Electron-Ion Collider for Nuclear and Particle Physics

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Input to this Talk

Abhay Deshpande's EICAC talk to Jefferson Lab Users
http://www.jlab.org/conferences/ugm/talks/Monday/Deshpande.pdf

Zein-Eddine Meziani's EICAC talk is at
https://indico.bnl.gov/getFile.py/access?contribId=0&resId=1&materialId=slides&confId=727

Richard Milner's talk at EIC14 is at
http://jacow.web.psi.ch/cgi-bin/conf/EIC2014/editor.zipdownload?paper_id=FRXAUD1&wanted_file=FRXAUD1_TALK.PDF&hcheck=481C104FDF7CBE67F07A01928399BB4B

Janwei Qiu EIC talk at Santa Fe QCD Evolution Conference:
http://www.jlab.org/conferences/qcd2014/monday-am/Jianwei_Qiu.pdf

Rolf Ent, talk at INFN, CSN I Meeting, Elba
https://agenda.infn.it/materialDisplay.py?subContId=1&contribId=16&sessionId=9&materialId=slides&confId=7567

Acknowledgements

I would like to acknowledge the efforts of many people, the conveners/authors of the White Paper, the authors of the talks cited on the previous pages from whom I took lots of material, the membership of the Electron Ion Collider Advisory Committee and colleagues Rolf Ent, Berndt Mueller, and Bob McKeown.

Framework

- Background – Current Program
- Electron Ion Collider – a QCD Laboratory
- Current status of Projects
- Political Status
- Summary

Current Program/Context

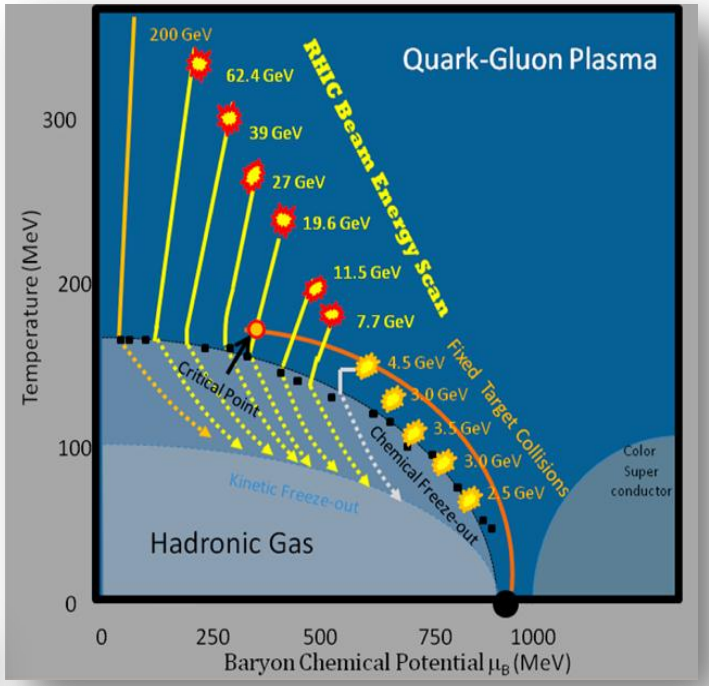
- RHIC Spin and Heavy Ion Programs
- FNAL (JPARC) Drell Yan program
- Compass Muon scattering
- Jefferson Lab 12 GeV

- Electron Ion Collider being considered by Brookhaven and Jefferson Lab communities.
- EIC Advisory Committee reports to both Labs.

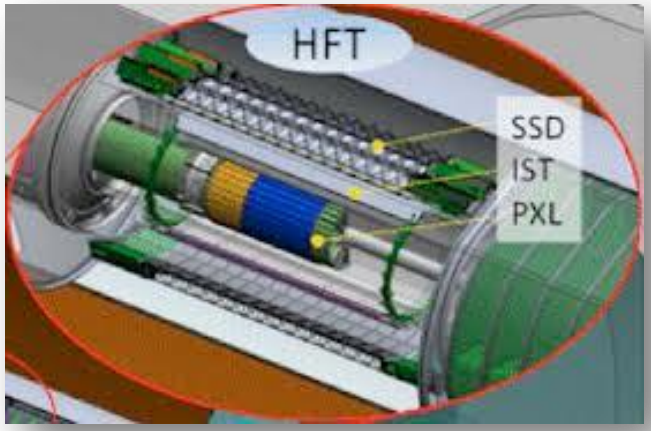
RHIC II Science Program

- RHIC-II upgrade complete
  - Luminosity upgrade via 3-D stochastic cooling
  - EBIS, 56MHz cavity, e-lenses, etc.
  - Si vertex detectors in STAR and PHENIX
- Install low energy e-cooling in 2017
- Install sPHENIX upgrade in 2020
- Complete the RHIC Mission in 3 campaigns:
  - 2014/15/16: Heavy flavor probes of the QGP
  - 2018/19: High intensity Beam Energy Scan II
  - 2021/22: Precision jet and quarkonium physics

Beam Energy Scan II



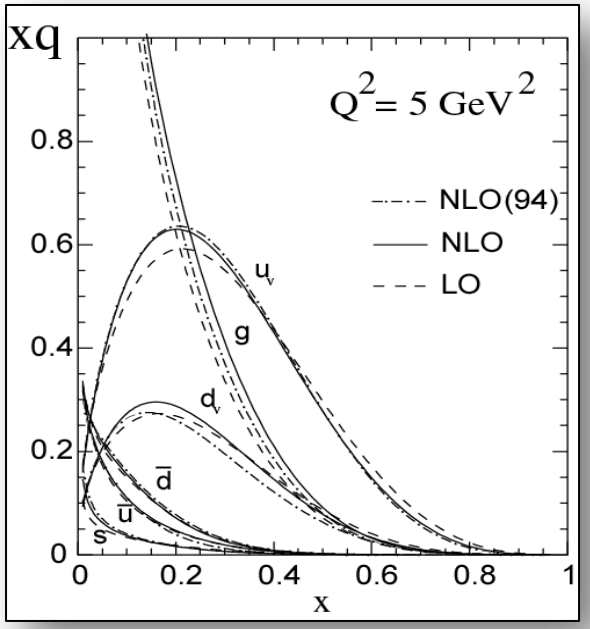
Heavy Flavor Tracker enables precision measurements of interactions of heavy quarks in the quark-gluon plasma



