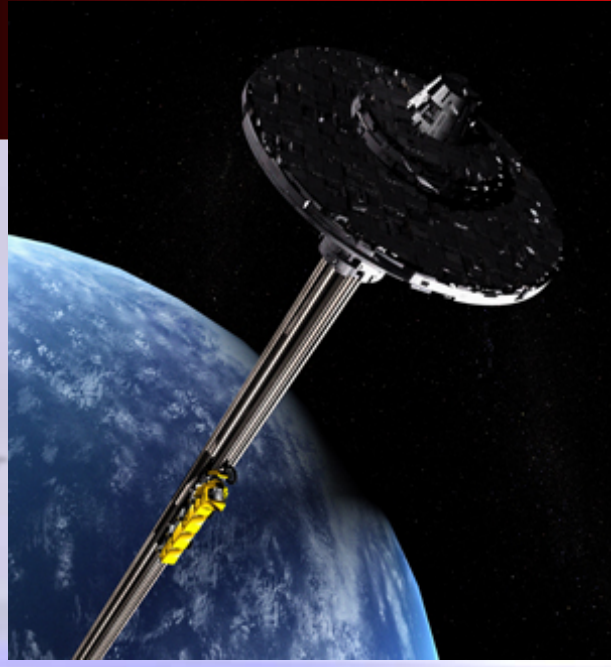
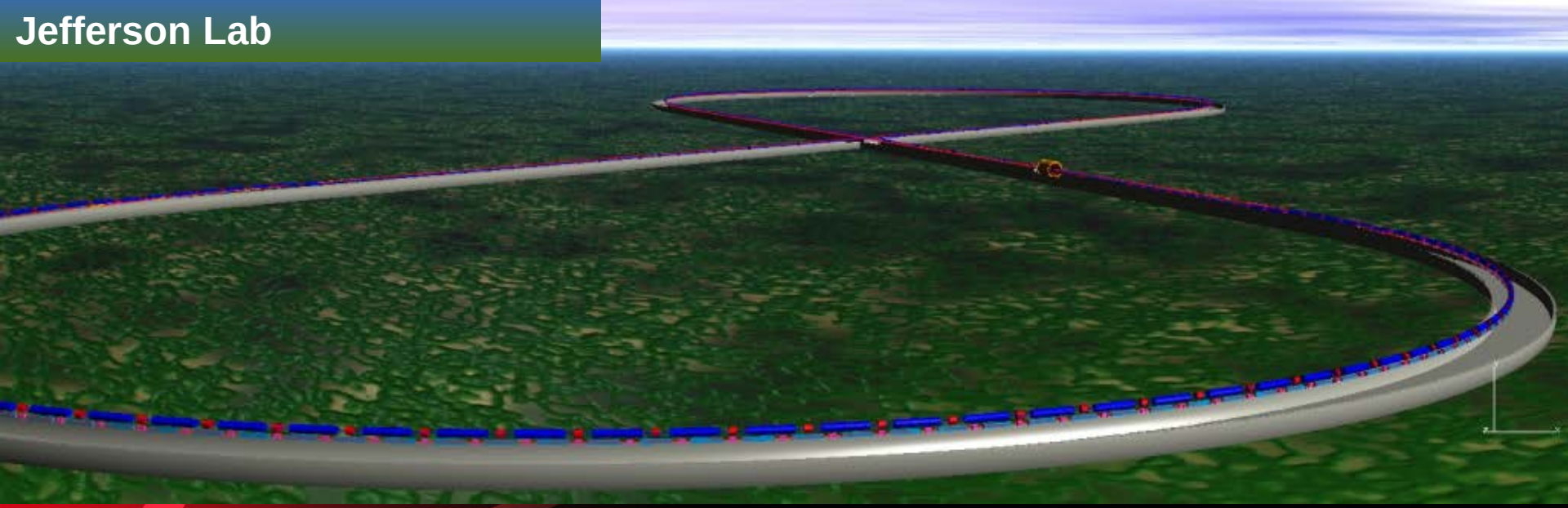
U.S. DEPARTMENT OF ENERGY | Office of Science | JSA



Why we need an EIC: the view from 10,000 meters

R. D. McKeown
Jefferson Lab



QCD Town Meeting
Sept. 13, 2014

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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.

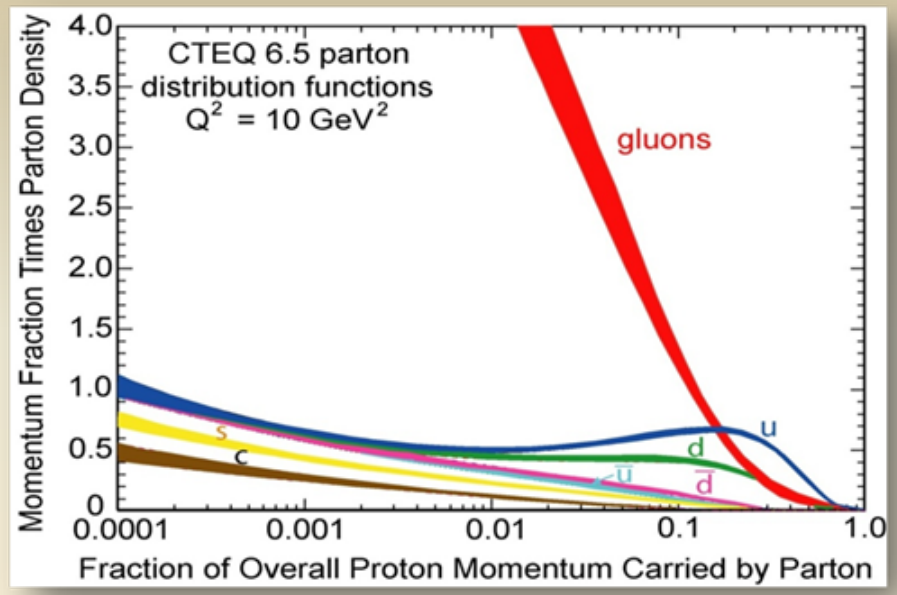
- We have new phenomenology to explore nucleon structure: Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent (TMDs) distributions that provide powerful “imaging” of quarks and gluons and access to orbital angular momentum. These studies will require high luminosity and polarized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

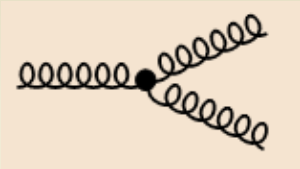
Science Questions

- What is the transverse spatial and momentum structure of the gluons and sea quarks? Are there non-perturbative structures and can one image them?
- How much do the gluons contribute to the nucleon spin? Is there significant orbital angular momentum?
- How is the gluon distribution in nuclei different than in the nucleon? How does this relate to nuclear binding or short range nucleon-nucleon correlations?
- Can one find evidence for saturation of the gluon density?
- How do quarks and gluons propagate in nuclear matter and join together to form hadrons?

