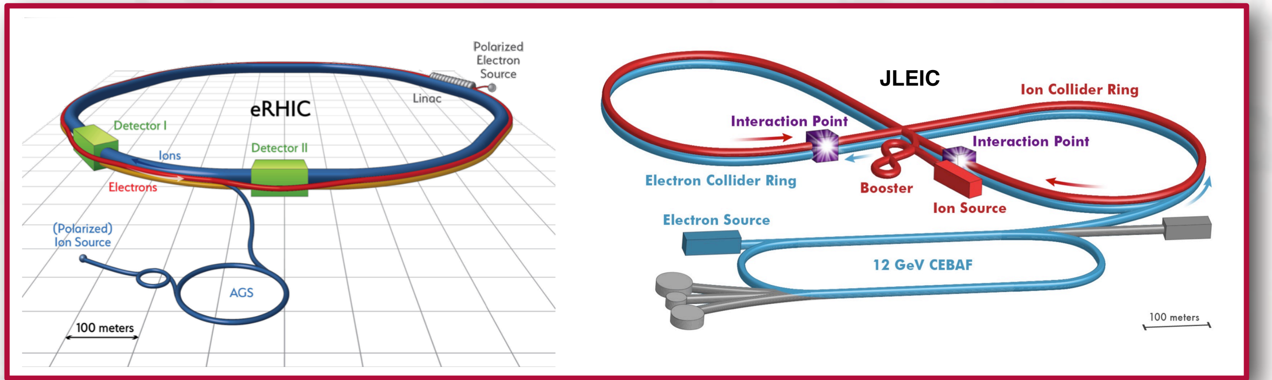
Lecture
Physics at a future Electron-Ion Collider (EIC)

Bernd Surrow

TEMPLE UNIVERSITY

Electron-Ion Collider facility concepts

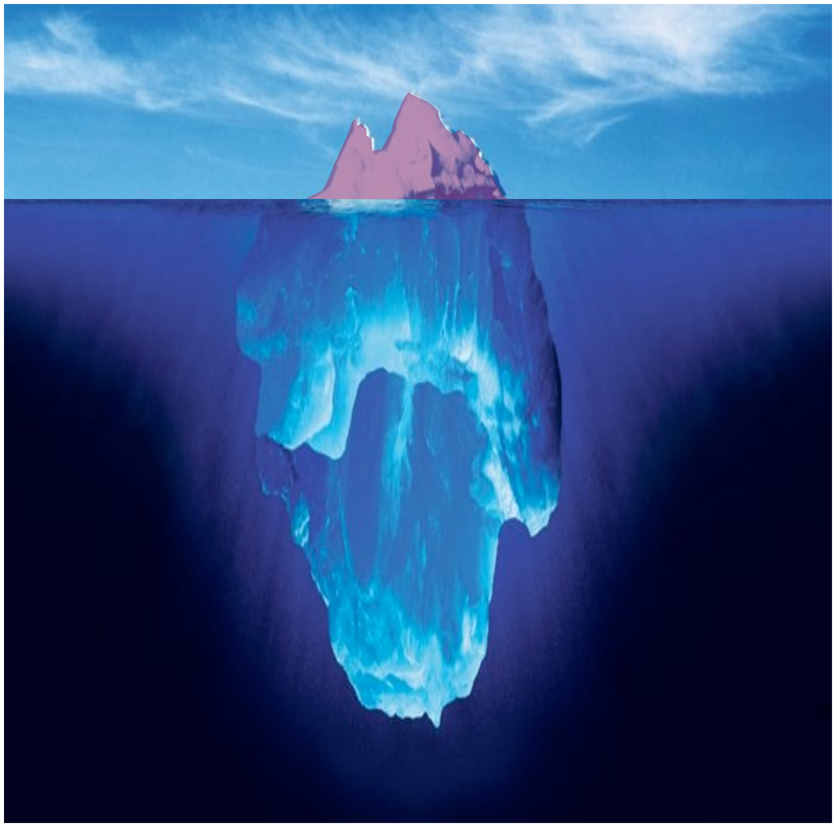


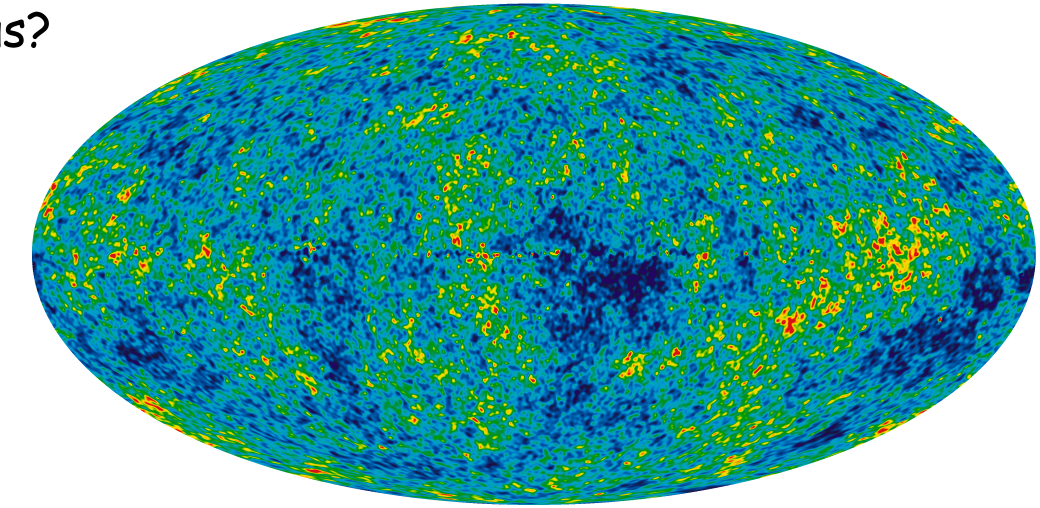
U.S. DEPARTMENT OF ENERGY Office of Science

DOE NP contract: DE-SC0013405

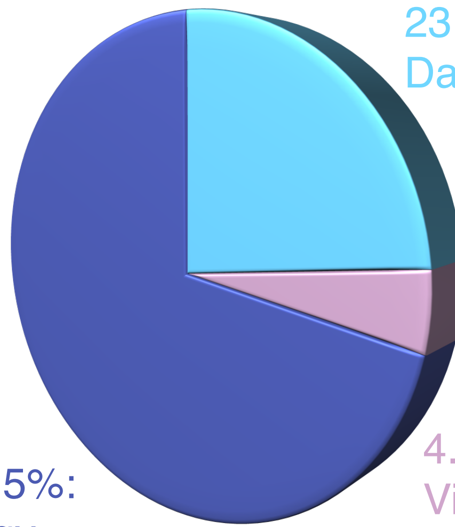
Introduction

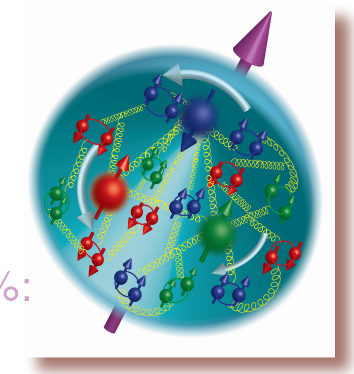
- What makes up the world around us?





https://map.gsfc.nasa.gov





Introduction

- Force carriers (Fields) and matter constituents within the Standard Model

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c²	Electric charge
γ photon	0	0
W^-	80.39	−1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin = 1		
Name	Mass GeV/c²	Electric charge
g gluon	0	0

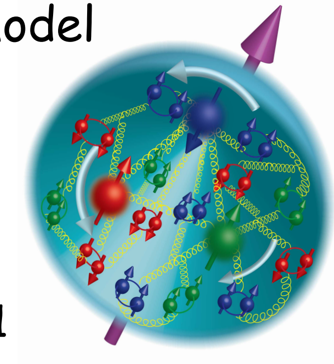
Higgs Boson spin = 0		
Name	Mass GeV/c²	Electric charge
H Higgs	126	0

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2		
Flavor	Mass GeV/c²	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0
e electron	0.000511	−1
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0
μ muon	0.106	−1
ν_H heaviest neutrino*	$(0.05-2)\times10^{-9}$	0
τ tau	1.777	−1

Quarks spin =1/2		
Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.002	2/3
d down	0.005	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	173	2/3
b bottom	4.2	−1/3

"20... ...glert and P. Higg... the theor... discovery of a mech... ...sm that contribu... to our understanding of the origin of mass of subatomic particles (e.g. quarks), and which recent... ...s confirmed throu... discovery of the ... ...ed f... ...al particle, by ... and CMS ...s at CERN's ...on Collider."



Proton charge:+1

Proton mass: ~ 1GeV

- m_u ~ 2MeV
- m_d ~ 5MeV
- m_g = 0
- Proton mass arises predominantly from interactions / energy in Gluon fields

Proton spin: 1/2

Introduction

- Fundamental interactions in nature

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

1916: A. Einstein: “Die Grundlagen der allgemeinen Relativitätstheorie”, Annalen der Physik.

2017: R. Weiss, B. C. Barish and K. S. Thorne: “for decisive contributions to the LIGO detector and the observation of gravitational waves.”

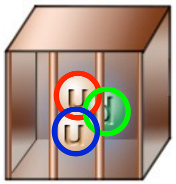
1979: S. L. Glashow, A. Salam and S. Weinberg: “for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current.”

1965: S. Tomonaga, J. Schwinger and R. P. Feynman: “for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles.”

2004: D. J. Gross, H. D. Politzer and F. Wilczek: “for the discovery of asymptotic freedom in the theory of the strong interaction.”

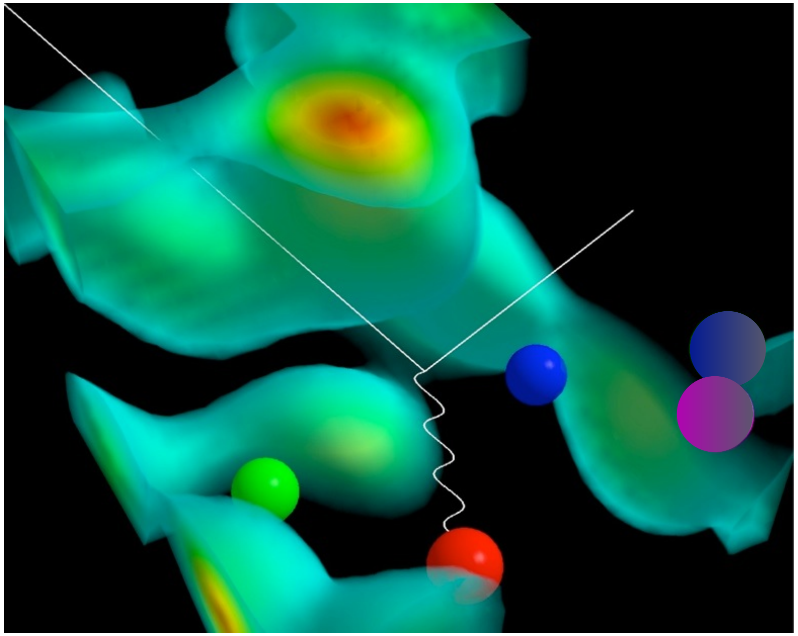
Introduction

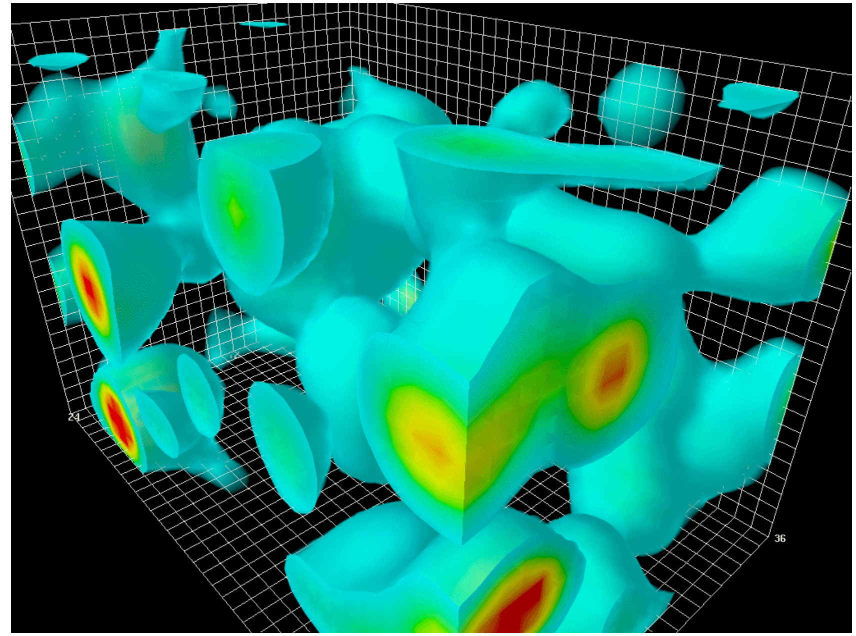
- Strong Interactions



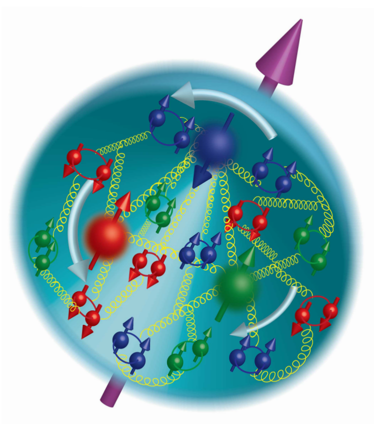
Proton=uud

Visible Matter consists of....:





(D. Leinweber: Action (~energy) density fluctuations of gluon-fields in QCD vacuum)



Protons & **Neutrons**

3 valence quarks +...

Silent Partners:

Virtual quark-antiquark pairs (QCD sea) ($\Delta E\ \Delta t \sim h$)

Gluons!

Introduction

- Mass in QCD

  - Quote from Nobel prize lecture in physics, 2004, given by Frank Wilczek:

Stated as $m=E/c^2$: Possibility of explaining mass in terms of energy.

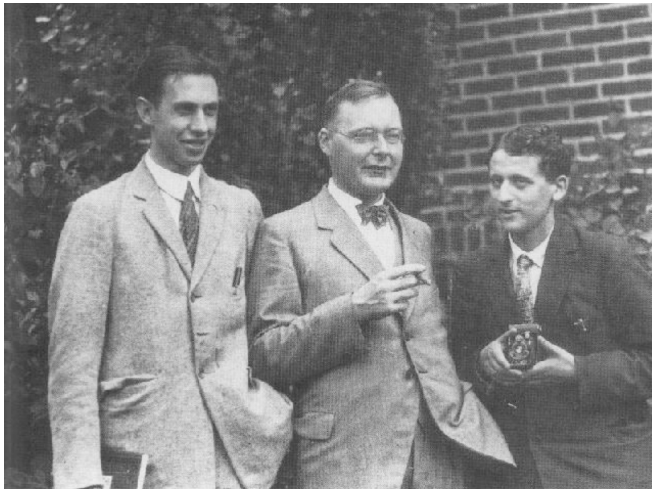
Einstein's original paper does not contain the equation $E=mc^2$, but rather $m=E/c^2$:

"Does the Inertia of a Body Depend Upon its Energy Content? "(A. Einstein, Annalen der Physik, 18 (1905) 639.)"

Modern QCD answers Einstein's question with a resounding "Yes!". Indeed, the mass of ordinary matter derives almost entirely from energy - the energy of massless gluons and nearly massless quarks, which are the ingredients from which protons, neutrons, and atomic nuclei are made.

