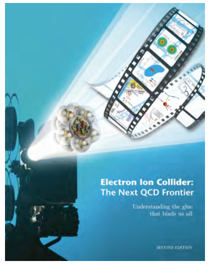
The Electron Ion Collider

Abhay Deshpande

Lecture 2 of 2

Center for Frontiers in Nuclear Science

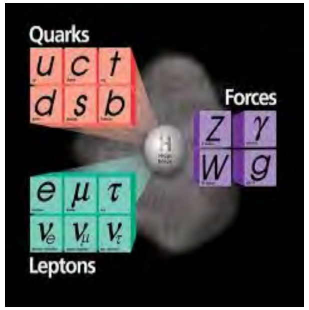


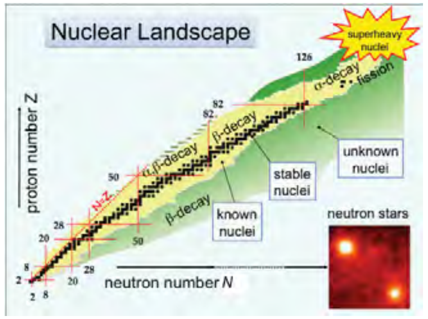
Electron Ion Collider: The next QCD frontier

Understanding the Glue that Binds Us All

Why the EIC? ➔ "Gluon Imaging"

To understand the role of gluons in binding quarks & gluons into Nucleons and Nuclei





QCD: The Holy Grail of Quantum Field Theories

- QCD : "nearly perfect" theory that explains nature's strong interactions, is a fundamental quantum theory of quarks and gluon fields
- QCD is rich with symmetries:

$$SU(3)_C \times SU(3)_L \times SU(3)_R \times U(1)_A \times U(1)_B$$

(1) (2) (3)

(1) Gauge "color" symmetry : unbroken but confined
(2) Global "chiral" flavor symmetry: exact for massless quarks
(3) Baryon number and axial charge (massless quarks) conservation
(4) Scale invariance for massless quarks and gluon fields
(5) Discrete C, P & T symmetries

- Chiral, Axial, Scale & P&T symmetries broken by quantum effects: Most of the visible matter in the Universe emerges as a result
- Inherent in QCD are the deepest aspects of relativistic quantum field theories: (confinement, asymptotic freedom, anomalies, spontaneous breaking of chiral symmetry) ➔ all depend on non-linear dynamics in QCD

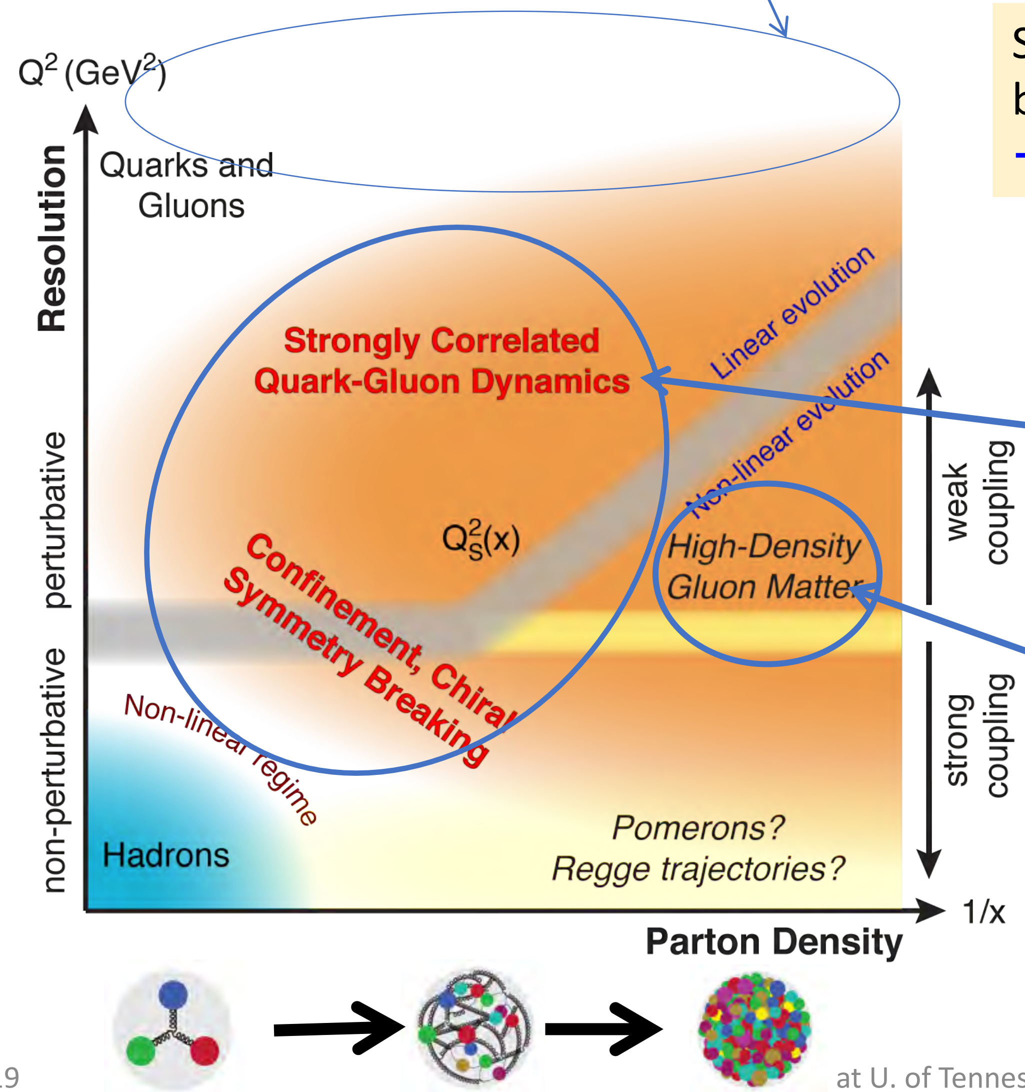
QCD Landscape to be explored by EIC

QCD at high resolution (Q^2) — weakly correlated quarks and gluons are well-described

Strong QCD dynamics creates many-body correlations between quarks and gluons
→ hadron structure emerges

EIC will systematically explore correlations in this region.

An exciting opportunity: Observation by EIC of a new regime in QCD of weakly coupled high density matter



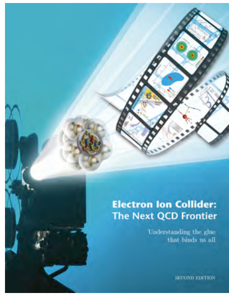
arXiv: 1708.01527

Non-linear Structure of QCD has Fundamental Consequences

Emergence of spin, mass & confinement, gluon fields

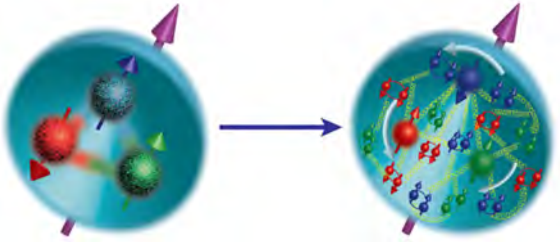
- Quark (Color) confinement:
  - Unique property of the strong interaction
  - Consequence of nonlinear gluon self-interactions
- Strong Quark-Gluon Interactions:
  - Confined motion of quarks and gluons – Transverse Momentum Dependent Parton Distributions (TMDs):
  - Confined spatial correlations of quark and gluon distributions – Generalized Parton Distributions (GPDs):
- Ultra-dense color (gluon) fields:
  - Is there a universal many-body structure due to ultra-dense color fields at the core of **all** hadrons and nuclei?

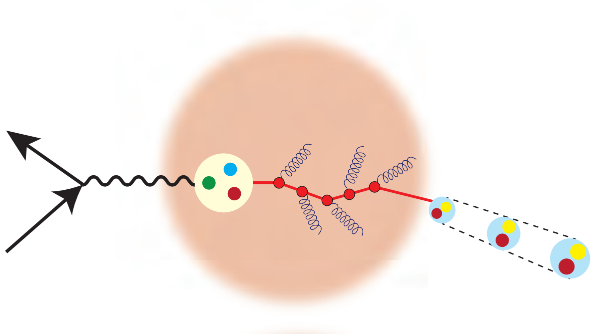
A new facility is needed to investigate, with precision, the dynamics of gluons & sea quarks and their role in the structure of visible matter



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?

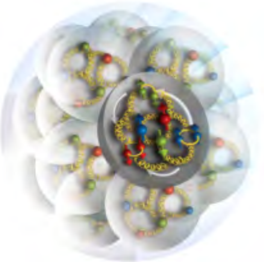




How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

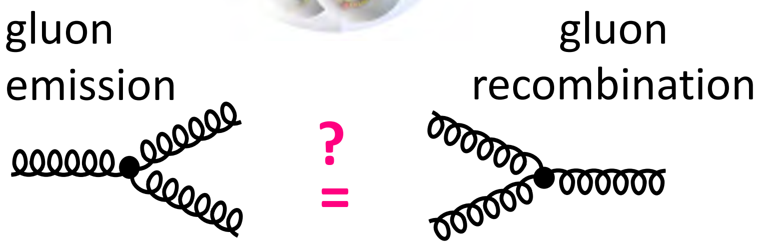
How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?

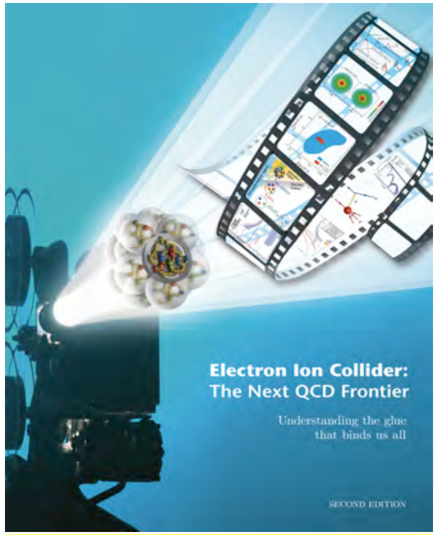


How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

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 Electron Ion Collider



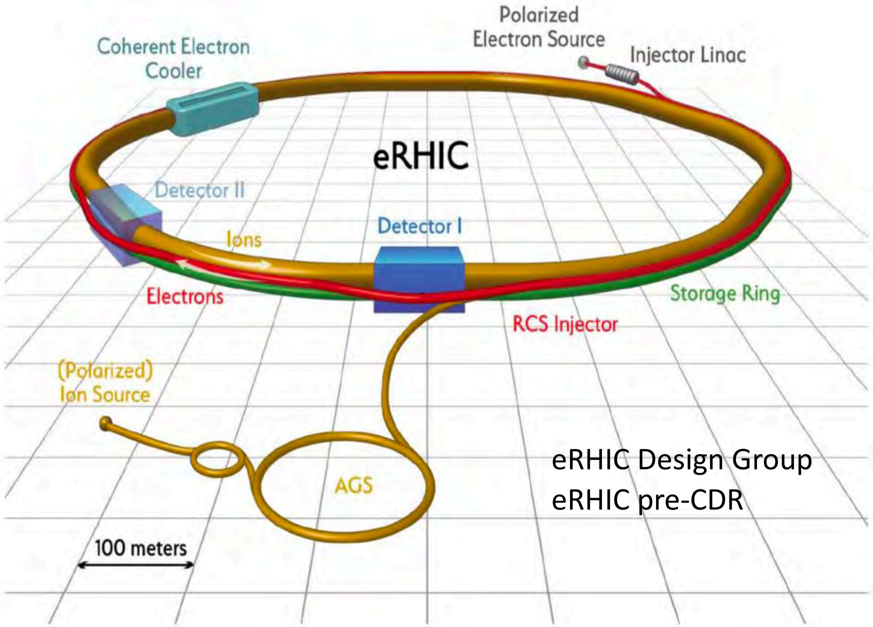
1212.1701.v3
A. Accardi et al
Eur. Phy. J. A, 52 9(2016)

For e-N collisions at the EIC:
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ $10^{33\text{-}34}$ cm^{-2}sec^{-1}
  100-1000 times HERA
  - ✓ 20-100 (140) GeV Variable CoM

For e-A collisions at the EIC:
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

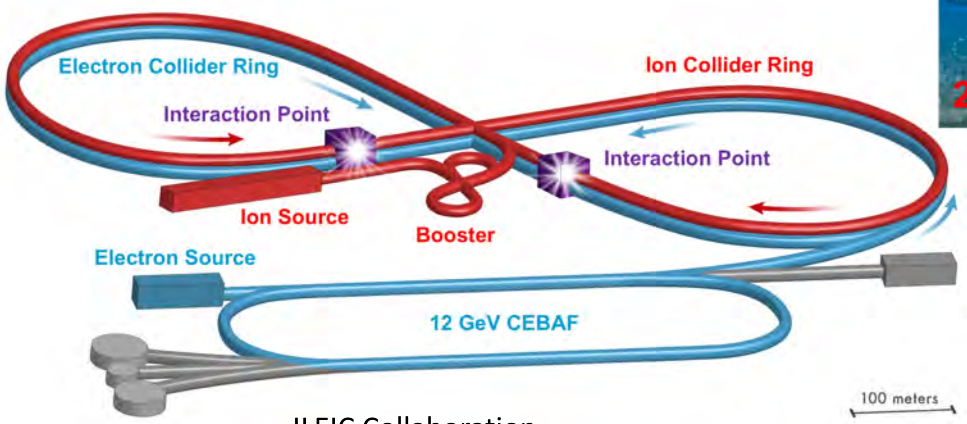
World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

Both designs use DOE's significant investments in infrastructure



eRHIC Design Group
eRHIC pre-CDR

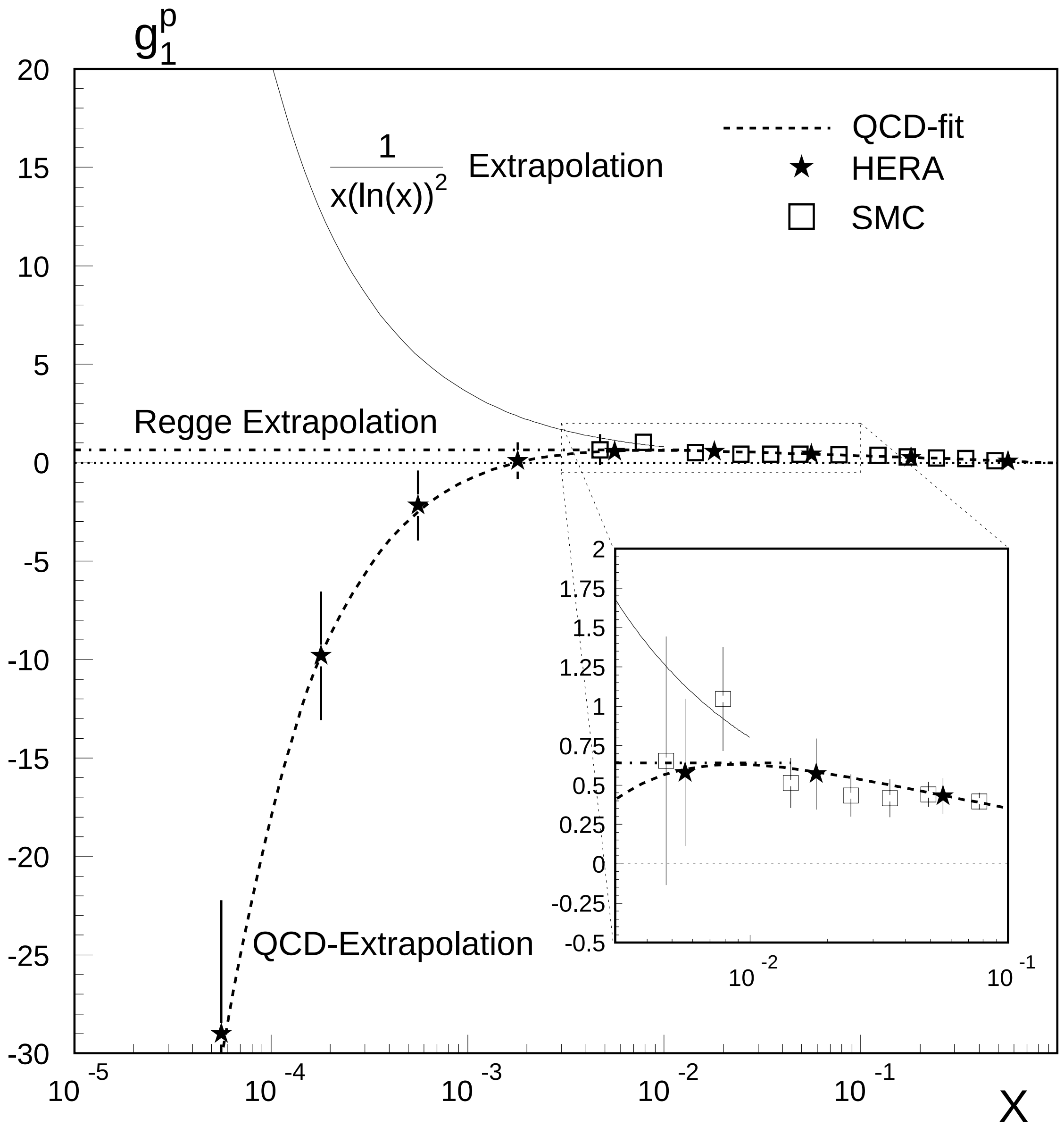
2018



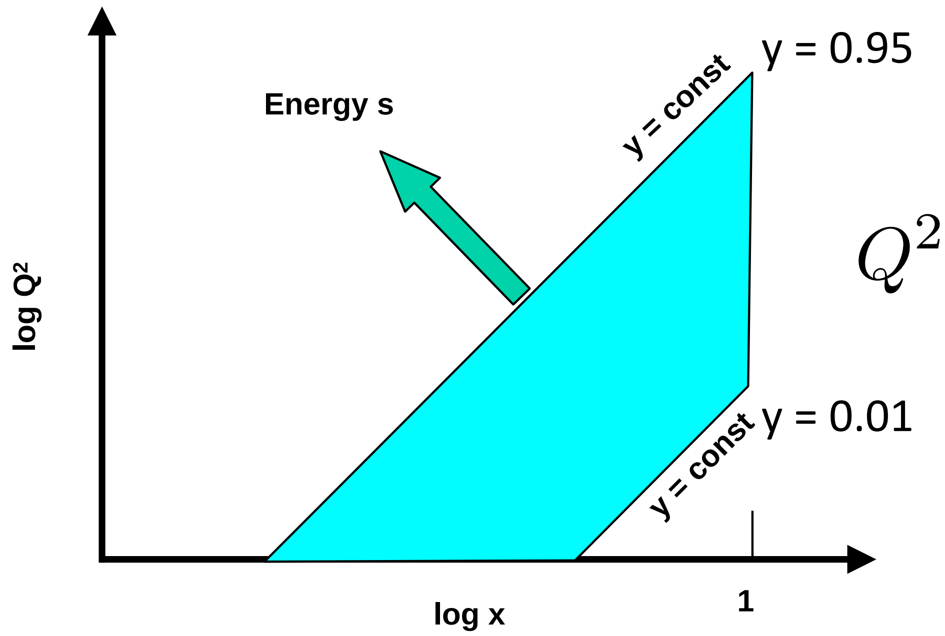
JLEIC Collaboration
JLEIC Pre-CDR about to be finalized