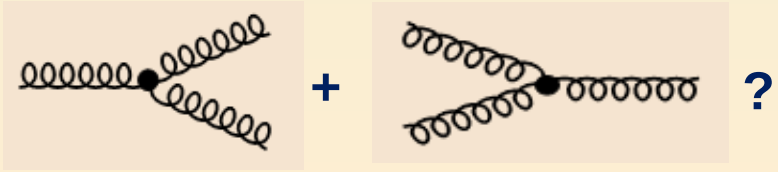
Present Knowledge



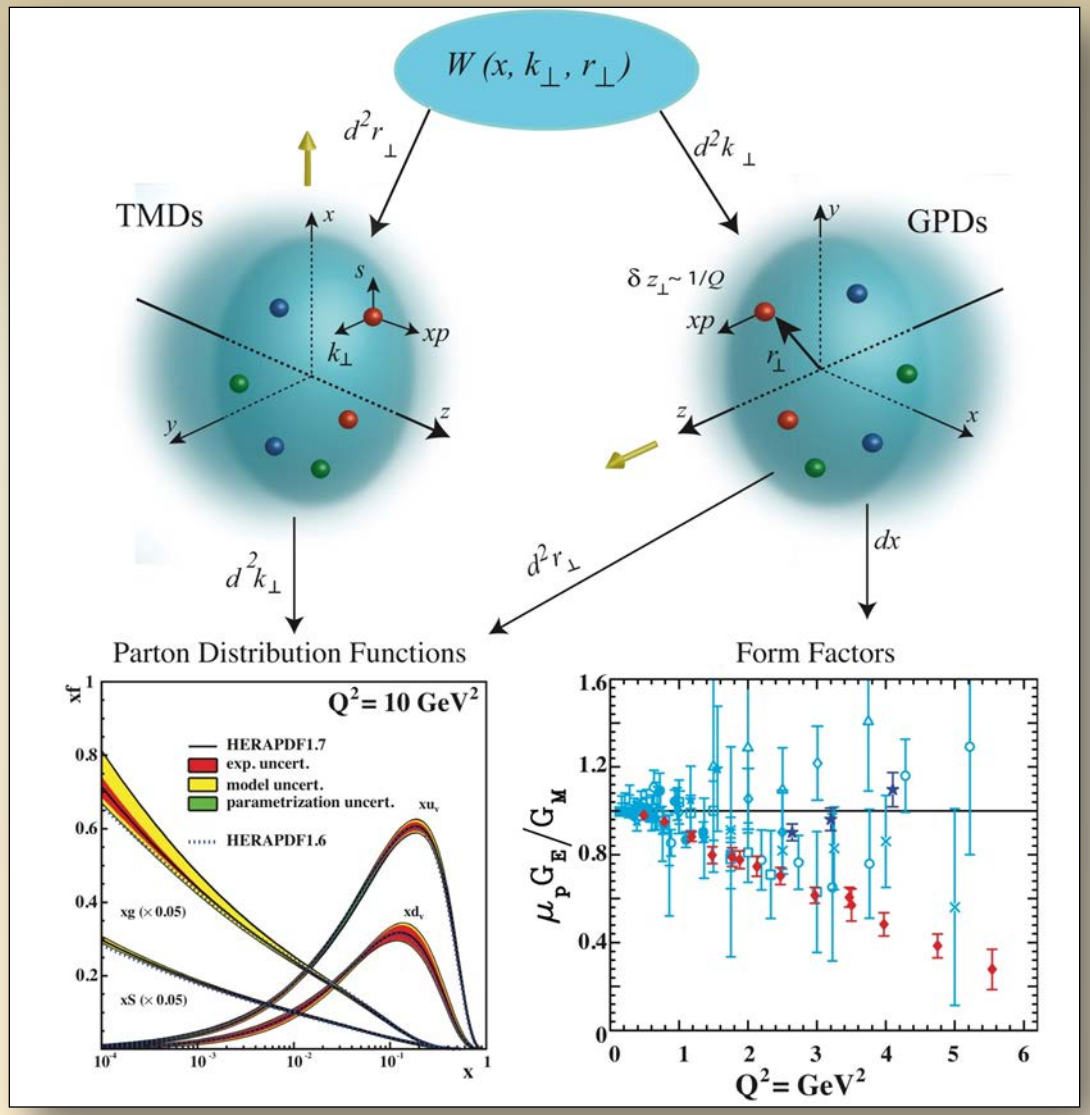
- Dramatic rise in gluon distribution discovered at HERA in 1990's.



- Gluon splitting drives the dynamics at x<0.1
- Otherwise the low x region is essentially unexplored.
- Generally expect saturation at lower x where high gluon density drives recombination – but where?



New Paradigm for Nucleon Structure



- **JLab12**
  3D imaging of valence quarks
- **EIC**
  3D imaging of sea and gluons

- **TMDs**
  - **Confined motion in a nucleon (semi-inclusive DIS)**
- **GPDs**
  - **Spatial imaging (exclusive DIS)**