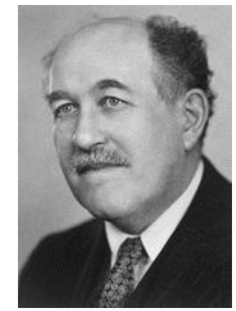
Introduction

Spin in QCD



- Traditional way to introduce spin in QM textbooks: Stern-Gerlach experiment (1922)
- Concept of spin: Long and tedious battle to understand splitting patterns and separations in line spectra
- Anomalous magnetic moment of proton by Stern et al. (1933)

Otto Stern
(1988-1969)

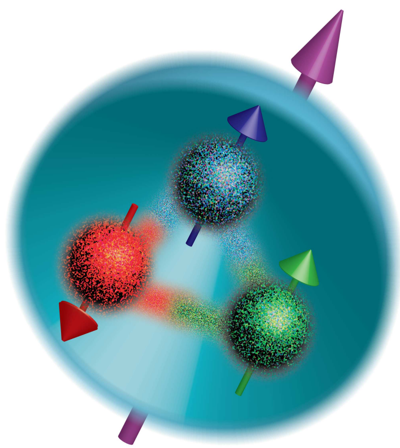


Proposal of self-rotating electron by George Uhlenbeck and Samuel Goudsmit (1925)

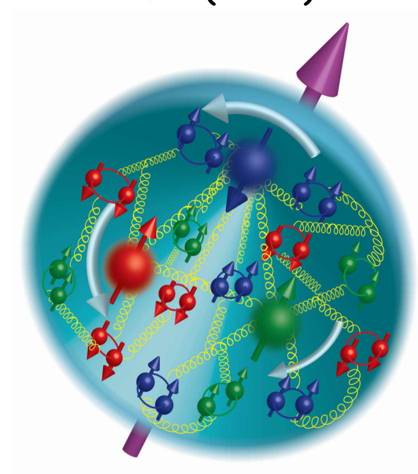
Nobel Prize Physics

1943: "for his contribution to the development of the molecular ray method and his discovery of the magnetic moment of the proton"

Paul Ehrenfest: "This is a good idea [self-rotating electron]. Your idea may be wrong, but since both of you are so young without any reputation, you would not loose anything by making a stupid mistake."



Quark Model



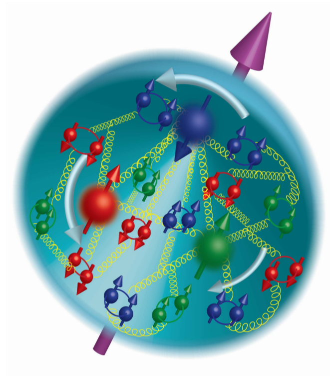
QCD (Spin....and Orbital motion)

Introduction

- Spin in everyday life

Paul C. Lauterbur (1929-2007)

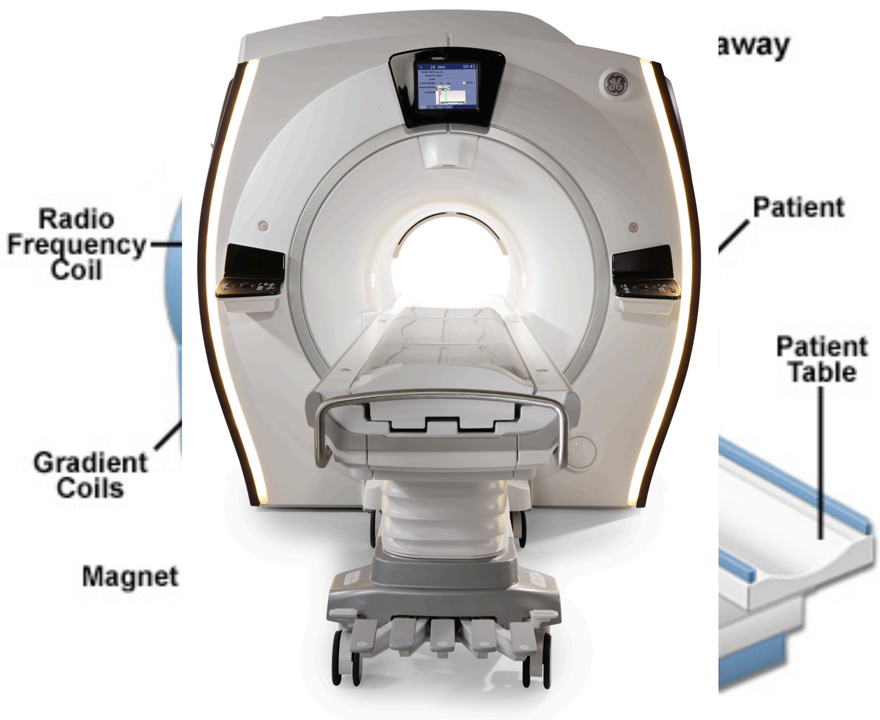
Sir Peter Mansfield (1933-2017)



Proton spins are used to image the structure and function of the human body using the technique of Magnetic Resonance Imaging (MRI)

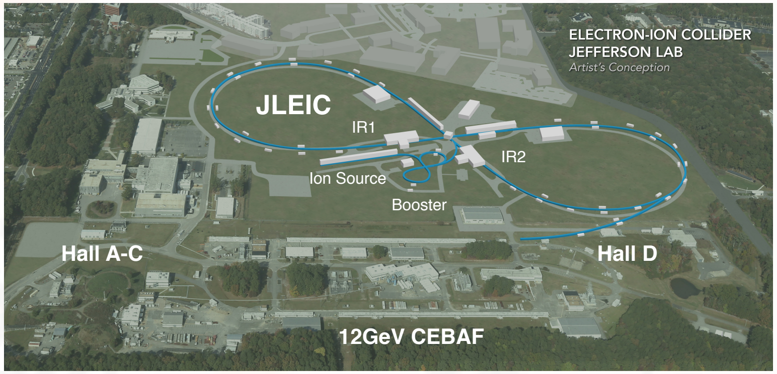
Nobel Prize Medicine

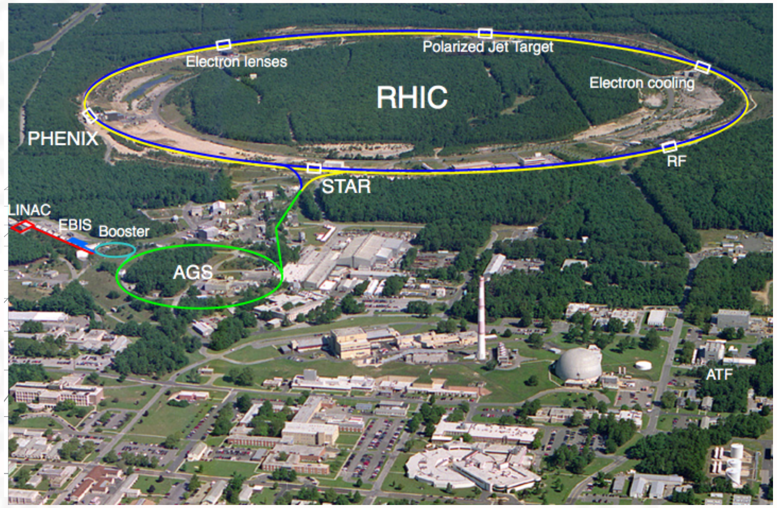
2003: “for their discoveries concerning Magnetic Resonance Imaging”



Outline

- Theoretical foundation
- The EIC Physics Pillars
- The EIC Accelerator Concepts (JLEIC at JLab / eRHIC at BNL): Requirements and Layout
- The EIC Detector Concepts: Requirements & Design
- The US NP Long-Range Plan and EIC Science Assessment by the National Academy of Sciences
- Anticipated next steps and plans
- The EIC Users Group
- Summary





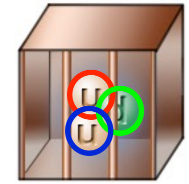
Theoretical foundation

- The Quest to Understand the Fundamental Structure of Matter ("Visible Matter")

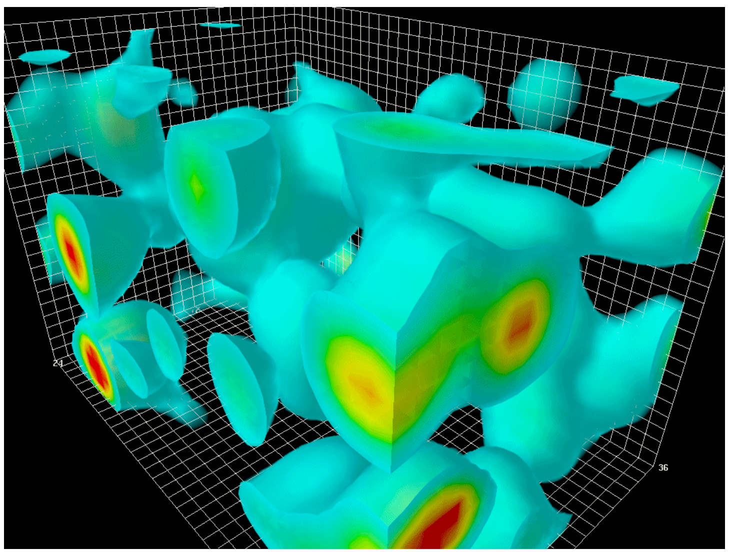
Theoretical foundation

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

$$\mathcal{L}_{QCD} = \sum_{j=1}^{n_f} \bar{\psi}_j \left(iD_\mu \gamma^\mu - m_j \right) \psi_j - \frac{1}{4} \mathrm{Tr}\, G^{\mu\nu} G_{\mu\nu}$$



- 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

Major goal:

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

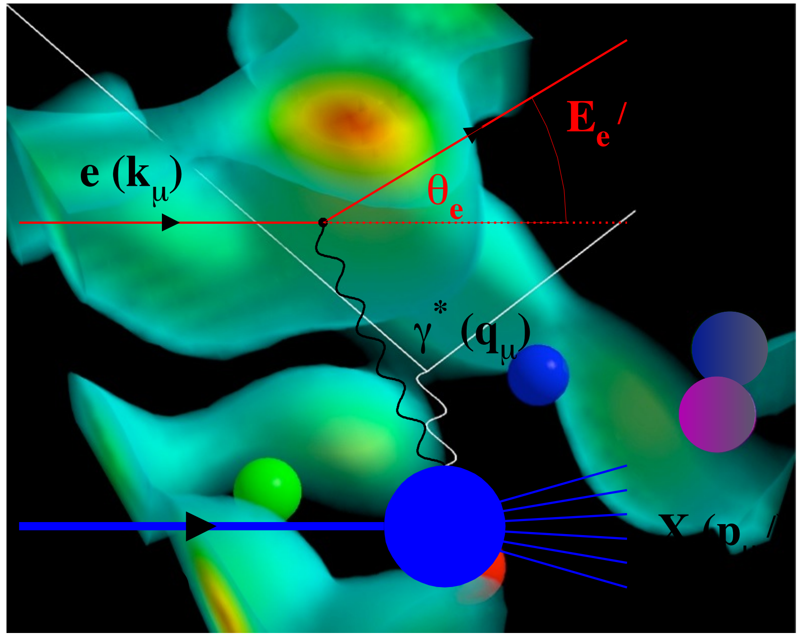
Essential elements looking forward:

1) Tomography of hadrons and nuclear matter in terms of quarks and gluons
2) Synergy of experimental progress and theory

Theoretical foundation

- DIS - Kinematics

$$k = \begin{pmatrix} E_e \\ 0 \\ 0 \\ -E_e \end{pmatrix}$$



$$k' = \begin{pmatrix} E'_e \\ E'_e \sin\theta'_e \cos\phi'_e \\ E'_e \sin\theta'_e \sin\phi'_e \\ E'_e \cos\theta'_e \end{pmatrix}$$

$$p = \begin{pmatrix} E_P \\ 0 \\ 0 \\ E_P \end{pmatrix}$$

$$p' = \begin{pmatrix} \sum_h E_h \\ \sum_h p_{X,h} \\ \sum_h p_{Y,h} \\ \sum_h p_{Z,h} \end{pmatrix}$$

$$Q^2 = -(k - k')^2 = -q^2$$

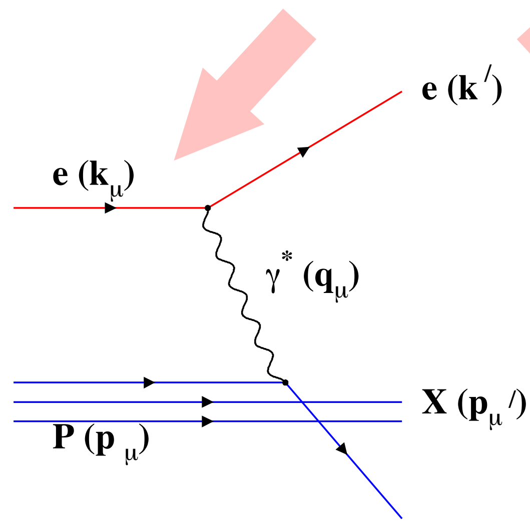
Measure of resolution power

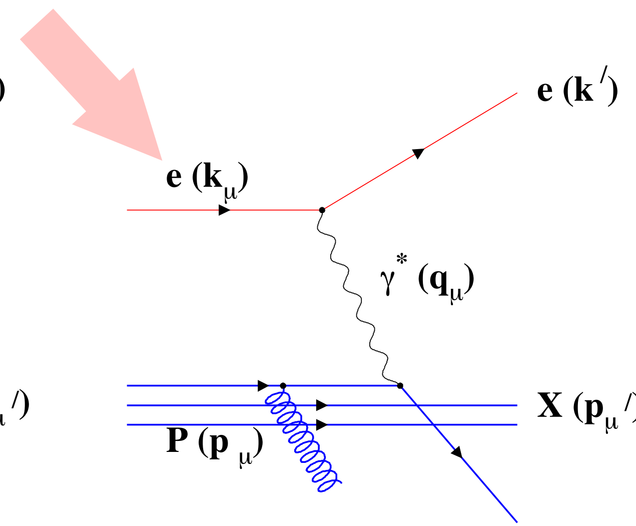
$$x = \frac{Q^2}{2(p \cdot q)}$$

Measure of momentum fraction by struck quark

$$y = \frac{p \cdot q}{p \cdot k}$$

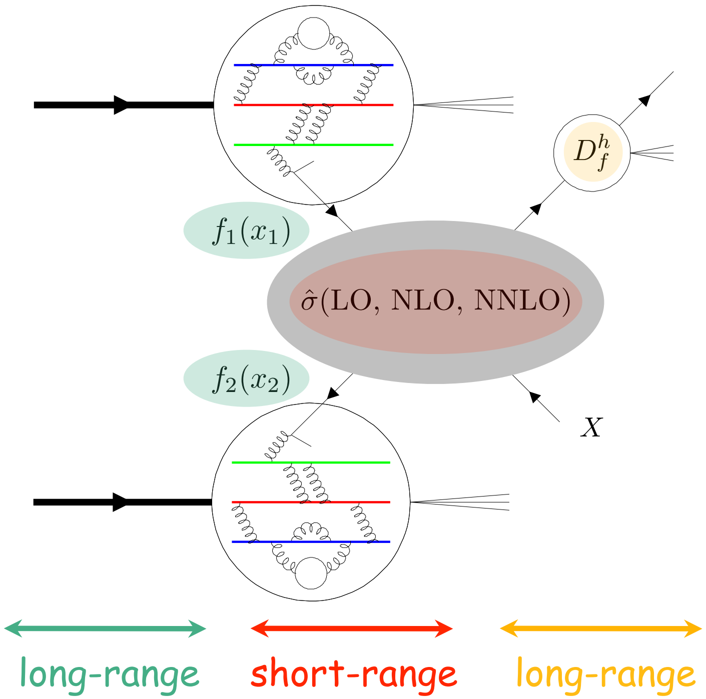
Measure of inelasticity



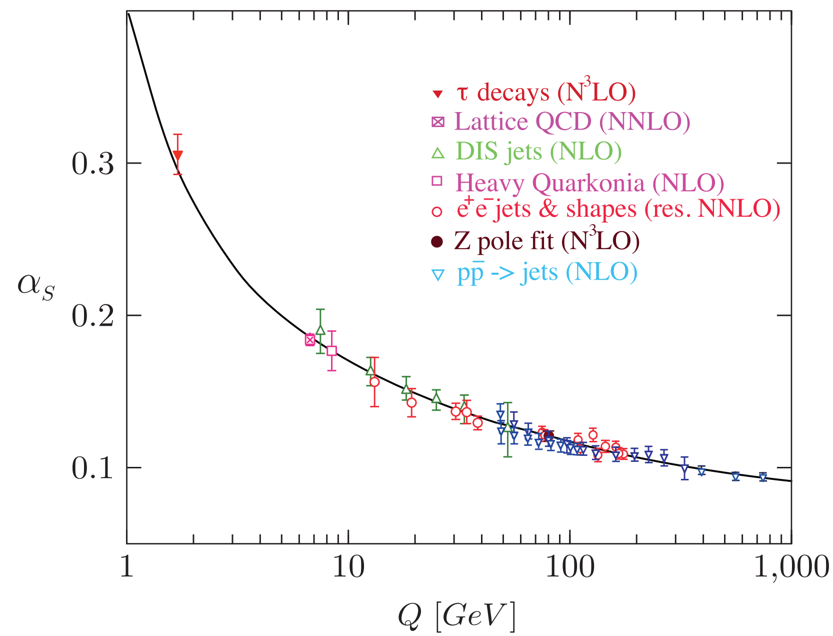


Theoretical foundation

- Basic ingredients of QCD



- **Asymptotic freedom:** $\alpha_s \to 0$ at short distances / Perturbative QCD
- **Evolution:** Predict Q^2 dependence related to level of gluon radiation / Constrain parton structure $f_i(x)$ using measured data
- **Factorization:** Formulate observables in terms of parton structure



