Overview of the EIC experimental program

Miguel Arratia

UC RIVERSIDE

14th Conference on the Intersections of Particle and Nuclear Physics, Lake Buena Vista, FL, August 29 2022

Disclaimer and bias disclosure

The content of the talk represent my own, biased opinion. It is not in any way trying to represent anyone other than yours truly.

The Electron-Ion Collider

- New facility to be located at BNL, partially based on RHIC

- Project started officially in 2020
  Project baseline expected in ~2024
  First collisions expected ~2032

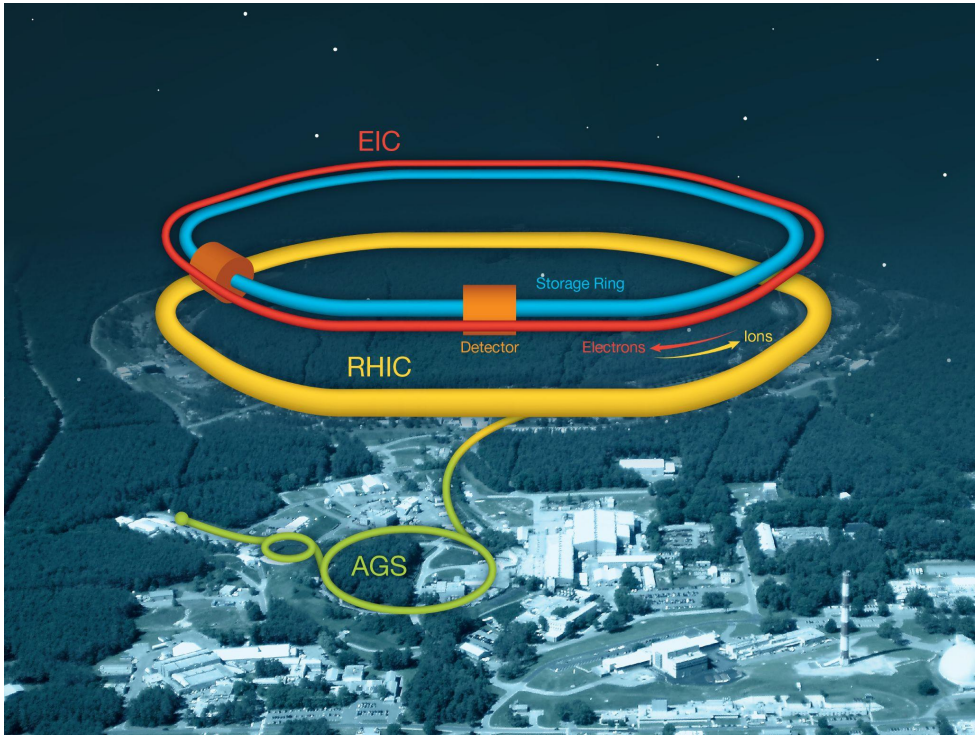
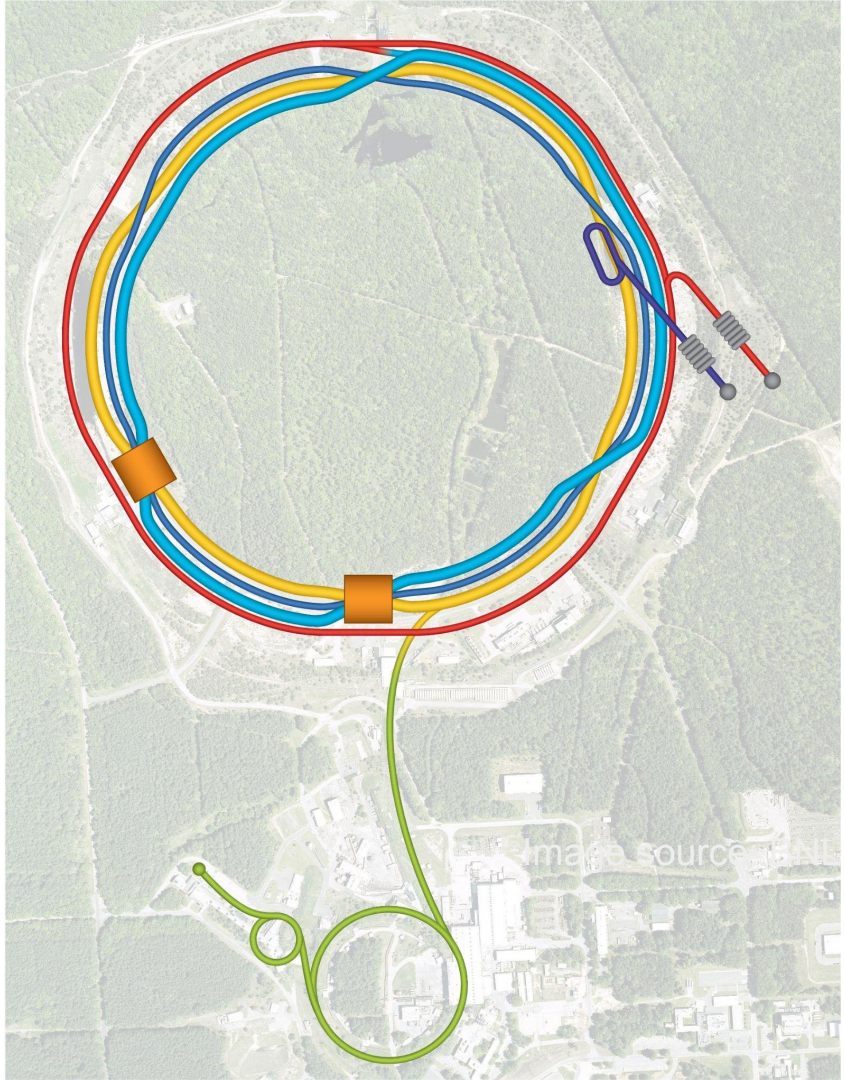


Image source: BNL

What is unique about EIC?

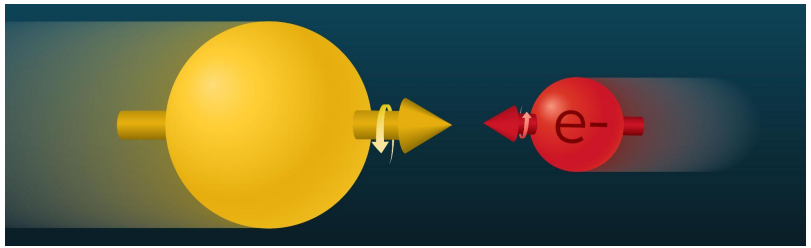
First-ever accelerator to yield collisions of **electrons and polarized-protons** (and polarized light ions)

First-ever accelerator to yield collisions of **electrons and nuclei**

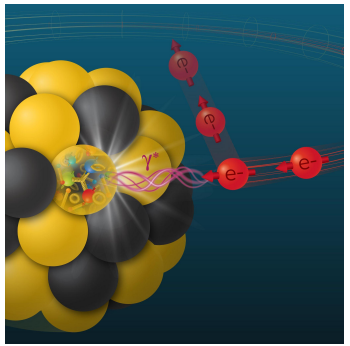


EIC: the first of its kind.