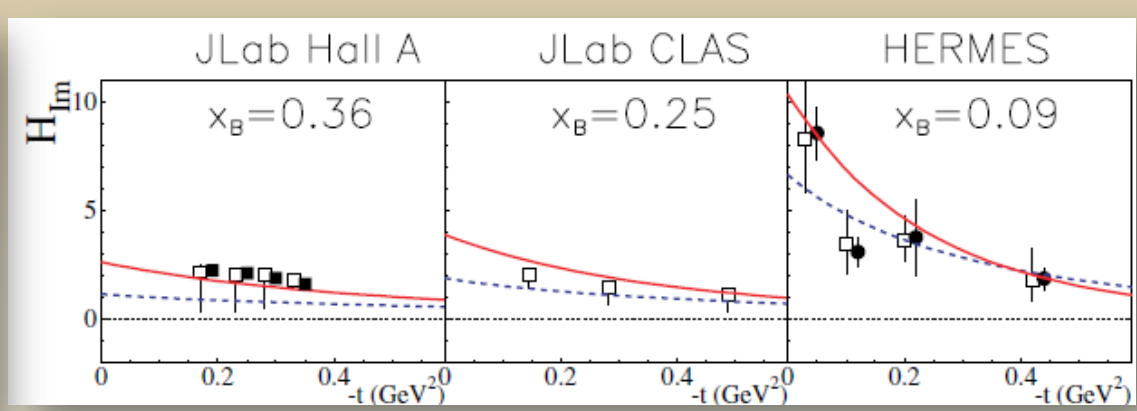
The First Crude Images

the GPD H in *Im* DVCS

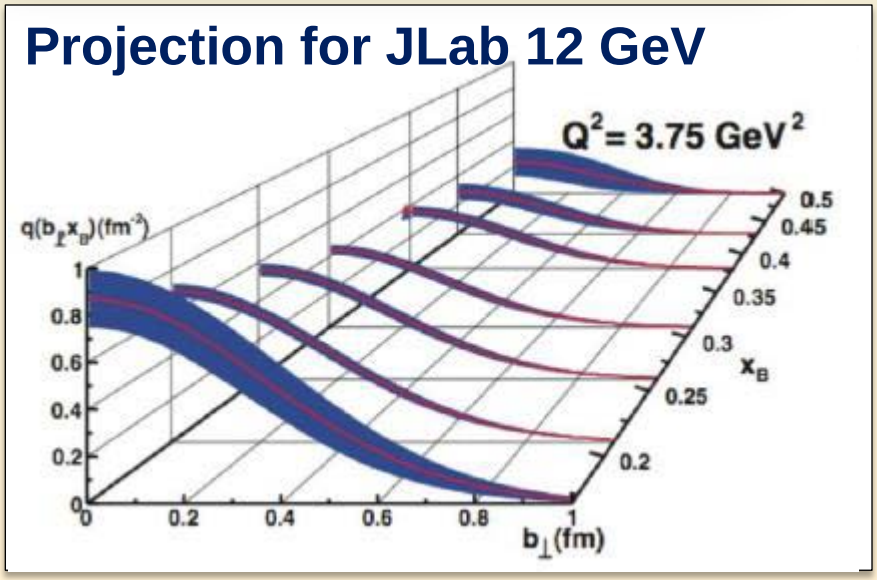
●○■□ Different local fits

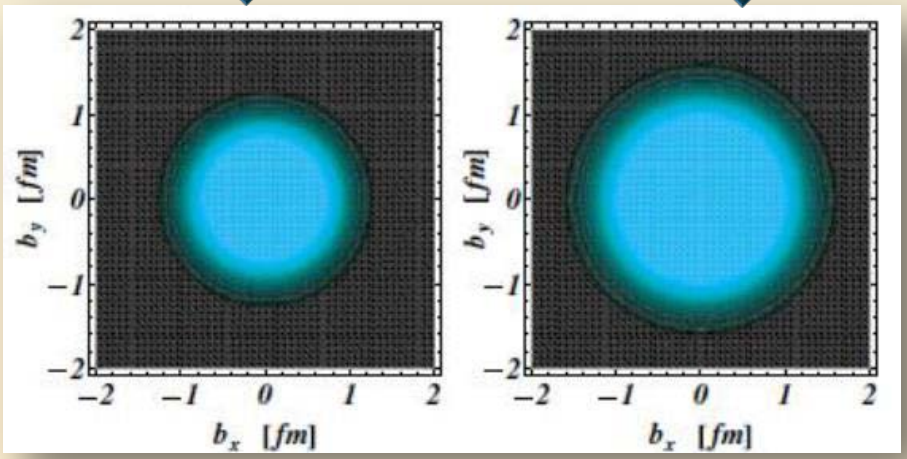
VGG model

KM10 global fit on the world data ranging from H1,ZEUS to HERMES, JLab

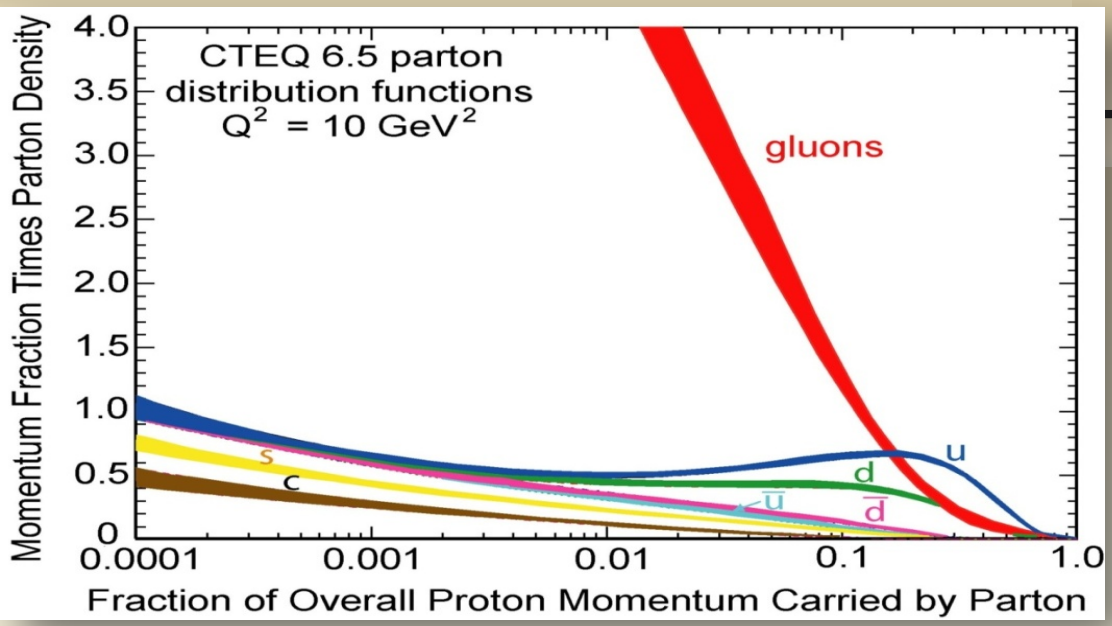


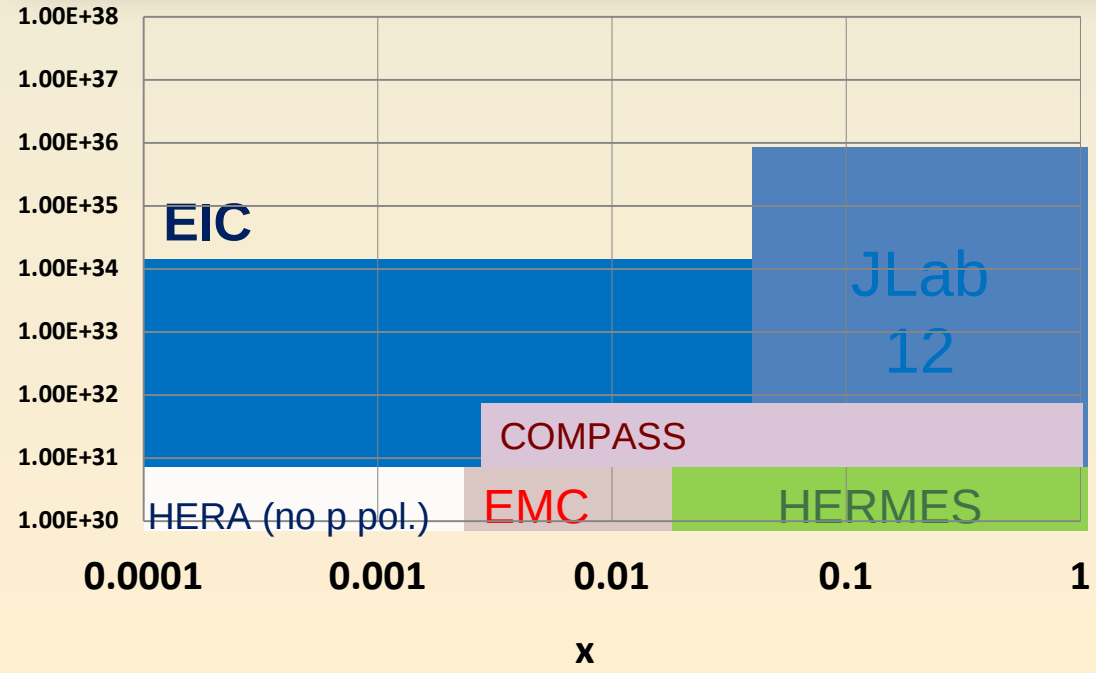
Projection for JLab 12 GeV





EIC:
The New QCD Frontier



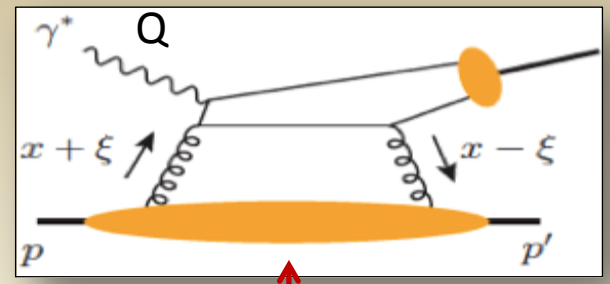