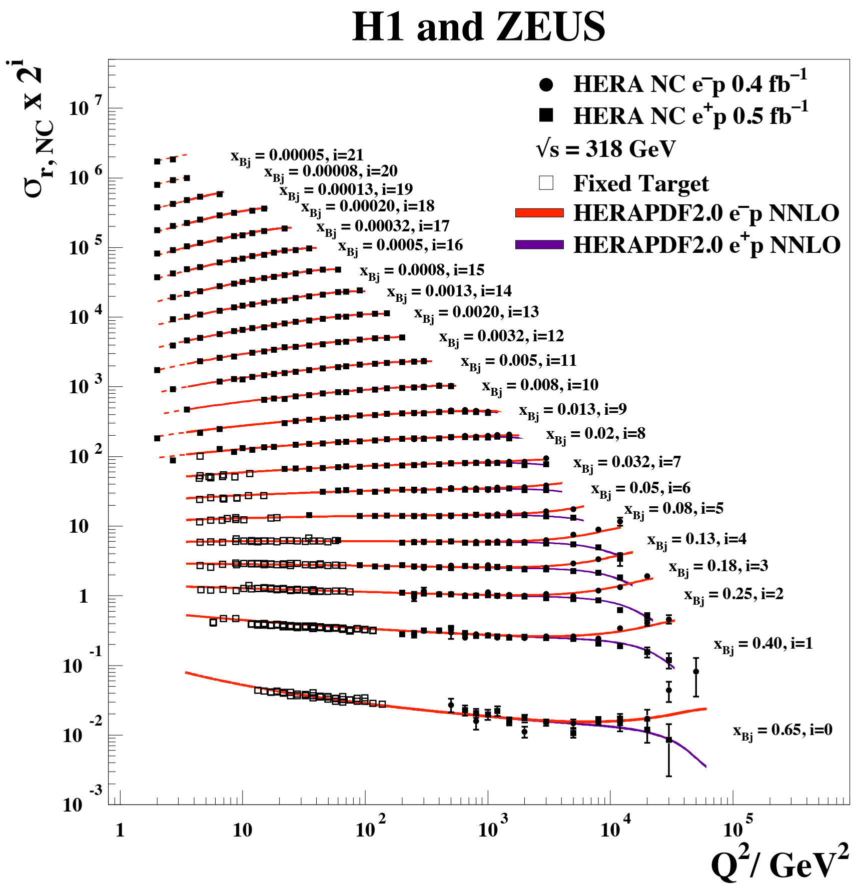
G. Dissertori, Adv. Ser. Direct. High Energy Phys. 26 (2016) 113.

$$\left(\frac{d\sigma}{dp_T}\right)^{p+p\to h+X} = \sum_{f_1,f_2,f} \int dx_1 dx_2 dz f_1(x_1,\mu^2) f_2(x_2,\mu^2) \times \left(\frac{d\hat{\sigma}}{dp_T}\right)(x_1 p_1, x_1 p_1, z, \mu) D_f^h(z,\mu^2)$$

Theoretical foundation

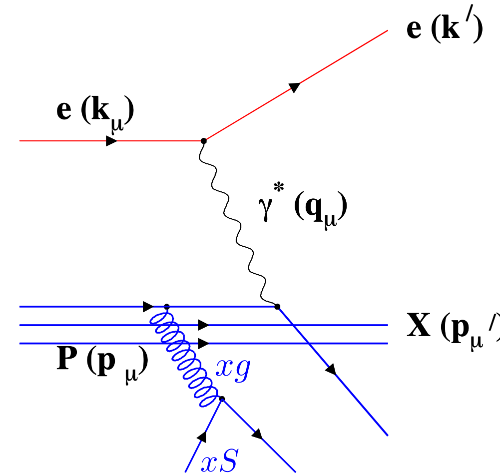
DIS - Parton structure: Unpolarized

H1 and ZEUS Collaborations (H. Abramowicz et al.), Eur.Phys.J. C75 (2015) no.12, 580.

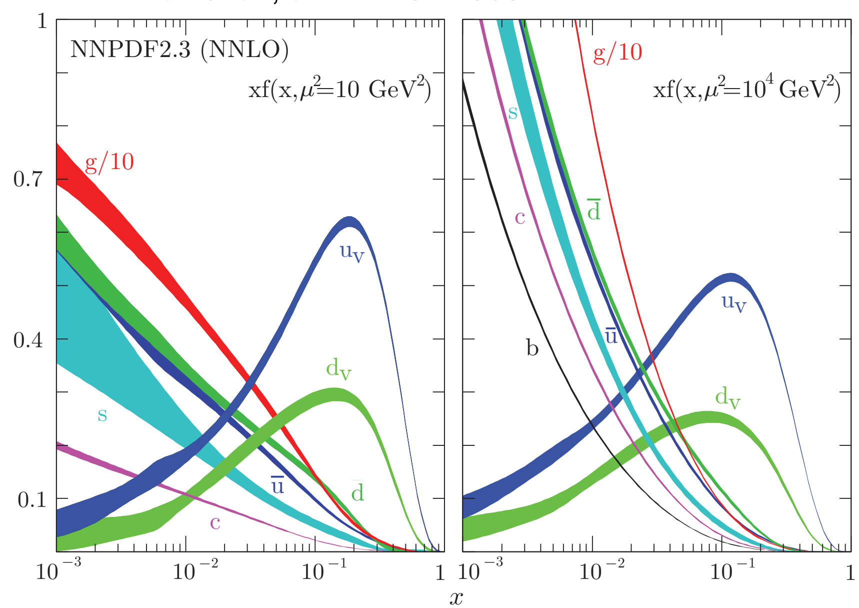


$$d\sigma_{eP} \propto F_2^P = \sum_i e_i^2\, x\, (q_i + \bar{q}_i)$$

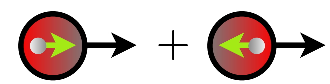
1990: J. I. Friedman, H. W. Kendall and R. E. Taylor: "for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics."



R. D. Ball et al., arXiv:1207.1303.



$f(x) =$



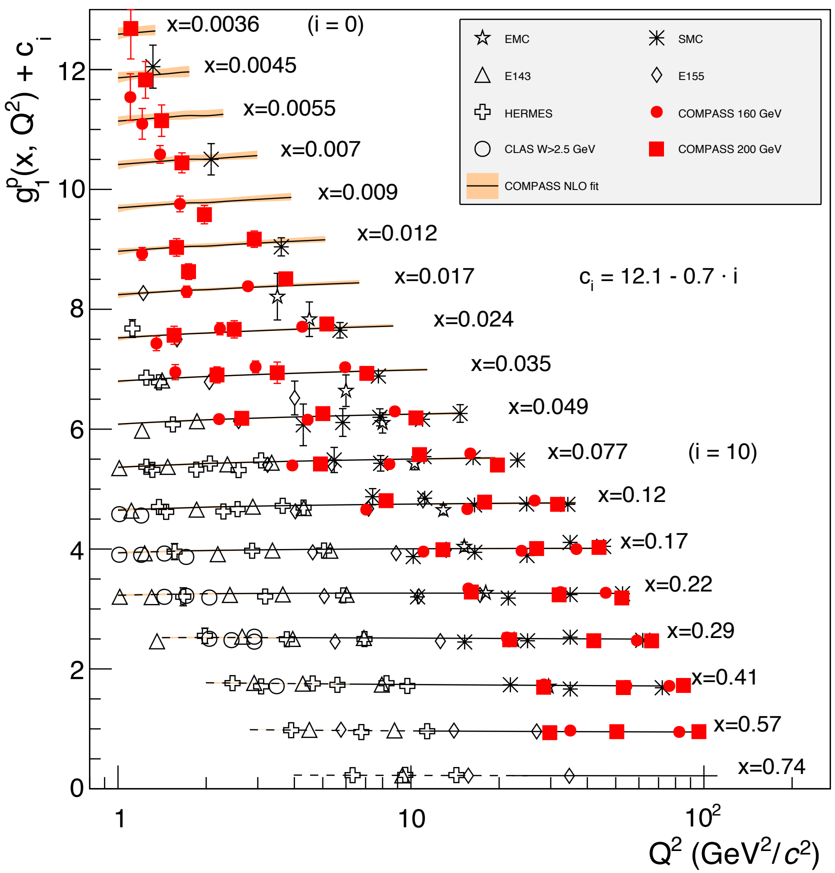
$f^+(x) + f^-(x)$

Measure of probability to find parton f with longitudinal momentum fraction x

Theoretical foundation

DIS - Parton structure: Polarized

COMPASS Collaboration (C. Adolph et al.), Phys.Lett. B753 (2016) 18.



$$g_1^P = \frac{1}{2}\sum_i e_i^2 \left(\Delta q_i + \Delta\bar{q}_i\right)$$

$$\overbrace{\frac{1}{2}\Delta\Sigma}$$

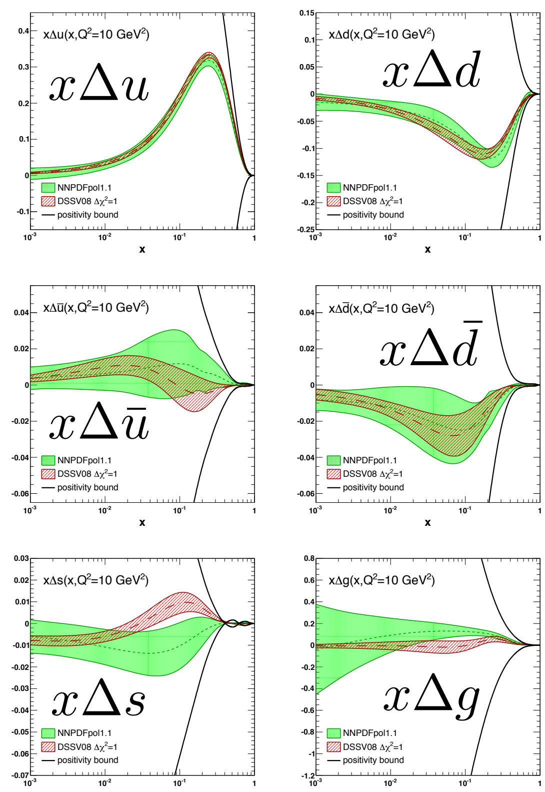
$$\frac{1}{2} = \langle S_q\rangle + \underbrace{\langle S_g\rangle}_{\Delta G} + \langle L_q\rangle + \langle L_g\rangle$$

(R.L. Jaffe and A. Manohar, Nucl. Phys. B337, 509 (1990))

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

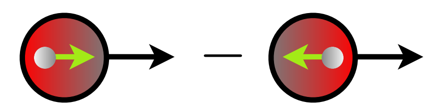
$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx$$

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$



NNPDF Collaboration (Emanuele R. Nocera et al.), Nucl.Phys. B887 (2014) 276-308

$$\Delta f(x) =$$



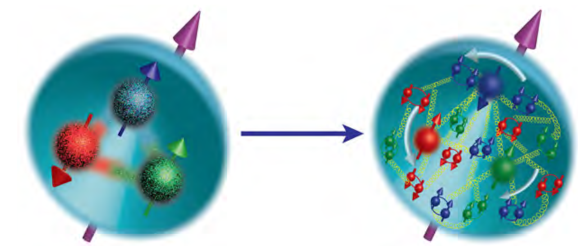
$$\underbrace{f^+(x) - f^-(x)}$$

Measure of probability to find parton f with spin aligned to anti-anti-aligned to proton spin at momentum fraction x

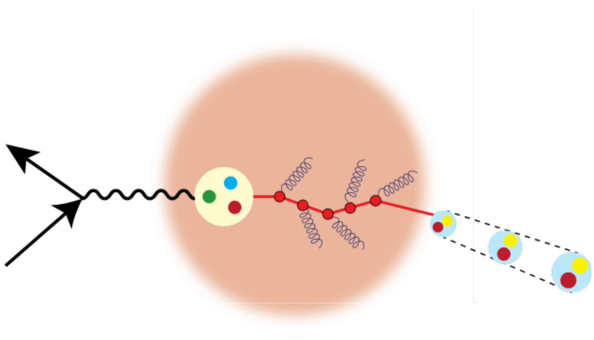
Theoretical foundation

Motivation - EIC program

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?



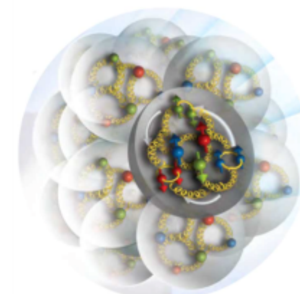
How do the nucleon properties emerge from them and their interactions?



How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?