Need access to low x, and perturbative Q^2 with polarized proton beams

7/15/2019



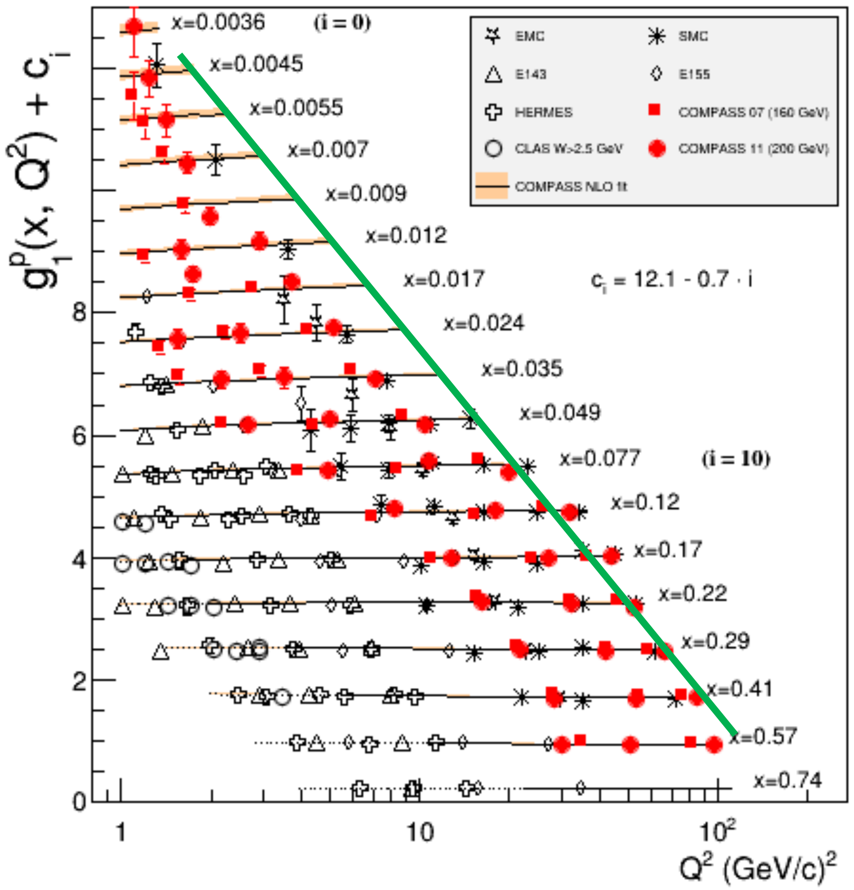
The x-Q^2 plane…

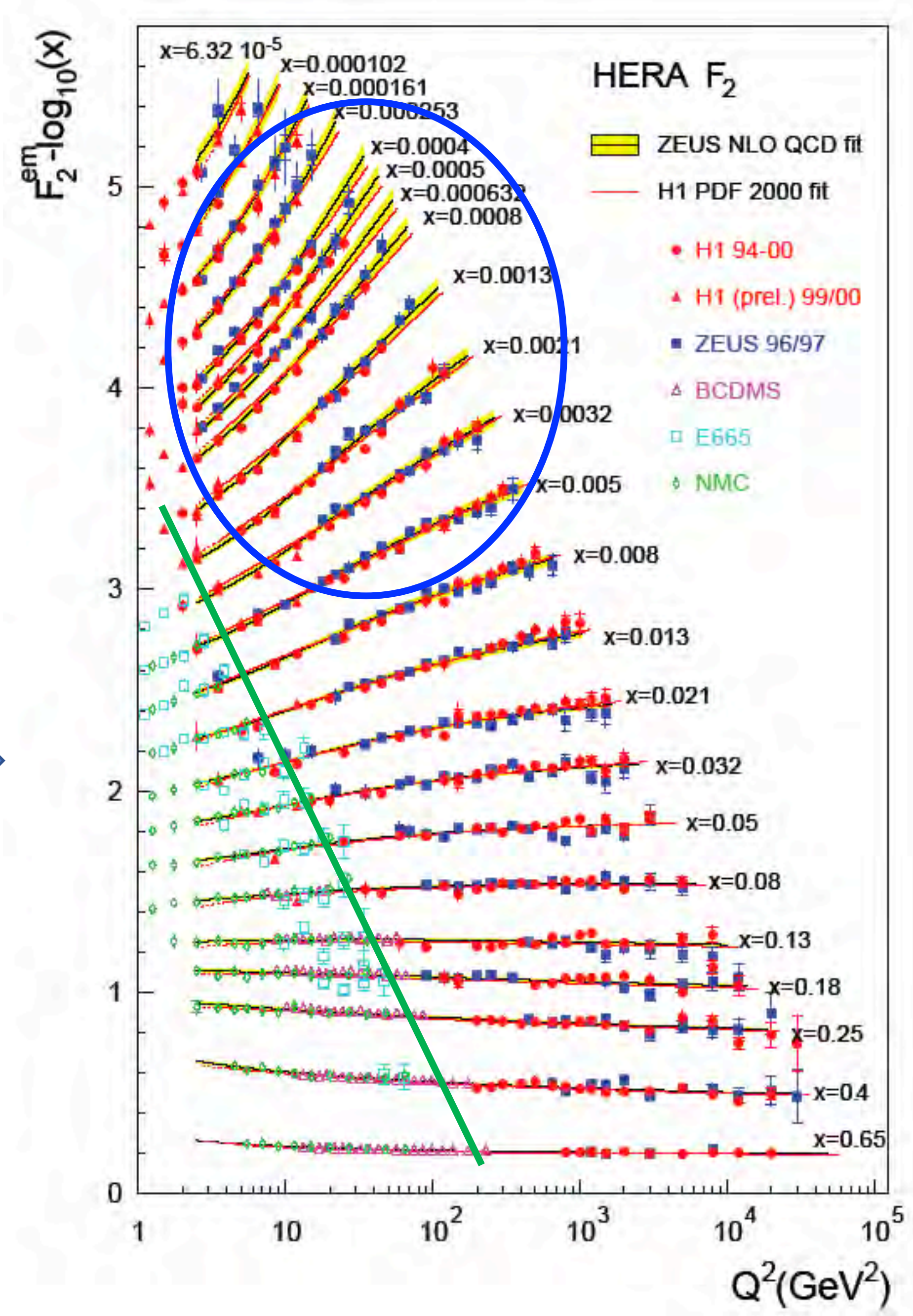


$$Q^2 \approx s \cdot x \cdot y$$

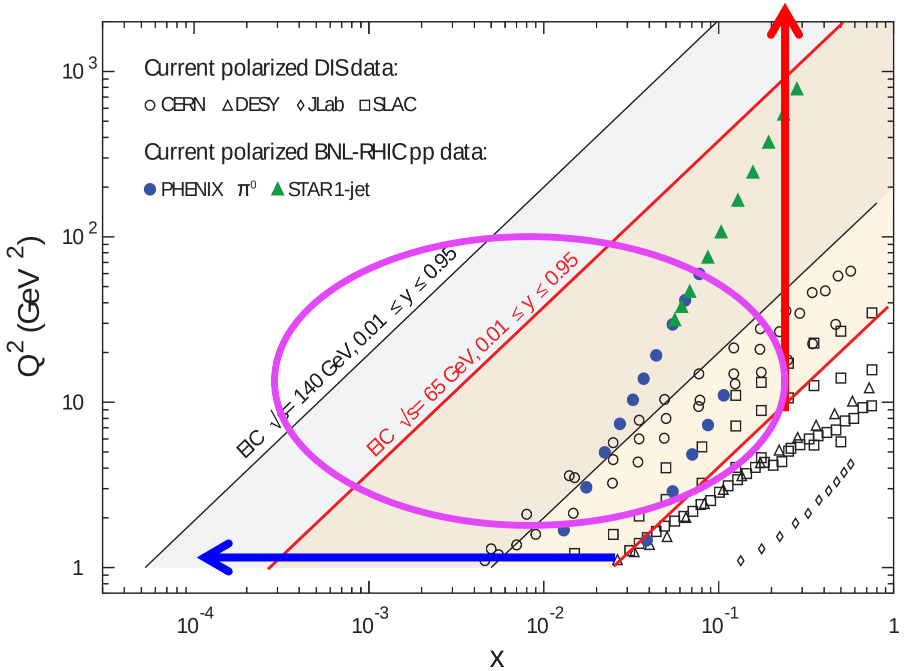
- Low-x reach requires large √s
- Large-Q^2 reach requires large √s
- *y* at colliders typically limited to 0.95 < y < 0.01

Cross over the x-Q^2 barrier for protons





EIC: Kinematic reach & properties

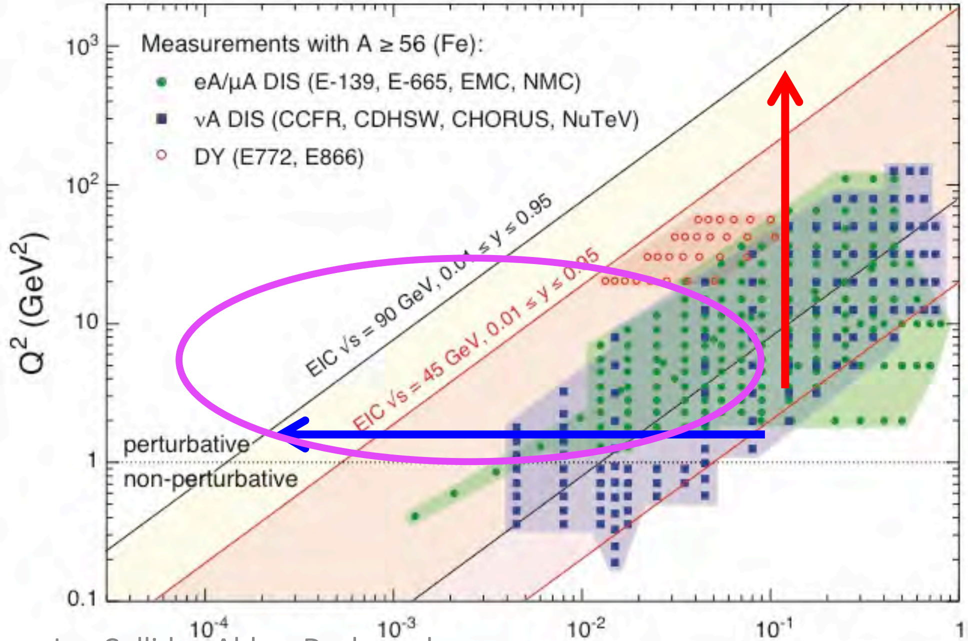


For e-N collisions at the EIC:

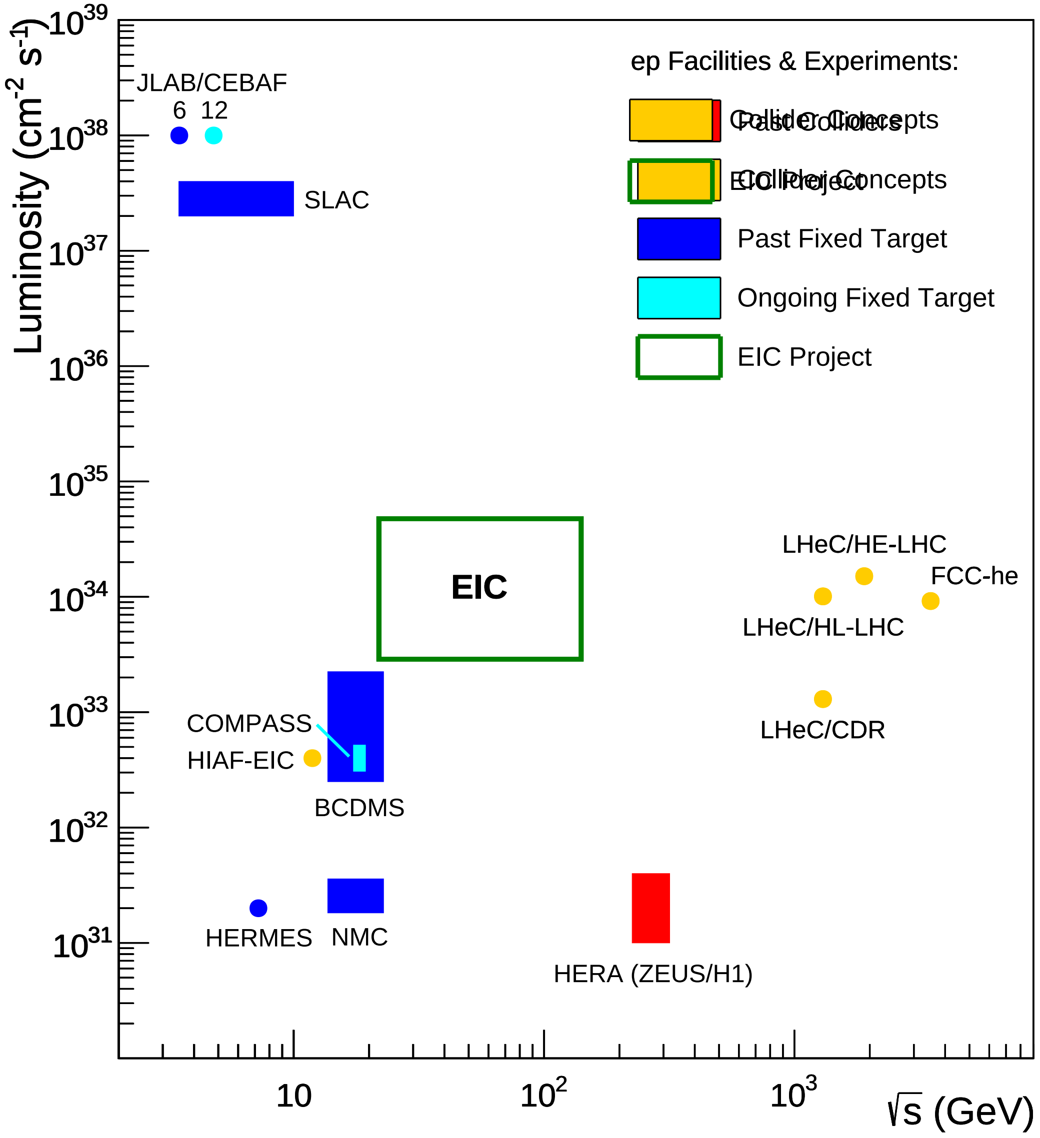
- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

For e-A collisions at the EIC:

- ✓ **Wide range in nuclei**
- ✓ Lum. per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)



Uniqueness of EIC among all DIS Facilities

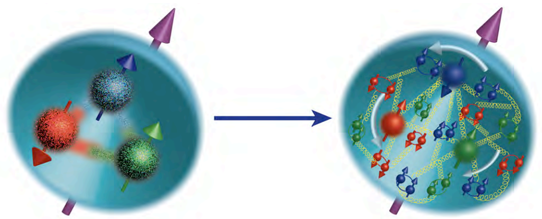


All DIS facilities in the world.