Low-energy e-cooling will improve statistics at $\sqrt{s} < 20$ GeV for high quality measurements of fluctuation properties in search of critical point in QCD phase diagram

Jefferson Lab CEBAF 12 GeV Physics

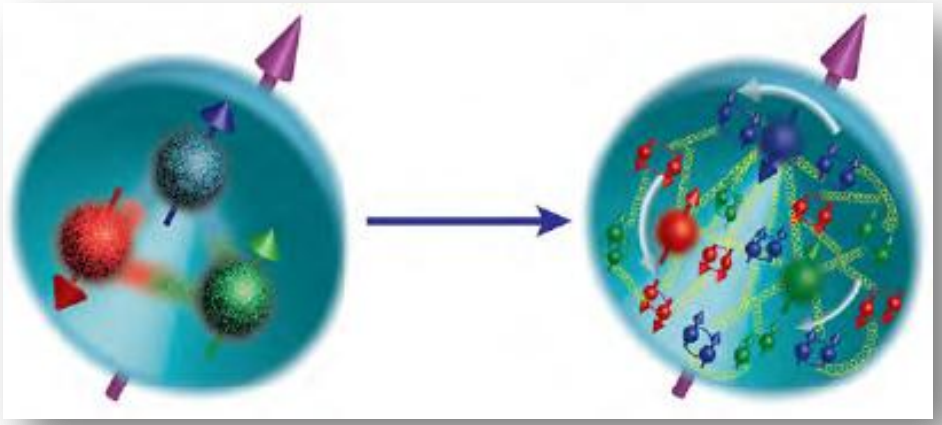
- The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)
- The transverse structure of the hadrons (Elastic and transition Form Factors)
- The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)
- The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)
- Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)
- Low-energy tests of the Standard Model and Fundamental Symmetries

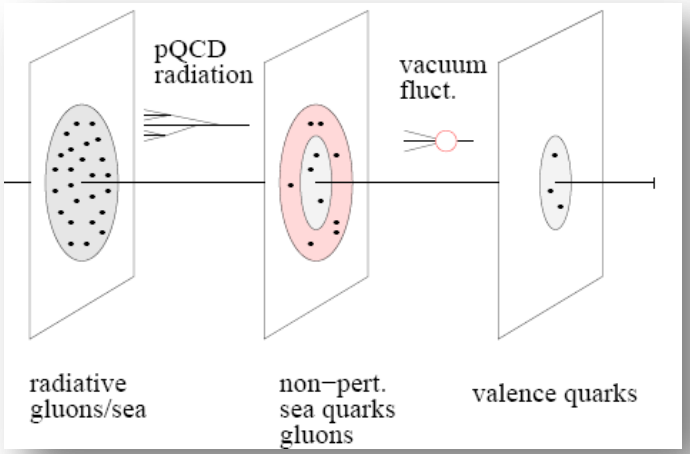


Valence Region

More than 7 years of approved program!

Electron Ion Collider: A QCD Laboratory

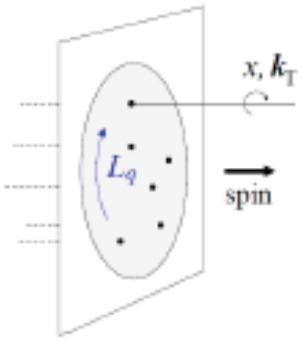




Understanding the "99%", the glue that binds us

- Tomography of the nucleus
- Gluon and sea quarks
  - spin
  - orbital angular momentum
- QCD at high gluon density
- Quark hadronization in depth
- [Ancillary Electro-weak program]

Multidimensional Parton Distributions



Theorists have developed a powerful formalism for studying the 3D partonic picture of the nucleon. It is encoded in **Generalized Parton Distributions** and **Transverse Momentum Dependent Distributions**