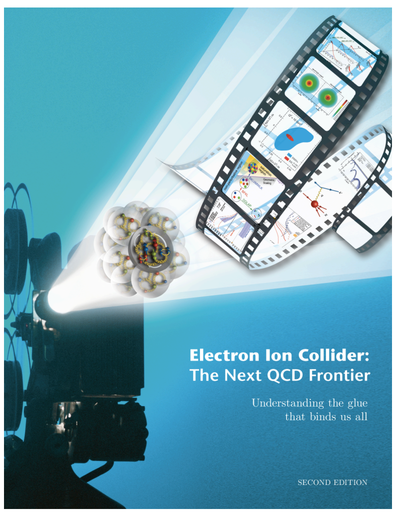
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

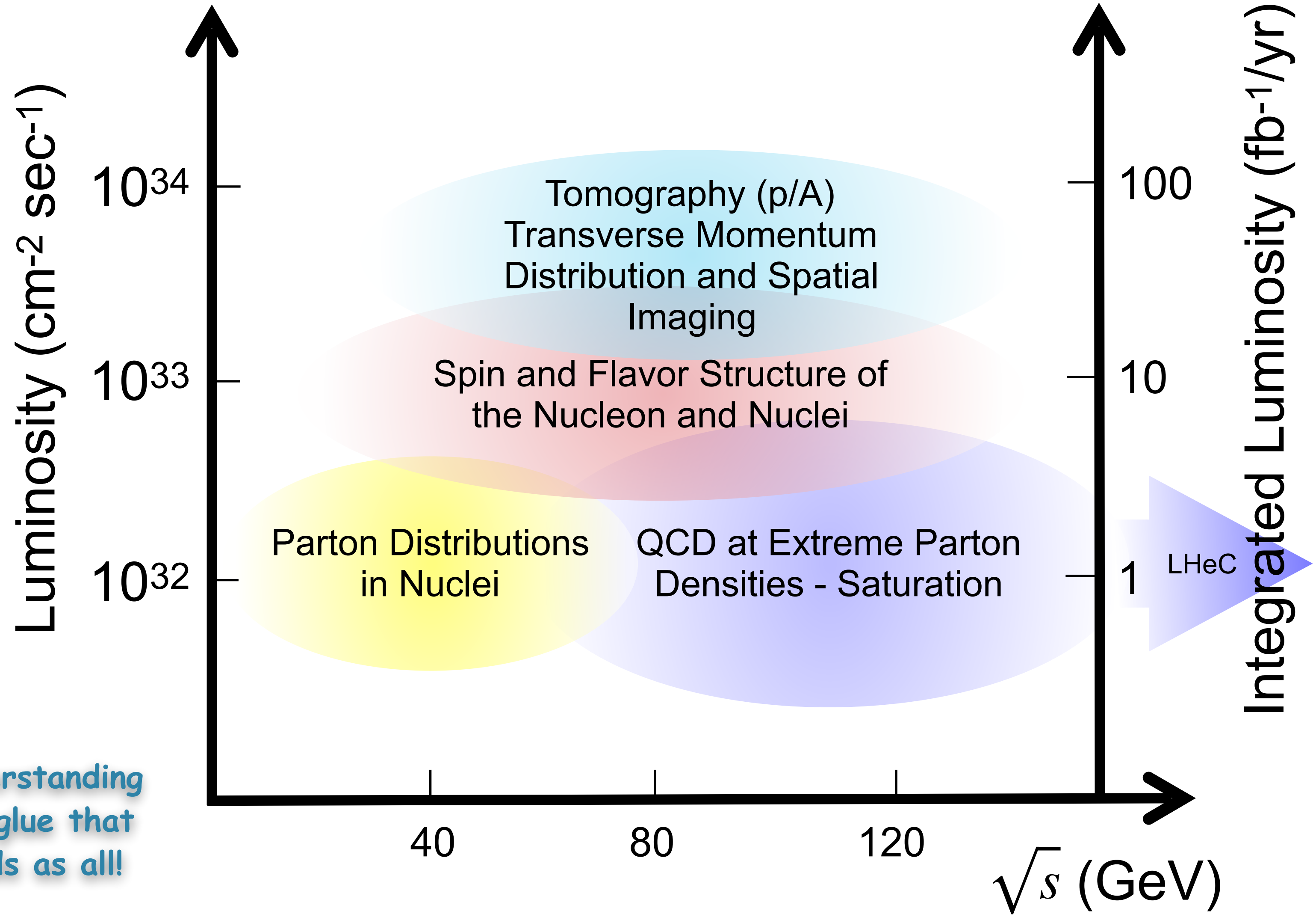
The EIC Physics Pillars

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

arXiv:1212.1701

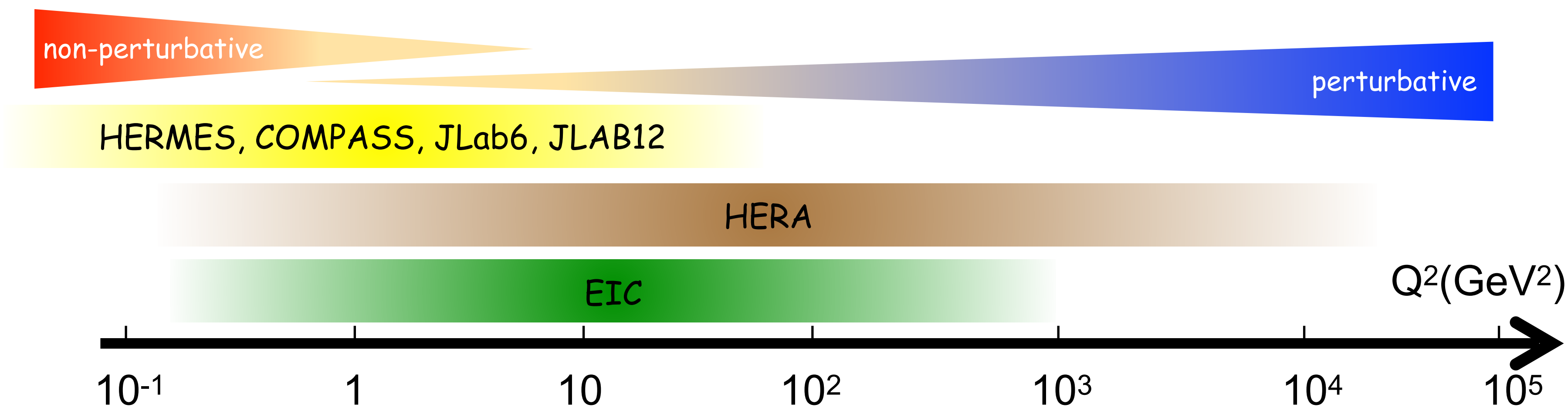


Understanding the glue that binds as all!



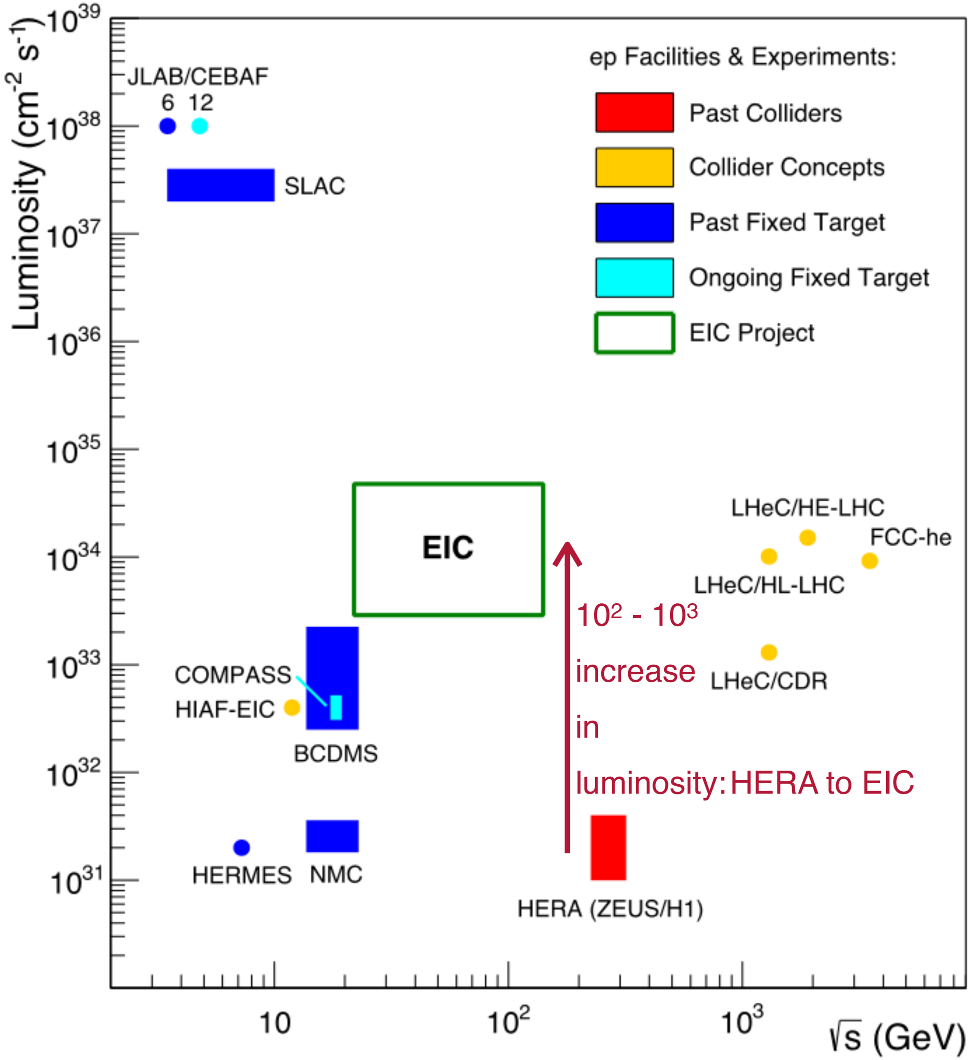
The EIC Physics Pillars

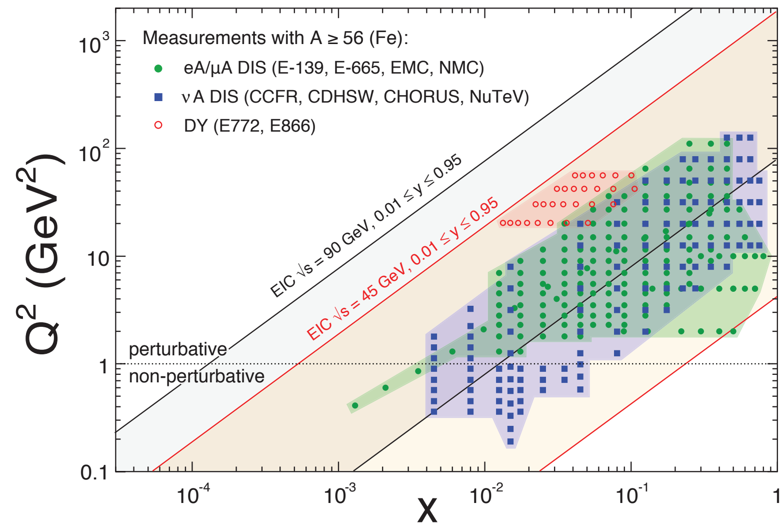
- Requirements
  - Machine:
    - High luminosity: $10^{33}cm^{-2}s^{-1}$ - $10^{34}cm^{-2}s^{-1}$
    - Flexible center-of-mass energy $\sqrt{s} = \sqrt{4\,E_e\,E_p}$: Wide kinematic range $Q^2 = s\,x\,y$
    - Highly polarized electron (0.8) and proton / light ion (0.7) beams: Spin structure studies
    - Wide range of nuclear beams (d to Pb/U): High gluon density
  - 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