- High Luminosity
  → 10^{34} cm^{-2}s^{-1}
- Low x regime
  x → 0.0001
- High Polarization
  → 70%

Discovery Potential!

Spatial Imaging of Gluon Density at EIC

Exclusive vector meson production:



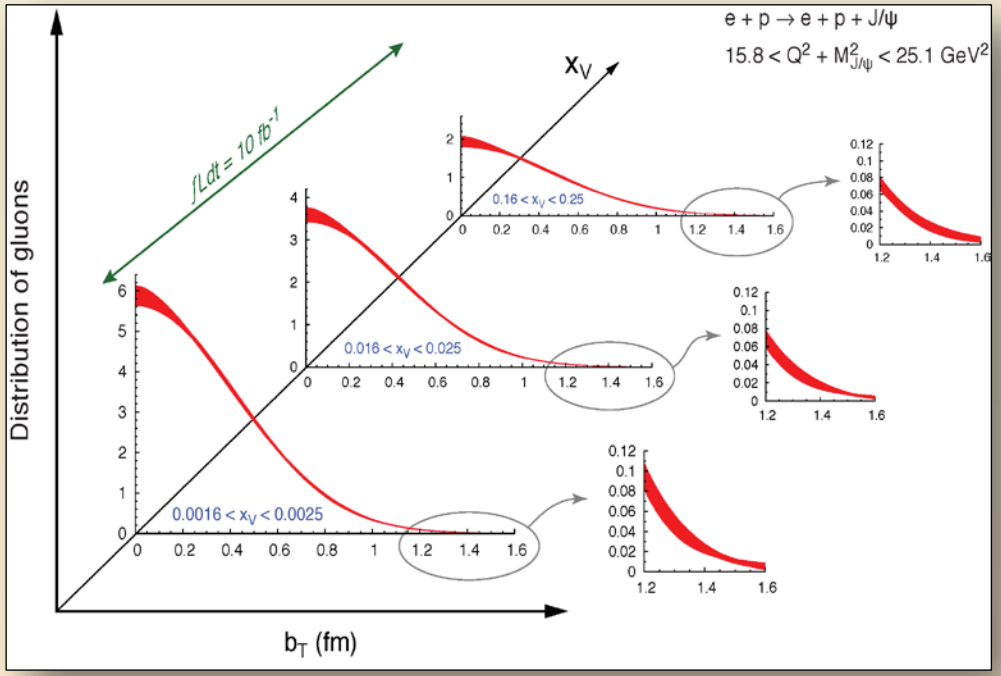
t-dep

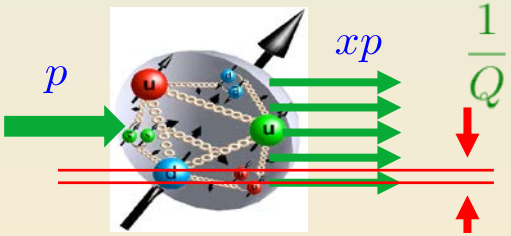
J/Ψ, Φ, …

$$\frac{d\sigma}{dx_B dQ^2 dt}$$

- ✧ Fourier transform of the t-dep
- ➡ Spatial imaging of glue density
- ✧ Resolution ~ 1/Q or $1/M_Q$

Gluon imaging from simulation:



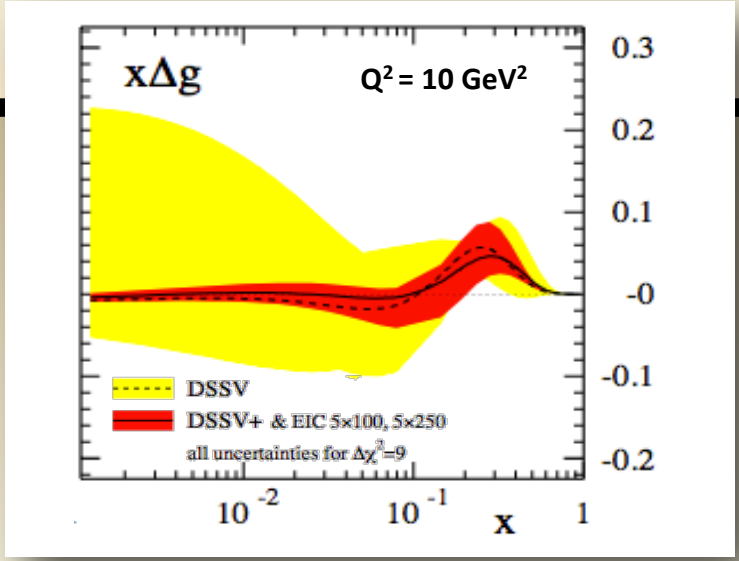


$$x_V = \frac{M_{J/\psi}^2 + Q^2}{W^2 + Q^2 - M_N^2}$$

$$W^2 = (p+q)^2; \quad M_N^2 = p^2$$

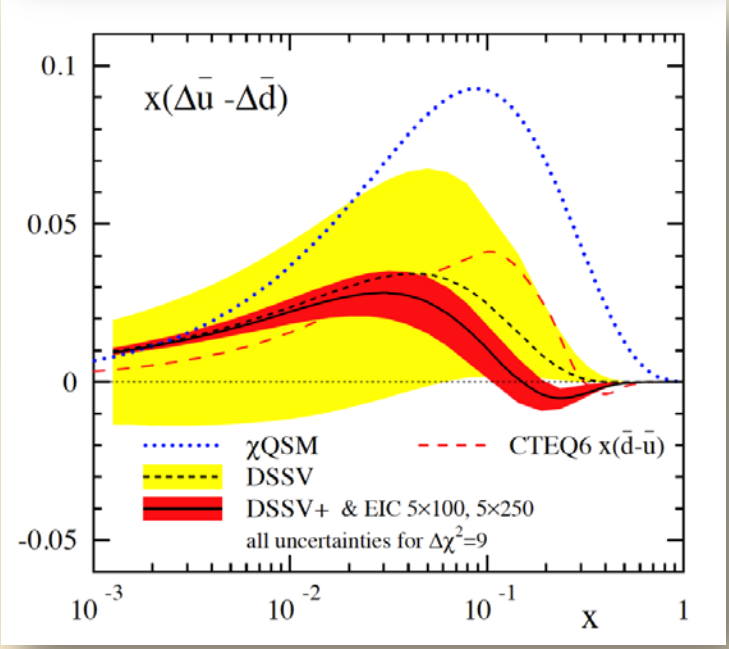
Images of gluons from exclusive J/ψ production

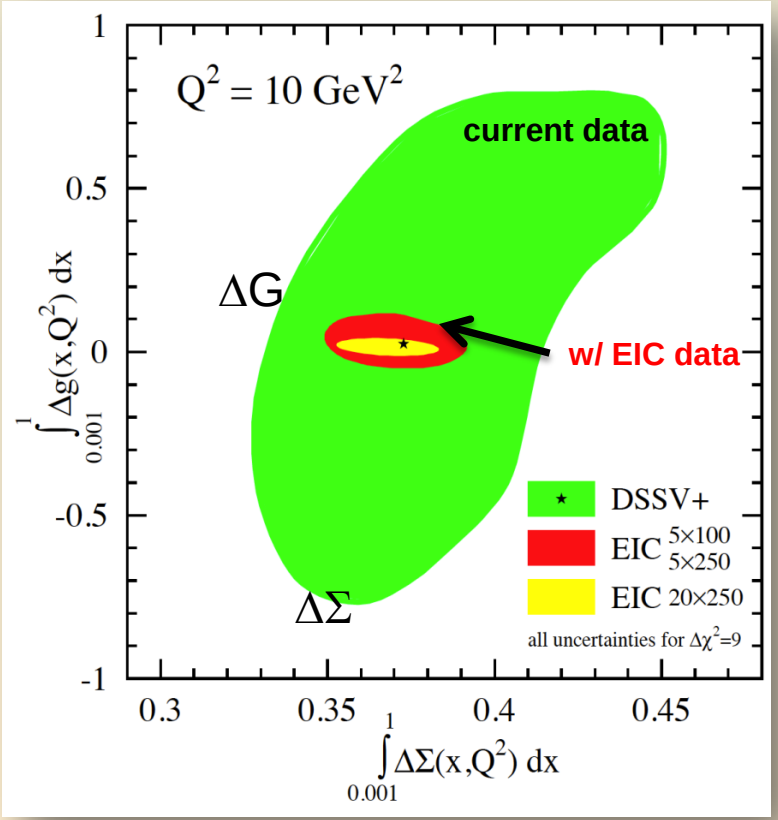
Helicity PDFs at an EIC



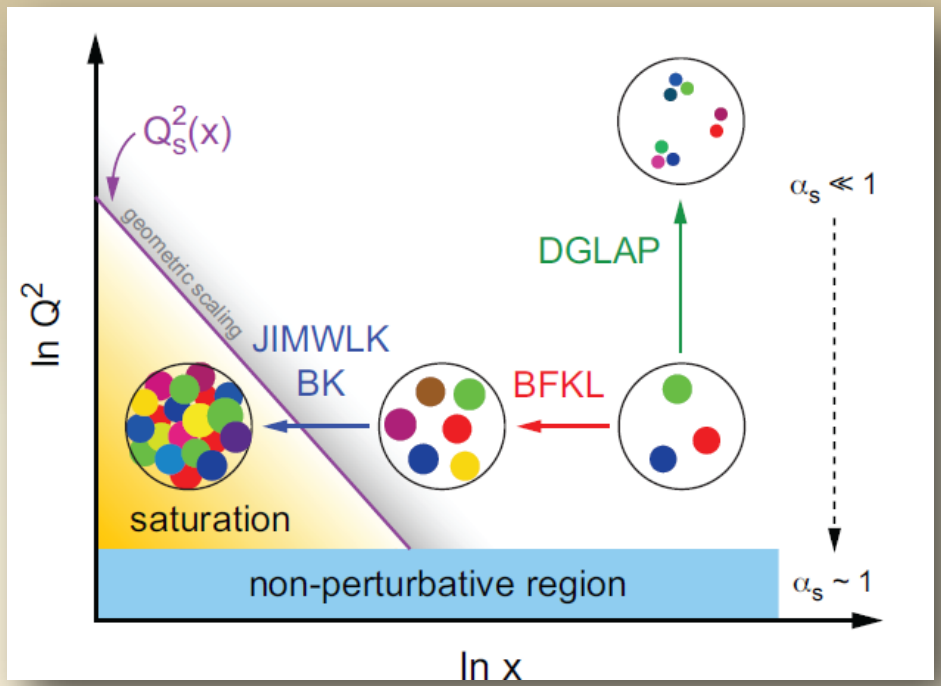
A Polarized EIC:

- Tremendous improvement on ΔG
- Good improvement in $\Delta\Sigma$
- Spin Flavor decomposition of the Light Quark Sea



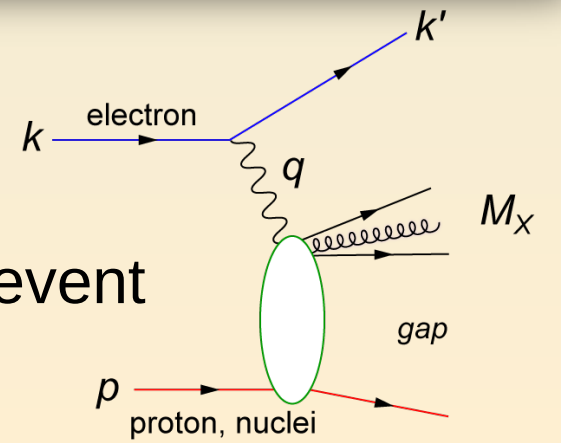


Gluon Saturation at EIC

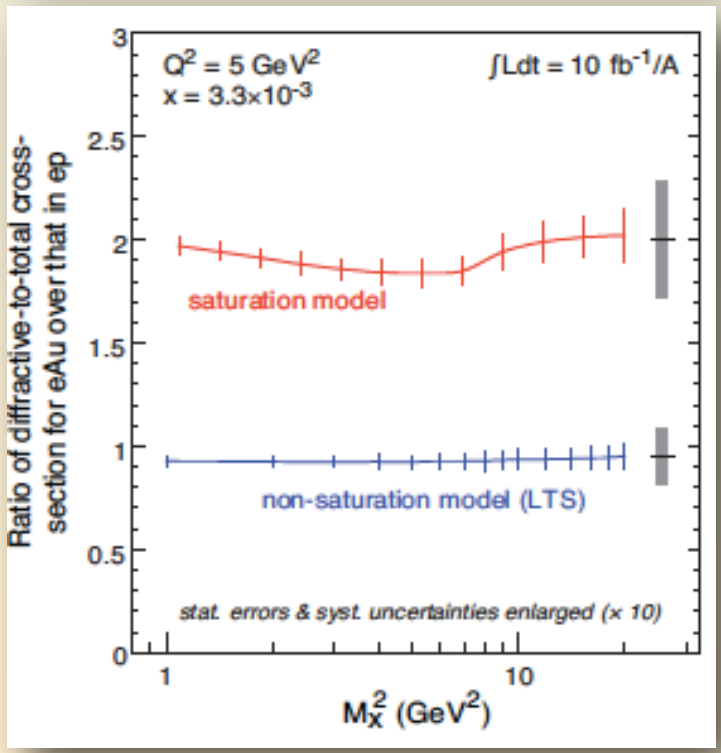


Radiation

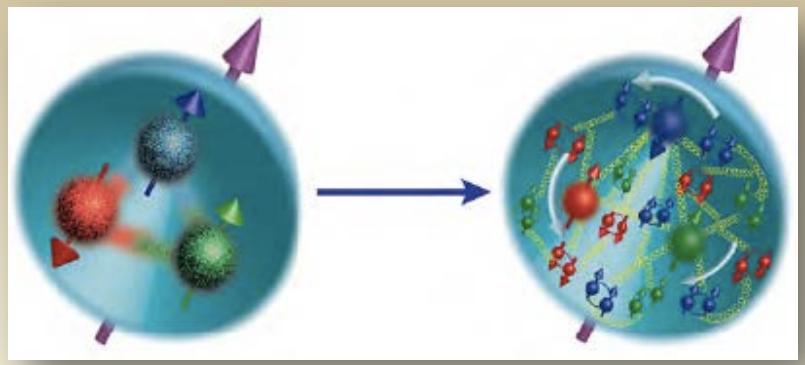
Recombination

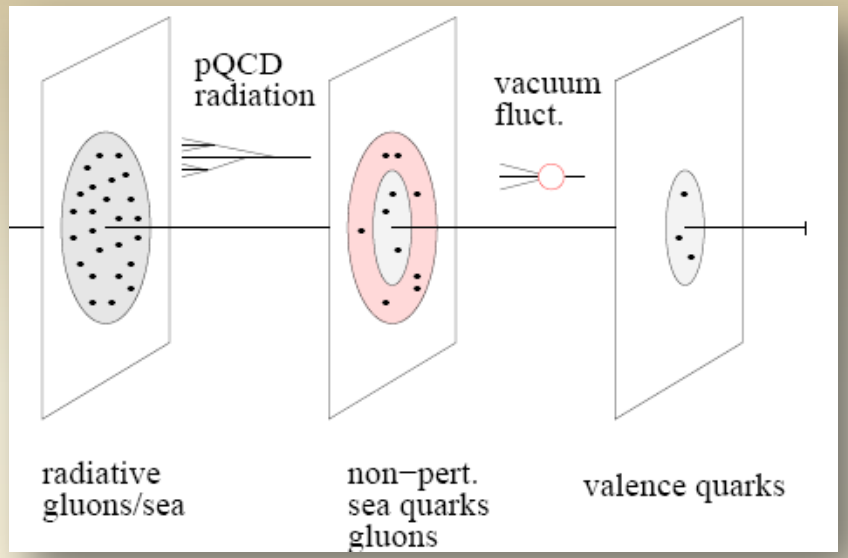


Diffractive event



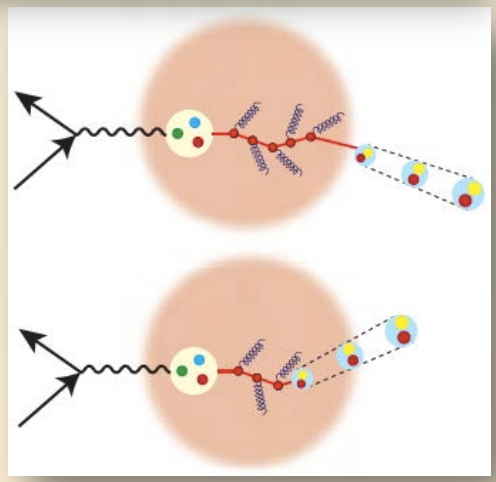
Electron Ion Collider: A QCD Laboratory





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

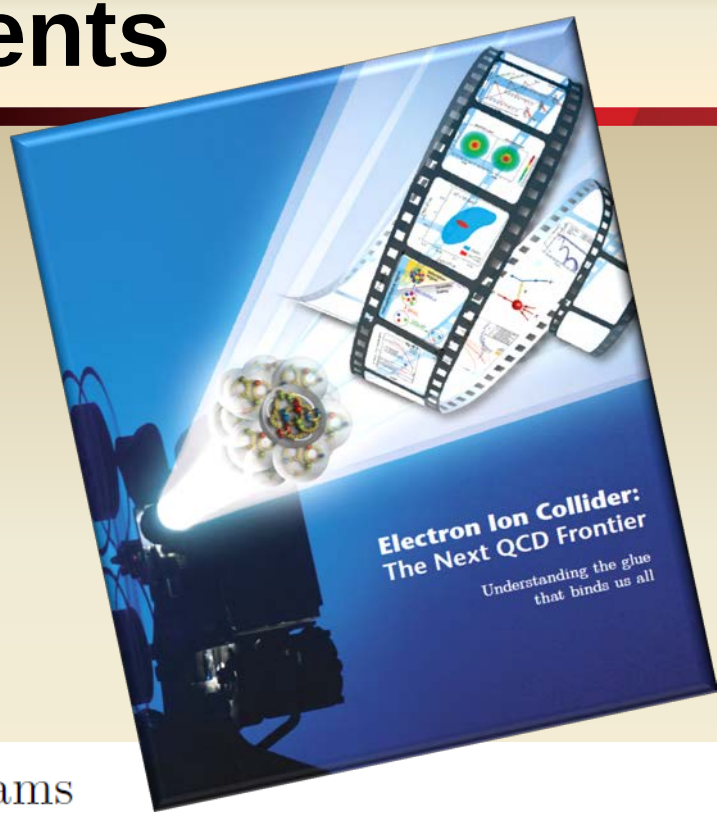
- Tomography of the nucleus
- Gluon and sea quarks
  - spin
  - orbital angular momentum
- QCD at high gluon density
- Propagation of color in nuclei, formation of hadrons



EIC Properties

- Access to low values of x~0.0001 (not available at JLab12), which requires collisions of high energy electrons with high energy nucleons and nuclei.
- Highly polarized beams of nucleons and light ions (not available at HERA), and polarized electrons to access the spin and orbital motion of the partons.
- High luminosity to enable 3D tomography of the distributions of partons (not available at HERA).