Wigner distribution

$W(\mathbf{p}, \mathbf{x})$

Transverse Momentum Dependent distributions

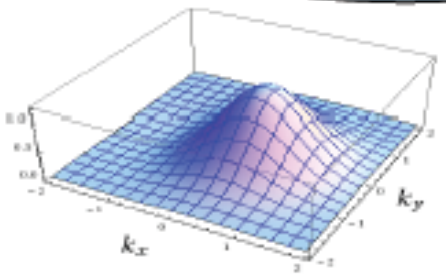
d^3r

d^3p

Generalized Parton Distributions

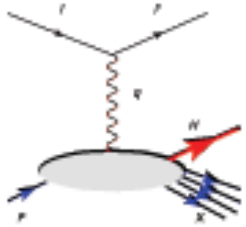
$f(x, \mathbf{k}_\perp)$

$H(x, \xi, t)$

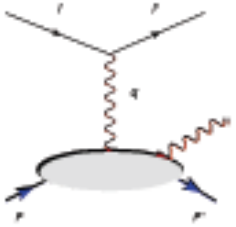


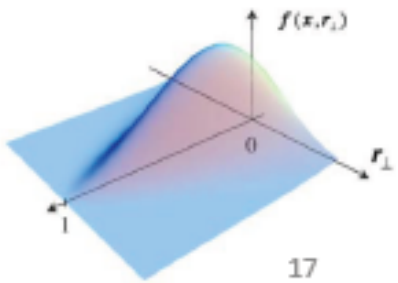
Richard Milner

SIDIS



DES





EIC 2014

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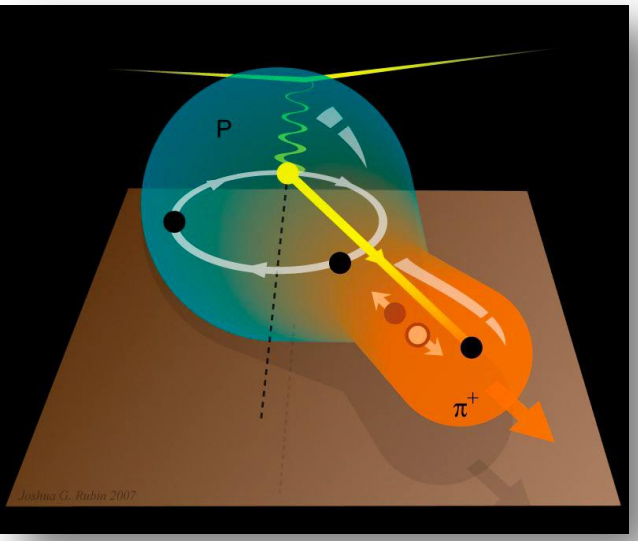
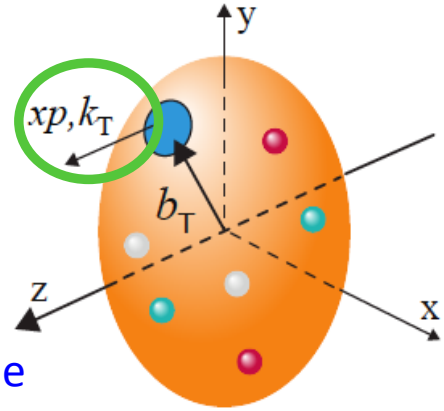
Semi-Inclusive DIS ➔ Transverse Momentum



- 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*

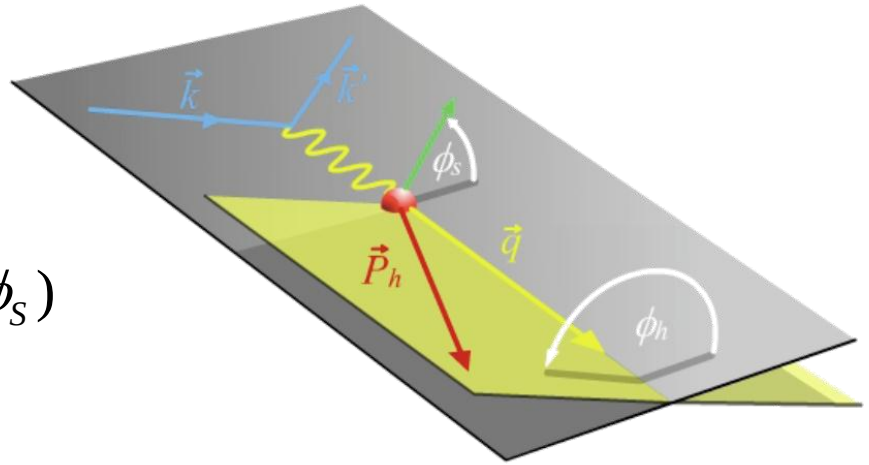


- Naturally, two planes:

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

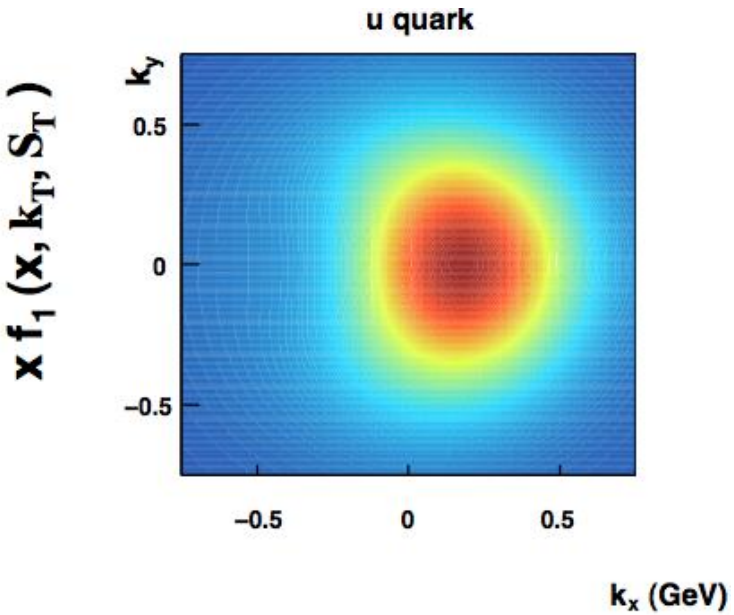
$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

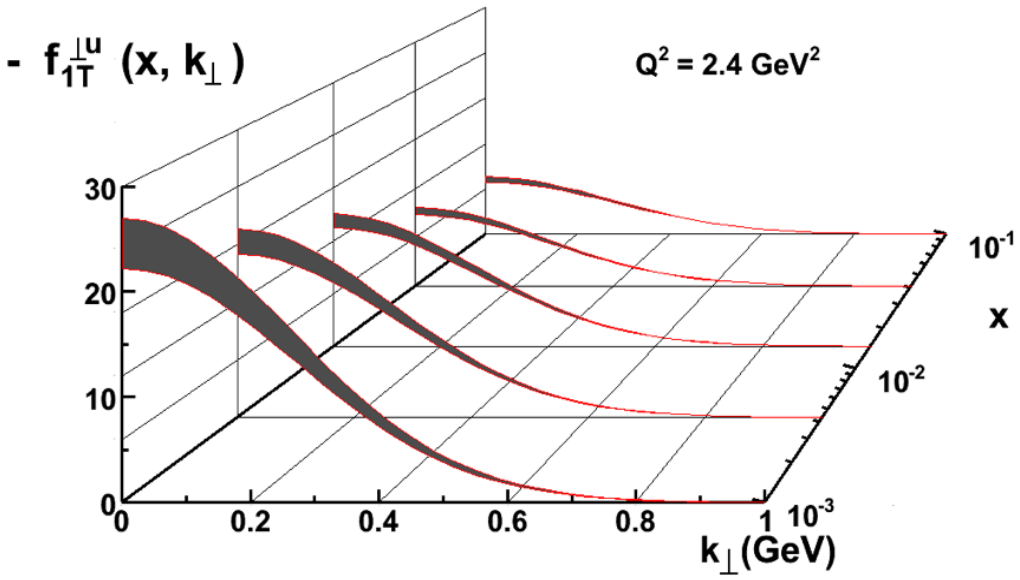
$$+ A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S)$$