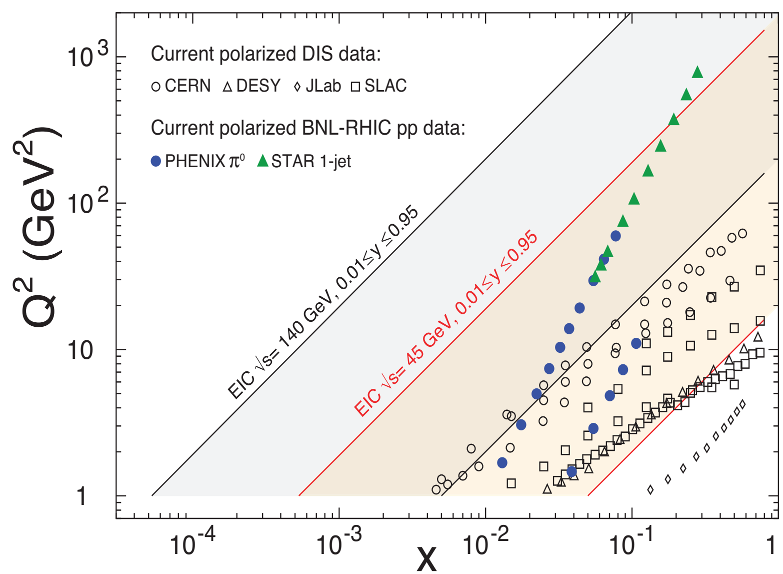
The EIC Physics Pillars

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





eA

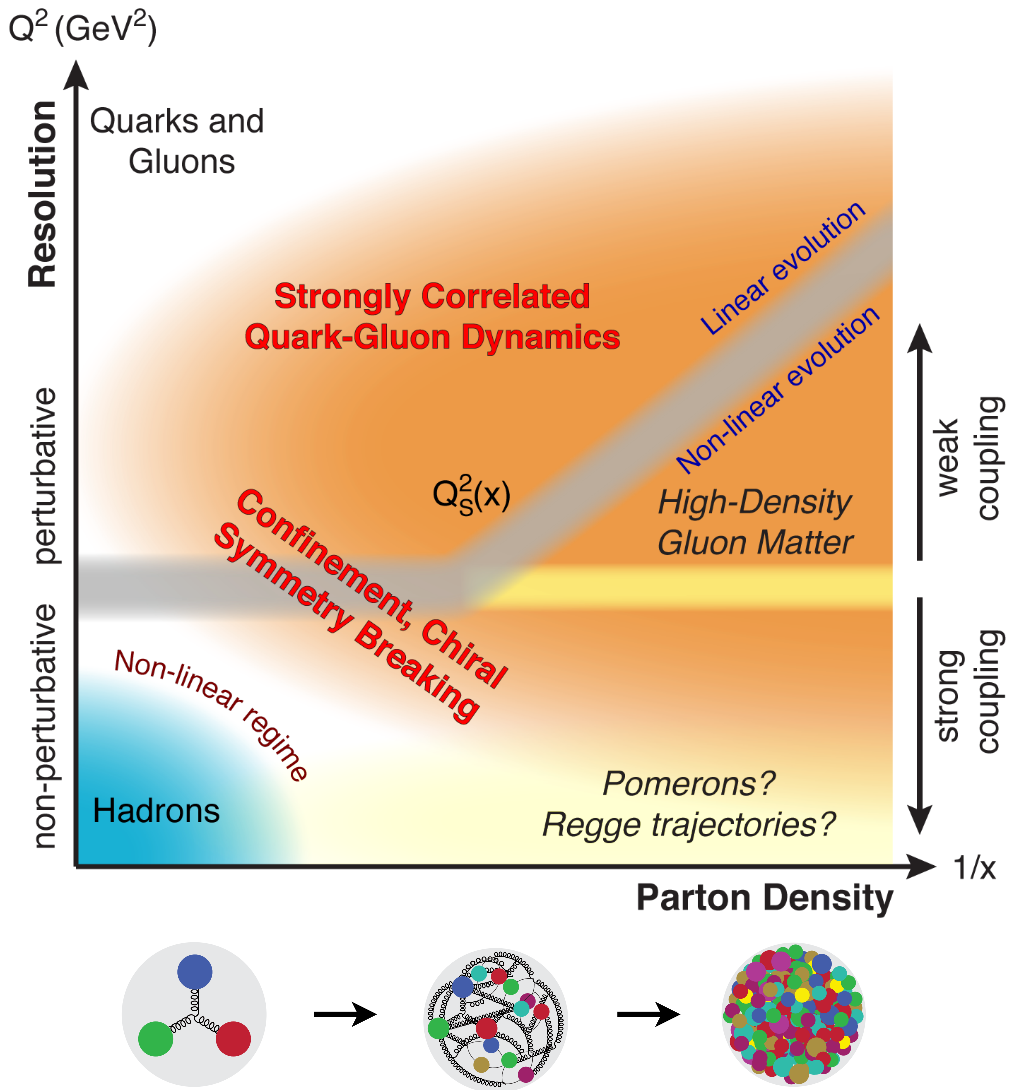


ep

The EIC Physics Pillars

- QCD dynamics / Parton distributions in nuclei

arXiv:1708.01527

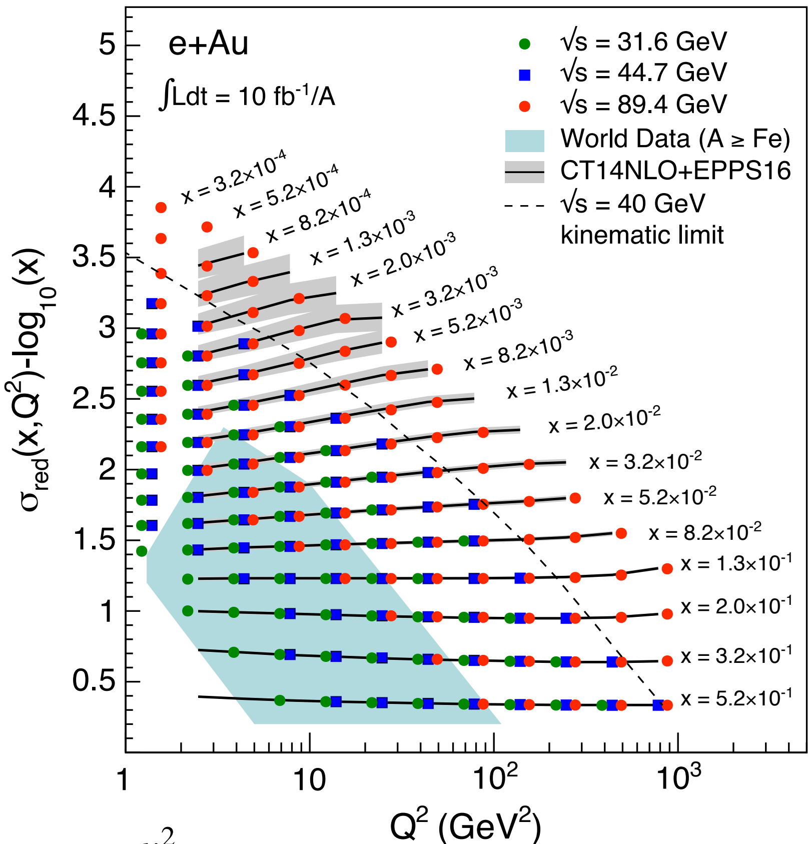


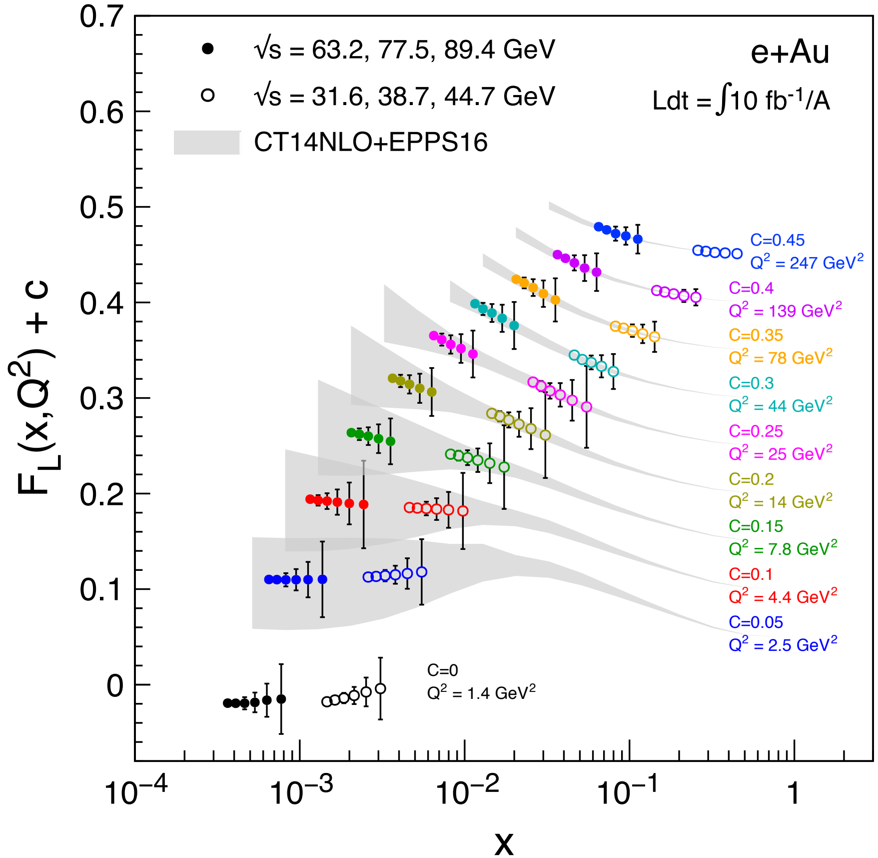
- Explore QCD landscape in various aspects over a wide range in x and Q^2
- Heavy nuclei at high energy critical to explore high-density gluon matter!

The EIC Physics Pillars

- Inclusive eA scattering measurements

arXiv:1708.01527





$$\sigma_{\rm red} = F_2 - \frac{y^2}{Y_+} F_L$$

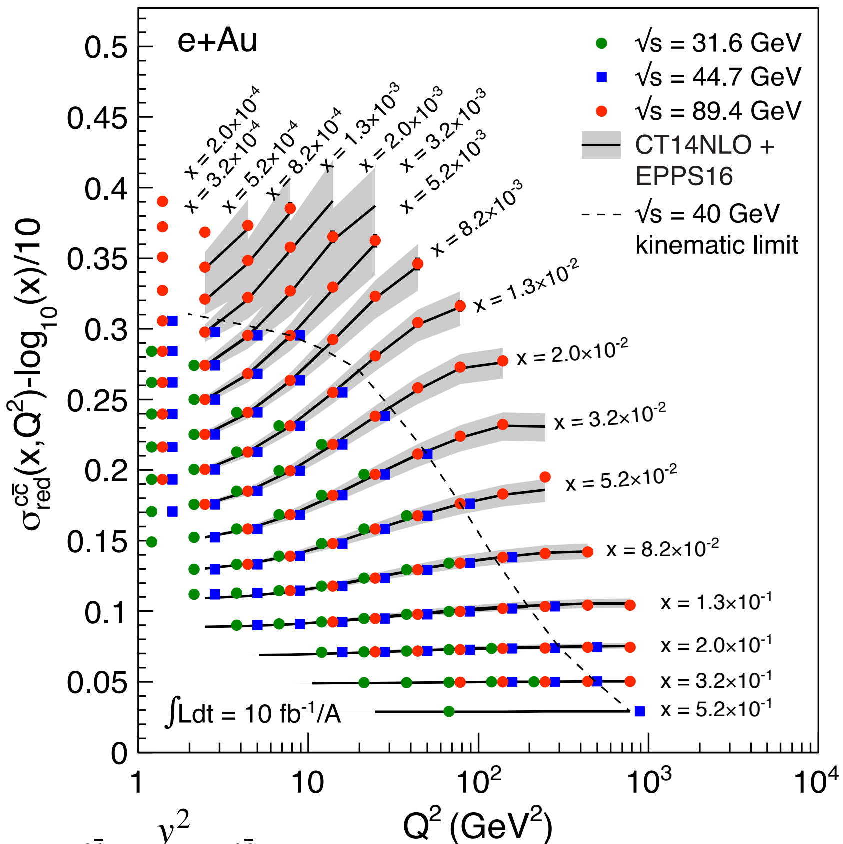
$$\left(\frac{d^2\sigma}{dx\,dQ^2}\right) = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L\right)$$

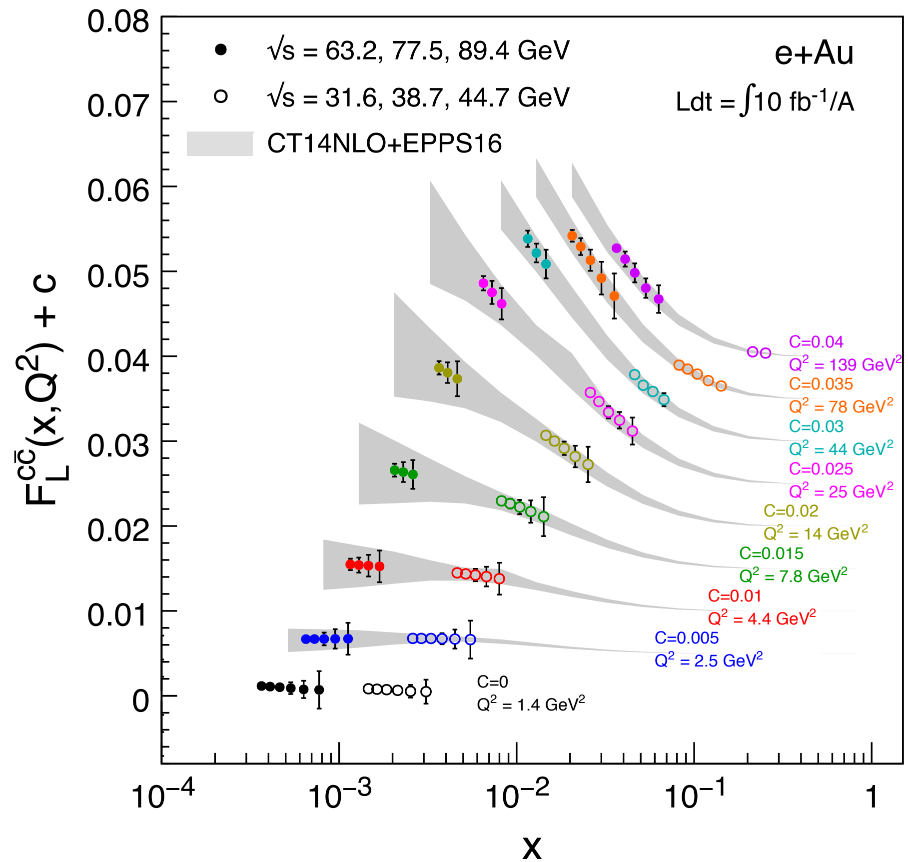
$$Y_+ = 1 + (1-y)^2$$

The EIC Physics Pillars

- Charm-associated eA scattering measurements

arXiv:1708.01527





$$\sigma_{\rm red}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{Y_+} F_L^{c\bar{c}}$$

$$\left(\frac{d^2\sigma}{dx\,dQ^2}\right)^{c\bar{c}} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2^{c\bar{c}} - \frac{y^2}{Y_+}F_L^{c\bar{c}}\right)$$

$$Y_+ = 1 + (1-y)^2$$

The EIC Physics Pillars

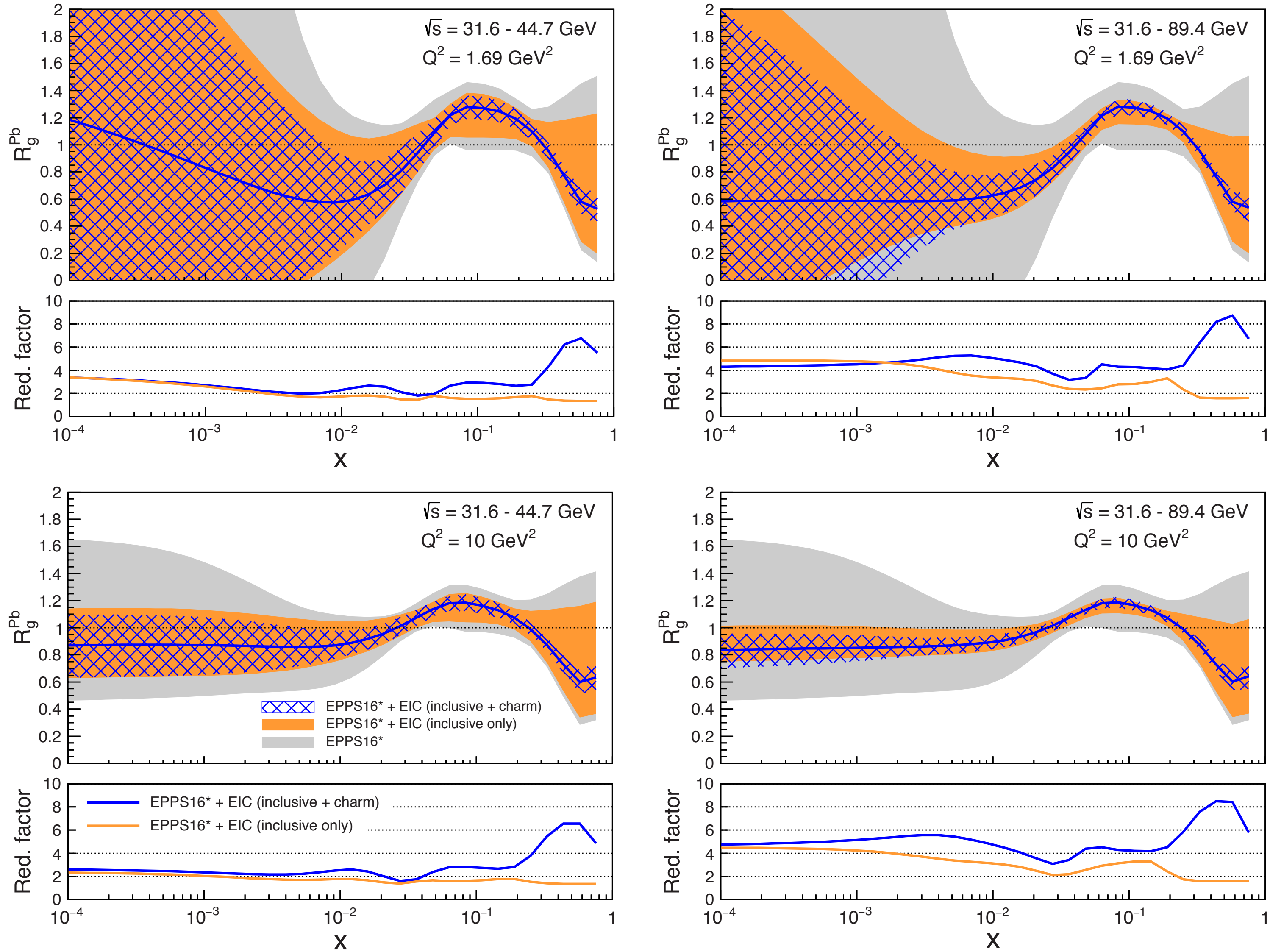
- Impact on nuclear gluon behavior in eA scattering

arXiv:1708.01527

Modifications of nuclear environment:

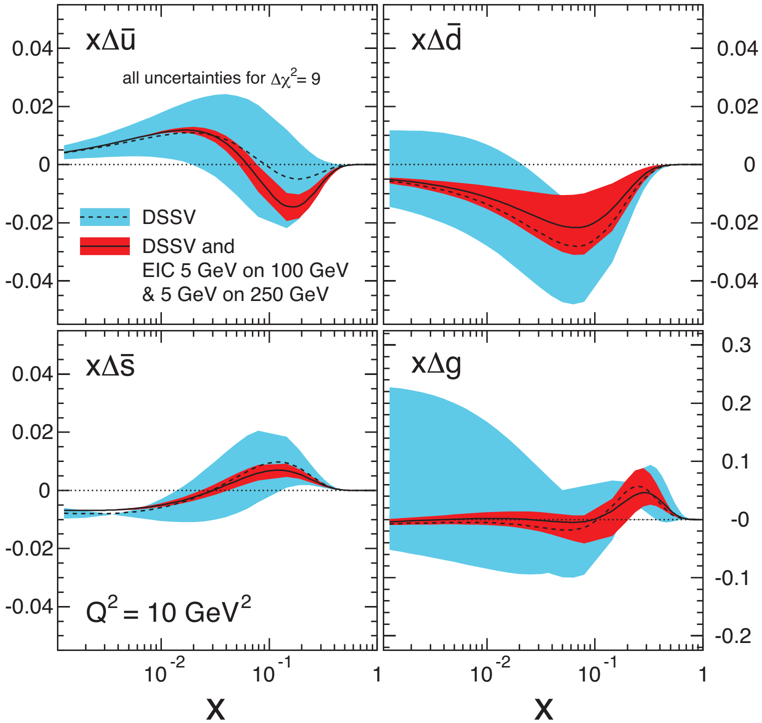
R_g^{Pb}

Ratio of gluon distribution in Pb compared to proton

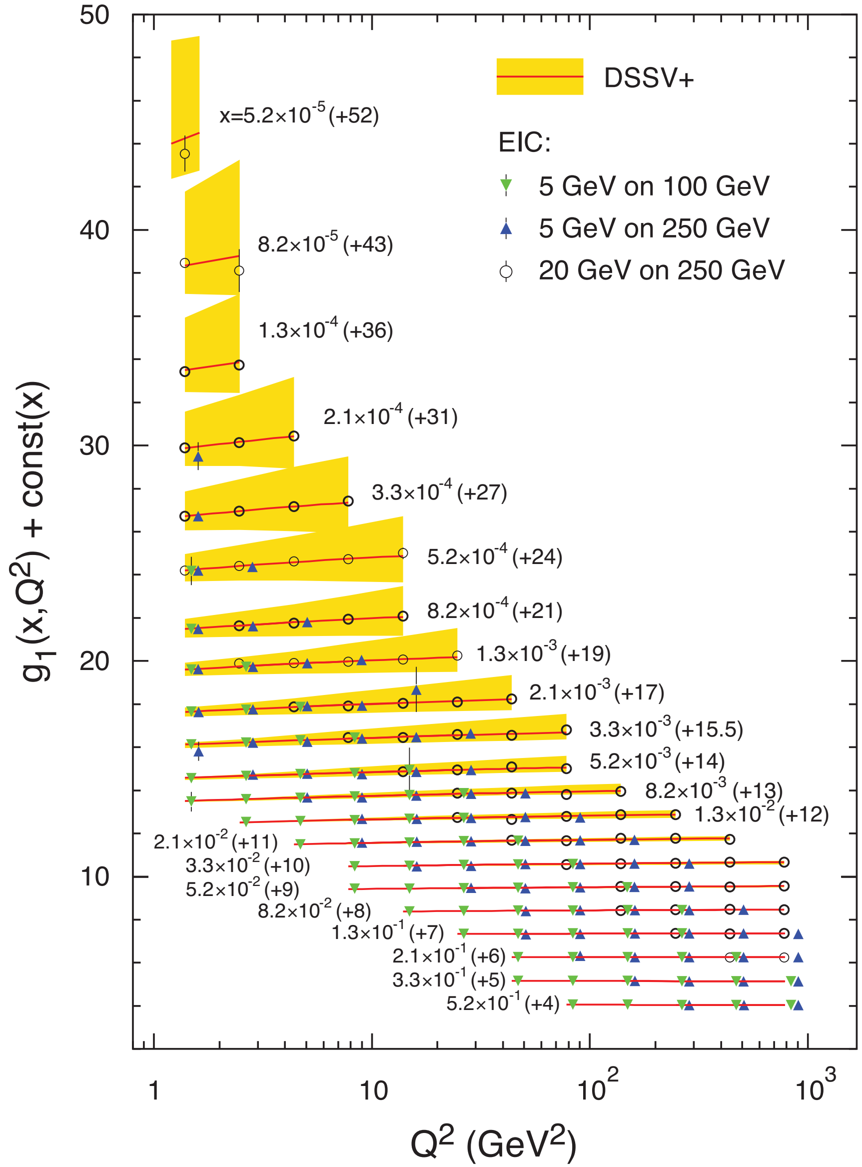


The EIC Physics Pillars

- Spin and Flavor Structure of the Nucleon



arXiv:1212.1701

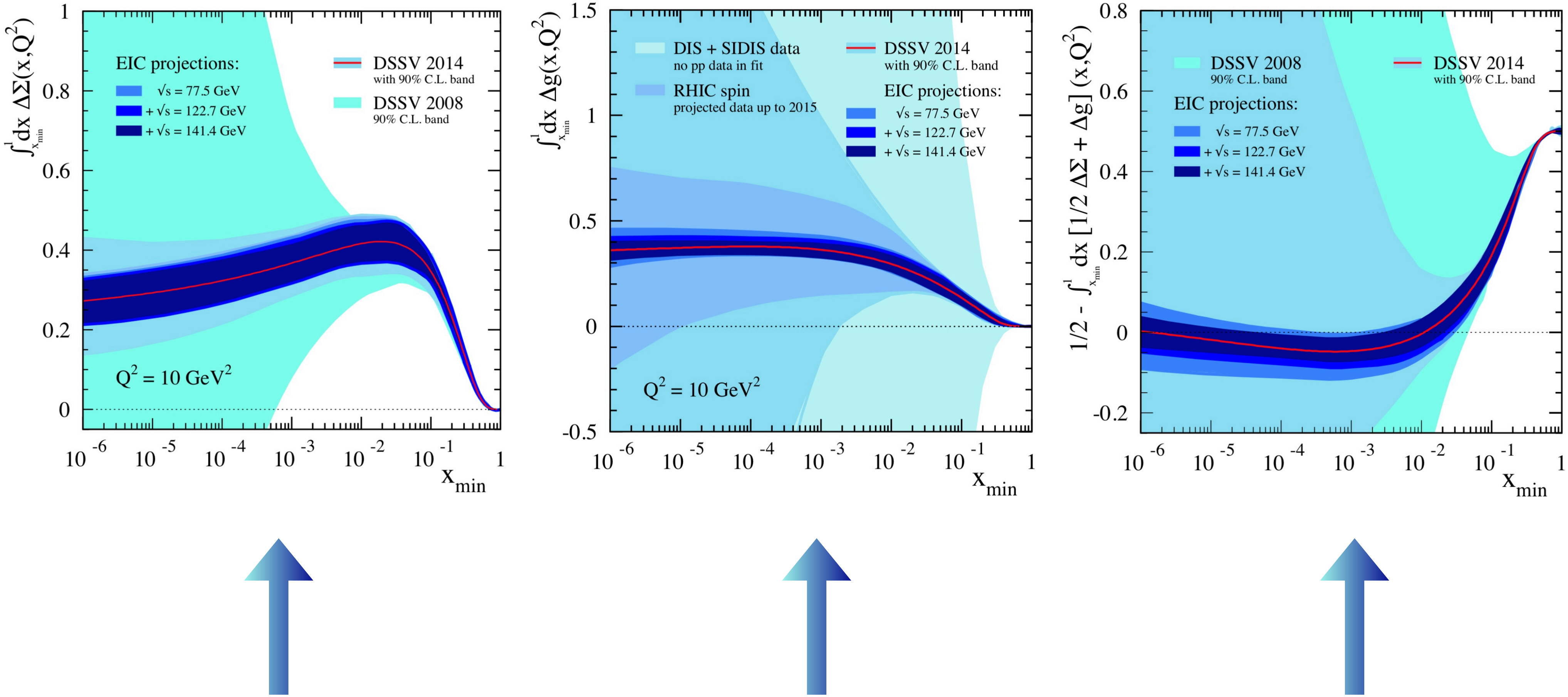


- g_1 stat. uncertainty projections for 10fb^{-1} for range of CME in comparison to DSSV+ predictions incl. uncertainties
- EIC impact on helicity distributions of anti-u, anti-d and s quarks together with gluons

The EIC Physics Pillars

- Impact on proton spin

E. Aschenauer, R. Sassot and M. Stratmann, Phys. Rev. D92 (2015) 094030.



Quark Spin

Gluon Spin

Orbital Angular Momentum

The EIC Physics Pillars

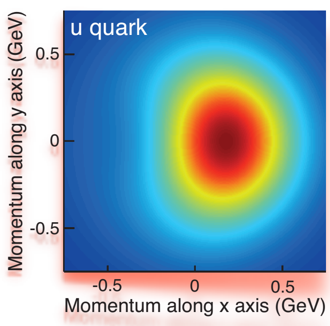
- Transverse Momentum Distribution and Spatial Imaging

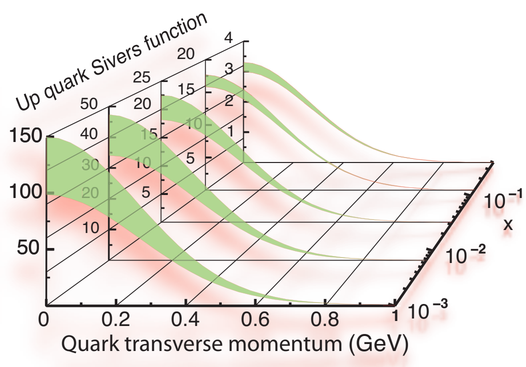
arXiv:1212.1701

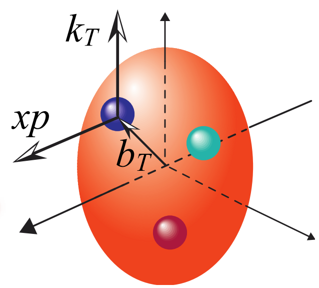
$f(x, k_T)$ 1+2D $\quad \int d^2b_T \quad W(x, b_T, k_T) \quad \int d^2k_T \quad$ $f(x, b_T)$ 1+2D

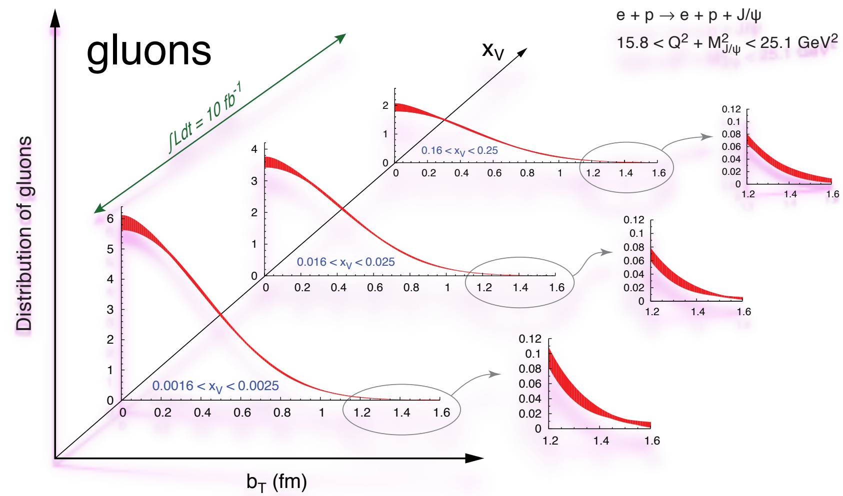
Transverse Momentum Distribution (TMD) — Wigner Distribution — Impact Parameter Distribution

quarks









Fourier transf.
$b_T \longleftrightarrow \Delta$: $t = -\Delta^2$

$H(x, 0, t)$

$\xi = 0$

$H(x, \xi, t)$

Generalized Parton Distribution (GPD)

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

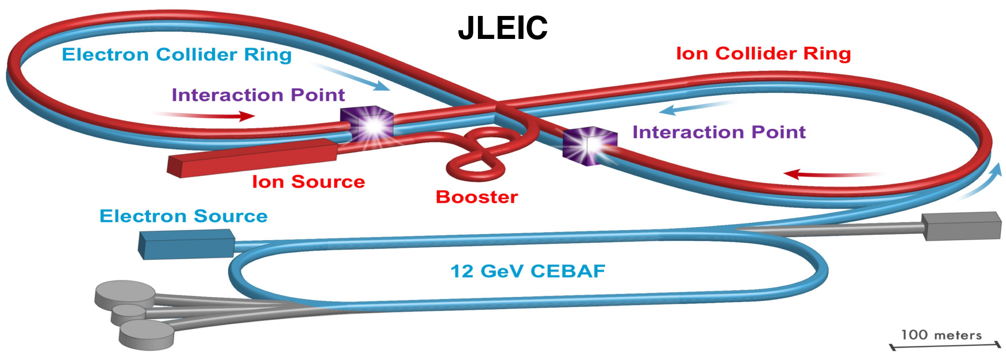
The EIC Facility Concepts

- EIC accelerator design at JLab and BNL

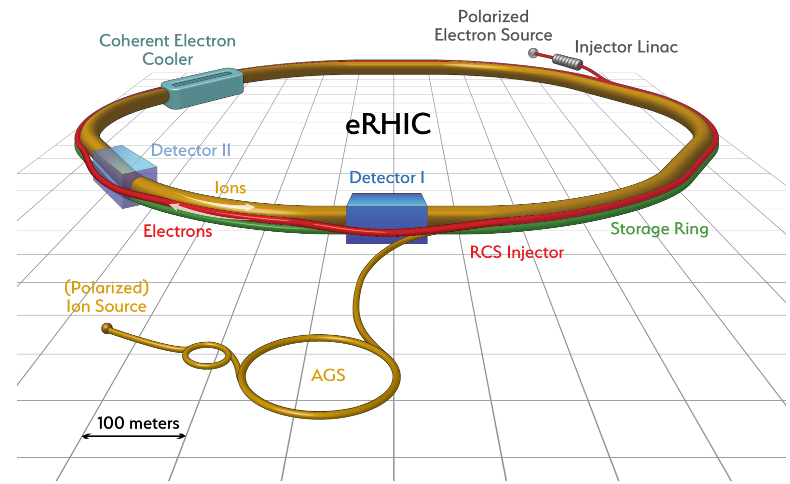
Highly polarized electron / Highly polarized proton and lights ions / Unpolarized heavy ion colliding beams

CME: ~20-100GeV

Luminosity: ~$10^{33-34}cm^{-2}s^{-1}$



JLEIC Collaboration



eRHIC 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

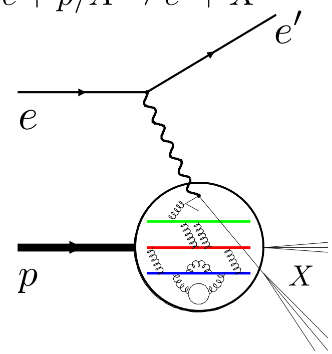
- Polarized electron source and 400MeV injector linac
- Polarized proton beams and ion beams based on existing RHIC facility
- 2 detector IP's integrated into IR design

The EIC Detector Concepts

Overview of processes and final states

arXiv:1212.1701

$e + p/A \rightarrow e' + X$

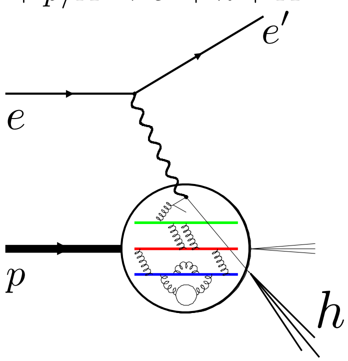


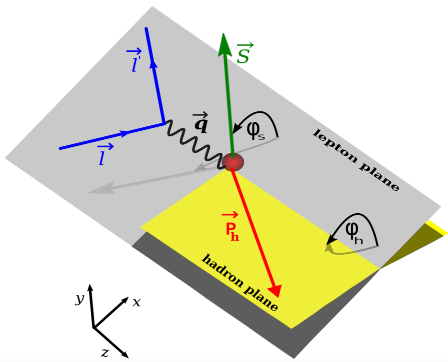
Inclusive DIS

- 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

Semi-Inclusive DIS (SDIS)