- Collisions of electrons with atomic nuclei (not available at HERA), up to the heaviest available, to provide information on the effect of the nuclear medium on the parton distributions as well as the properties of partons traversing the nuclear medium.

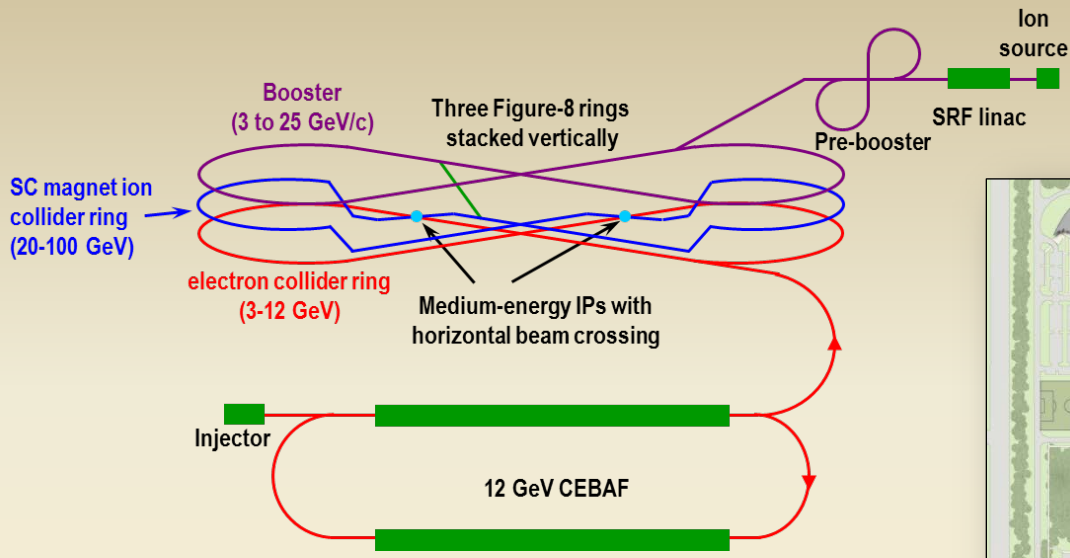
EIC Requirements



From the 2013 EIC White Paper:

- Highly polarized ($\sim 70\%$) electron and nucleon beams
- Ion beams from deuteron to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from $\sim 20 - \sim 100$ GeV, upgradable to ~ 150 GeV
- High collision luminosity $\sim 10^{33-34}$ cm^{-2}s^{-1}
- Possibilities of having more than one interaction region

Medium Energy EIC@JLab



JLab Concept

- Initial configuration (MEIC):
  - 3-12 GeV on 20-100 GeV ep/eA collider
  - Fully-polarized, longitudinal and transverse
  - Luminosity:
    up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- Upgradable to higher energies
  250 GeV protons + 20 GeV electrons

MEIC Design Goals

Energy

Full coverage of √**s** from **15** to **70** GeV
Electrons **3-12** GeV, protons **20-100** GeV, ions **12-40** GeV/u

Ion species

Polarized light ions: **p**, **d**, **^{3}He**, and possibly **Li**
Un-polarized light to heavy ions up to A above 200 (Au, Pb)