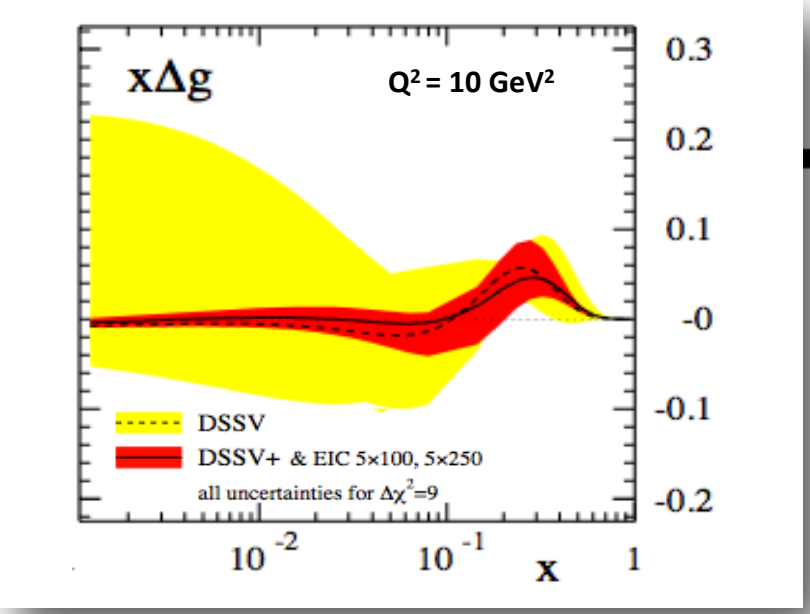
Nucleon Tomography

- Tomographic images of K_X/K_y of partons as functions of Bjorken-x: u quark distribution for transversely polarized proton.
- ***With EIC: low x partonic plots like these are possible!***