A high-luminosity (x1000 HERA), high-polarization, precision machine to yield electron-scattering from



Polarized protons (and light ions)
both longitudinal and transverse



Heavy nuclei
(including with a wide variety of species)

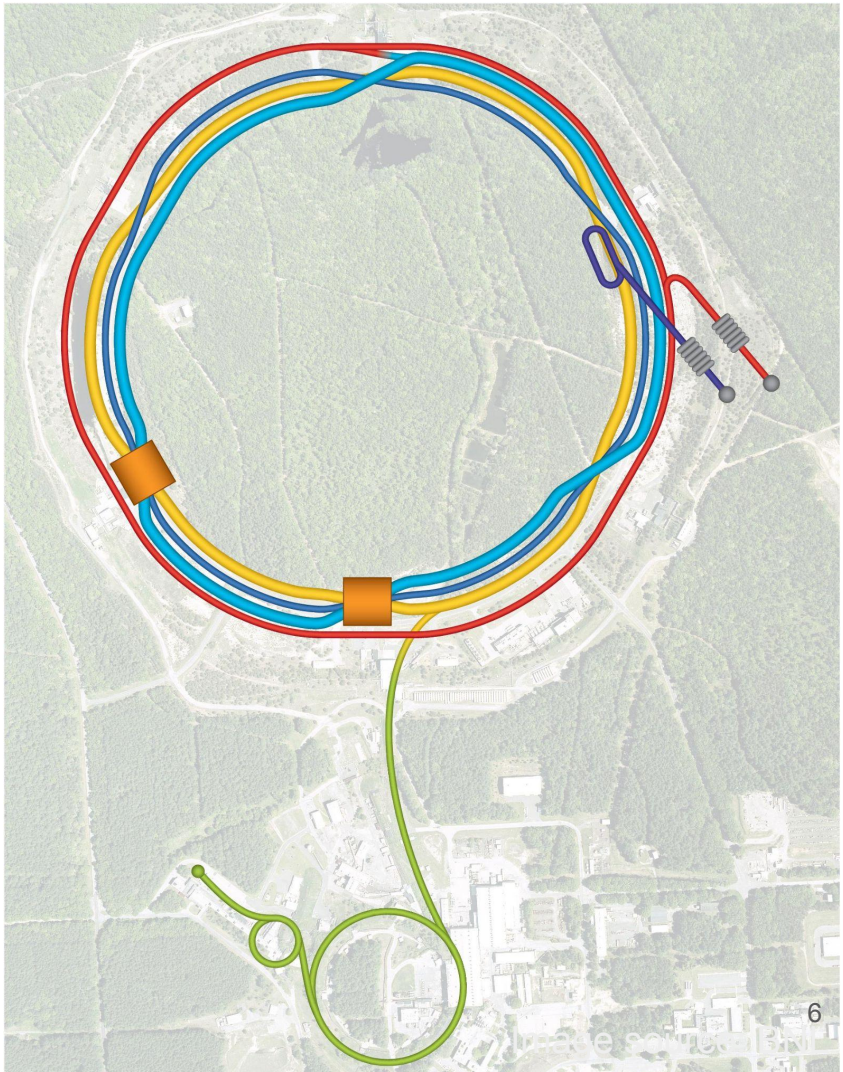
With CM energy from 40 to 140 GeV, or 90 GeV for nuclear (great leap from fixed-target experiments)

Image source: BNL

Why is interesting?

EIC will be the first collider of its kind,
so it will offer **great discovery potential**

Most likely, the most-exciting
discovery will be unexpected.



Official motivation is to address:

- What is the origin of mass?
- What is the origin of the proton spin?
- What are the properties of an ultradense system of gluons?

As detailed in a decade worth of reports:

Electron-Ion Collider: The Next QCD Frontier (PDF)

The Electron-Ion Collider: Assessing the Energy Dependence of Key Measurements (PDF)

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

Conceptual Design Report for the Electron-Ion Collider (PDF, 170 Mb)

Science Requirements and Detector Concepts for the Electron-Ion Collider (PDF)

The EIC will explore

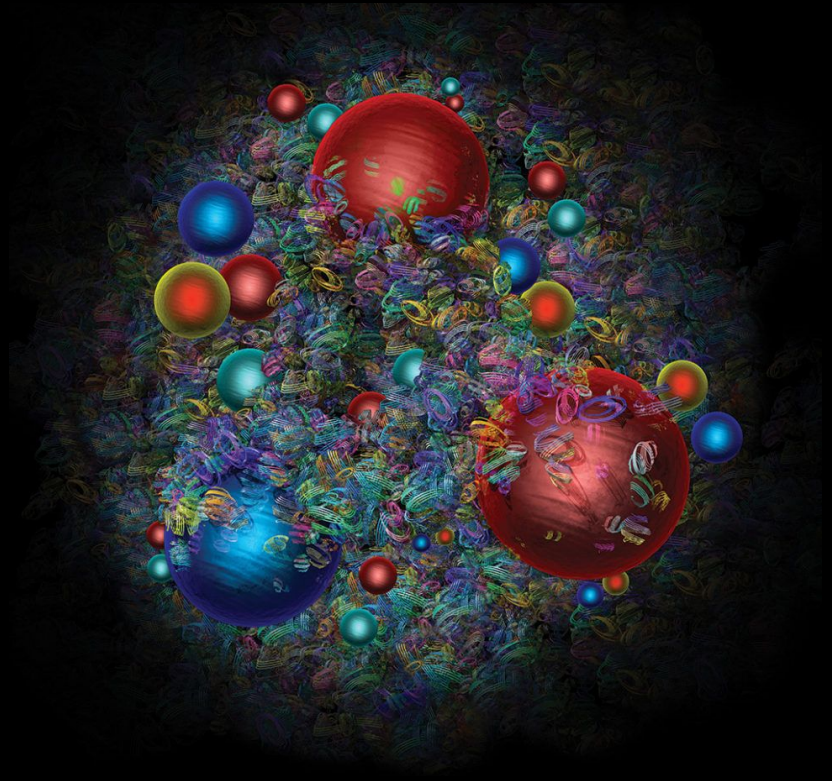
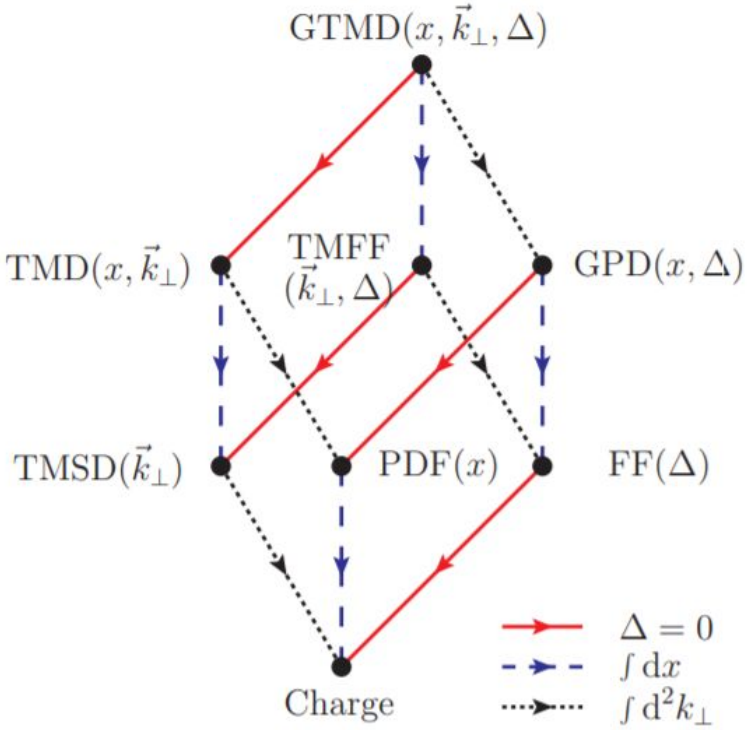
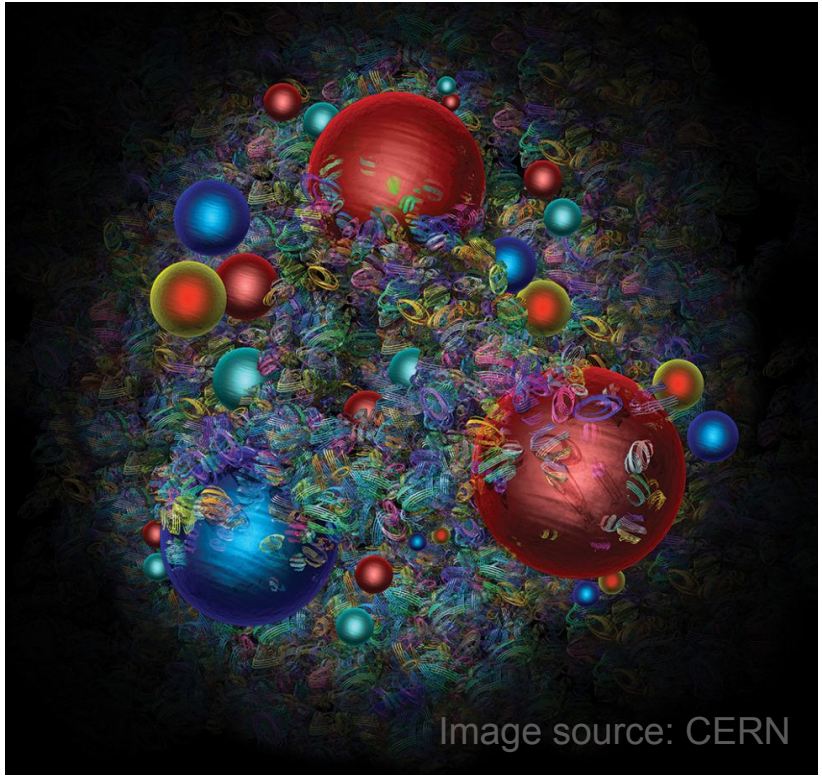