However, if we ask for:

- high luminosity & wide reach in √s
- polarized lepton & hadron beams
- nuclear beams

EIC stands out as unique facility …

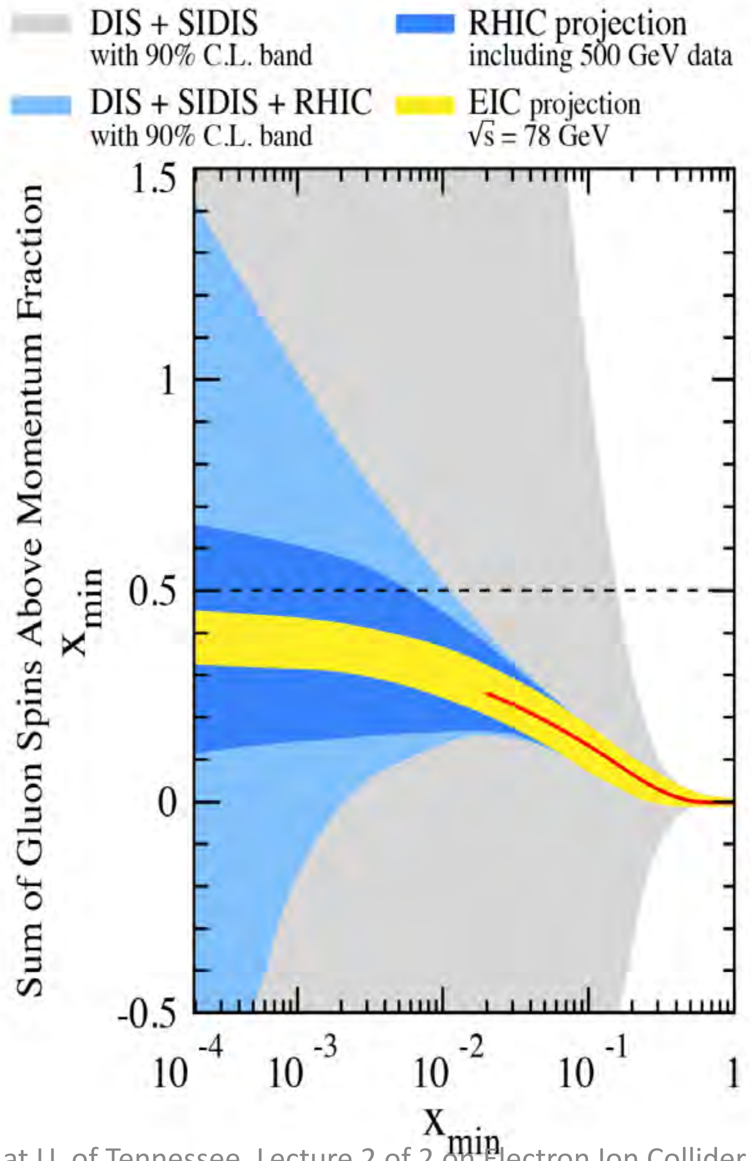


Understanding of Nucleon Spin

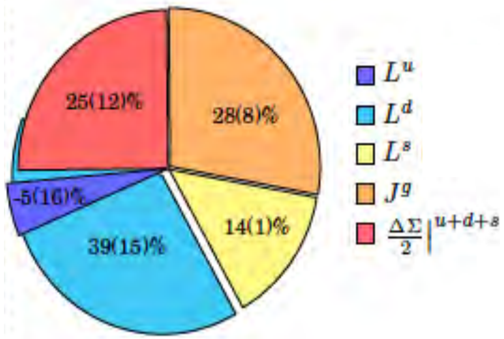
$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + [\Delta g + L_G]$$

$\Delta\Sigma/2$ = Quark contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom
Δg = Gluon contribution to Proton Spin
L_G = Gluon Orbital Ang. Mom

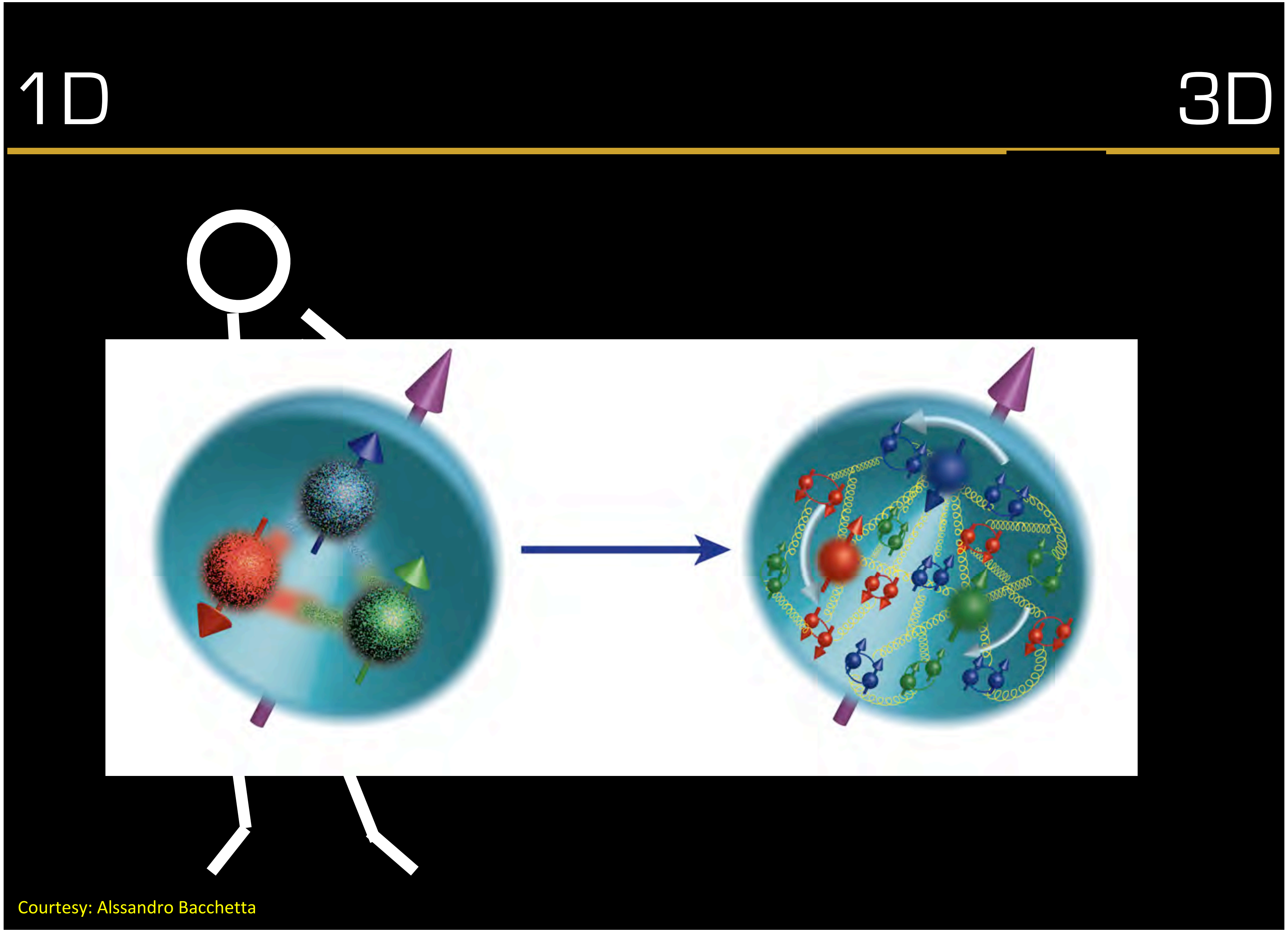
Precision in $\Delta\Sigma$ and Δg ➔ A clear idea Of the magnitude of L_Q+L_G



Spin and Lattice:
Recent Activities



- **Gluon's spin contribution on Lattice: S_G = 0.5(0.1):** Yi-Bo Yang et al. PRL **118**, 102001 (2017)
- **J_q calculated on Lattice QCD:** χQCD Collaboration, PRD91, 014505, 2015


1D
3D
Courtesy: Alssandro Bacchetta

3-Dimensional Imaging Quarks and Gluons

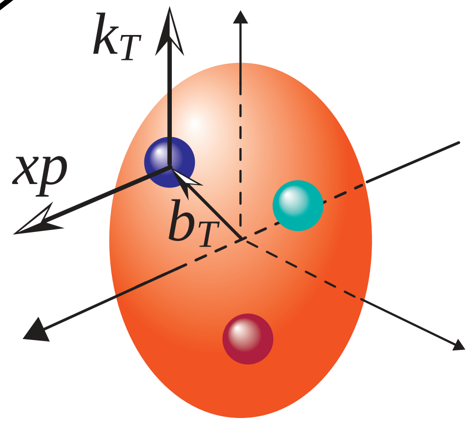
Wigner functions $W(x,b_T,k_T)$

offer unprecedented insight into confinement and chiral symmetry breaking.

$$W(x,b_T,k_T)$$

Momentum space $\int d^2b_T$ → $f(x,k_T)$

$\int d^2k_T$ → $f(x,b_T)$ ***Coordinate space***



Spin-dependent 3D momentum space images from semi-inclusive scattering

→ **TMDs**

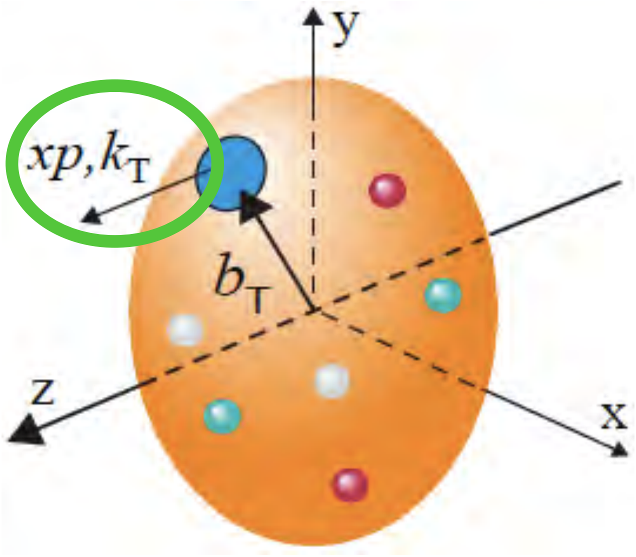
Spin-dependent 2D coordinate space (transverse) + 1D (longitudinal momentum) images from exclusive scattering

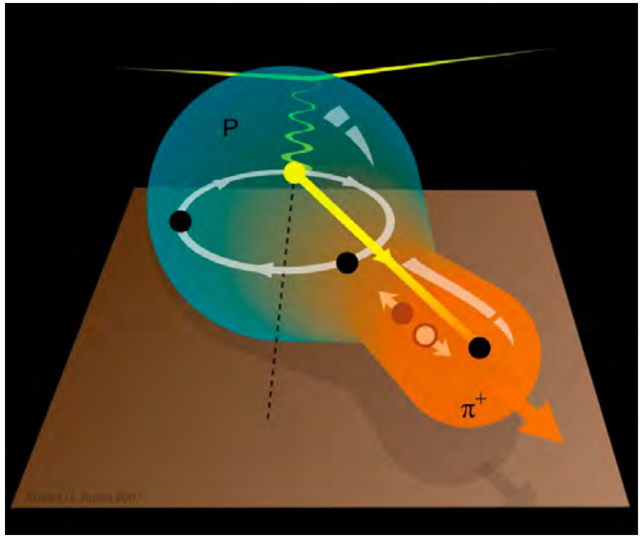
→ **GPDs**

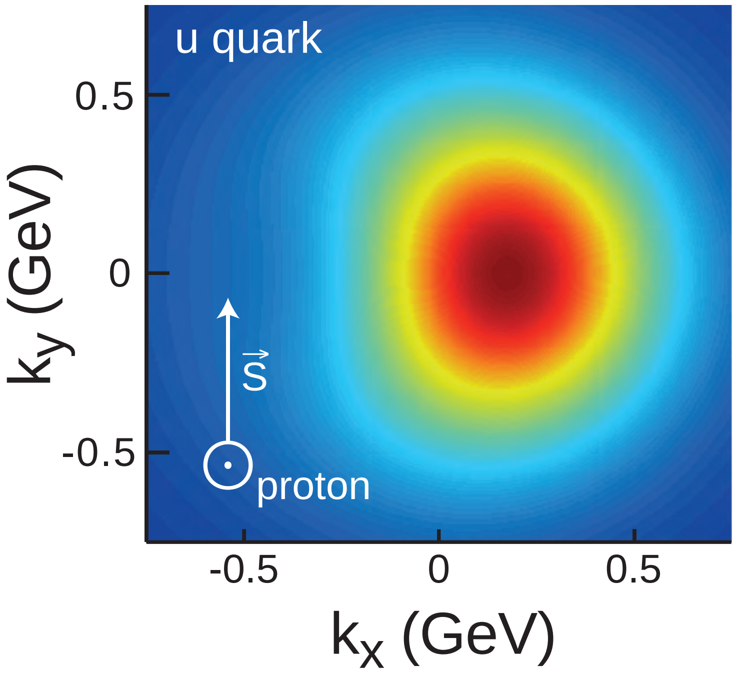
Position and momentum → Orbital motion of quarks and gluons

Measurement of Transverse Momentum Distribution

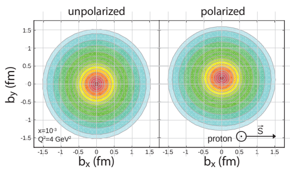
Semi-Inclusive Deep Inelastic Scattering







- Naturally, two scales:
  - ✧ high Q – localized probe To "see" quarks and gluons
  - ✧ Low p_T – sensitive to confining scale To "see" their confined motion
  - ✧ *Theory – QCD TMD factorization*

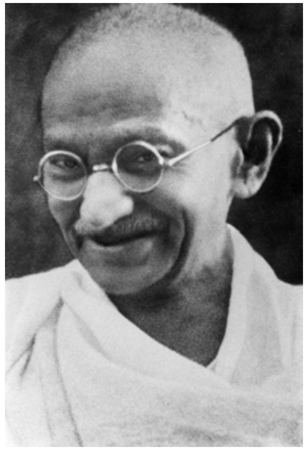


Spatial Imaging of quarks & gluons

Generalized Parton Distributions

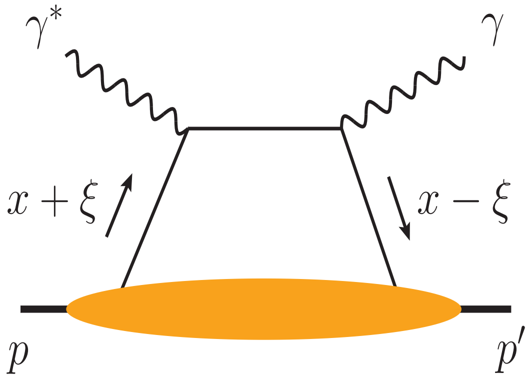
Historically, investigations of nucleon structure and dynamics involved breaking the nucleon…. (exploration of internal structure!)

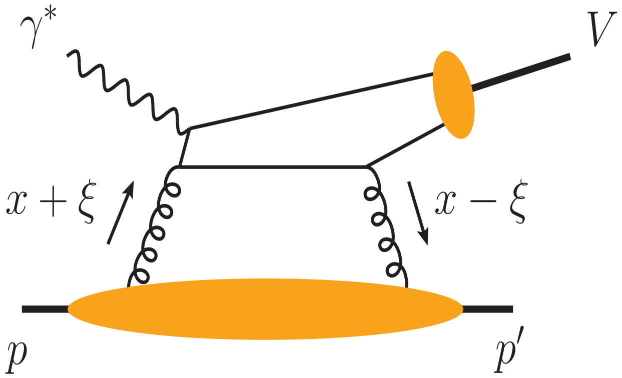
To get to the **orbital motion** of quarks and gluons we need **non-violent collisions**



Exclusive measurements → measure "everything"

Quarks Motion





Gluons: Only @ Collider

Deeply Virtual Compton Scattering

Measure all three final states

e + **p** → e'+ **p'**+ γ

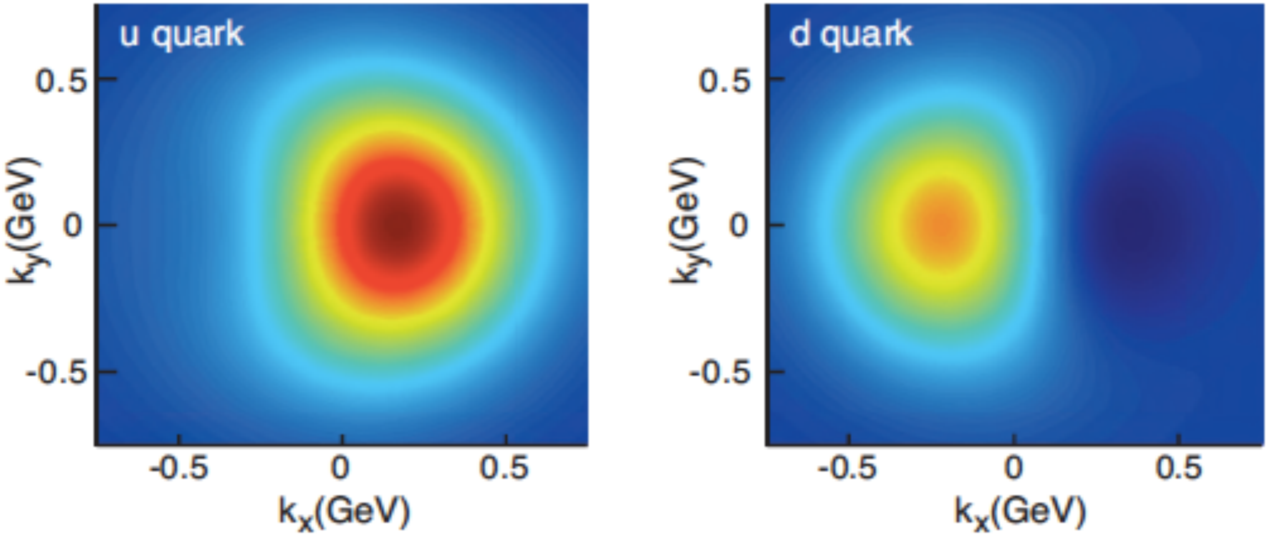
Fourier transform of momentum transferred=(p-p') → Spatial distribution

2+1 D partonic image of the proton with the EIC

Spin-dependent 3D momentum space images from semi-inclusive scattering

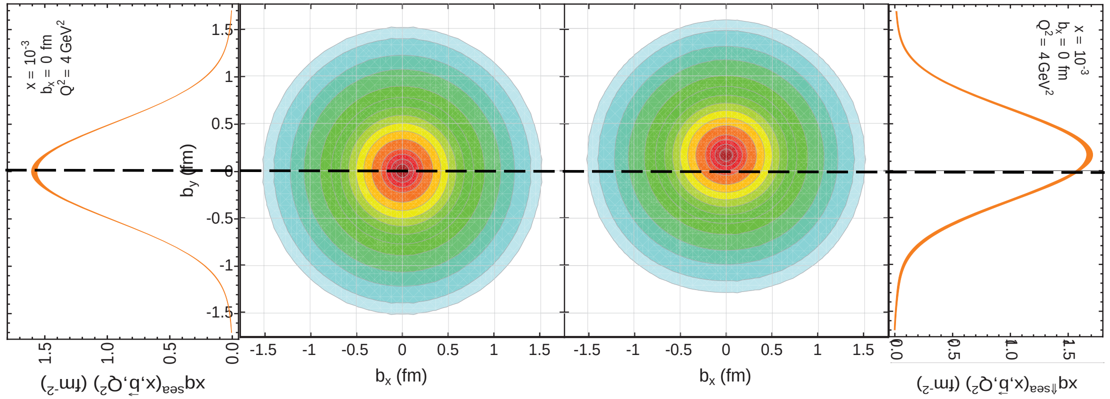
Spin-dependent 2D coordinate space (transverse) + 1D (longitudinal momentum) images from exclusive scattering