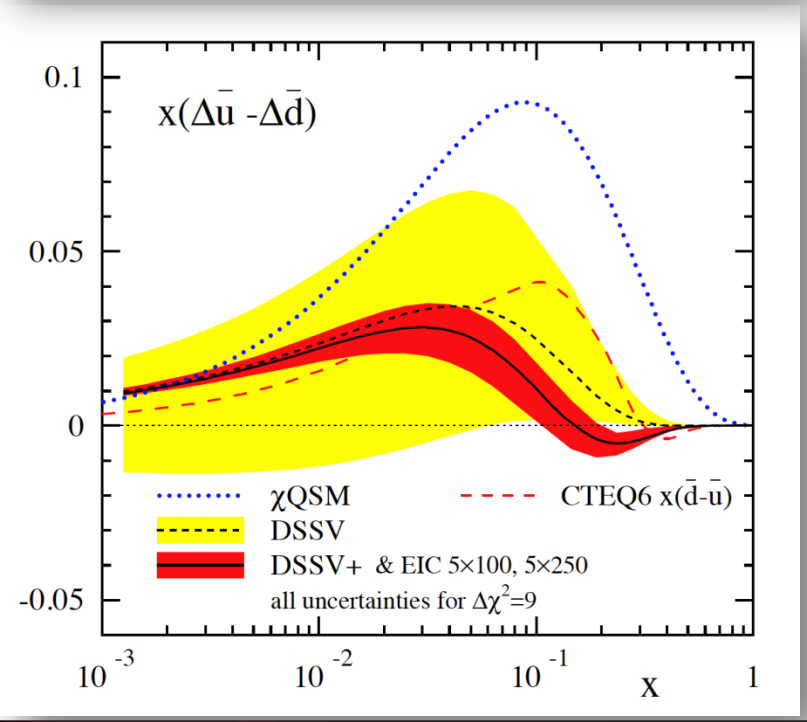


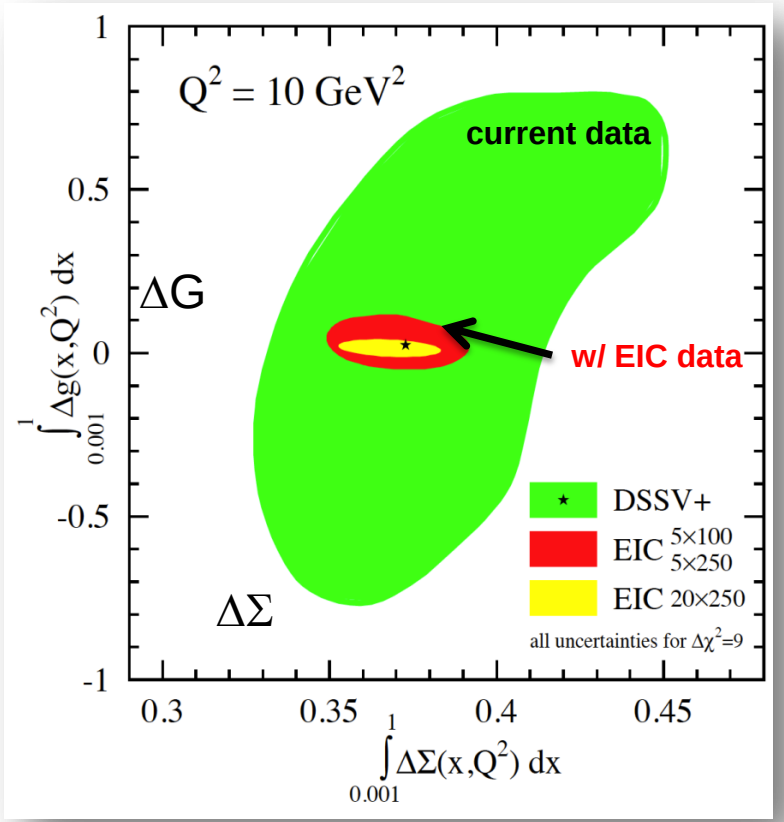
Helicity PDFs at an EIC



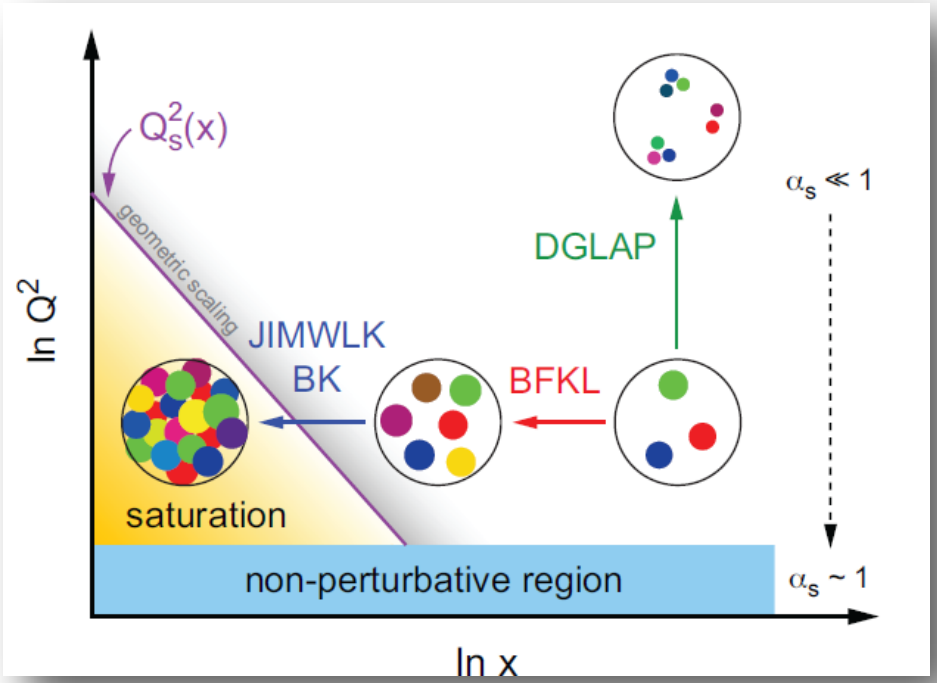
A Polarized EIC:

- Tremendous improvement on ΔG
- Good improvement in ΔΣ
- Spin Flavor decomposition of the Light Quark Sea

