the proton's internal structure including the origin of its spin, and explore a new QCD frontier of ultra-dense gluon fields in nuclei at high energy. These advances are made possible by the EIC's unique capability to collide polarized electrons with polarized protons and light ions at unprecedented luminosity and electrons with heavy nuclei at high energy. EIC will be absolutely essential to maintain U.S. leadership in fundamental nuclear physics research in the coming decades.

Recommendation:

A high luminosity, high-energy polarized Electron Ion Collider (EIC) is the highest priority of the U.S. QCD community for new construction.

Draft Recommendation

Example: Recent input from PJ

The EIC will image the gluons and sea quarks in the proton and nuclei with unprecedented precision and probe their ***multi-body correlations in detail, providing access for the first time to this fundamental aspect in QCD***. It will resolve ***definitively*** the proton's internal structure including the origin of its spin, and explore QCD frontier of ultra-dense gluon fields in nuclei at high energy. These advances are made possible by the EIC's unique capability to collide polarized electrons with polarized protons and light ions at unprecedented luminosity and electrons with heavy nuclei at high energy. EIC will be absolutely essential to maintain U.S. leadership in fundamental nuclear physics research in the coming decades.

Recommendation:

A high luminosity, high-energy polarized Electron Ion Collider (EIC) is the highest priority of the U.S. QCD community for new construction.

The 2 page narrative for the QCD White Paper Executive Summary(ies)

Atomic nuclei are built from protons and neutrons, which themselves are composed of quarks that are bound together by gluons. Neither quarks nor gluons appear in isolation. Unlike quarks, gluons do not carry an electric charge and are thus not *directly* visible to electrons, photons, and other common probes of the structure of matter. Gluons' role in forming the visible matter in the universe remains largely un-understood.

The Electron Ion Collide (EIC) with its unique capability to collide polarized electrons with polarized protons and light ions at unprecedented luminosity, and with heavy nuclei at high energy, will be a precision microscope to explore how gluons bind quarks to form protons and nuclei at the heart of the visible matter. By precisely imaging gluons and sea quarks inside the proton and nuclei, the EIC will address some of the deepest and most puzzling questions nuclear physicists ask:

Where are the gluons and sea quarks, and their spins, distributed in space and momentum inside the nucleon? What is the role of the orbital motion of sea quarks and gluons in building the nucleon spin?

What happens when gluons are packed densely inside a large nucleus? Does the gluon density saturate, and if so, how? Does this mechanism give rise to a universal component of matter in all nuclei, even the proton, when viewed at close to the speed of light?

How does the nuclear environment affect the distributions of quarks and gluons and their interactions in nuclei? How does nuclear matter respond to a fast moving color charge passing through it? How do quarks dress themselves to become hadrons?

Quantum Chromo-Dynamics (QCD), the gauge theory of the strong interaction, not only determines the structure of hadrons but also provides the fundamental framework to understand the properties and structure of atomic nuclei at all energy scales in the universe. QCD is based on the exchange of massless gauge bosons called *gluons* between the constituents of hadrons, *quarks.* Without gluons there would be no protons, no neutrons, and no atomic nuclei. The interactions between gluons and quarks, and among gluons themselves, determine the unique features of the strong interactions. Understanding the interior structure and interactions of nucleons and nuclei in terms of the properties and dynamics of the quarks and gluons as dictated by QCD is thus a fundamental and central goal of modern nuclear physics.

A full understanding of QCD, especially in the regime relevant to the structure and properties of hadrons and nuclei, demands a new era of precision measurements that are capable of probing the structure of these particles in its full complexity. Theoretical advances over the past decade have resulted in the development of a powerful formalism that provides quantitative links between such measurements and the questions QCD physicists are trying to answer, such as the gluon

- distribution in the proton, the fraction of the proton spin carried by sea quarks, and the scale at which the gluon density in a heavy nucleus saturates. A second important advance in recent years is the increasing precision and reach of *ab initio* calculations performed with lattice QCD techniques. Using the experimental data from an EIC, physicists will, be able to undertake the detailed comparative study between experimental measurements and the predictions made by lattice QCD, as well as elucidate aspects of the structure of hadrons and nuclei that are still beyond the reach of lattice calculations.