Image source: CERN

The EIC will provide a quantum tomography of the nucleon (and nuclei)





The EIC will explore

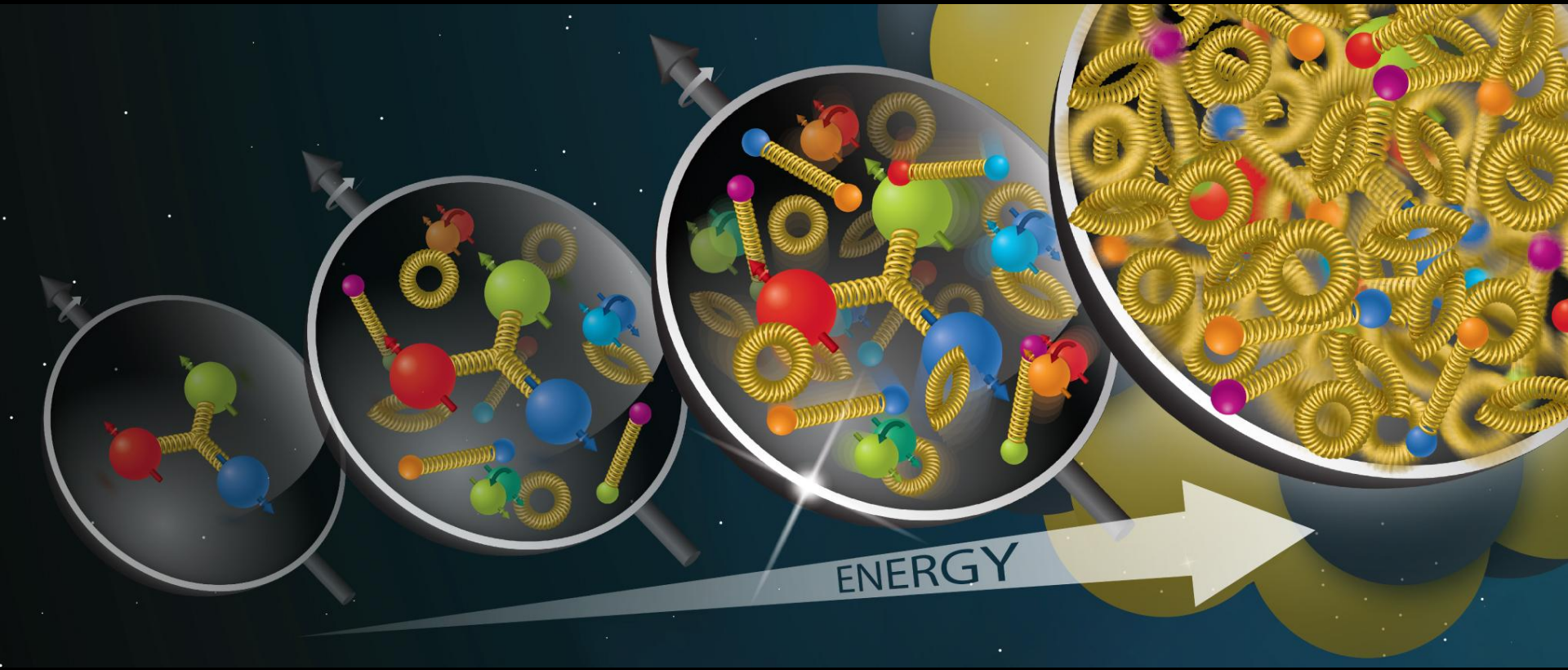
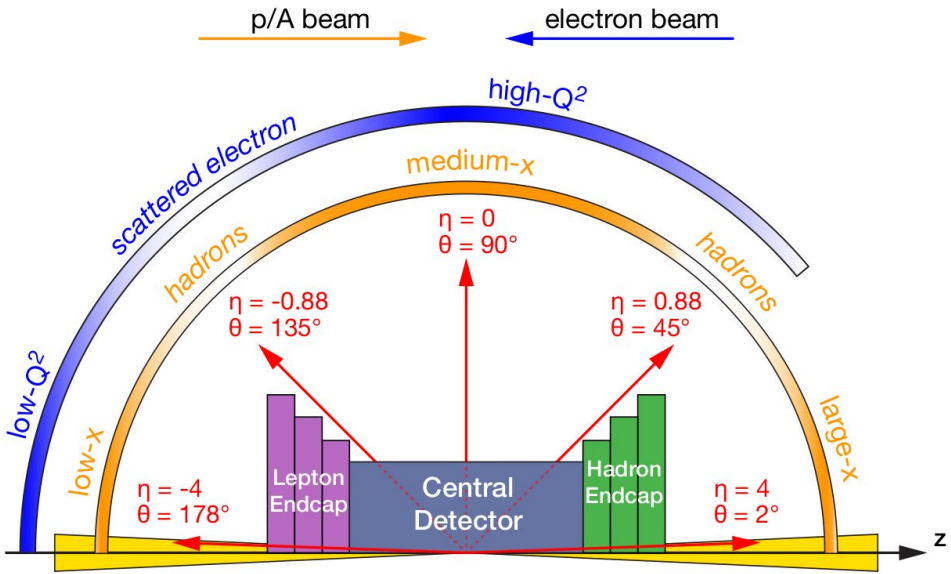


Image source: BNL

The physics calls for a 4π general purpose detector, plus far-forward detectors highly-integrated with accelerator



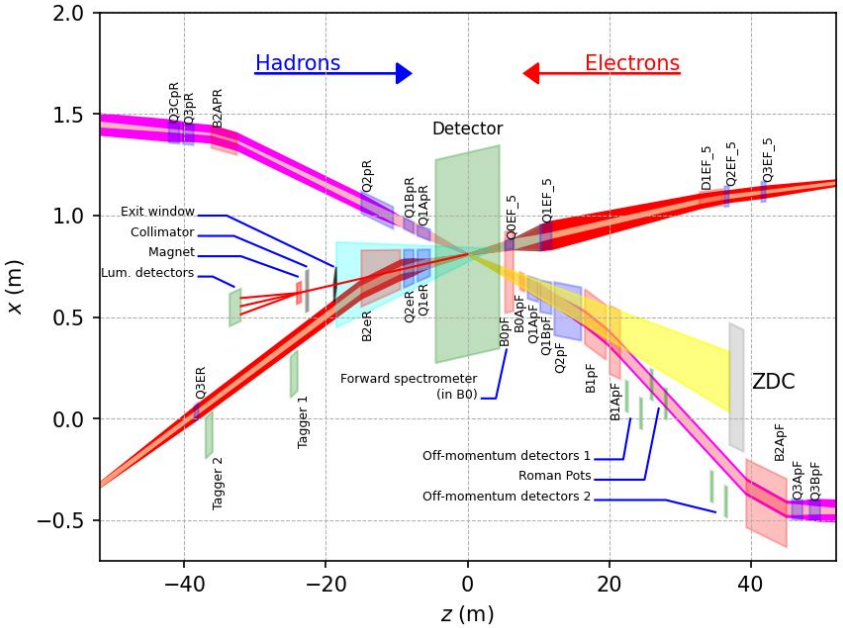
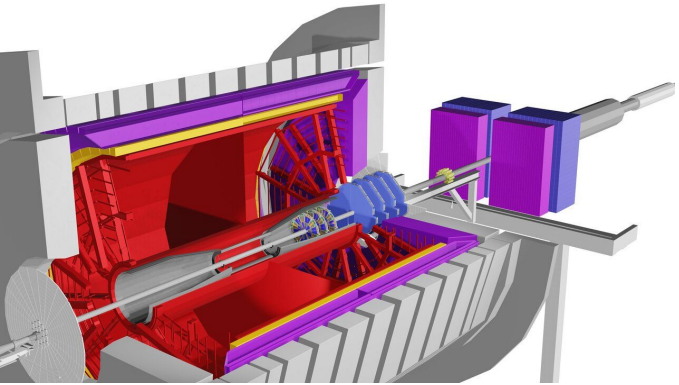