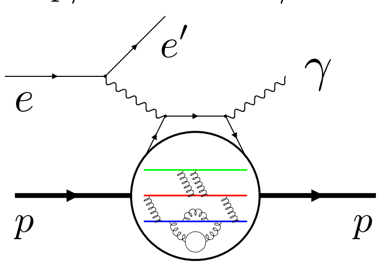
$e + p/A \rightarrow e' + h + X$





- 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

$e + p/A \rightarrow e' + N'/A' + \gamma/m$

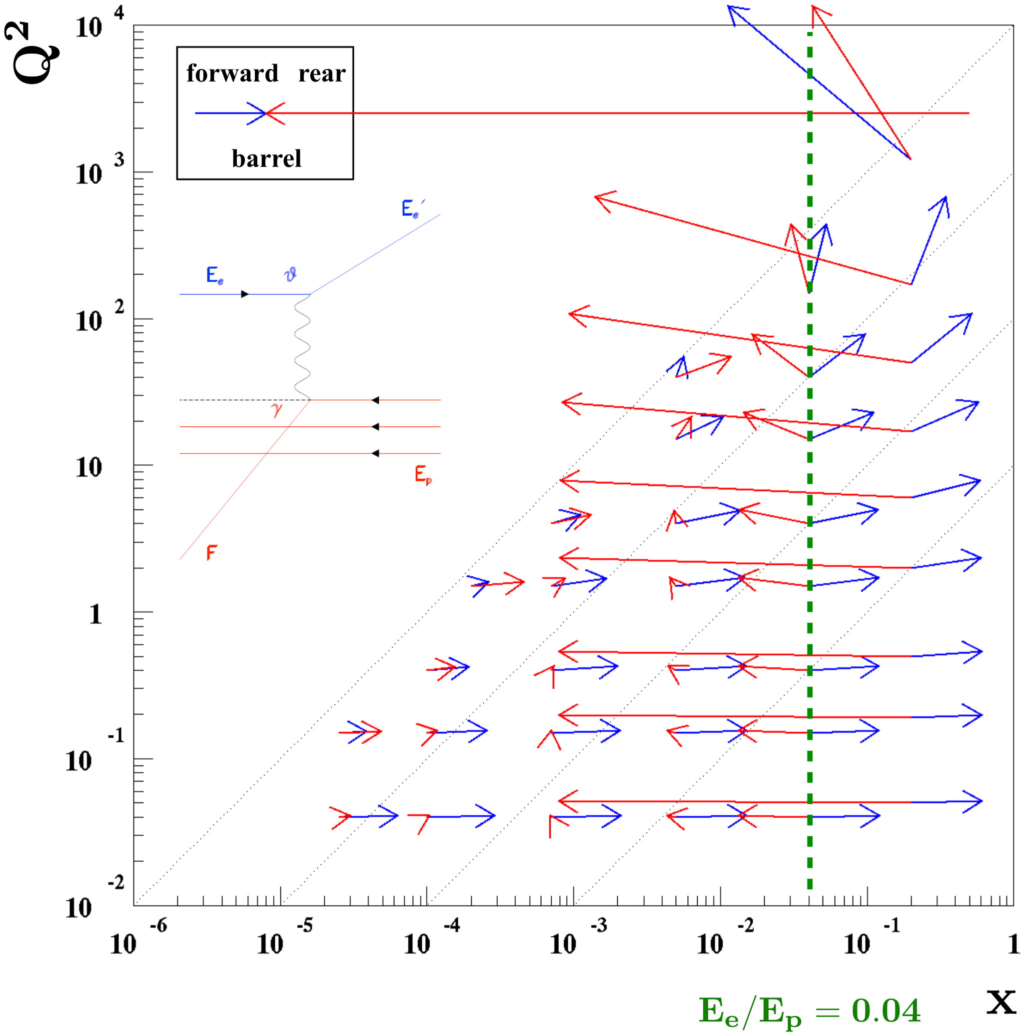


Deeply-Virtual Compton Scattering (DVCS)

- 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

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

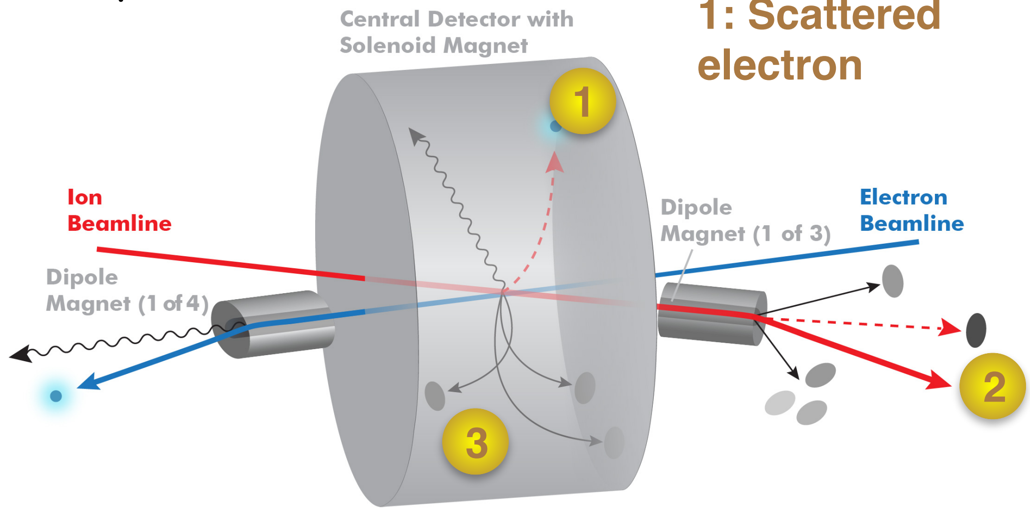


Kinematic peak location!

The EIC Detector Concepts

- Overview of general requirements

arXiv:1212.1701



- 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
- Low dead material budget in particular in rear direction (~5% X/X_0)
- Good momentum resolution $\Delta p/p$ ~ few %
- Electron ID for e/h separation varies with θ / η at the level of $1:10^4$ / ~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)
- High spatial vertex resolution ~ 10-20μm 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

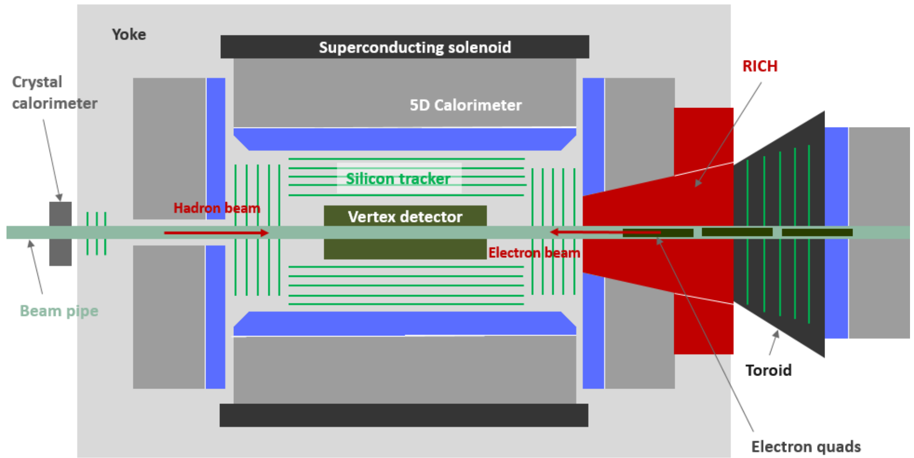
- Generic Detector R&D program for an EIC
  - In January 2011, BNL, in association with JLab and the DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC facility.
  - Goals:
    - Enable successful design and timely implementation 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 /

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

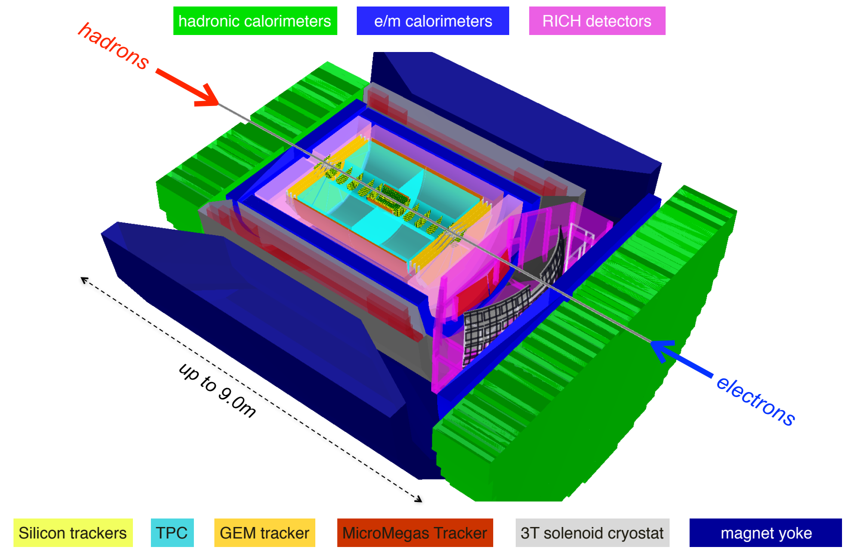
The EIC Detector Concepts

- EIC detector design at JLab and BNL

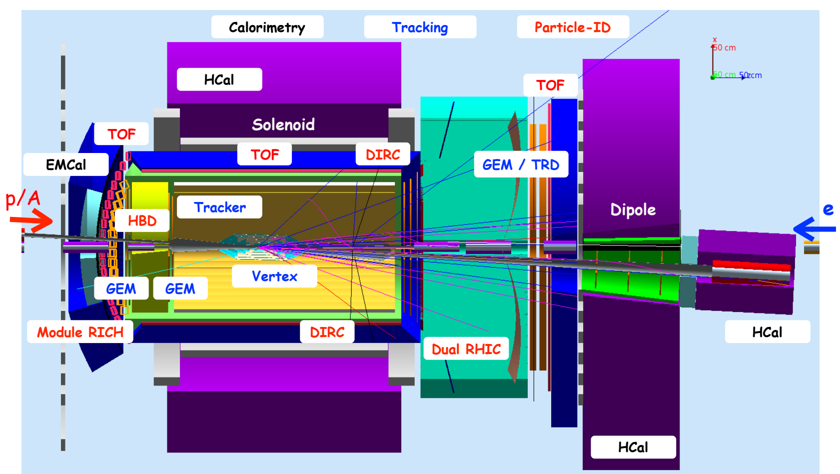
(a) TOPSIDE at JLab:



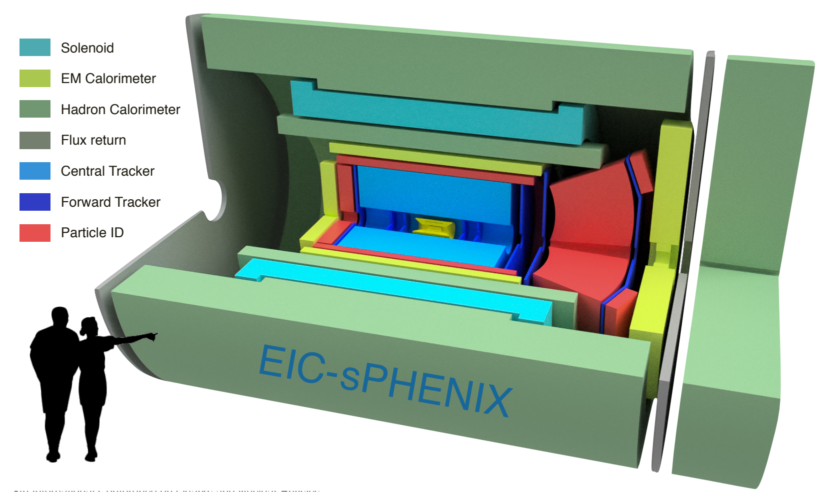
(c) BEAST detector design at BNL:



(b) JLEIC detector design at JLab:

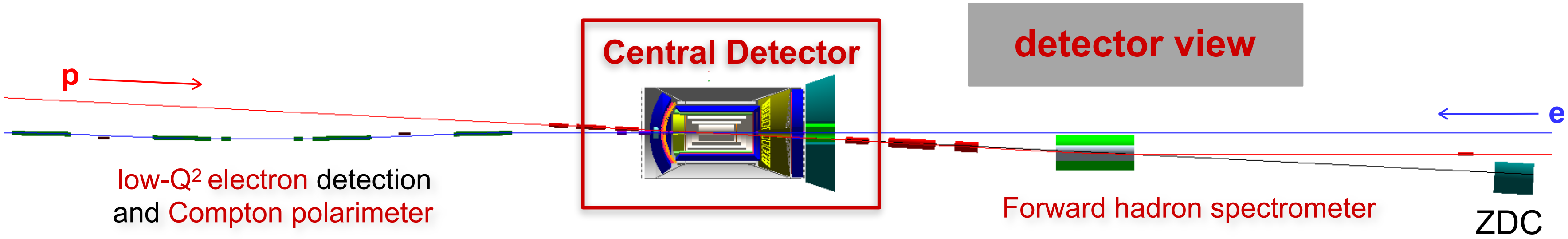


(d) sPHENIX-EIC detector design at BNL:



The EIC Detector Concepts

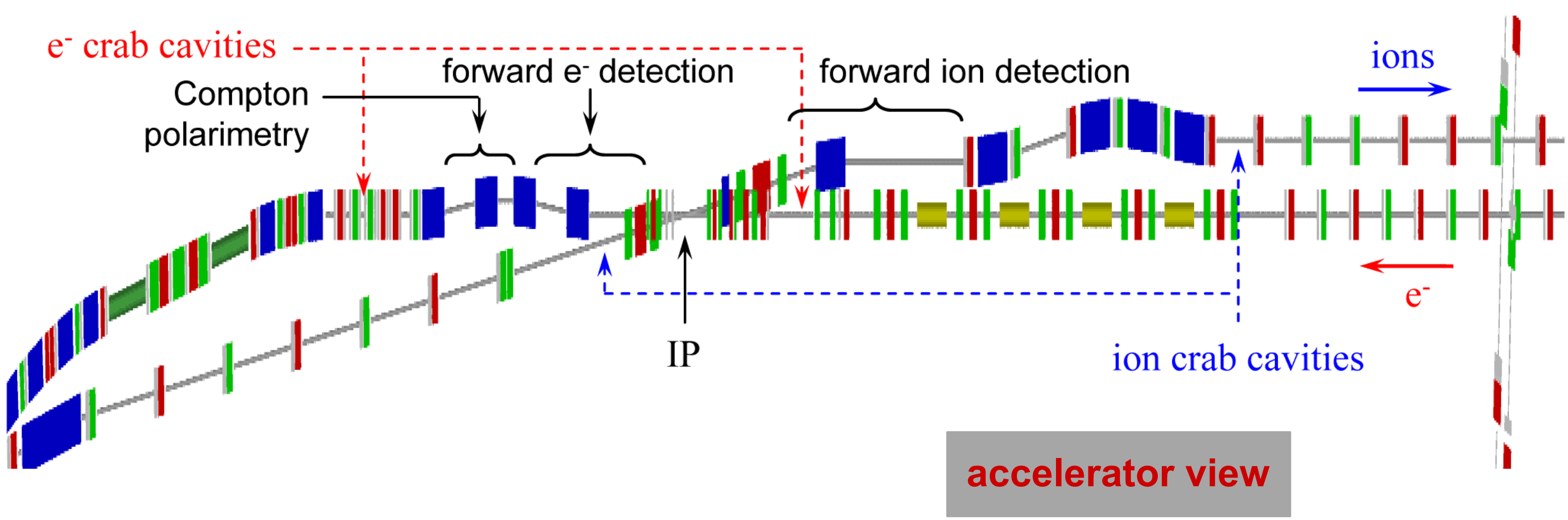
- Detector design: JLEIC (2) - JLab



Extended detector: 80m

30m for multi-purpose chicane, 10m for central detector, 40m for the forward hadron spectrometer

fully integrated with accelerator lattice



The EIC Detector Concepts

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

arXiv:1212.1701

Luminosity (Absolute / Relative)

- Bethe-Heitler process ($e+p \rightarrow e+\gamma+p$) successfully used at HERA I/II (QED theory precision ~0.2%) / Systematic uncertainty achieved ~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.

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%.

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.