Transverse Momentum Distributions



Transverse Position Distributions

sea-quarks
unpolarized polarized

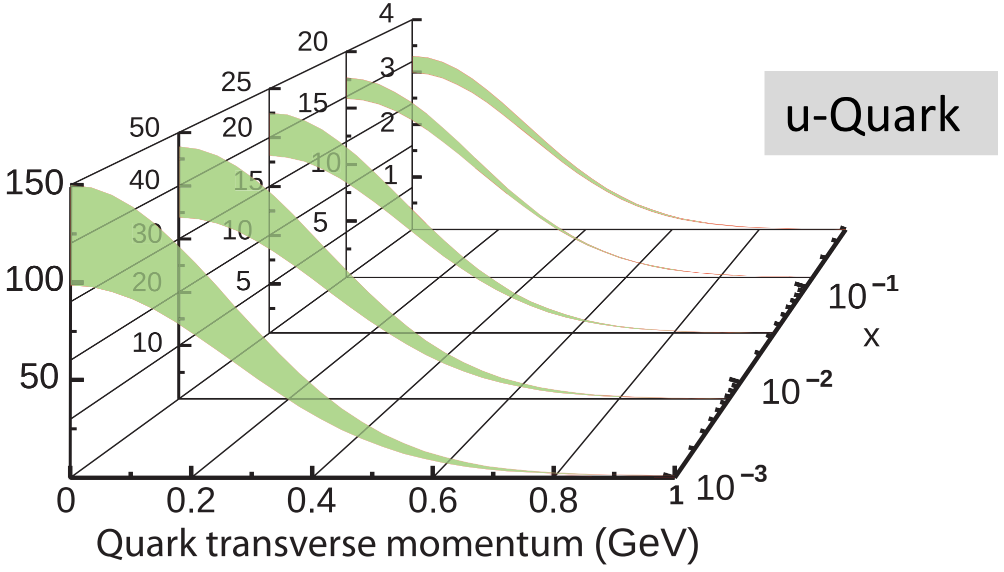


2+1 D partonic image of the proton with the EIC

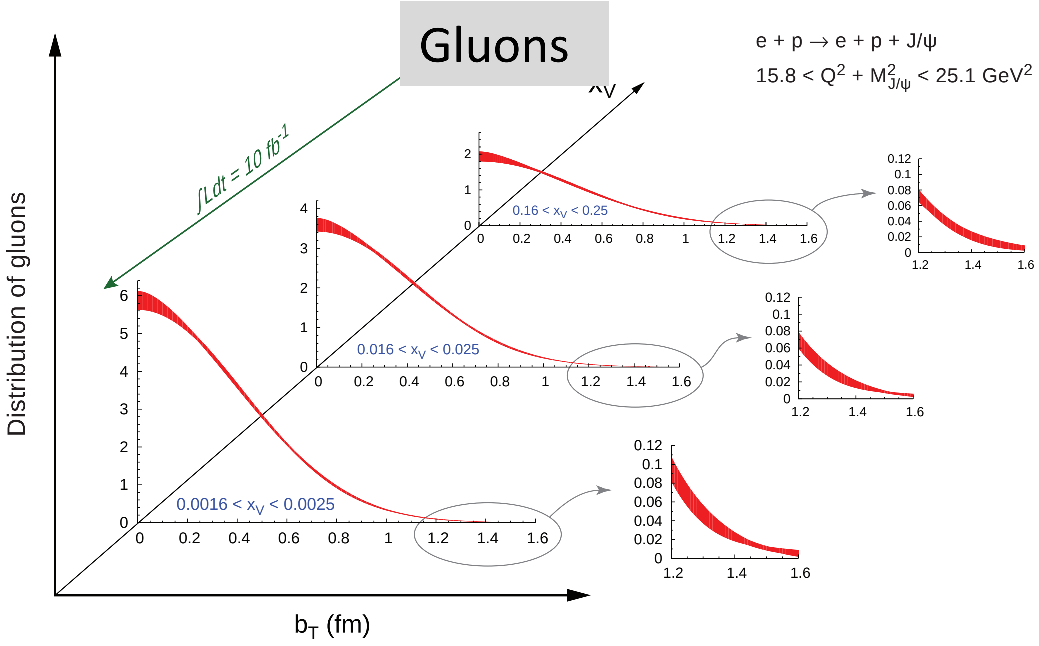
Spin-dependent 3D momentum space images from semi-inclusive scattering

Spin-dependent 2D coordinate space (transverse) + 1D (longitudinal momentum) images from exclusive scattering

Transverse Momentum Distributions



Transverse Position Distributions



Study of internal structure of a watermelon:

A-A (RHIC)

1) Violent collision of melons

2) Cutting the watermelon with a knife

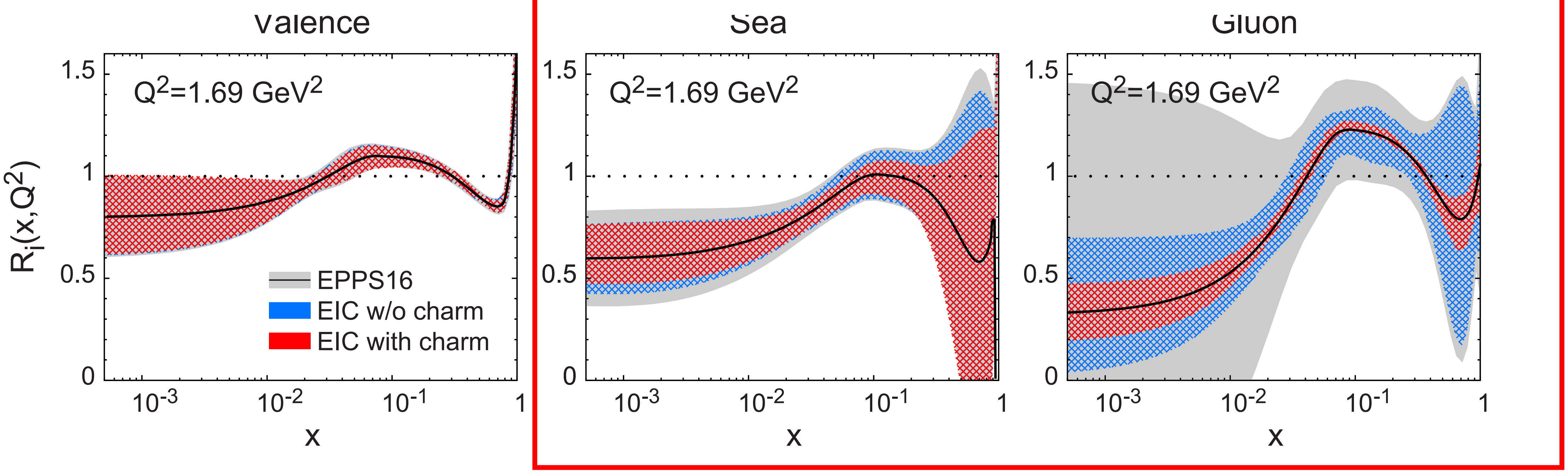
Violent DIS e-A (EIC)

3) MRI of a watermelon

Non-Violent e-A (EIC)

Use of Nuclei as a Laboratory for QCD :

EIC: impact on the knowledge of 1D Nuclear PDFs

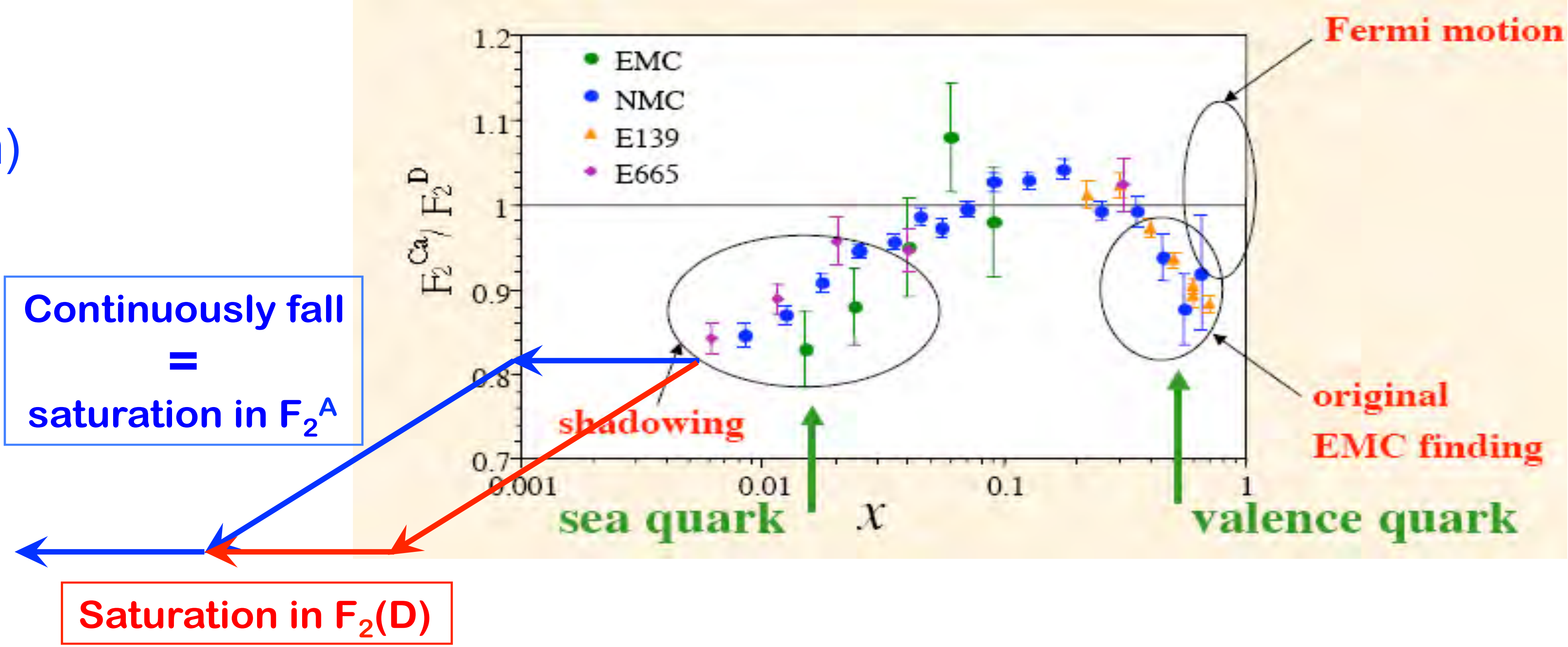


Ratio of Parton Distribution Functions of Pb over Proton:

- Without EIC, large uncertainties in **nuclear sea quarks and gluons** ➔EIC will significantly reduce uncertainties
- Complementary to RHIC and LHC pA data. Provides information on initial state for heavy ion collisions.
- Does the nucleus behave like a proton at low-x? ➔ such color correlations relevant to the understanding of astronomical objects

❑ Ratio of F_2: EMC effect, Shadowing and Saturation:

An easy measurement (early program)



❑ Questions:

Will the suppression/shadowing continue fall as x decreases?

Could nucleus behaves as a large proton at small-x?

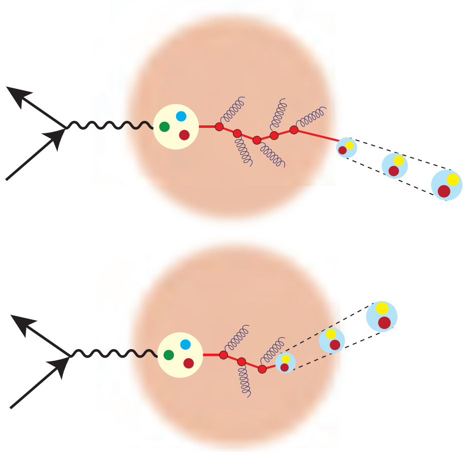
Range of color correlation – could impact the center of neutron stars!

Emergence of Hadrons from Partons

Nucleus as a Femtometer sized filter

Unprecedented ν, the virtual photon energy range
@ EIC : *precision & control*

$$\nu = \frac{Q^2}{2mx}$$

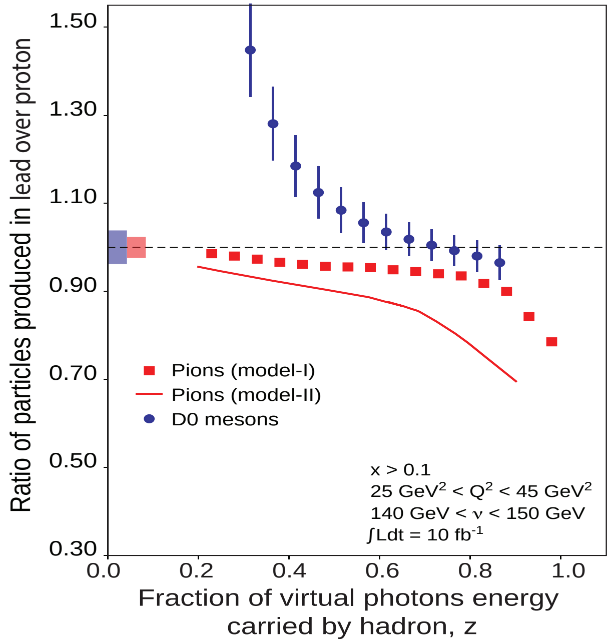


Control of ν by selecting kinematics;

Also under control the nuclear size.

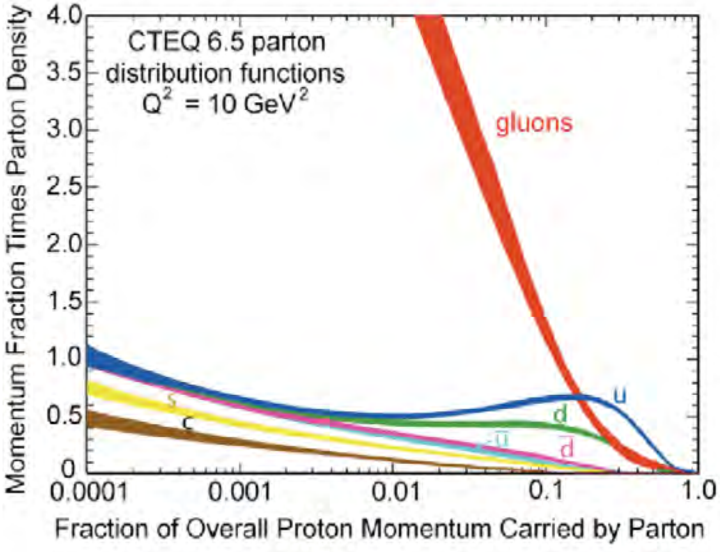
(colored) Quark passing through cold QCD matter emerges as color-neutral hadron ➔ Clues to color-confinement?

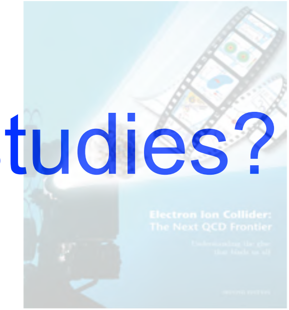
Energy loss by light vs. heavy quarks:



Identify π vs. D^0 **(charm)** mesons in e-A collisions:
Understand energy loss of light vs. heavy quarks
traversing the cold nuclear matter:
Connect to energy loss in Hot QCD

Need the collider energy of EIC and its control on parton kinematics

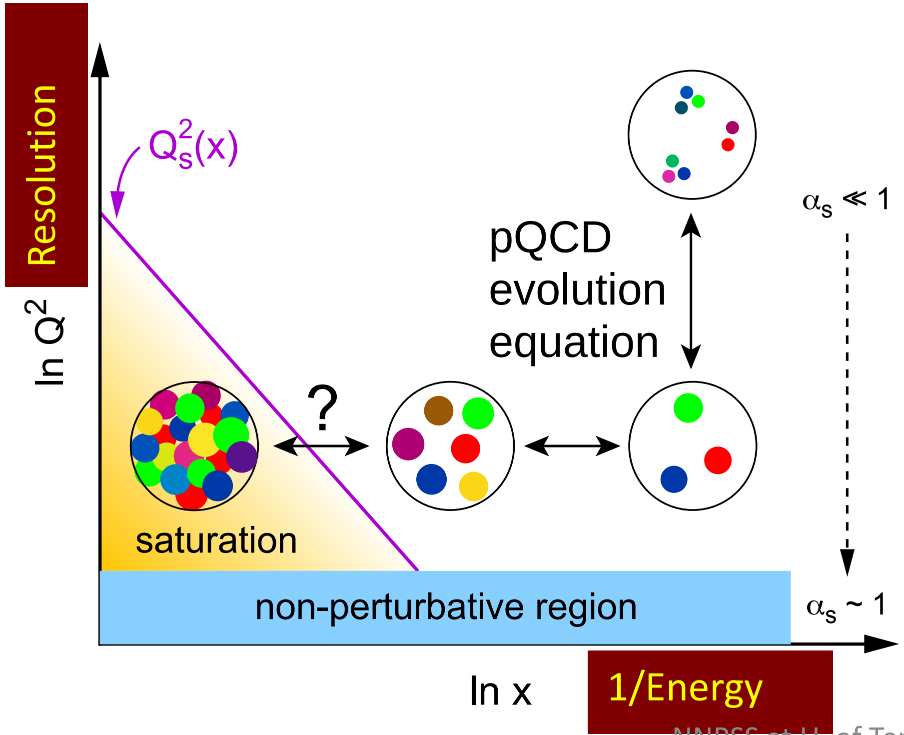




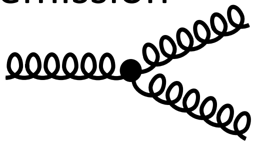
What do we learn from low-x studies?

What tames the low-x rise?