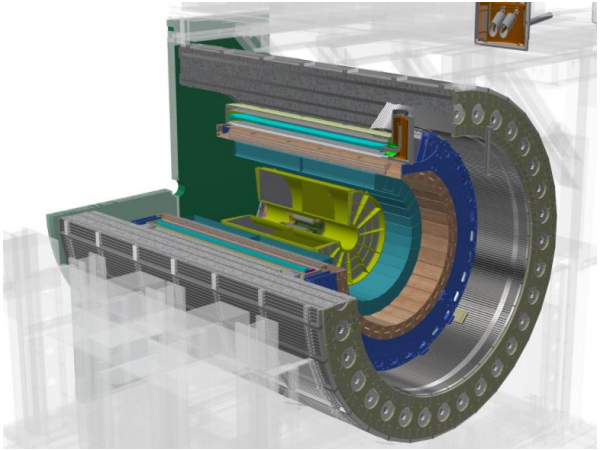
Image source: EIC YR

A “4π detector” is a new concept in the history of “Nuclear Physics”

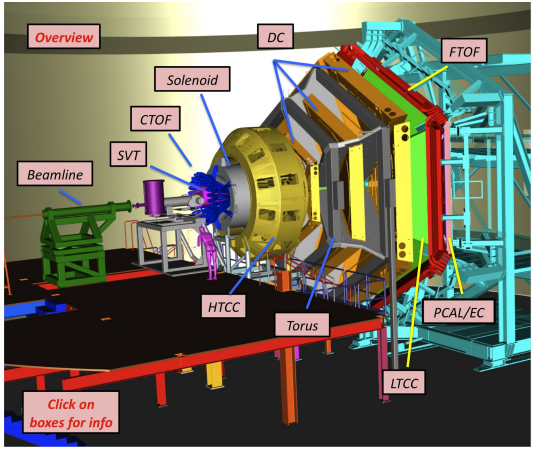
For perspective, look at some running examples at RHIC and JLab



STAR at BNL (non-hermetic barrel + some forward endcap + far-forward detectors)



sPHENIX at BNL (hermetic barrel + far-forward detectors)



CLAS12 at JLab (forward spectrometer)

The EIC “central detectors” will look something like

The concept in EIC yellow report:

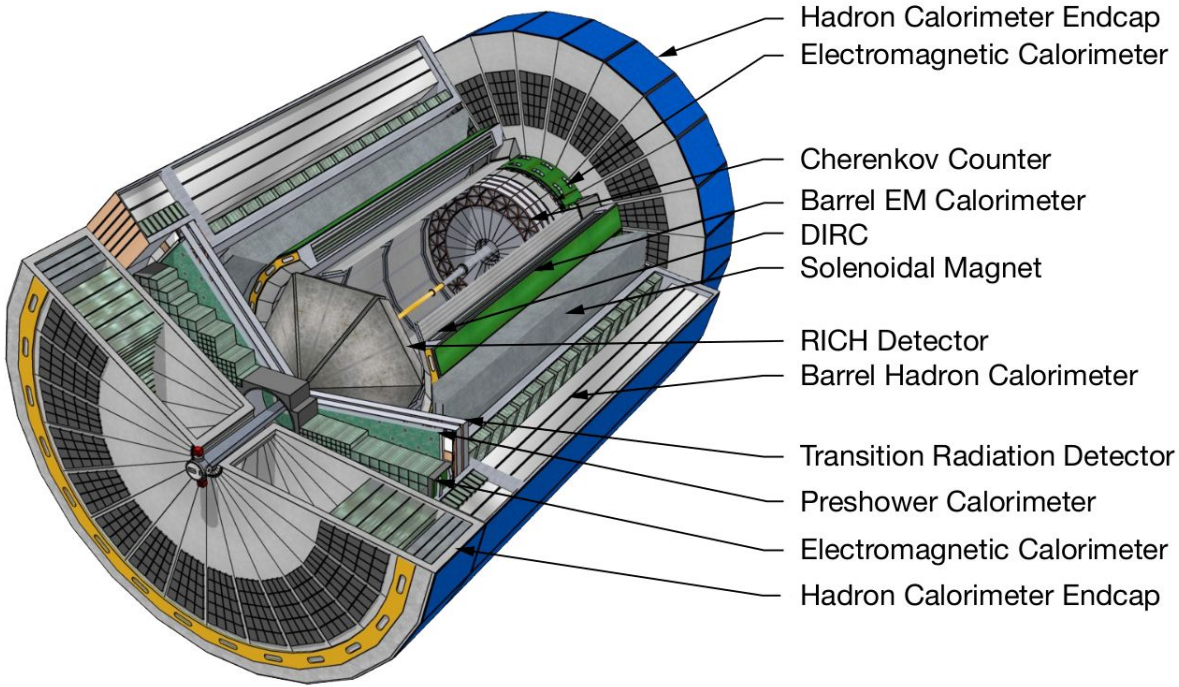


Image source: EIC YR

- After proposal review, plan looks fairly similar in the grand scheme of things. Now called “EPIC”
- Solenoidal magnet ~1.5 T (maybe up to ~2.0 T) with bore diameter of ~2.8 m

The EIC “far-forward detectors” will look something like:

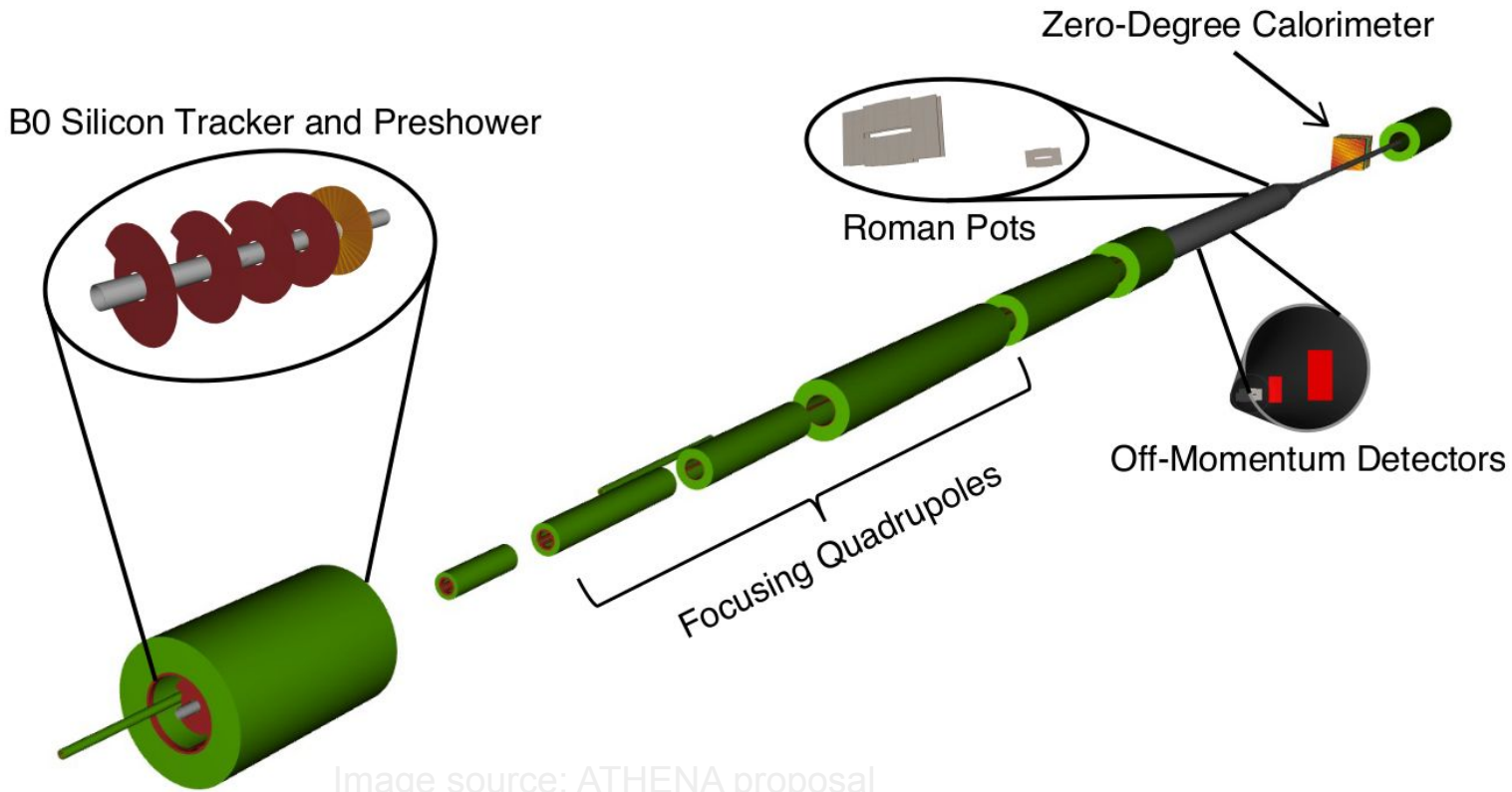
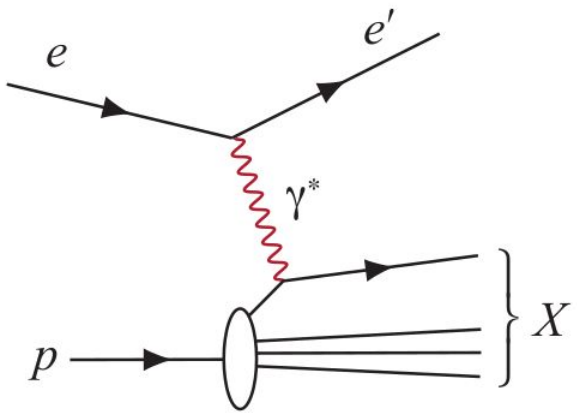