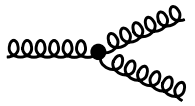




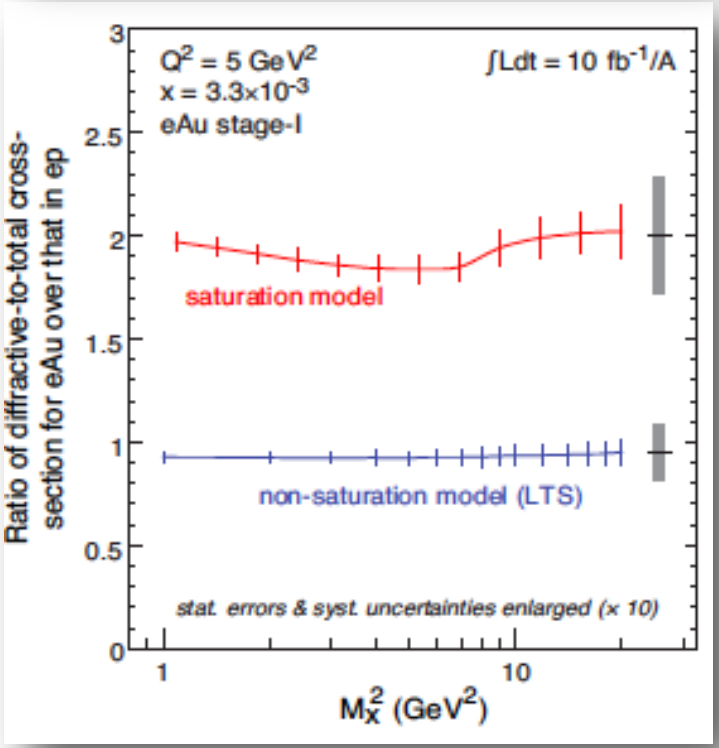
Gluon Saturation



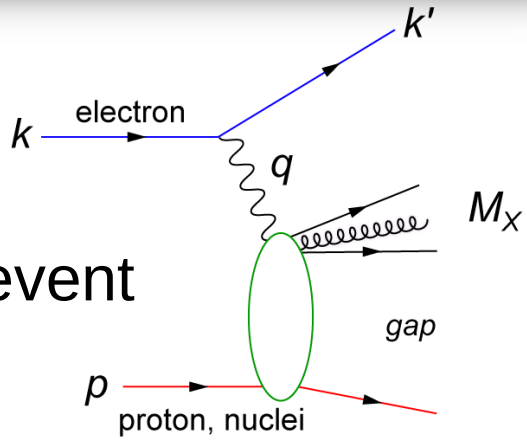
Radiation



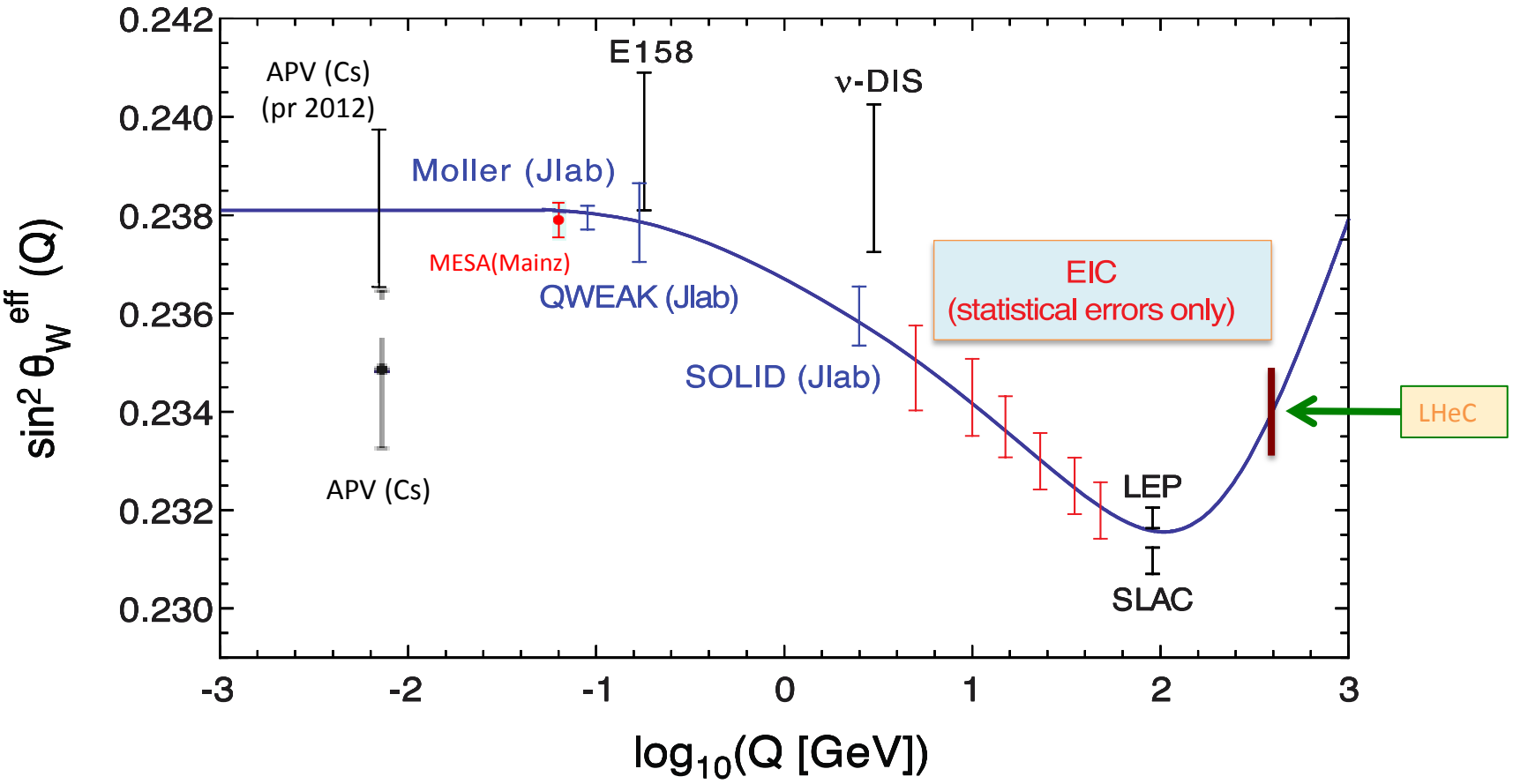
Recombination



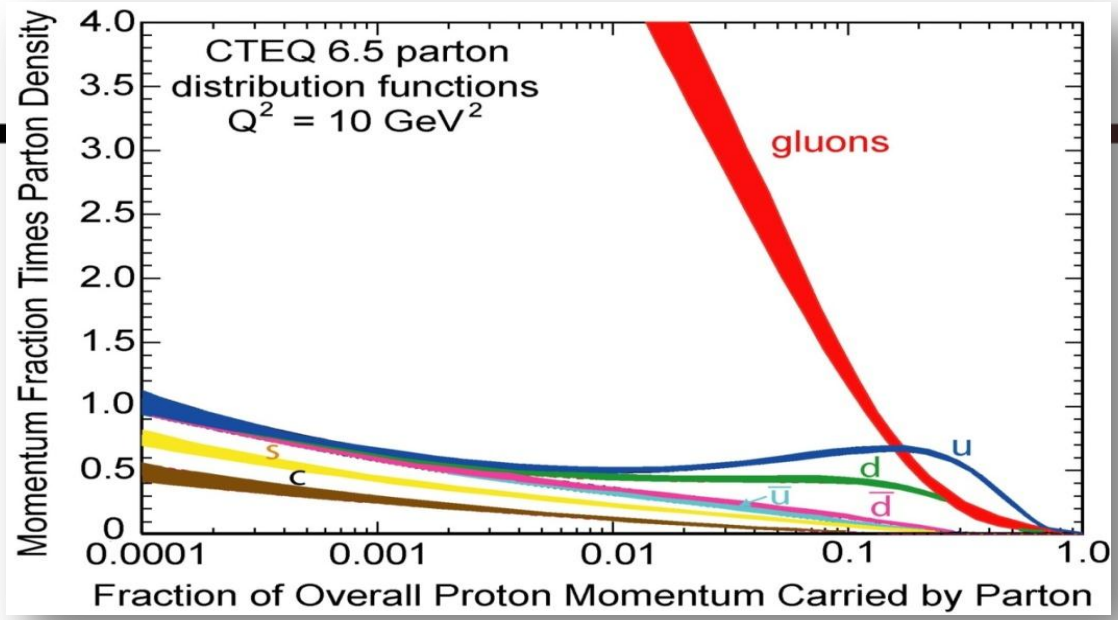
Diffractive event

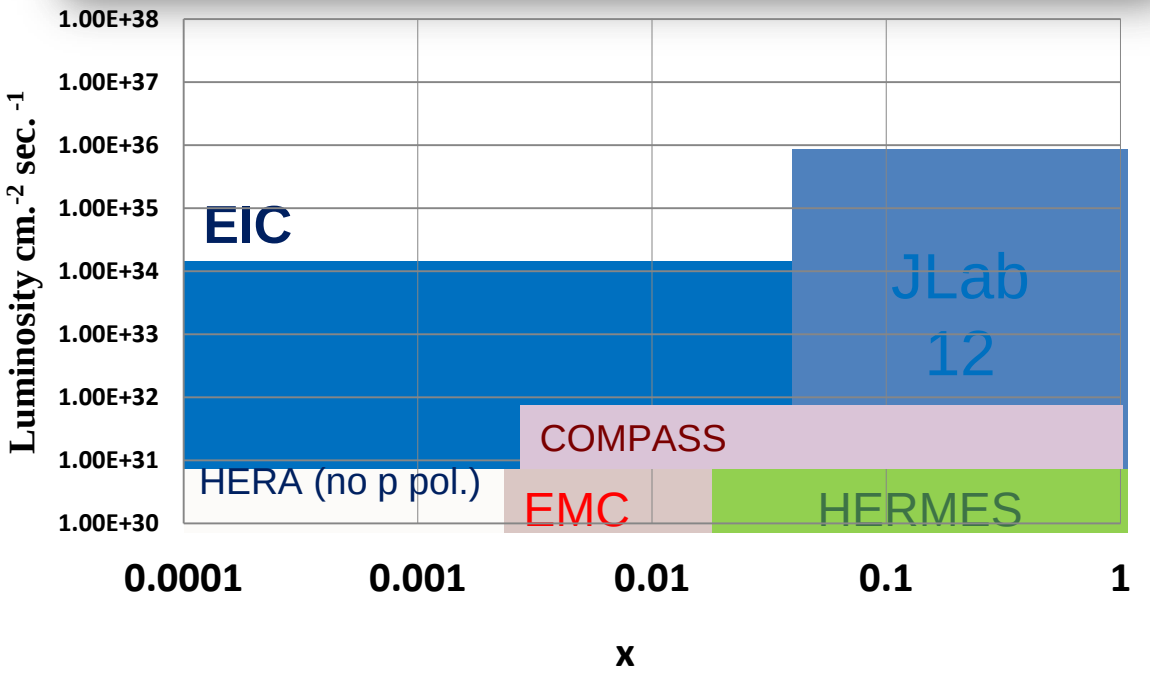


Electroweak Physics



The Reach of EIC





- High Luminosity
  → 10^{34} cm^{-2}s^{-1}
- Low x regime
  x → 0.0001
- High Polarization
  → 70%

Discovery Potential!