- New evolution eqn.s @ low x & moderate Q^2
- Saturation Scale $Q_S(x)$ where gluon emission and recombination comparable

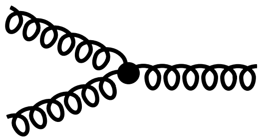


gluon emission



=

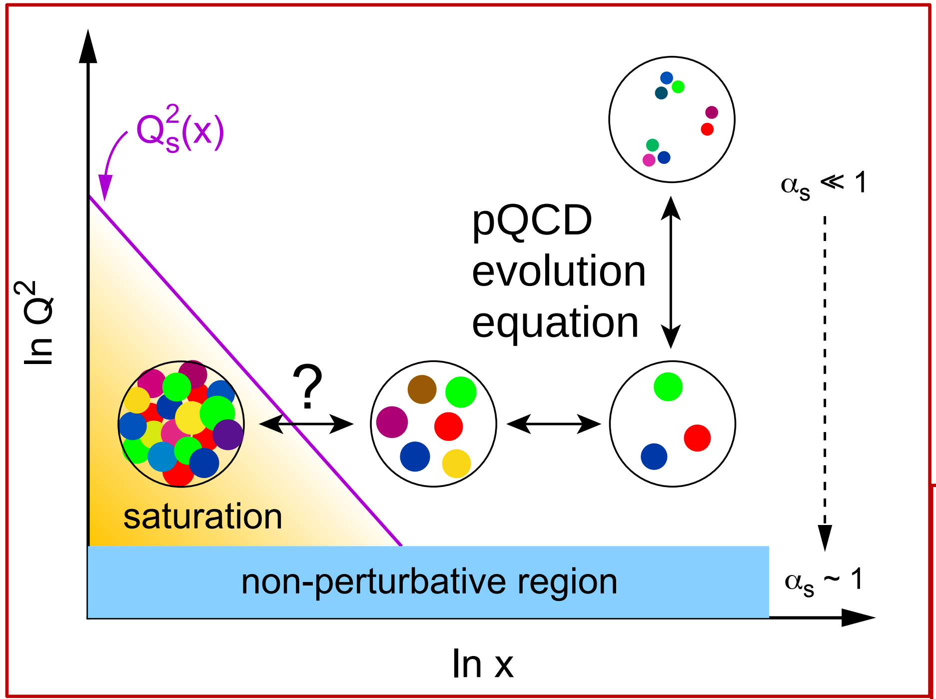
gluon recombination

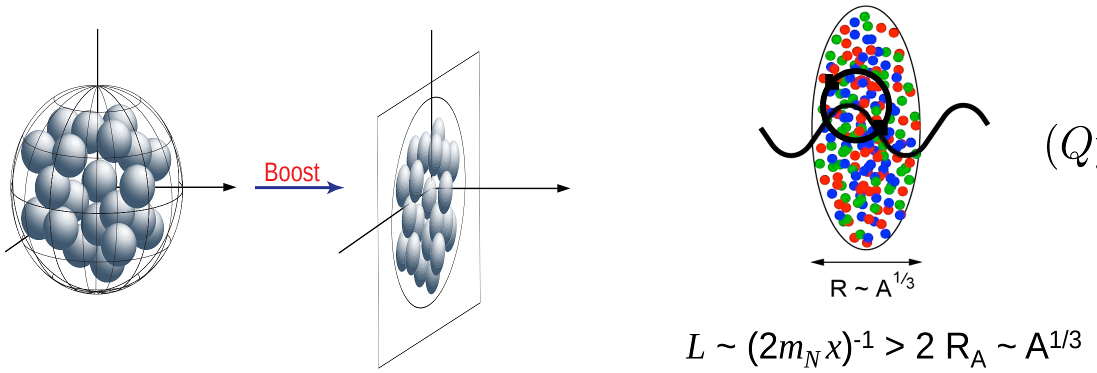


At Q_S

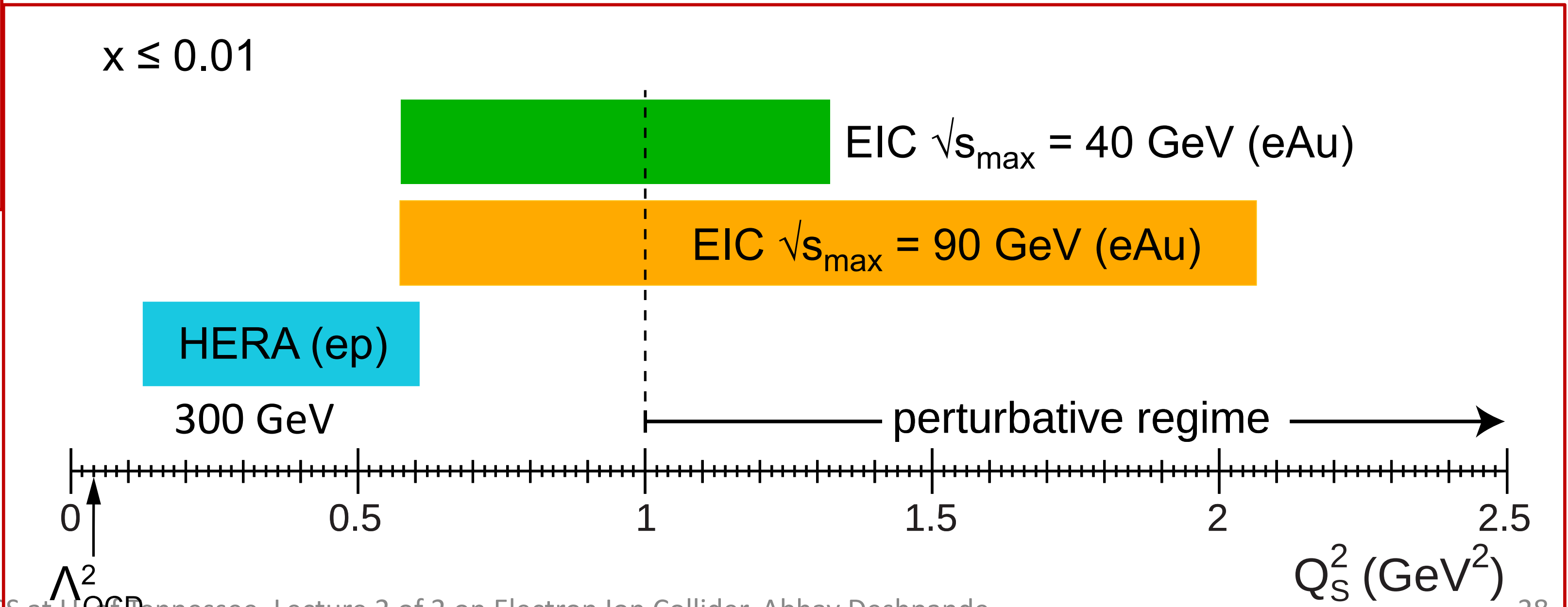
First observation of gluon recombination effects in nuclei:
➔leading to a *collective* gluonic system!
First observation of g-g recombination in *different* nuclei
→ Is this a universal property?
→ Is the Color Glass Condensate the correct effective theory?

Advantage of the nucleus over proton





$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$



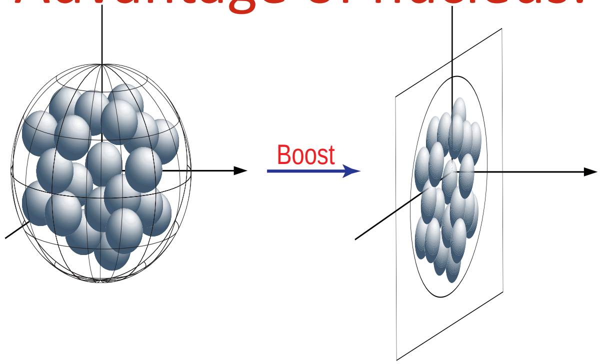
Accessible range of saturation scale Q_s^2 at the EIC with e+A collisions.
arXiv:1708.01527

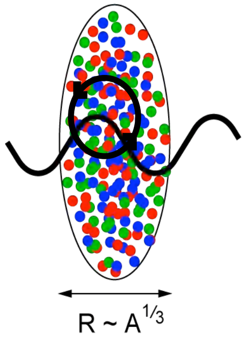
How to explore/study this new phase of matter?

(multi-TeV) e-p collider OR **a (multi-10s GeV) e-A collider**

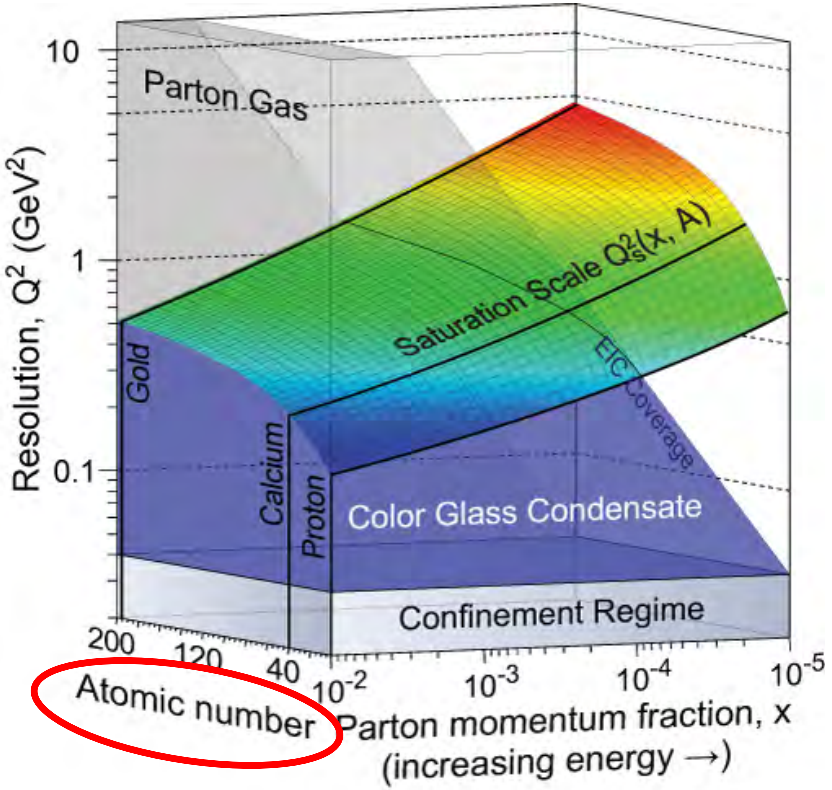
Teaney, Kowalski
Kovchegov et al.

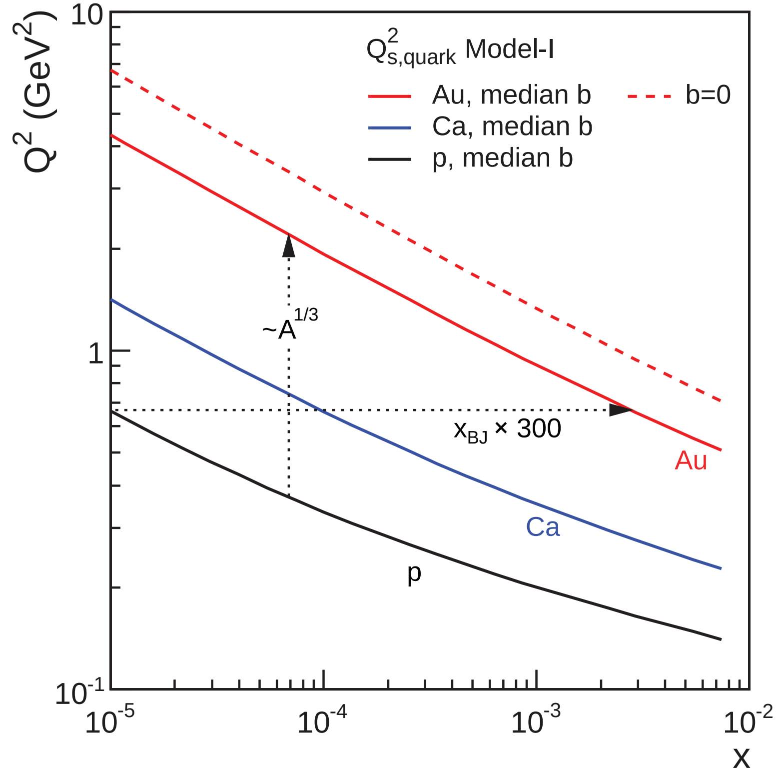
Advantage of nucleus:





$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$





$L \sim (2m_N x)^{-1} > 2\, R_A \sim A^{1/3}$

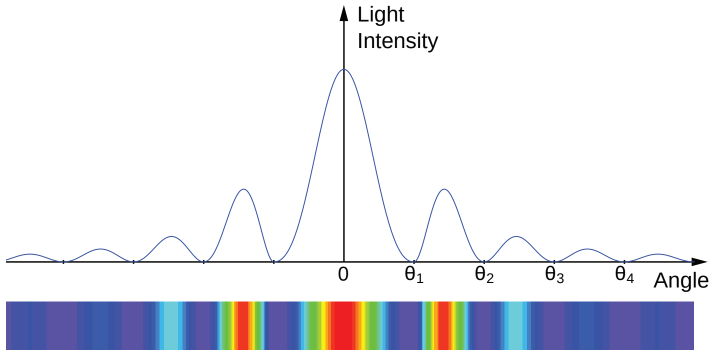
Enhancement of Q_S with A:
Saturation regime reached at significantly lower energy (read: "cost") in nuclei

Diffraction : Optics and high energy physics

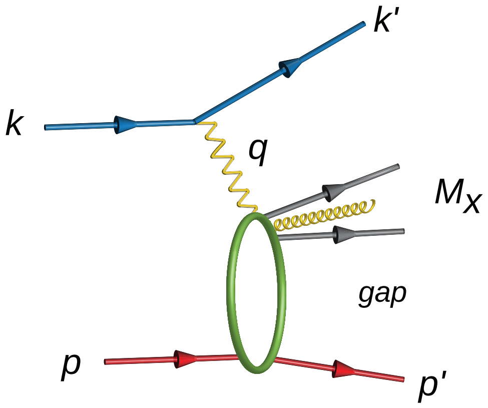
Light with wavelength λ obstructed by an opaque disk of radius R suffers diffraction:

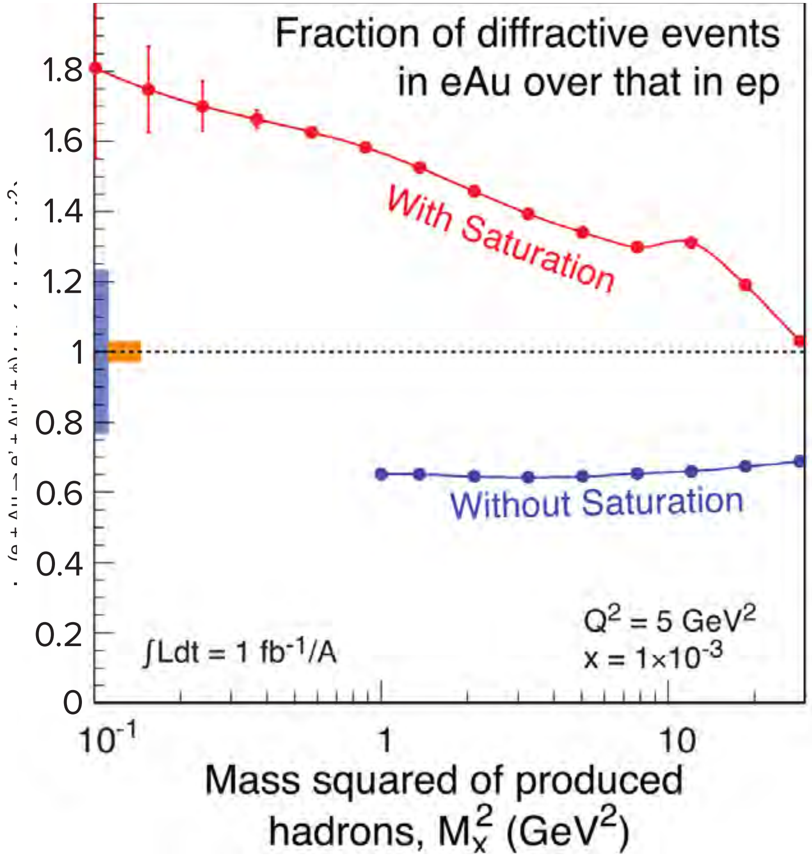
k → wave number

$$|t| \approx k^2\theta^2 \quad \theta_i \sim \frac{1}{(kR)}$$



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



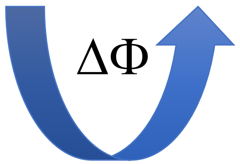


At HERA : ep: 10-15% diffractive

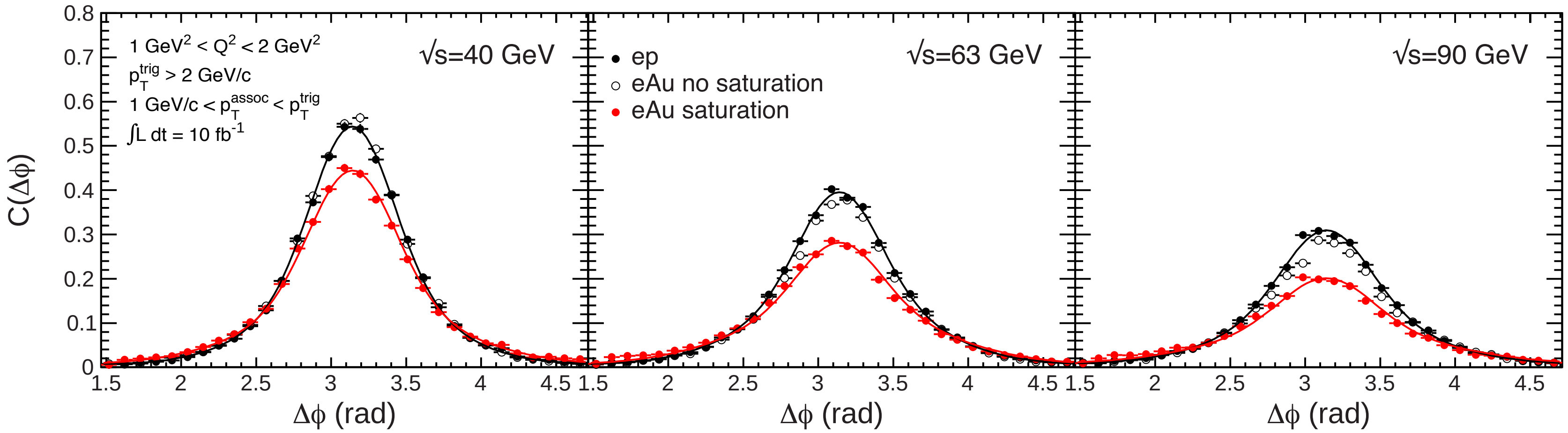
At EIC eA, if Saturation/CGC eA: 25-30% diffractive