- The experimental study of how hadrons and nuclei emerge from the laws of QCD is a high scientific priority. Two world-leading facilities in the U.S., CEBAF at Jefferson Lab and RHIC at BNL, are international centers for the study of nuclear QCD. With the increase of its beam energy to 12 GeV, Jefferson Lab operates a unique electron microscope that will precisely and systematically map the structure of protons and other nuclei in the valence quark region, and search for new types of hadrons with yet unobserved structure. In addition to its discovery and continuing exploration of the strongly coupled quark gluon plasma (QGP), RHIC has used its unique capability as a polarized proton collider to make a first direct determination of the contribution of the gluons to the proton's spin.

- A high energy, high luminosity polarized EIC will extend these capabilities to image the transverse momentum and position distributions of quarks and gluons inside fast moving hadrons. The EIC will be a true "QCD Laboratory", unique of its kind in the world. In addition to providing three-dimensional images of the confined motion of quarks and gluons and their spatial distributions, the EIC will study the way in which gluons interact with each other by splitting and fusing. When hadrons move at nearly the speed of light, the low-momentum gluons contained in their wave functions become experimentally accessible. By colliding electrons with heavy nuclei, the EIC will provide access to a conjectured, if not fully confirmed, regime of matter where abundant gluons dominate its behavior. Such universal cold gluon matter is an emergent phenomenon of QCD dynamics. Its properties and its underlying QCD dynamics are critically important for understanding the dynamical origin of the creation of the almost perfect liquid Quark Gluon Plasma (QGP) from the collision of two relativistic heavy ions.

- The EIC was designated in the 2007 Nuclear Physics Long Range Plan as "*embodying the vision for reaching the next QCD frontier*". In 2013 the NSAC Subcommittee report on Future Scientific Facilities declared an EIC to be "*absolutely essential in its ability to contribute to the world-leading science in the next decade*". The EIC will extend the current scientific programs at the CEBAF and RHIC in dramatic and fundamentally important ways. Its versatile range of kinematics, beam species and polarization will allow the most central questions to be addressed at a single facility, thereby maintaining U. S. leadership in a central area of fundamental physics research.

PX: “Emphasis in this paragraph”

Blah blah blah..

Blah, blah, important Bla, important bla,

Blah, blah

P1: Gluons in nature: importance, un-understood

Atomic nuclei are built from protons and neutrons, which themselves are composed of quarks that are bound together by gluons. Neither quarks nor gluons appear in isolation. Unlike quarks, gluons do not carry an electric charge and are thus not *directly* visible to electrons, photons, and other common probes of the structure of matter. Gluons' role in forming the visible matter in the universe remains largely un-understood.

P2: Define EIC & what it will do:

The Electron Ion Collide (EIC) with its unique capability to collide polarized electrons with polarized protons and light ions at unprecedented luminosity, and with heavy nuclei at high energy, will be a precision microscope to explore how gluons bind quarks to form protons and nuclei at the heart of the visible matter. By precisely imaging gluons and sea quarks inside the proton and nuclei, the EIC will address some of the deepest and most puzzling questions nuclear physicists ask:

- Bullet 1
- Bullet 2
- Bullet 3

Science of EIC

- How are the gluons and sea quarks, and their spins, distributed in space and momentum inside the nucleon? What is the role of the orbital motion of sea quarks and gluons in building the nucleon spin?

- What happens when gluons are packed densely inside a large nucleus? Does the gluon density saturate, and if so, how? Does this mechanism give rise to a universal component of matter in all nuclei, even the proton, when viewed at close to the speed of light?

- How does the nuclear environment affect the distributions of quarks and gluons and their interactions in nuclei? How does nuclear matter respond to a fast moving color charge passing through it? How do quarks dress themselves to become hadrons?