The US Long-Range Plan

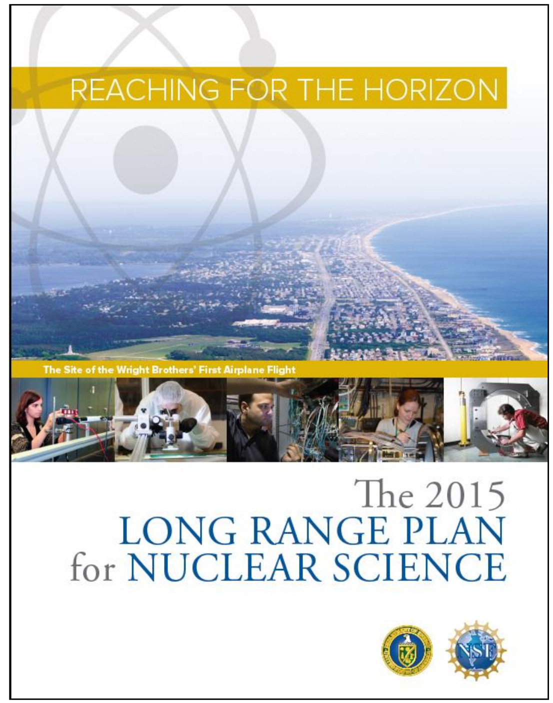
T. Hallman

- 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

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   June 2, 2017   16

The US Long-Range Plan and US NAS review

T. Hallman

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

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

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   June 2, 2017   19

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

- 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!

Click to download report!

The National Academies of SCIENCES ENGINEERING MEDICINE

Home | About Us | Organization | Events & Activities | Resources | Newsroom | Search... | Contact Us | Operating Status

NEWS The National Academies of SCIENCES · ENGINEERING · MEDICINE

July 24, 2018

FOR IMMEDIATE RELEASE

A Domestic Electron Ion Collider Would Unlock Scientific Mysteries of Atomic Nuclei, Maintain U.S. Leadership in Accelerator Science, New Report Says

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.

An Assessment of U.S.-Based Electron-Ion Collider Science

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 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 neutrons and protons, 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 nuclei 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 Laboratory (JLab) 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.

The committee added that along with advancing nuclear science, an EIC would also benefit other areas such as astrophysics, particle physics, accelerator physics, and theoretical and computational modeling. It would also play a valuable role in sustaining the U.S. nuclear physics workforce in the coming decades. Moreover, it would have a significant role in advancing more broadly the technologies that would result from the research and development undertaken in the implementation and construction of an EIC in the U.S. The report emphasizes that an EIC is the only high-energy collider being planned for construction in the U.S. currently, and building such a facility would maintain U.S. leadership in accelerator collider science while benefiting the physical sciences.

"The science that an EIC would achieve is simply unique and would ensure U.S. leadership in nuclear science as well as the accelerator science and technology of colliders around the world," said committee co-chair Ani Aprahamian, Freimann Professor of Experimental Nuclear Physics at the University of Notre Dame.

The study was sponsored by DOE. The National Academies of Sciences, Engineering, and Medicine are private, nonprofit institutions that provide independent, objective analysis and advice to the nation to solve complex problems and inform public policy decisions related to science, technology, and medicine. The National Academies operate under an 1863 congressional charter to the National Academy of Sciences, signed by President Lincoln. For more information, visit http://national-academies.org.

Contacts:
Kacey Templin, Media Relations Officer
Joshua Blatt, Media Relations Associate
Office of News and Public Information
202-334-2138; e-mail news@nas.edu

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.

An Assessment of
U.S.-Based Electron-Ion Collider Science

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

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

A Consensus Study Report of

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

Anticipated next steps and plans

T. Hallman

- NSAC Presentation by Dr. T. Hallmam (Associate Director, DOE NP Office)

Current Status and Path forward for the EIC

The "wickets" are substantially aligned for a major step forward on the EIC

- A Mission Need Statement for an EIC has been approved by DOE
- An Independent Cost Review (ICR) Exercise mandated by DOE rules for projects of the projected scope of the EIC has been completed
- DOE is moving forward towards a request for CD-0 (approve "Mission Need")
- DOE convened a panel to assess options for siting between two proposed concepts.
- The Deputy Secretary is the Acquisition Executive for this level of DOE Investment
- The FY 2020 President's Request includes \$ 1.5 million OPC. The FY 2020 House Mark identifies \$ 10 million OPC and \$ 1 million TEC. Senate Mark identifies \$ 10 million OPC and \$ 1 million TEC.

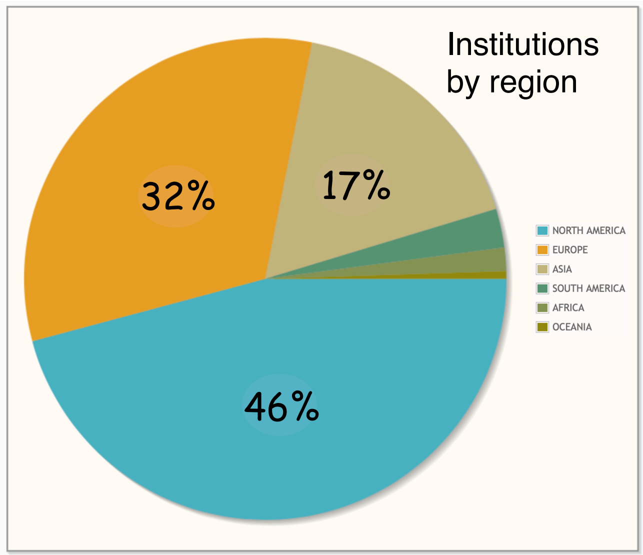
U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   October 18, 2019   16

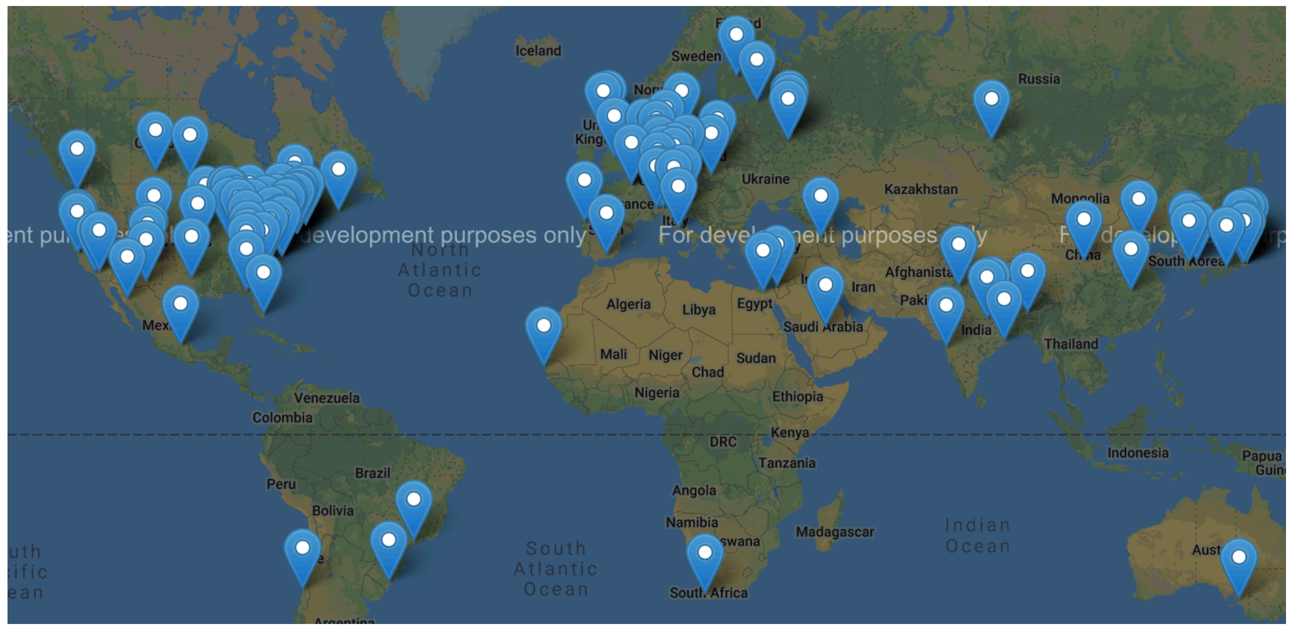
The EIC Users Group

- EIC User Group and R&D activities

WWW-page: www.eicug.org

  - EIC User Group:
    - EICUG organization established in summer 2016
    - In numbers….: 945 members (Experimental scientists: 544 / Theory scientists: 221 / Accelerator scientists: 142 / Support: 3 / Other: 39), 192 institutions, 30 countries, 6 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

Internationalization is critical!

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

EIC²
EIC Center at Jefferson Lab

  - Co-Directors: Douglas Higinbotham / Amber Boehnlein / Jianwei Qiu
  - WWW-page: https://www.eiccenter.org

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 collier (EIC) facility. Particular emphasis is on the close connection of EIC science to the current Jefferson Lab 12 GeV CEBAF science program.

- BNL/Stony Brook University: Center for Frontiers in Nuclear Science

  - Director: Abhay Deshpande

Center for Frontiers in Nuclear Science

  - WWW-page: https://www.stonybrook.edu/cfns/

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.

The EIC Users Group

- EIC community activities / Conferences and Workshops

Highly Active EIC Community!

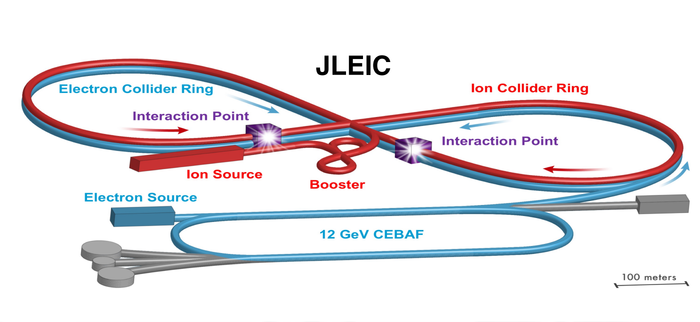
Programs related to EIC

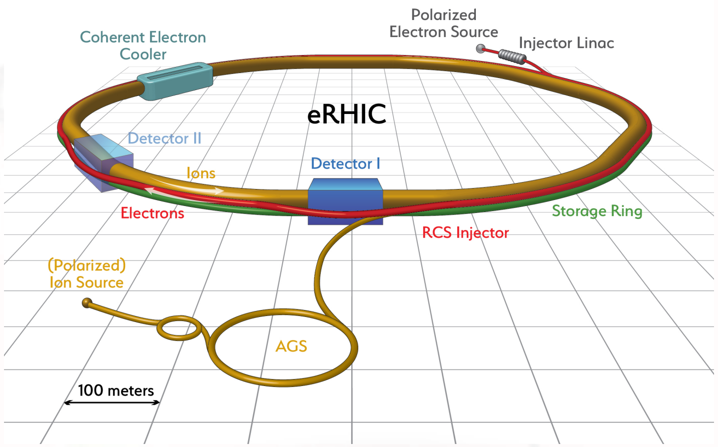
The EIC Users Group

- Physics and Detector Conceptual Design - Yellow Report Workshop series
  - Purpose:
    - Advance state of documented physics studies and detector concepts in preparation for the EIC.
    - Provide basis for further development of concepts for experimental equipment best suited for science needs, including complementarity of two detectors.
    - Input towards future Technical Design Reports (TDRs).
  - Approach:
    - Two WG: Physics requirement and Detector concepts - 4 conveners each.
    - Several sub-groups each, ~2 conveners/sub-group.
    - Time limited effort: ~1 year.
  - Meetings:
    - December 12-13, 2019, MIT: Kick-off organizational meeting.
    - Workshops:
      - March 19-21, 2020, Temple U., Philadelphia
      - May 22-24, 2020, U. of Pavia, Pavia, Italy
      - September 17-19, 2020, CUA, Washington D.C.
      - November 19-21, 2020, UCB / LBNL, Berkeley, CA

Summary

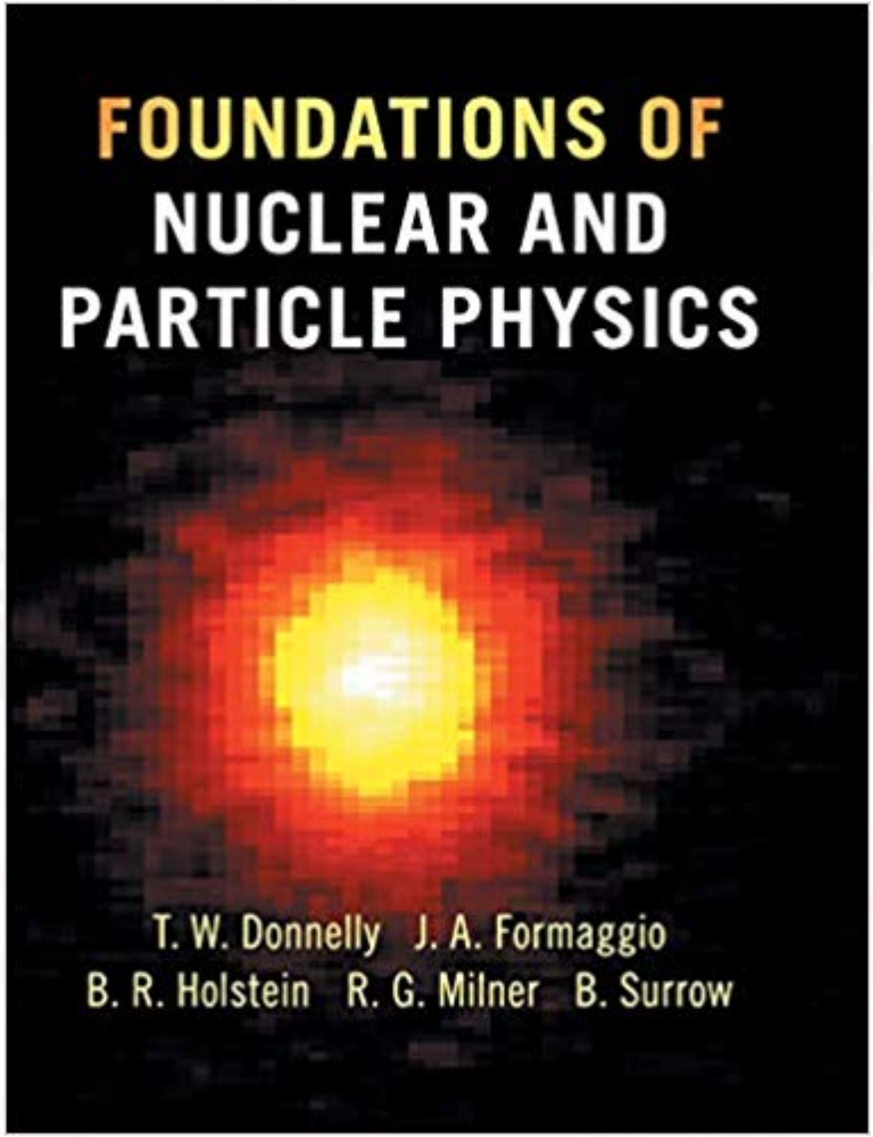
- **EIC Physics Pillars**: EIC facility will address fundamental questions on the structure and dynamics of nucleons and nuclei in terms of quarks and gluons using precision measurements including:
  - Parton Distributions in Nuclei / QCD at Extreme Parton Densities - Saturation
  - Spin and Flavor Structure of the Nucleon and Nuclei
  - Tomography (p/A) Transverse Momentum Distribution and Spatial Imaging
- **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: ~$10^{33\text{-}34}$cm^{-2}s^{-1}
  - Polarized e/p and unpolarized heavy ion beams / CME ~20-100GeV
- **EIC Status and Plans:**
  - NAS review completed - Glowing NAS report / Possible CD0 mission statement ~FY19
  - EIC facility construction after FRIB completion realistically in FY22/ FY23 timeframe
  - EIC facility completion in roughly a decade from now!





An exciting time is ahead of us to realize a future EIC facility!

Textbook



ISBN 978-0-521-76511-4