Exp. Signal for Saturation

Di-hadron Correlations: $e + A \to e' + h_1 + h_2 + X$



arXiv: 1708.01527



Comparison between

- e-A with saturation (red filled),
- e-p non-saturation (**black full points**) , and
- e-A non-Saturation model (black-hollow points)

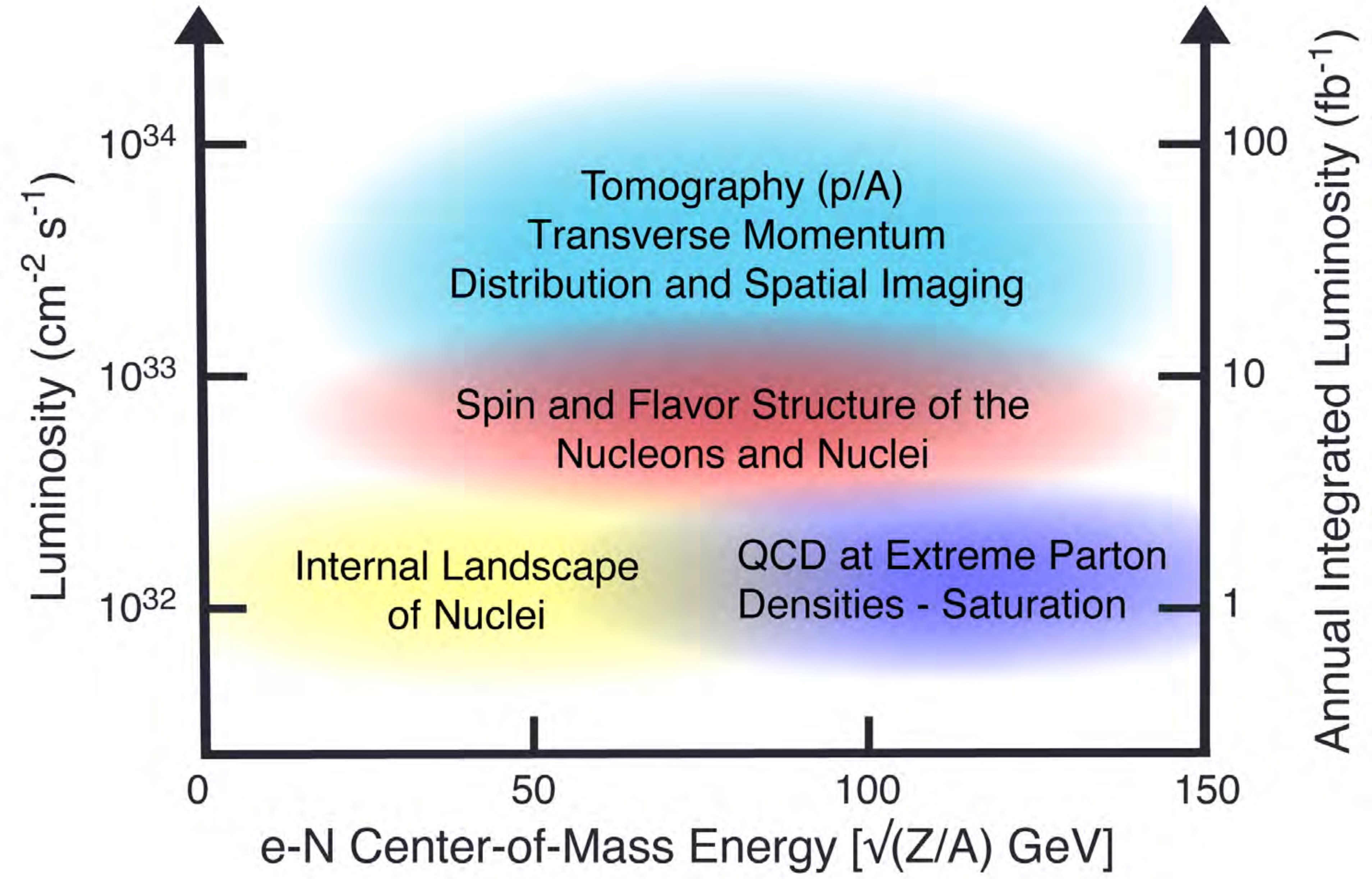
Other important measurements under considerations

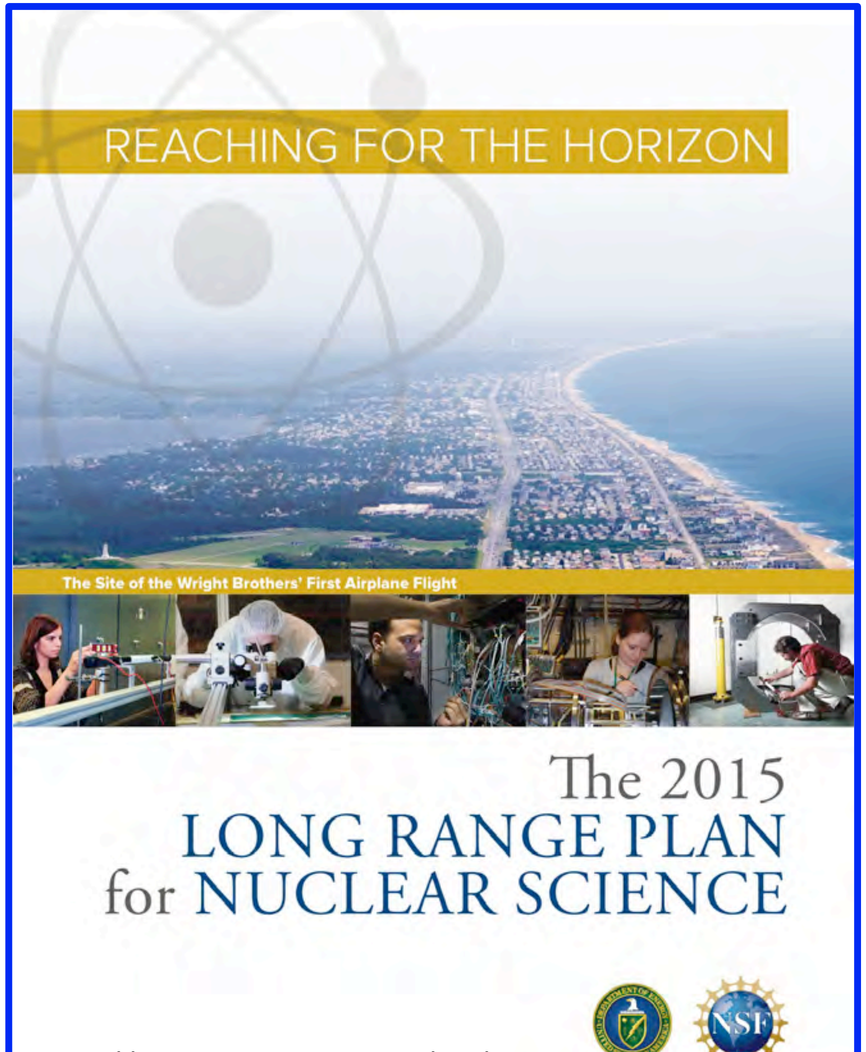
- Energy variation, an excellent detector with particle ID: ➔ test of sum roles for nuclear PDF's flabor dependent ant-shadowing studies
- Sivers effect studies, Collins fragmentation studies
- Heavy quark distribution at high x
- Physics of hidden color
- Color transparency
- Spectroscopy
- Jets structure studies (their internal distribution), then use the jets to study cold QCD mater
- And many other studies of interest

Opportunities for YOU: Physics beyond the EIC White Paper:

- Impact of super-precise PDFs in x > 0.0, $1 < Q^2 < 100\ GeV^2$ for future Higgs studies (some insight through LHeC studies, but serious effort on EIC beginning now).
- What role would TMDs in e-p play in W-Production at LHC?
- Heavy quark and quarkonia (c, b quarks) studies beyond HERA, with 100-1000 times luminosities (??) Does polarization of hadron play any role?
- Quark Exotica: 4,5,6 quark systems…?
- Internal structure of jets with variability of CM 50-140 GeV^2, in comparison with HERA, Tevatron & LHC energies, and with controlled electron & proton polarizations (jet fragmentation studies) aided by knowledge from e+e- physics at BaBar/Belle & in future Super-Belle ("Collins Functions")
- Jet propagation in nuclei… energy loss in cold QCD medium: a topic interest
- Initial state affects QGP formation!….. p-A, d-A, A-A at RHIC and LHC: many puzzles
- Gluon TMDs at low-x!

Summary: EIC Physics: CM vs. Luminosity vs. Integrated luminosity





http://science.energy.gov/np/reports

RECOMMENDATION:

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

Initiatives:

Theory

Detector & Accelerator R&D

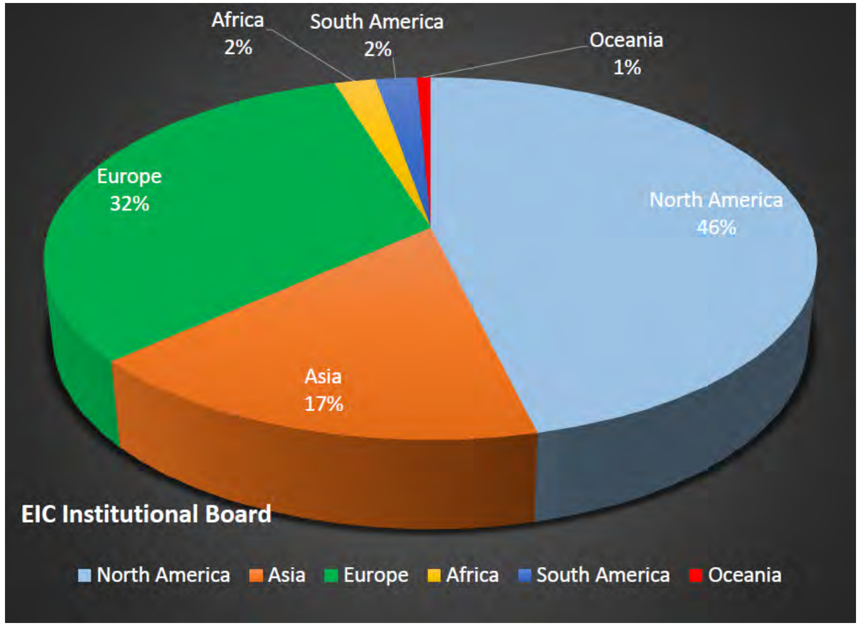
Detector R&D money ~1.3M/yr since 2011
Significant increase anticipated soonr

Since FY 2017
EIC Accelerator R&D already assigned $7m/yr

The EIC Users Group: [EICUG.ORG]

Formally established in 2016
847 Ph.D. Members from 30 countries, 177 institutions

New:
Center for Frontiers in Nuclear Science (at Stony Brook/BNL)
EIC^2 at Jefferson Laboratory



EICUG Structures in place and active.

EIC UG Steering Committee (w/ European Representative)
EIC UG Institutional Board
EIC UG Speaker's Committee (w/European Rep.)

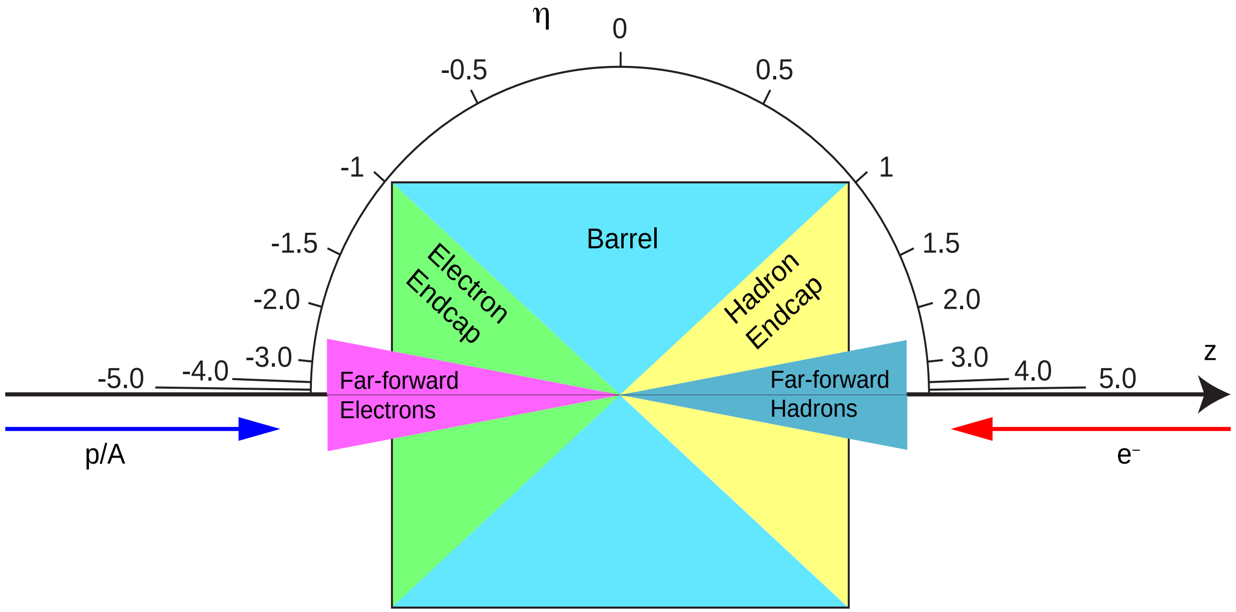
Task forces on:
-- Beam polarimetry
-- Luminosity measurement
-- Background studies
-- IR Design

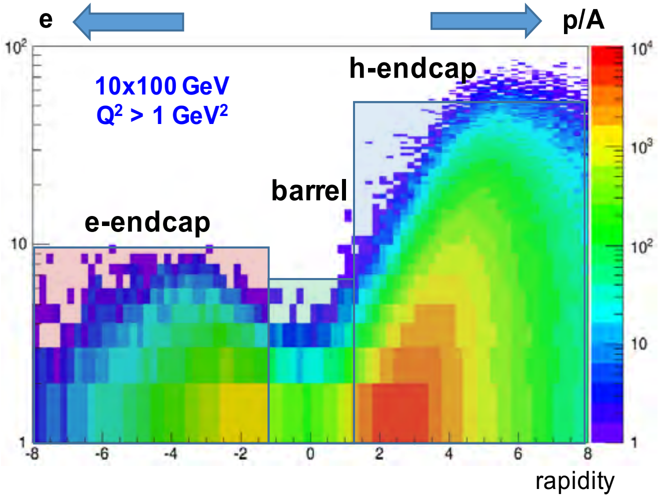
Annual meetings: Stony Brook (2014), Berkeley (2015), **ANL (2016)**, **Trieste (2017)**, **CAU (2018)**, **Paris (2019)**

Requirement are mostly site-independent with some slight differences in the forward region (IR integration)

In Short:

- Hermetic detector, low mass inner tracking, good PID (e and π/K/p) in wide range, calorimetry
- Moderate radiation hardness requirements, low pile-up, low multiplicity





Detector requirements for the EIC

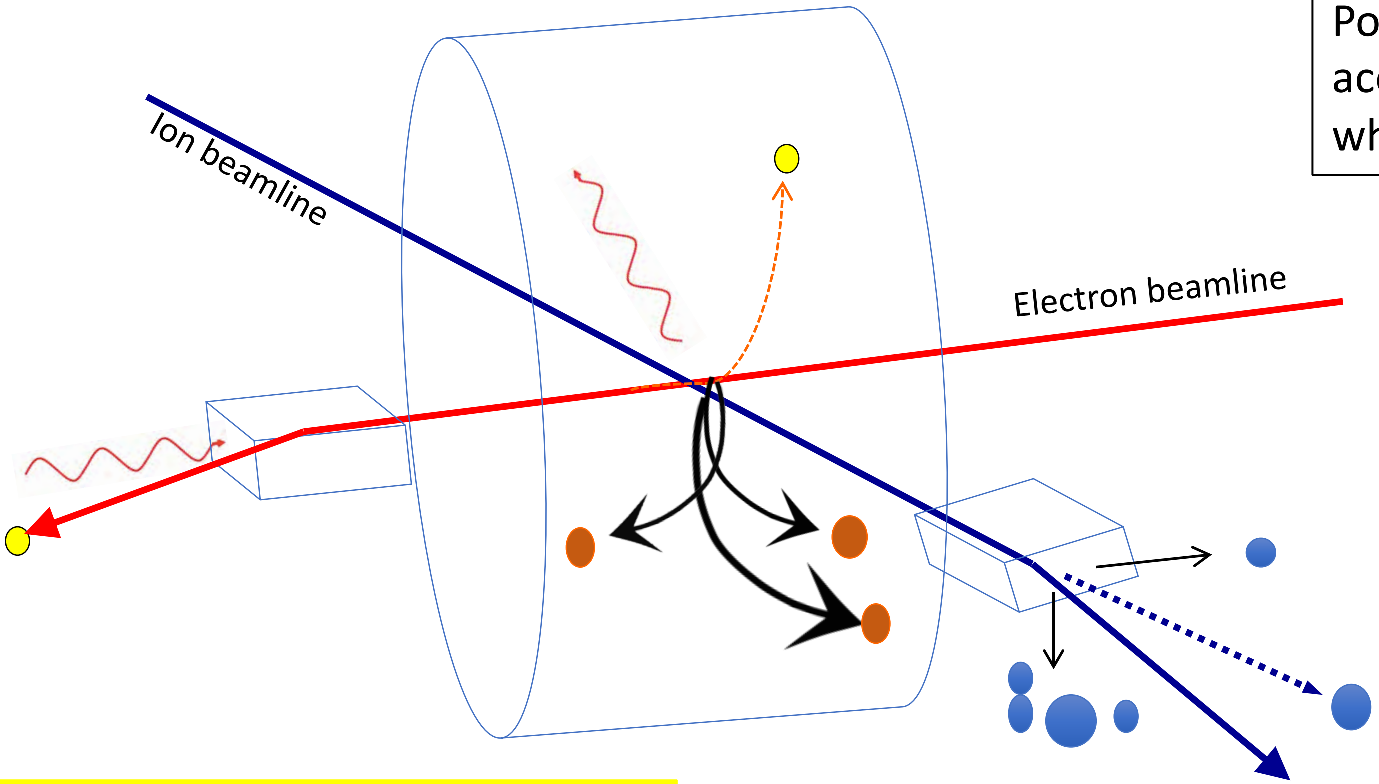
Requirement	Detector
Vertexing Event vertex, secondary vertices, track impact parameter	Vertex detector Central tracker and solenoid
Electron identification and measurement $-4 < \eta < +4$	Central tracker and solenoid Calorimeter
Hadronic jet measurement Excellent energy resolution, kinematic reconstruction	Central tracker and solenoid Calorimeter
Pion/kaon/proton separation For most of the solid angle PID needed for p < 7 GeV/c In forward direction needed for p < 50 GeV/c	Central tracker and solenoid Forward dipole/toroid TOF or Čerenkov
Forward proton/ion detection and measurement	Roman pots with timing
Forward neutron detection and measurement	0^0 calorimeter