Electron Ion Colliders

Past

Possible Future

	Europe	US		China	Europe
		EIC		CEIC	
	HERA@DESY	LHeC@CERN	eRHIC@BNL	MEIC@JLab	HIAF@CAS	ENC@GSI
E_{CM} (GeV)	320	800-1300	70-150	12-70 → 140	12 → 65	14
proton x_{min}	1×10^{-5}	5×10^{-7}	4×10^{-5}	5×10^{-5}	7×10^{-3} → 3×10^{-4}	5×10^{-3}
ion	p	p to Pb	p to U	p to Pb	p to U	p to ~^{40}Ca
polarization	-	-	p, ^{3}He	p, d, ^{3}He (^{6}Li)	p, d, ^{3}He	p,d
L [cm^{-2} s^{-1}]	2×10^{31}	$10^{33\text{-}34}$	10^{33} → 10^{34}	$10^{34\text{-}35}$	$10^{32\text{-}33}$ → 10^{35}	10^{32}
IP	2	1	2+	2+	1	1
Year	1992-2007	2025?	2025	2025	2019 → 2030	upgrade to FAIR
		Followed by FCC-he?		Figure-8 layout	Figure-8 layout	Not Active

High-Energy Physics

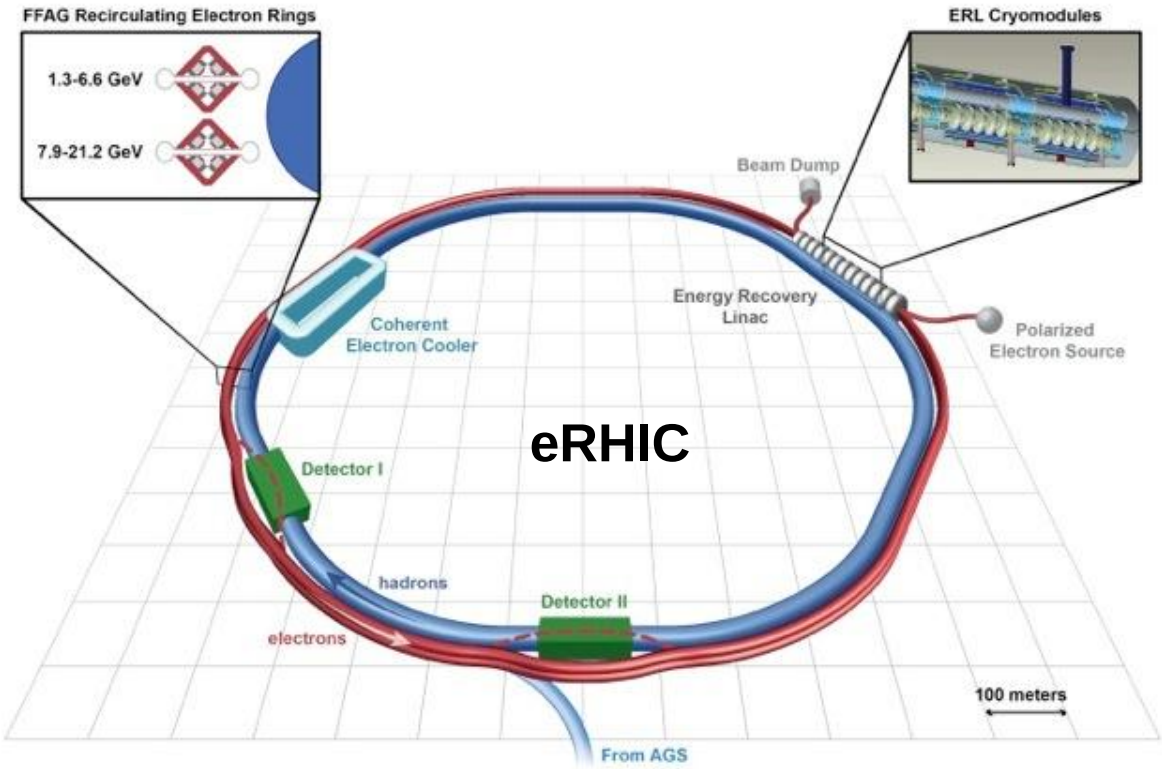
Hadron Physics

Note: x_{min} ~ x @ Q^2 = 1 GeV^2

BNL's EIC Concept

eRHIC ERL + FFAG ring design @ $10^{33}/cm^2s$

15.9 GeV e^- + 255 GeV p or 100 GeV/u Au.



ePHENIX and eSTAR Letters of Intent

When completed, eRHIC will be the most advanced and energy efficient accelerator in the world

EIC at Jefferson Lab

Jefferson Lab Design

- 12 GeV CEBAF is electron injector
- Figure 8 → high polarization
- Crab crossing → high luminosity
- Initial configuration (MEIC):
  3-12 GeV on 20-100 GeV ep/eA collider
- Upgradable to higher energies
  250 GeV protons + 20 GeV electrons

Present Activities

- Site evaluation
- Design optimization
- Accelerator, detector R&D
- Cost estimation