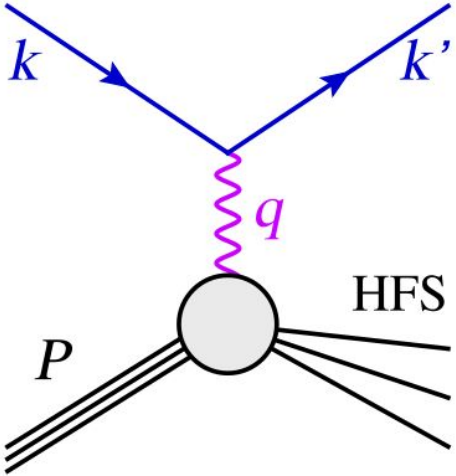
Image source: ATHENA proposal

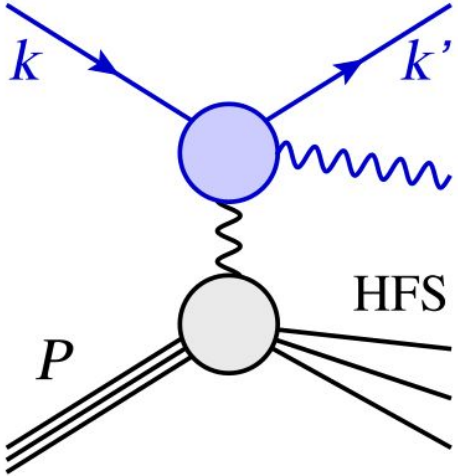
Neutral-current Inclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + X$; for this process, it is essential to detect the scattered electron, e', with high precision. All other final state particles (X) are ignored. The scattered electron is critical for all processes to determine the event kinematics.

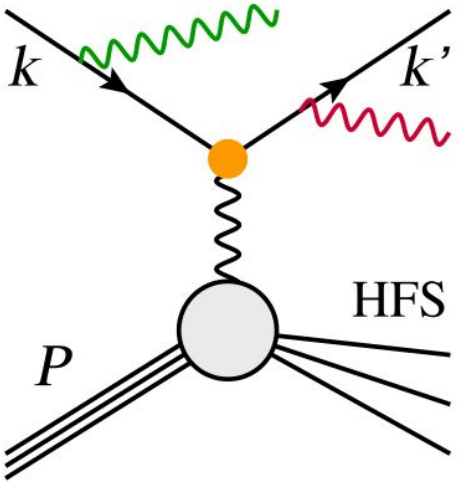


Source: EIC YR

But QED radiation…

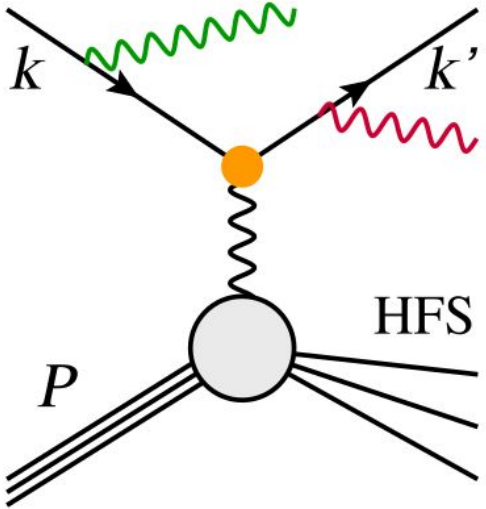






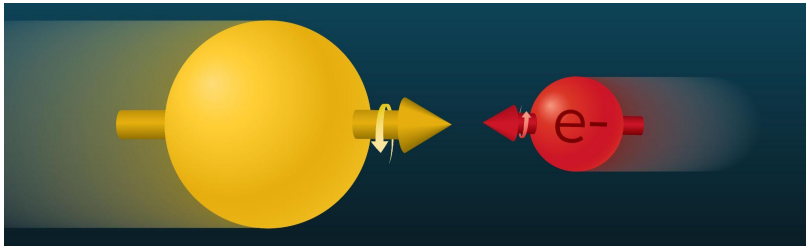
What we will most likely actually do

Neutral-current Inclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + X$; for this process, it is essential to detect the scattered electron, e', with high precision. All other final state particles (X) are ignored. The scattered electron is critical for all processes to determine the event kinematics.

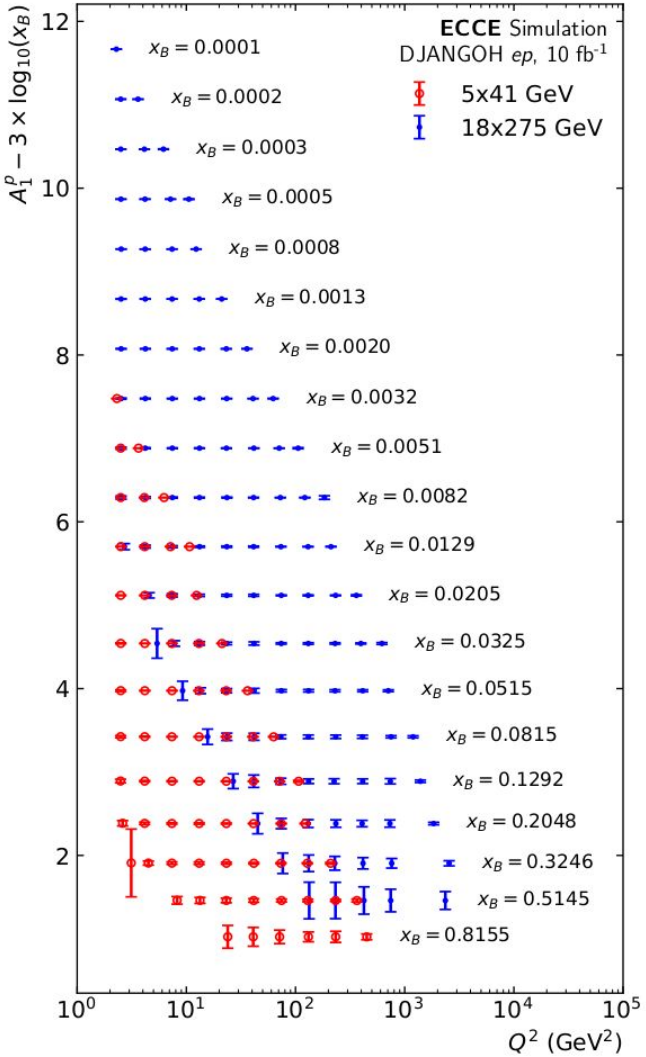


used to constrain QED radiation via missing-energy measurements (using Bayesian "kinematic fit" or AI/ML methods)