J. Repond

Detector integration with the Interaction Region

Lessons learned from HERA

Possible to get ~100% acceptance for the whole event



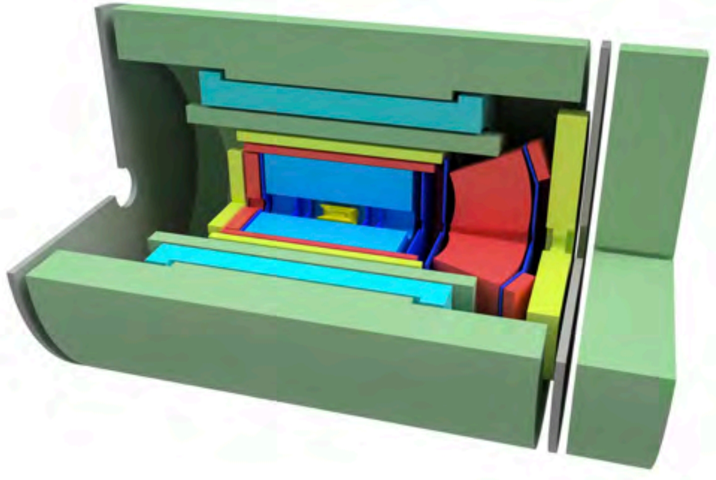
Total acceptance detector (and IR)

Crossing angles:
eRHIC: 10-22 mrad
JLEIC : 40-50 mrad

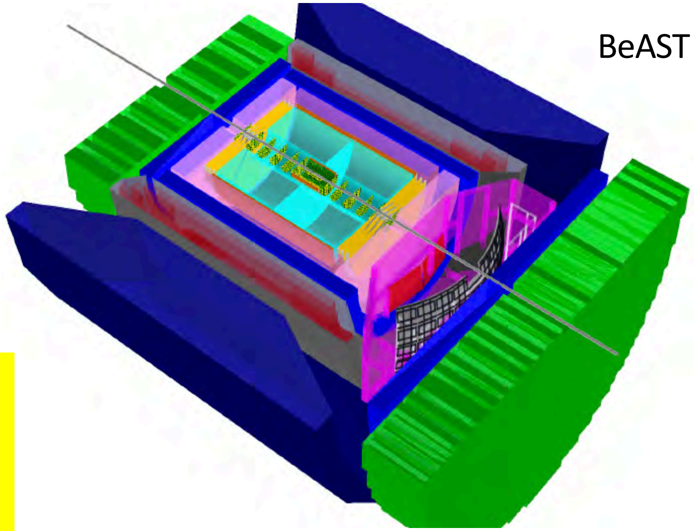
Figure Courtesey: Rik Yoshida

EIC Detector Concepts, others expected to emerge

EIC Day 1 detector, with BaBar Solenoid

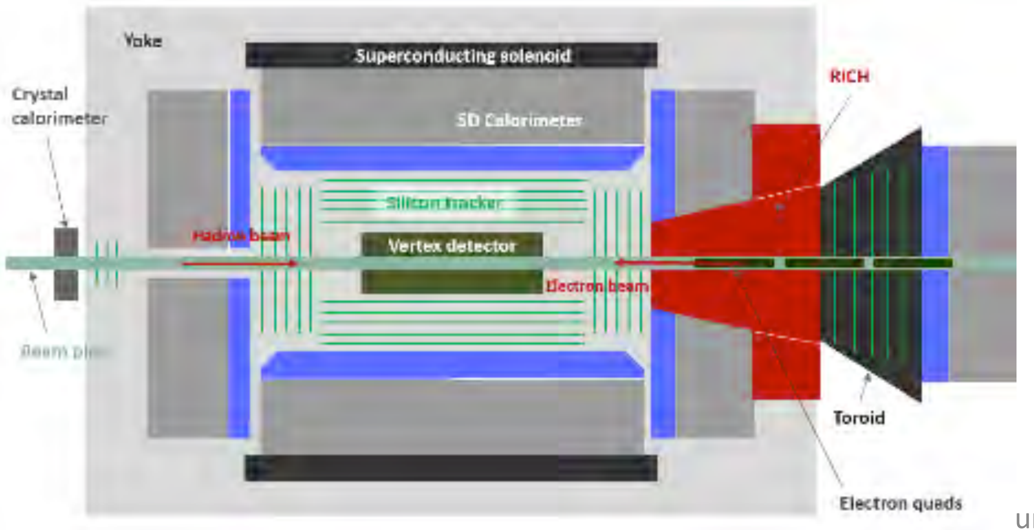


BeAST at BNL

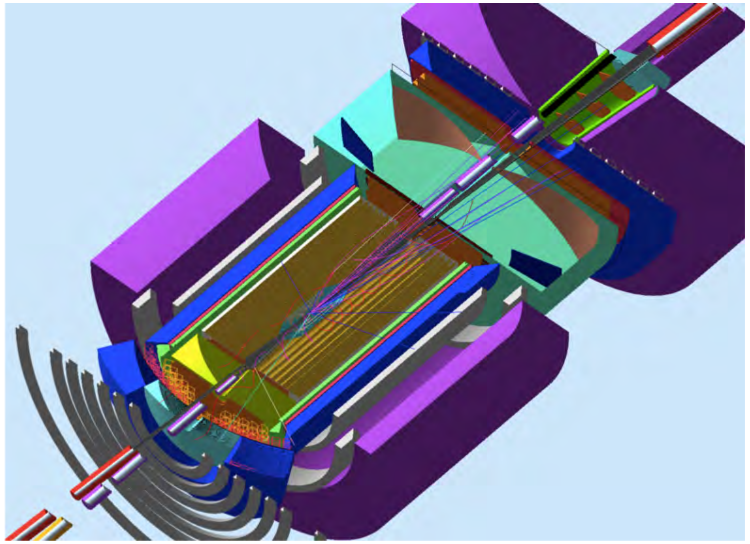


Ample opportunity and need for additional contributors and collaborators

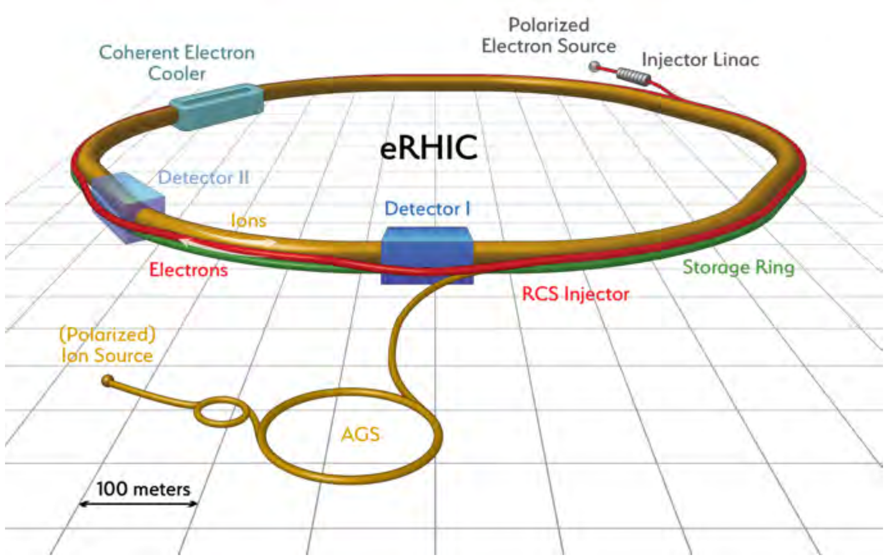
TOPSiDE: Time Optimized PID Silicon Detector for EIC

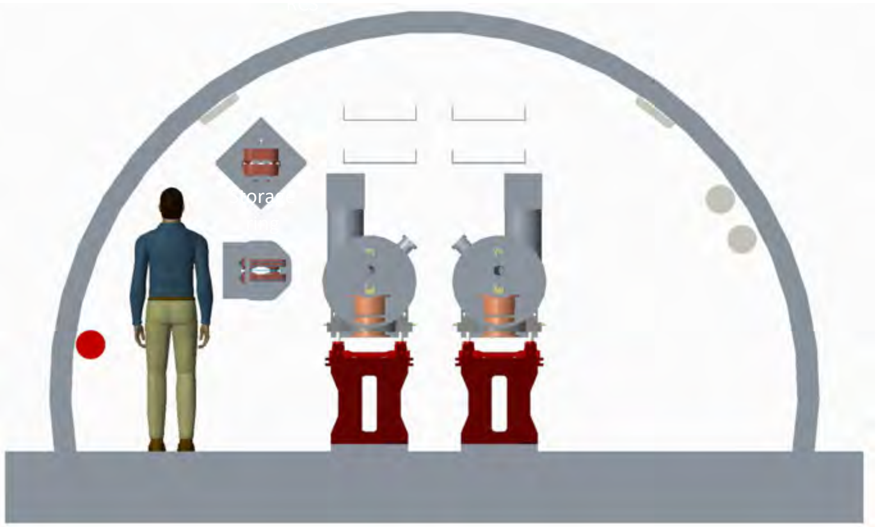


JLEIC Detector Concept, with CLEO Solenoid



pCDR eRHIC Design Concept





✧**Hadron Beam**

- ✧ entirely re-uses injection chain and one of RHIC rings (Yellow ring)
- ✧ partially re-uses components of other ion RHIC ring
- ✧ A $2.5B investment in RHIC is reused

✧**Electron Accelerator** added inside the existing RHIC tunnel:

- ✧ 5-18 GeV Storage Ring
- ✧ On-energy injector: 18 GeV Rapid Cycling Synchrotron
- ✧ Polarized electron source & 400 MeV injector LINAC: 10nC, 1 Hz

✧**Hadron cooling system** required for $L= 10^{34} cm^{-2} s^{-1}$
Without cooling the peak luminosity reaches $4.4 \ 10^{33} cm^{-2} s^{-1}$

✧Wide Center of mass energy: 29-140 GeV

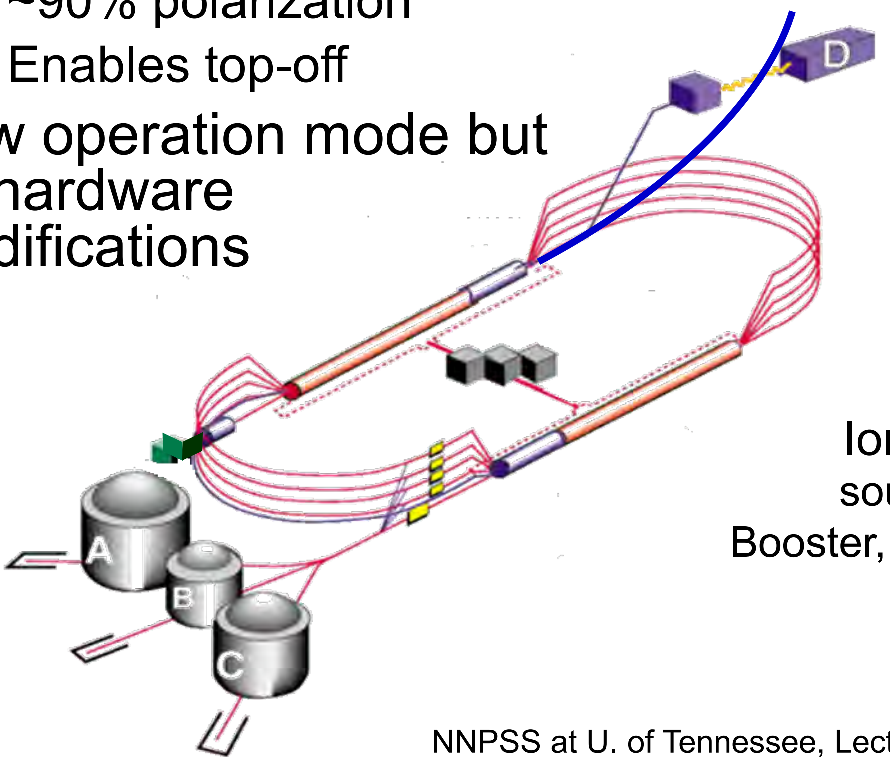
✧Large acceptance detectors integrated in the accelerator IR for forward particle detectors

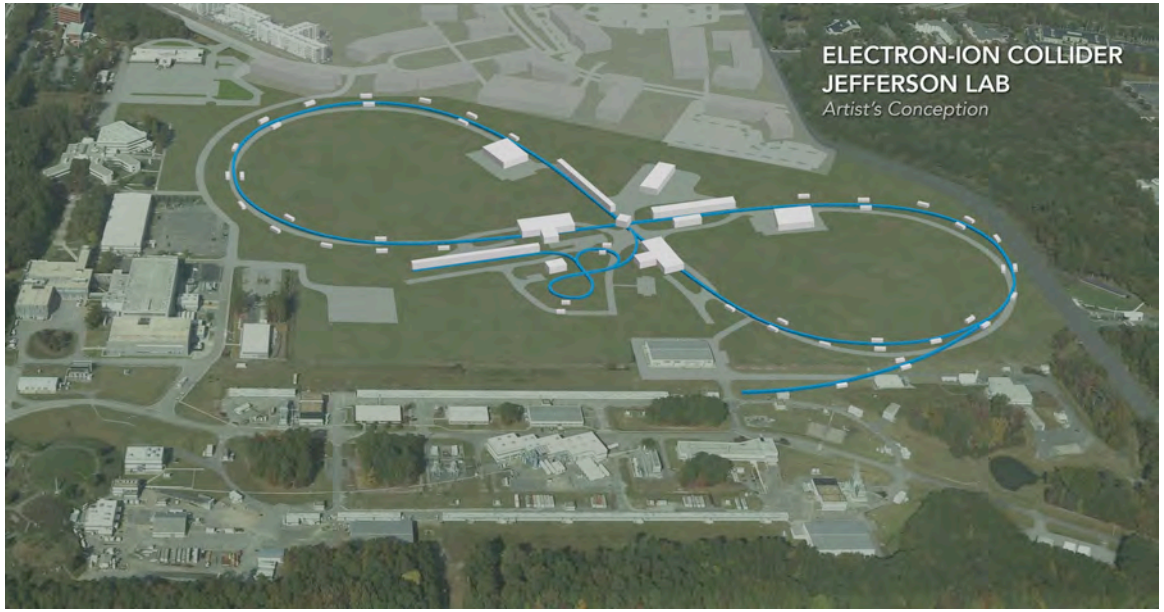
✧Polarized e, p, D and ^{3}He beams planned for the physics program

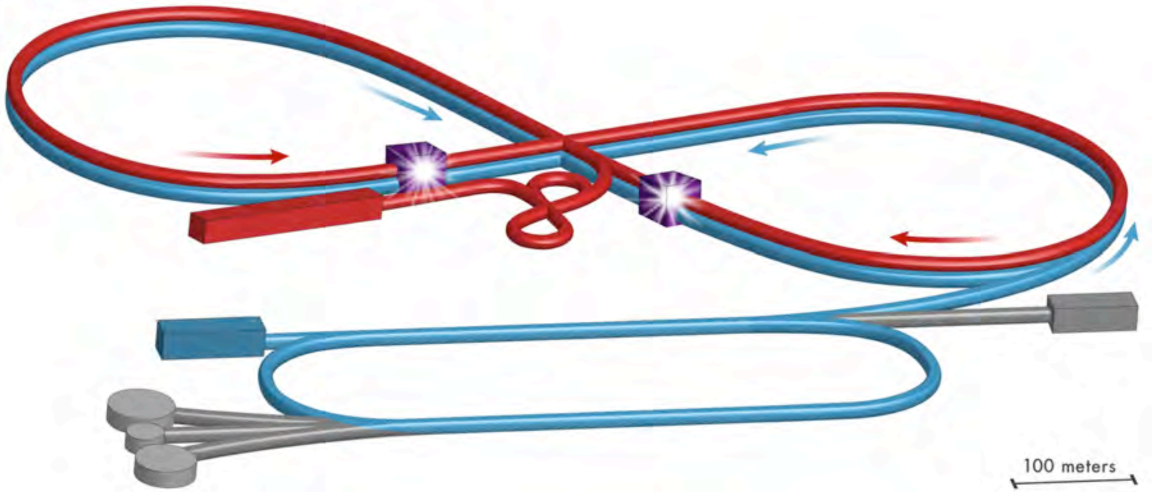
JLEIC electron-ion collider design – built up on CEBAF

- CEBAF extensive fixed-target science program
  - Fixed-target program compatible with concurrent JLEIC operations
- CEBAF 12 GeV : JLEIC injector
  - Fast fill of collider ring
  - Full energy
  - ~90% polarization
  - Enables top-off
- New operation mode but no hardware modifications