At least 2 detectors

Full acceptance is critical for the primary detector

Luminosity

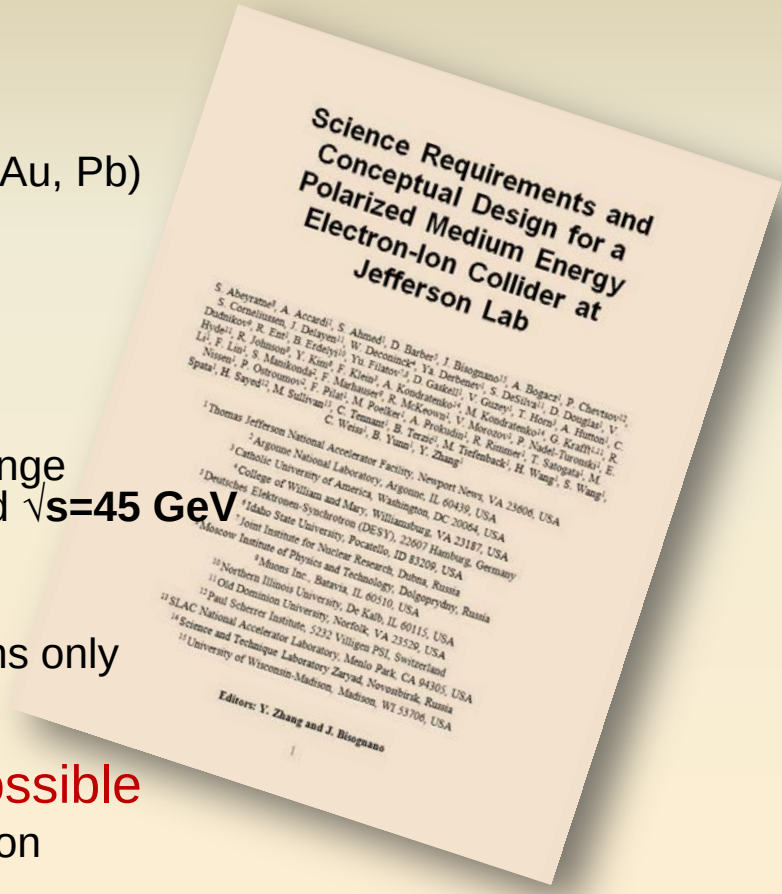
Above 10^{33} cm^{-2}s^{-1} per IP in a *broad* CM energy range
Maximum luminosity >10^{34} optimized to be around **√s=45 GeV**

Polarization

At IP: longitudinal for both beams, transverse for ions only
All polarizations >70%

Upgrade to higher energies and luminosity possible

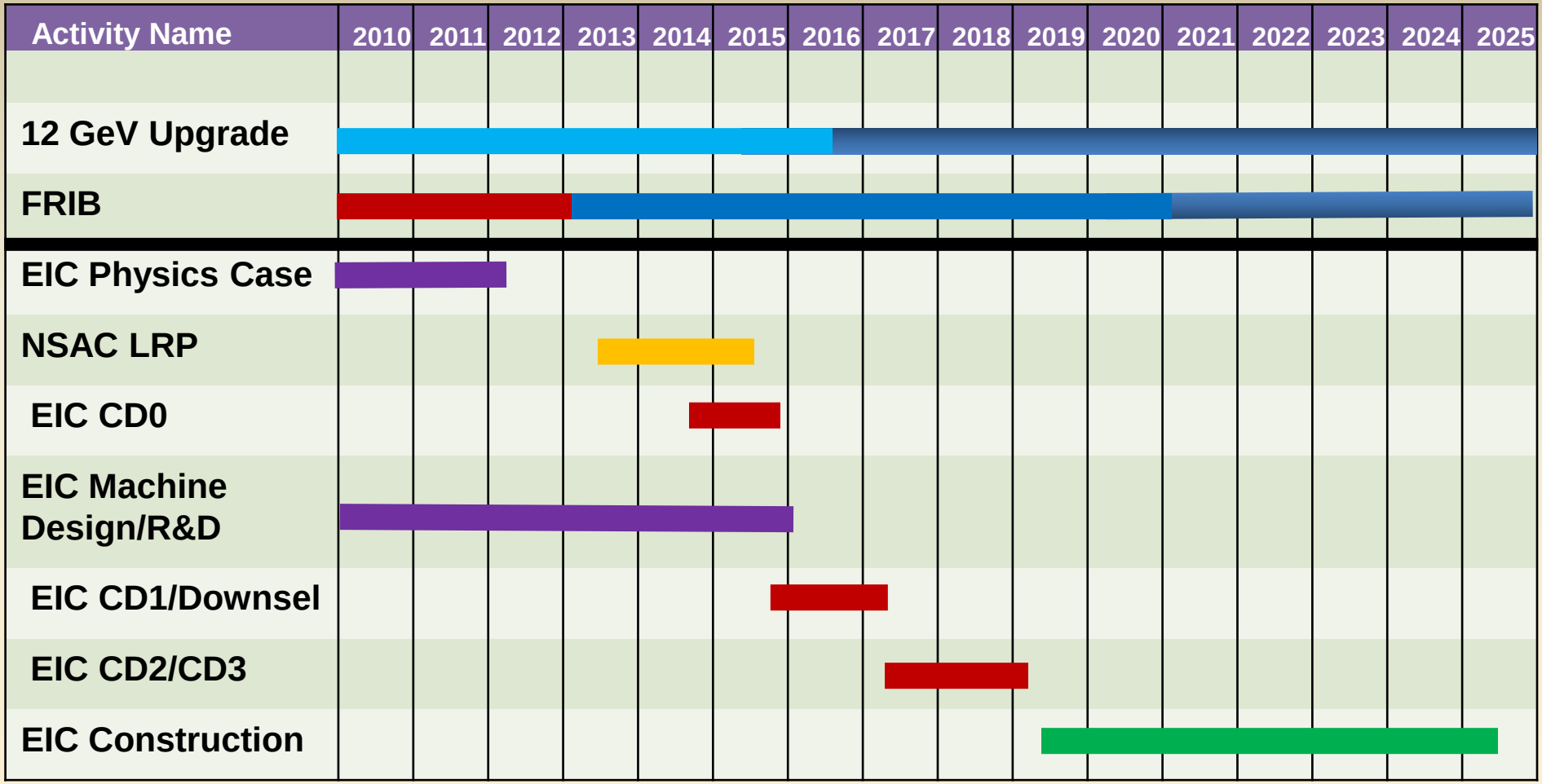
20 GeV electron, **250 GeV** proton, and **100 GeV/u** ion


Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-Ion Collider at Jefferson Lab

Editors: Y. Zhang and J. Biegnano

Design goals consistent with the White Paper requirements

EIC Realization Imagined



Assumes endorsement for an EIC at the next NSAC Long Range Plan
Assumes relevant accelerator R&D for down-select process done around 2016

Summary & Outlook

- Science case is much advanced → white paper
- Common set of facility requirements – 2 viable facility designs are emerging
- Support of Hot and Cold QCD communities is essential
- Must articulate the science case for NP community and also broader audience
  - US leadership in nuclear science
  - US leadership in accelerator science and technology
- NSAC LRP Recommendation → CD-0


HOW EXCITING!!
PLEASE TELL ME
MORE!!