Double-helicity asymmetry
On DIS off proton and light nuclei

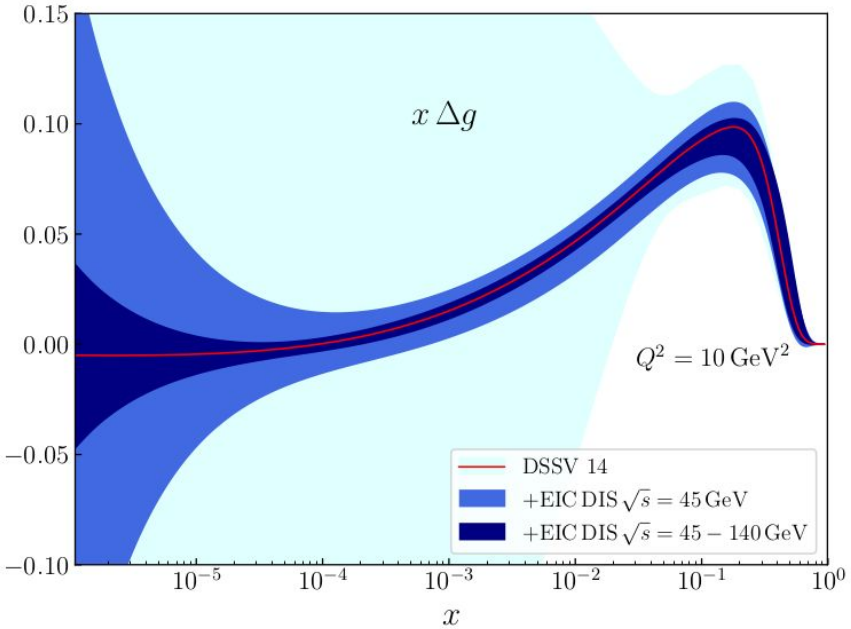


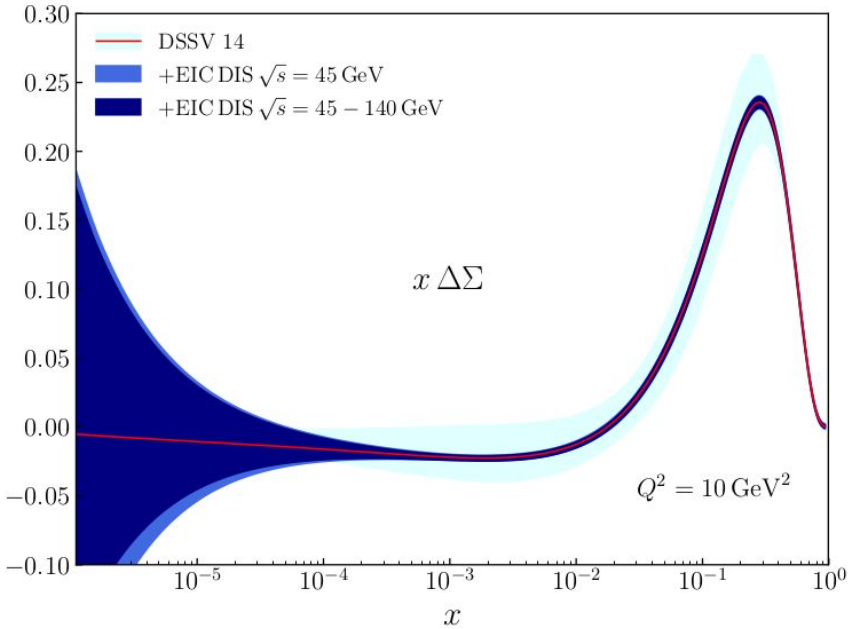
Source: BNL



Source: ECCE proposal

Impact on gluon and quark helicity PDFs





Source: EIC YR

Will be precise enough to constrain possible “orbital angular momentum” indirectly

Semi-inclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} + \mathrm{X}$, which requires measurement of *at least one* identified hadron in coincidence with the scattered electron.

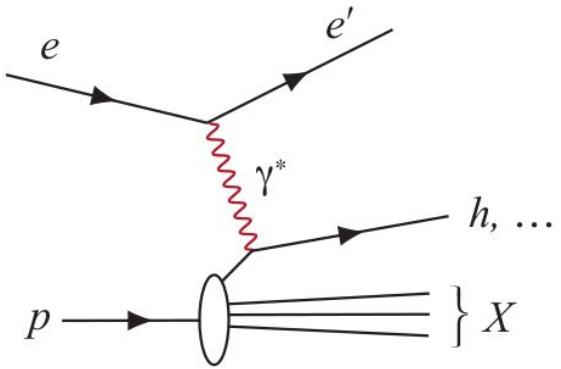
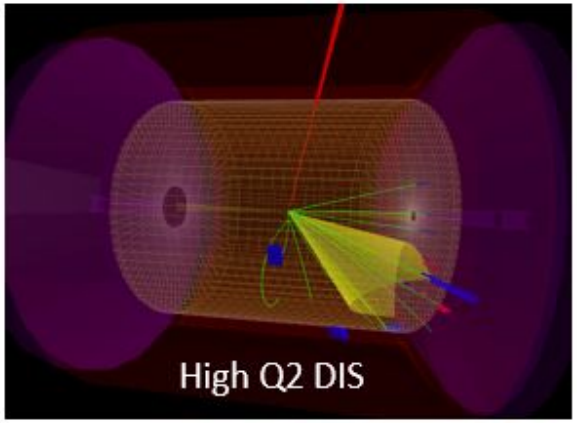
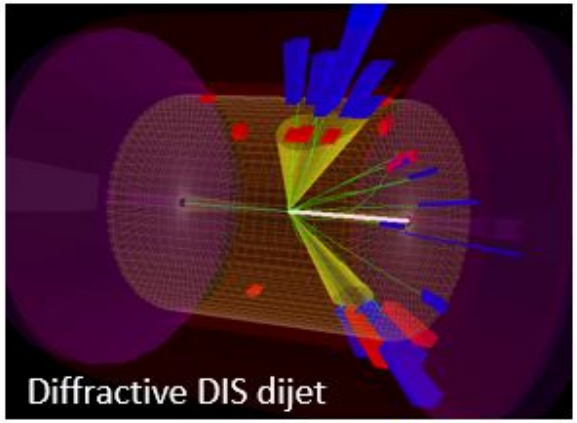
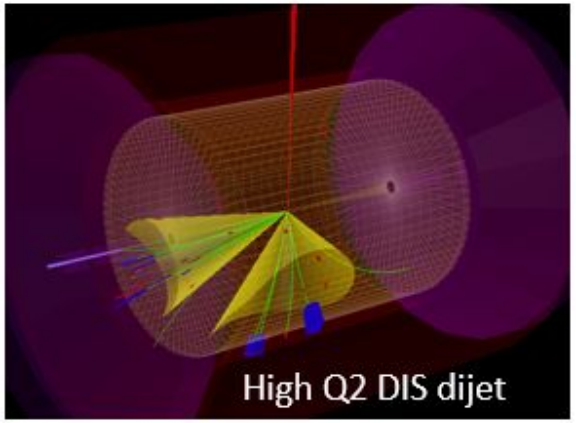