Electron Ion Collider

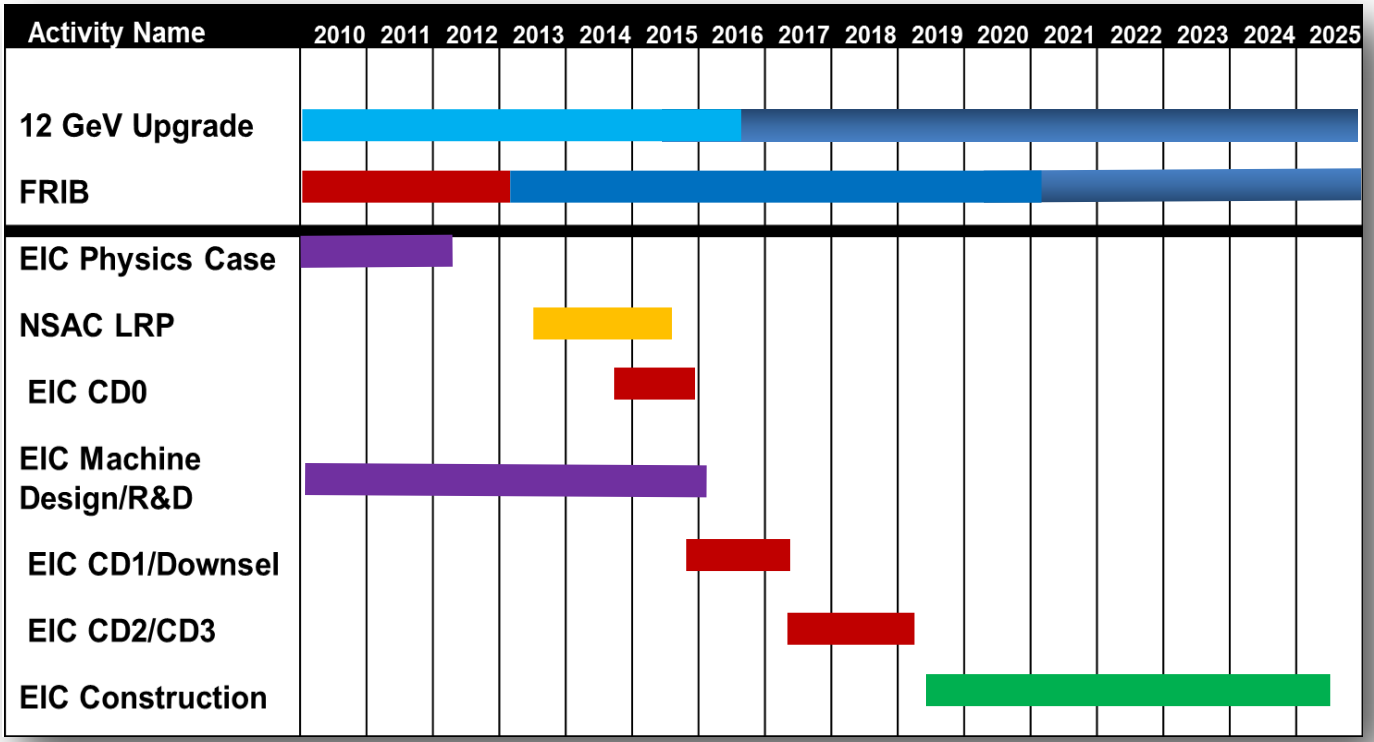
Energy 20 – ~100 GeV

High Luminosity → 10^{33} - 10^{34} cm^2s^{-1}

Low x regime x → 0.0001

High polarizations 70%

Ion beams up to U or PB



Electron Ion Collider White Paper

Overall Editors:
A. Deshpande (Stony Brook), Z-E. Meziani (Temple), J. Qiu (BNL)

Gluon Saturation in e+A:
T. Ullrich (BNL) and Y. Kovchegov (Ohio State)

Nucleon spin structure (inclusive e+N):
E. Sichtermann (LBNL) and W. Vogelsang (Tübingen)

GPD's and exclusive reactions:
M. Diehl (DESY) and F. Sabatie (Saclay)

TMD's and hadronization and SIDIS:
H. Gao (Duke) and F. Yuan (LBNL)

Parton Propagation in Nuclear Medium:
W. Brooks (TSFM) and J. Qiu(BNL)

Electroweak physics:
K. Kumar (U Mass) and M. Ramsey-Musolf (Wisconsin)

Accelerator design and challenges:
A. Hutton (JLab) and T. Roser (BNL)

Detector design and challenges:
E. Aschenauer (BNL) and T. Horn (CUA)

Senior Advisors:
A. Mueller (Columbia) and R. Holt (ANL)

Successful thanks to many other co-authors and contributions

EIC Developments

- NSAC Long Range Plan (2007)
  - EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities.
- NSAC Facilities Report (Redwine - 2013)
  - EIC absolutely central to future Nuclear Physics
- EICAC meeting (2/28-3/1 2014, BNL)
- EIC14 Accelerator workshop at Jefferson Lab (Mar 17-21, 2014)
- EIC Users Meeting SUNY Stony Brook, (June 24-27, 2014)
  - http://skipper.physics.sunysb.edu/~eicug/meetings/SBU.html
- NSAC Long Range Plan is considering EIC (2014-2015)

Why We Need EIC

- HERA discovered a very large abundance of soft gluons inside the proton. However, the role of gluons in nucleon structure and dynamics is still unclear.

- The origin of nucleon spin and the distributions of quarks and gluons in nuclei remain mysteries after decades of study.

- We have new phenomenology to explore nucleon structure: Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent (TMDs) distributions that provide powerful “imaging” of quarks and gluons and access to orbital angular momentum. These studies will require high luminosity and polarized beams.

- A new facility, EIC, with a versatile range of kinematics, beam polarizations, and beam species, is required to precisely image the sea quarks and gluons in nucleons and nuclei, to explore the new QCD frontier of strong color fields in nuclei, and to resolve outstanding issues in understanding nucleons and nuclei in terms of QCD.

Conclusions

- An Electron Ion Collider is a natural next step in the exploration of the structure of matter and its theory, QCD
- There is a broad consensus with respect to the essential physics parameters:
  - High Polarization
  - High Luminosity
  - Moderate energy
- The physics goals are accessible
- An appropriate machine is buildable
- The US Nuclear Physics Long Range Plan process is considering this issue.
- International participation in the plan for the physics and the construction of the machine and detectors would be welcome.