Up to 12 GeV to JLEIC







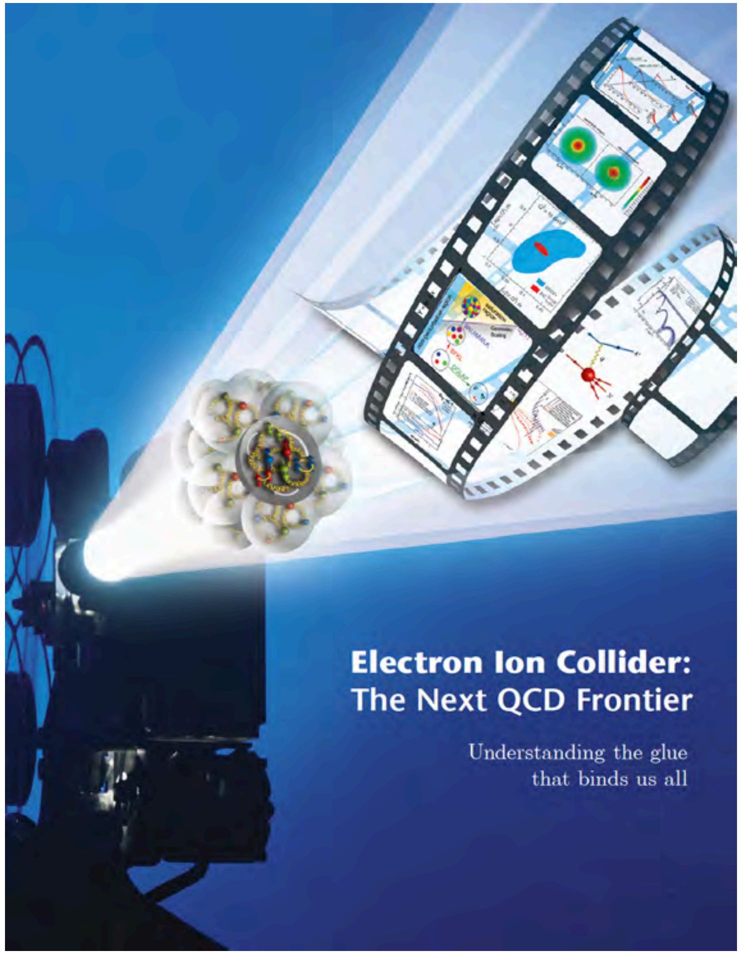
Ion complex: Ion source, SRF linac, Booster, Ion collider ring

Statement of Task from the Office of Science (DOE/NSF) to the

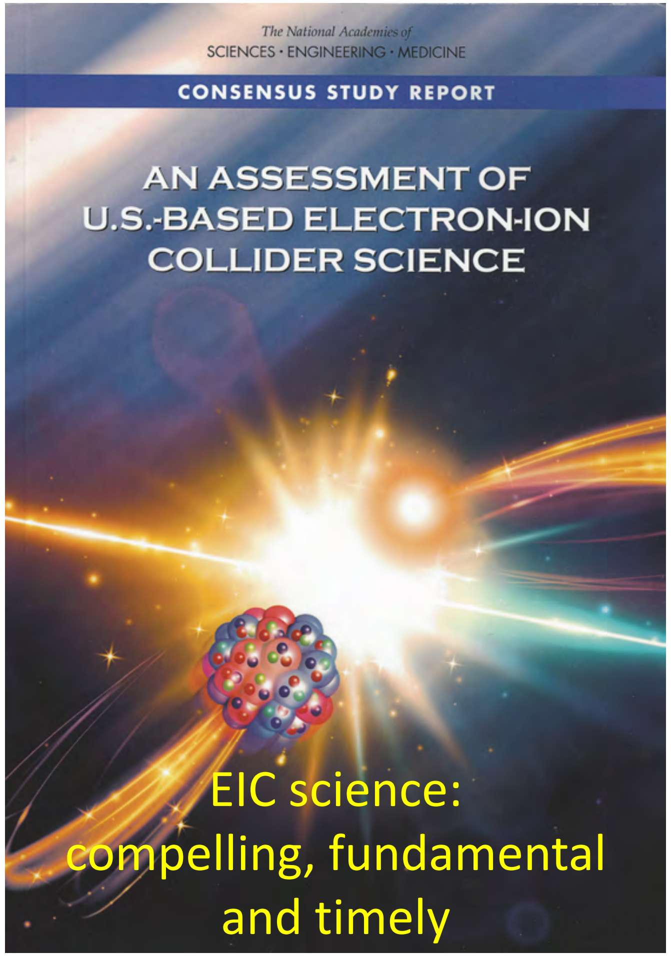
National Academy of Science, Engineering & Medicine (NAS)

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.

EIC Science Endorsed Unanimously by the NAS



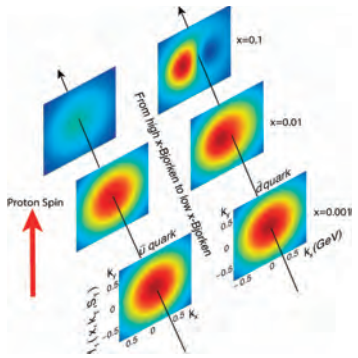
Developed by US QCD community over two decades



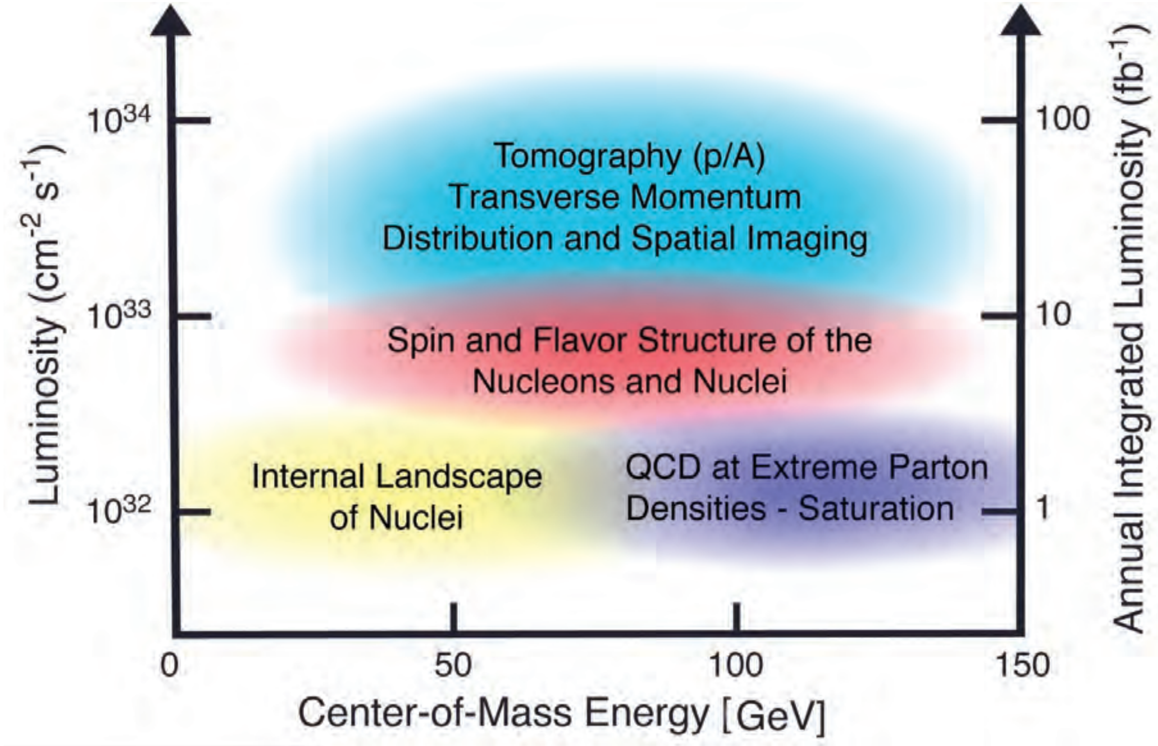
A consensus report
July 26, 2018

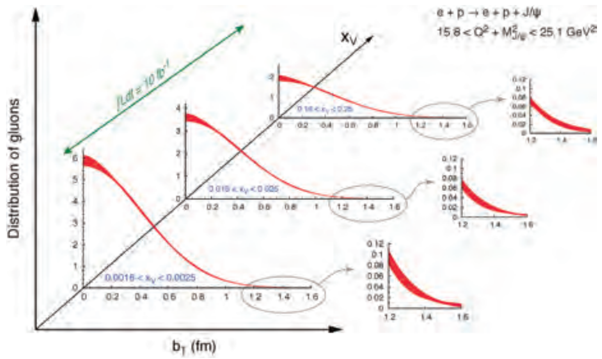
Developed by NAS with broad science perspective

EIC science and required luminosity

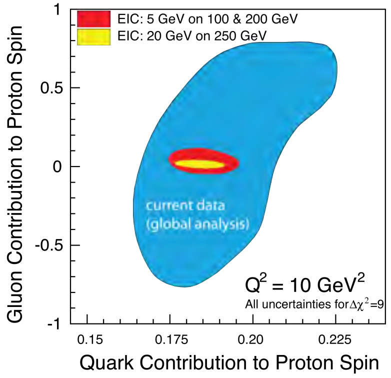


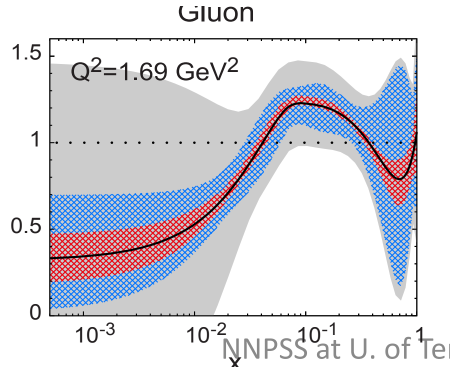
2+1D imaging of quarks and gluons, dynamics, and emergence of spin & mass

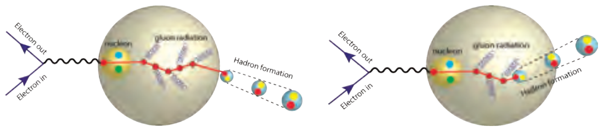




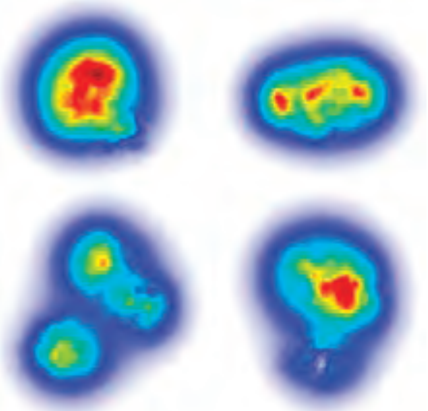
Gluon imaging in nucleons







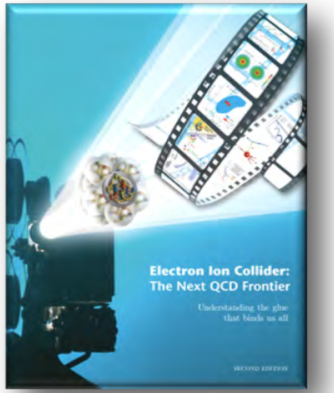
Color propagation, neutralization in nuclei & hadronization

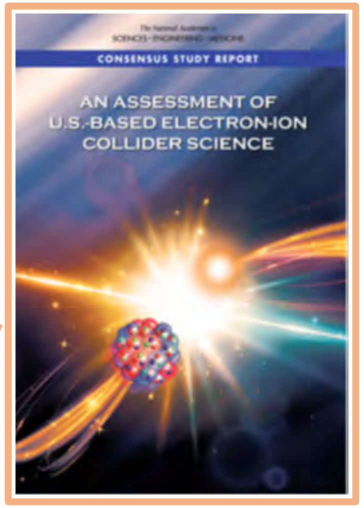


Gluons at high energy in nuclei:
(Gluon imaging in nuclei)

In order to definitively answer the compelling scientific questions elaborated in Chapter 2, including the origin of the mass and spin of the nucleon and probing the role of gluons in nuclei, a new accelerator facility is required, an electron-ion collider (EIC) with unprecedented capabilities beyond previous electron scattering programs. An EIC must enable the following:

- Extensive center-of-mass energy range, from ~20-~100 GeV, upgradable to ~140 GeV, to map the transition in nuclear properties from a dilute gas of quarks and gluons to saturated gluonic matter.
- Ion beams from deuterons to the heaviest stable nuclei.
- Luminosity on the order of 100 to 1,000 times higher than the earlier electron-proton collider Hadron-Electron Ring Accelerator (HERA) at Deutsches Elektronen-Synchrotron (DESY), to allow unprecedented three-dimensional (3D) imaging of the gluon and sea quark distributions in nucleons and nuclei.
- Spin-polarized (~70 percent at a minimum) electron and proton/light-ion beams to explore the correlations of gluon and sea quark distributions with the overall nucleon spin. Polarized colliding beams have been achieved before only at HERA (with electrons and positrons only) and Relativistic Heavy Ion Collider (RHIC; with protons only).





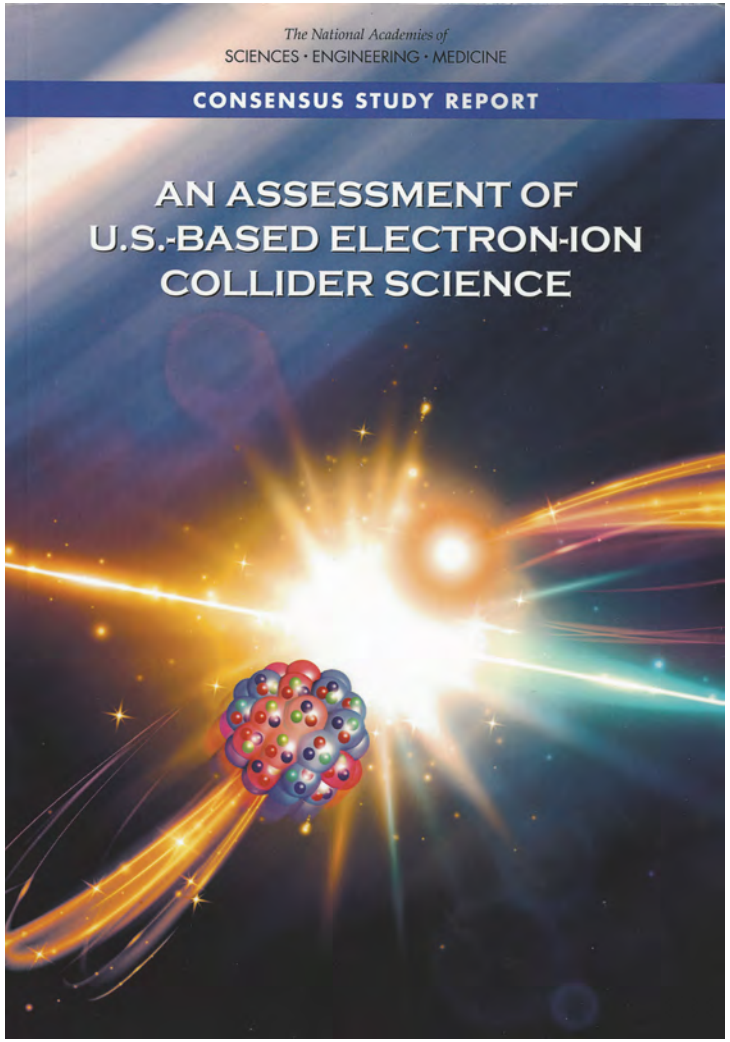
NAS Study endorses machine parameters suggested by the 2012 White Paper and 2015 NSAC Long Range Plan

National Academy's 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 3**: An EIC would be a unique facility in the world and would maintain U.S. leadership in nuclear physics.
- **Finding 4:** An EIC would maintain U.S. leadership in the accelerator science and technology of colliders and help to maintain scientific leadership more broadly.
- **Finding 5:** Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.

National Academy's Findings

- **Finding 6:** The current accelerator R&D program supported by DOE is crucial to addressing outstanding design challenges.
- **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.
- **Finding 8**: The U.S. nuclear science community has been thorough and thoughtful in its planning for the future, taking into account both science priorities and budgetary realities. Its 2015 Long Range Plan identifies the construction of a high-luminosity polarized EIC as the highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams (FRIB) at Michigan State University.
- **Finding 9:** The broader impacts of building an EIC in the United States are significant in related fields of science, including in particular the accelerator science and technology of colliders and workforce development.



Consensus Study Report on the US based Electron Ion Collider

Summary:

The science questions that an EIC will answer *are central* to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would *advance accelerator science and technology* in nuclear science; it would as well *benefit other fields of accelerator based science and society*, from medicine through materials science to elementary particle physics

Critical Decision Process DOE

PROJECT ACQUISITION PROCESS AND CRITICAL DECISIONS

Project Planning Phase		Project Execution Phase			Mission
Preconceptual Planning	Conceptual Design	Preliminary Design	Final Design	Construction	Operations

- **CD-0** Approve Mission Need
- **CD-1** Approve Preliminary Baseline Range
- **CD-2** Approve Performance Baseline
- **CD-3** Approve Start of Construction
- **CD-4** Approve Start of Operations or Project Closeout

Expected Soon (2019)

Technical feasibility (~2029)

CD-0	CD-1	CD-2	CD-3	CD-4
Actions Authorized by Critical Decision Approval				
• Proceed with conceptual design using program funds • Request PED funding	• Allow expenditure of PED funds for design	• Establish baseline budget for construction • Continue design • Request construction funding	• Approve expenditure of funds for construction	• Allow start of operations or project closeout

PED: Project Engineering & Design

Summary:

- Science of EIC: Gluons that bind us all… understanding their role in QCD
- The US EIC project has significant momentum on all fronts right now:
  - National Academy's positive evaluation → Science compelling, fundamental and timely
  - EIC Users Group is energized, active and enthusiast: organized
    - EICUG led working groups on polarimetry, luminosity measurement, IR design evolving
  - Funding agencies taking note of the momentum: not just in the US but also internationally
  - The science of EIC, technical designs (eRHIC and JLEIC) moving forward pre-conceptual design reports (Pre-CDRs) being prepared

- Center for Frontiers in Nuclear Science (CFNS) setup to support scientists world-wide hoping/planning to work on EIC science (http://www.stonybrook.edu/cfns) → Cite Non-Specific (eRHIC or JLEIC)
- EIC^2 at Jlab established in the JLEIC Users before research money becomes available

- **Exciting times ahead…. I hope many of you will join us and work on the theoretical and experimental aspects solving some of the most compelling, exciting and yet challenging problems in QCD**