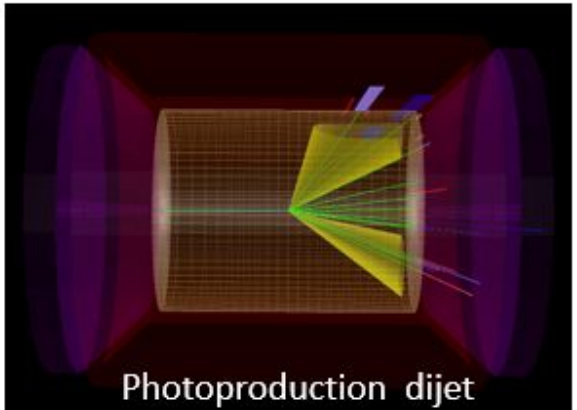
Image source: EIC YR

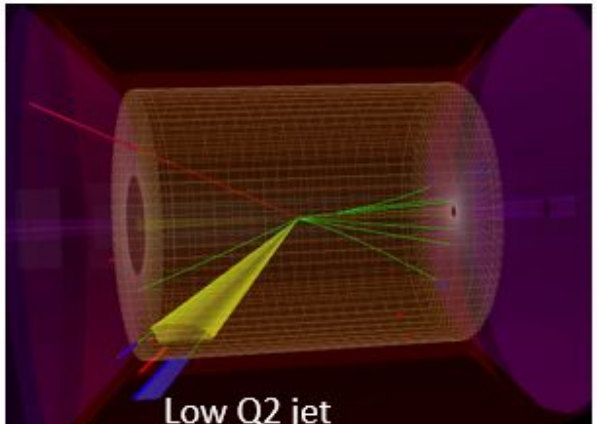
The EIC, a jet factory, will make the first jets in nuclear DIS and proton-polarized DIS

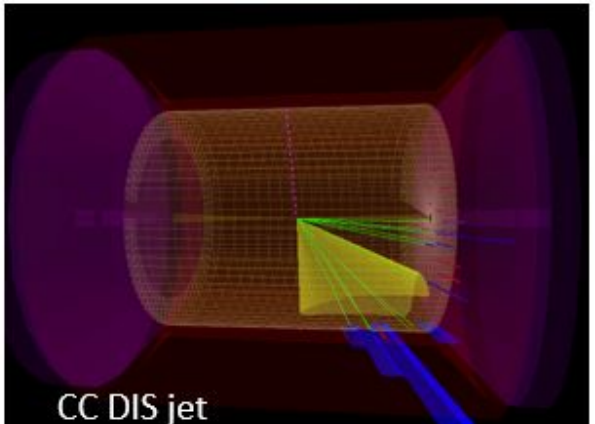








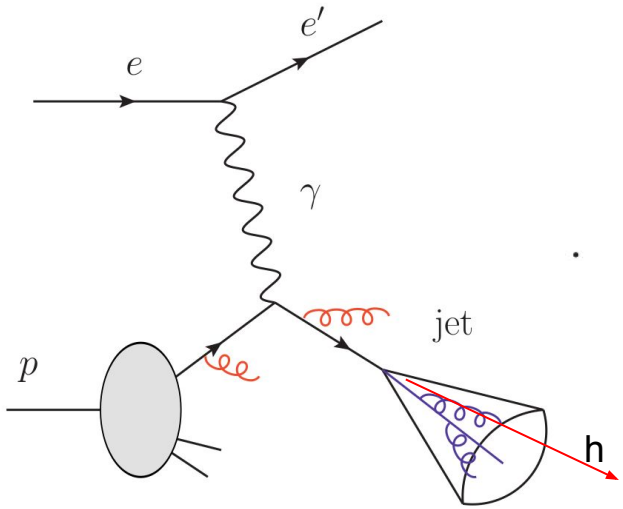




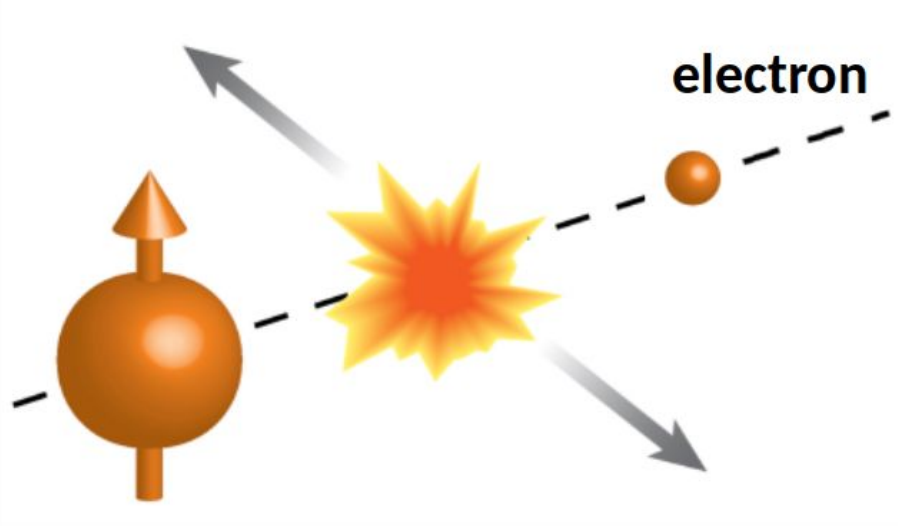
What we will most likely actually do

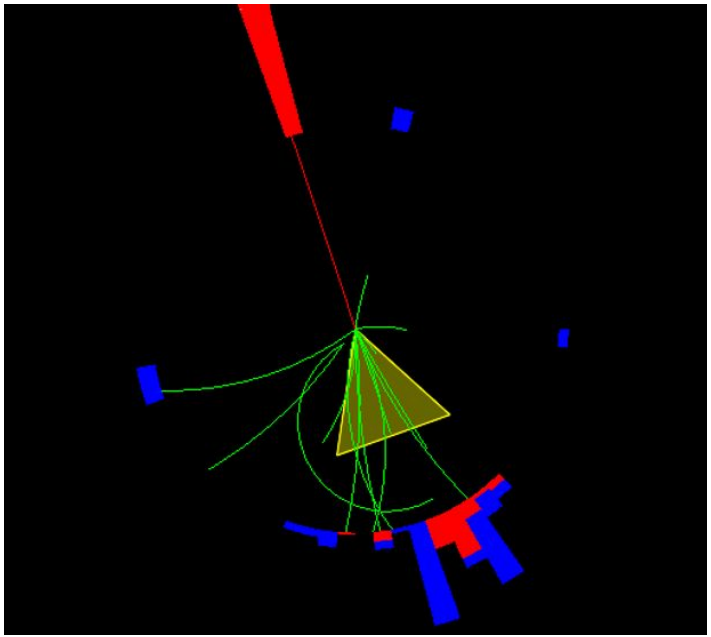
$$e + p/\mathrm{A} \longrightarrow e' +$$ **+h (in jet) + X**

Semi-inclusive DIS: ~~$e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} +$~~ X, which requires measurement of *at least one* identified hadron in coincidence with the scattered electron. **and a jet**