P3: The critical role of gluons in QCD

Quantum Chromo-Dynamics (QCD), the gauge theory of the strong interaction, not only determines the structure of hadrons but also provides the fundamental framework to understand the properties and structure of atomic nuclei at all energy scales in the universe. QCD is based on the exchange of massless gauge bosons called *gluons* between the constituents of hadrons, *quarks.* Without gluons there would be no protons, no neutrons, and no atomic nuclei. The interactions between gluons and quarks, and among gluons themselves, determine the unique features of the strong interactions. Understanding the interior structure and interactions of nucleons and nuclei in terms of the properties and dynamics of the quarks and gluons as dictated by QCD is thus a fundamental and central goal of modern nuclear physics.

P4: Tools developed. Ready for new era of QCD studies…

A full understanding of QCD, especially in the regime relevant to the structure and properties of hadrons and nuclei, demands a new era of precision measurements that are capable of probing the structure of these particles in its full complexity. Theoretical advances over the past decade have resulted in the development of a powerful formalism that provides quantitative links between such measurements and the questions QCD physicists are trying to answer, such as the gluon distribution in the proton, the fraction of the proton spin carried by sea quarks, and the scale at which the gluon density in a heavy nucleus saturates. A second important advance in recent years is the increasing precision and reach of *ab initio* calculations performed with lattice QCD techniques. Using the experimental data from an EIC, physicists will be able to undertake the detailed comparative study between experimental measurements and the predictions made by lattice QCD, as well as elucidate aspects of the structure of hadrons and nuclei that are still beyond the reach of lattice calculations.

P5: Significance of existing facilities…

The experimental study of how hadrons and nuclei emerge from the laws of QCD is a high scientific priority. Two world-leading facilities in the U.S., CEBAF at Jefferson Lab and RHIC at BNL, are international centers for the study of nuclear QCD. With the increase of its beam energy to 12 GeV, Jefferson Lab operates a unique electron microscope that will precisely and systematically map the structure of protons and other nuclei in the valence quark region, and search for new types of hadrons with yet unobserved structure. In addition to its discovery and continuing exploration of the strongly coupled quark gluon plasma (QGP), RHIC has used its unique capability as a polarized proton collider to make a direct determination of the contribution of the gluons and sea quarks to the proton's spin, and a systematic study of transverse spin phenomena.

P6: EIC's potential to go beyond….

A high energy, high luminosity polarized EIC will extend these capabilities to image the transverse momentum and position distributions of quarks and gluons inside fast moving hadrons. The EIC will be a true "QCD Laboratory", unique of its kind in the world. In addition to providing three-dimensional images of the confined motion of quarks and gluons and their spatial distributions, the EIC will study the way in which gluons interact with each other by splitting and fusing. When hadrons move at nearly the speed of light, the low-momentum gluons contained in their wave functions become experimentally accessible. By colliding electrons with heavy nuclei, the EIC will provide access to a conjectured, if not fully confirmed, regime of matter where abundant gluons dominate its behavior. Such universal cold gluon matter is an emergent phenomenon of QCD dynamics. Its properties and its underlying QCD dynamics are critically important for understanding the dynamical origin of the creation of the almost perfect liquid Quark Gluon Plasma (QGP) from the collision of two relativistic heavy ions.

P7: “EIC” since the last LRP & US leadership

The EIC was designated in the 2007 Nuclear Physics Long Range Plan as “*embodying the vision for reaching the next QCD frontier*”. In 2013 the NSAC Subcommittee report on Future Scientific Facilities declared an EIC to be “*absolutely essential in its ability to contribute to the world-leading science in the next decade*”. The EIC will extend the current scientific programs at the CEBAF and RHIC in dramatic and fundamentally important ways. Its versatile range of kinematics, beam species and polarization will allow the most central questions to be addressed at a single facility, thereby maintaining U. S. leadership in a central area of fundamental physics research.