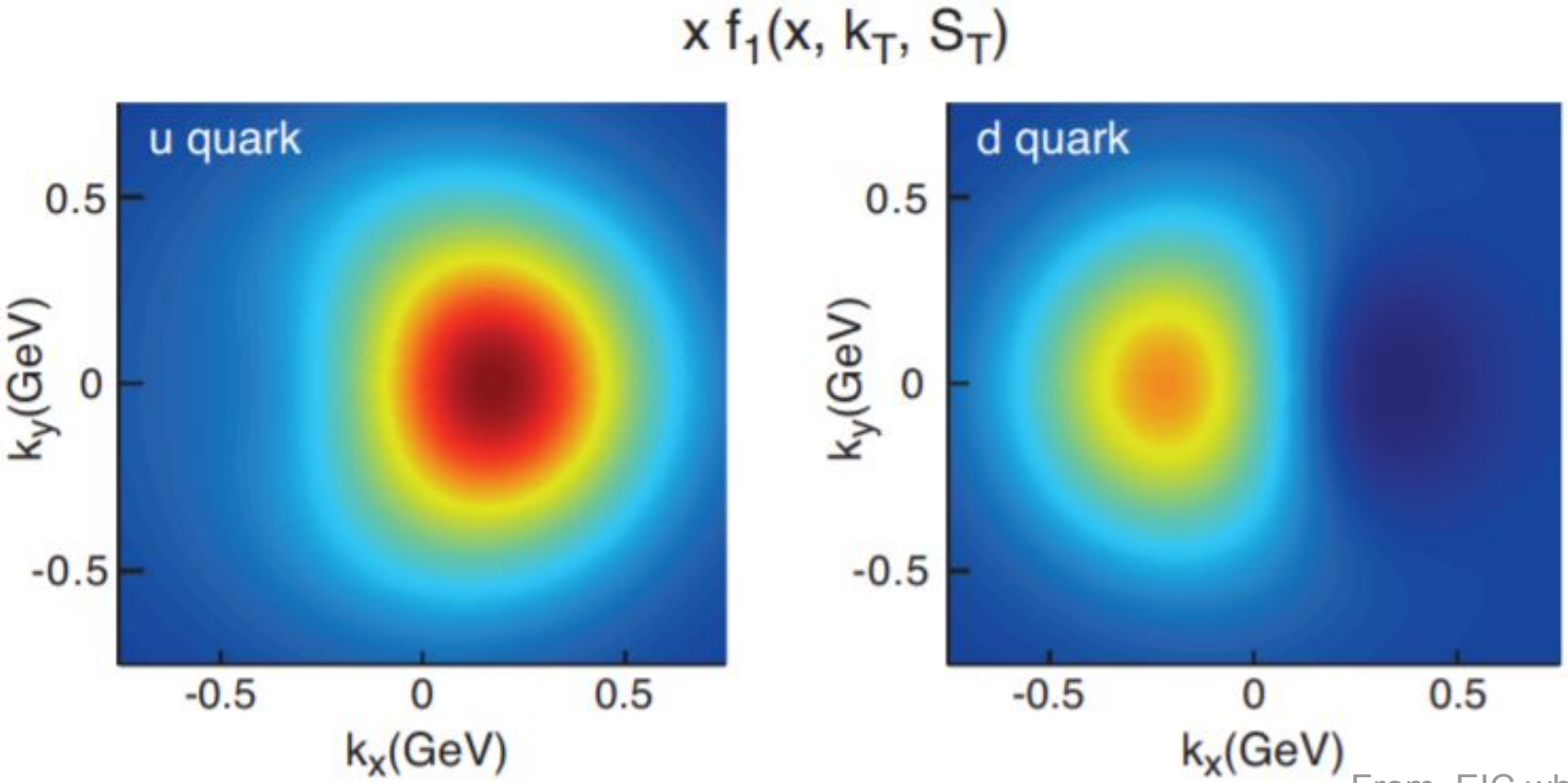


Spin-induced azimuthal asymmetries



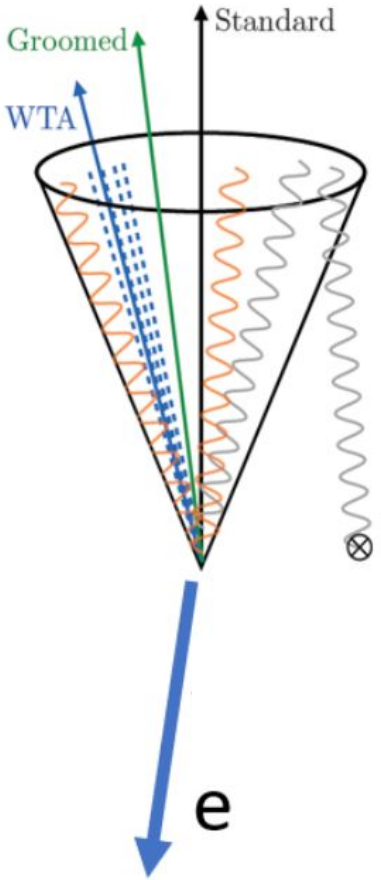


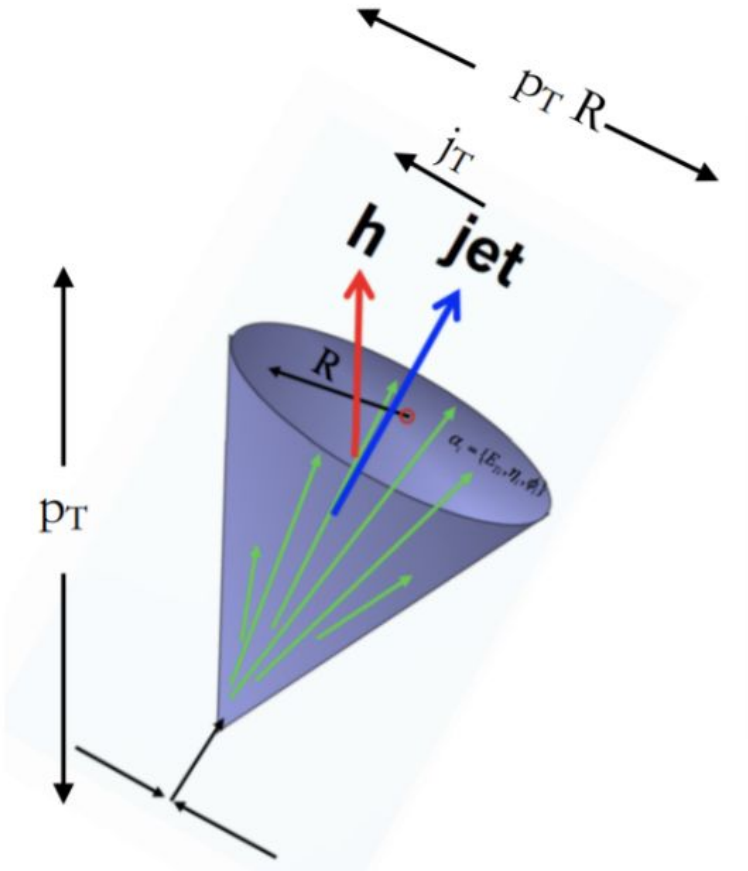
The asymmetry strength reflects a correlation between proton spin and quark momentum, “Sivers function”

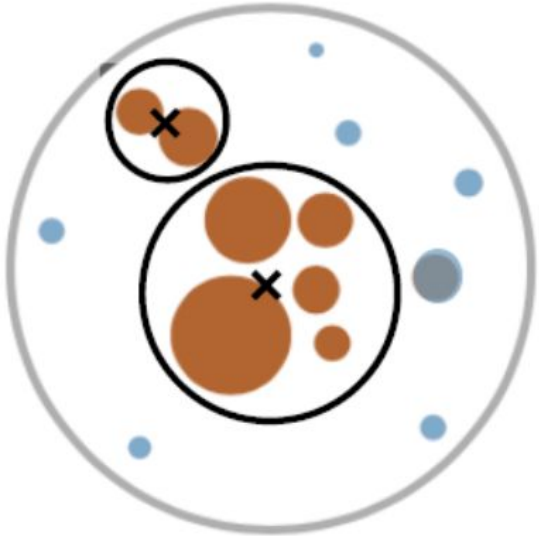


From EIC white paper

Jets have rich substructure, which encodes rich TMD dynamics

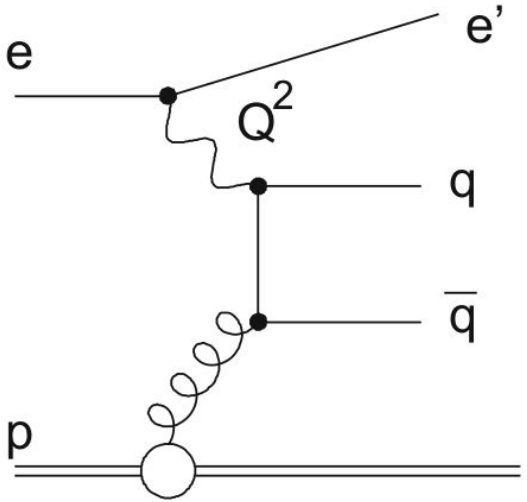


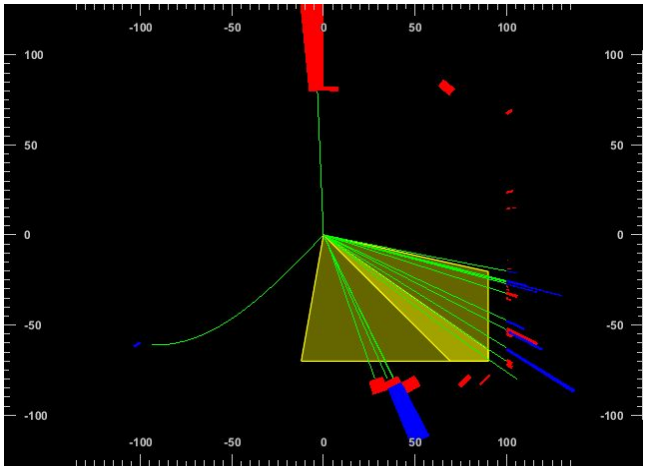


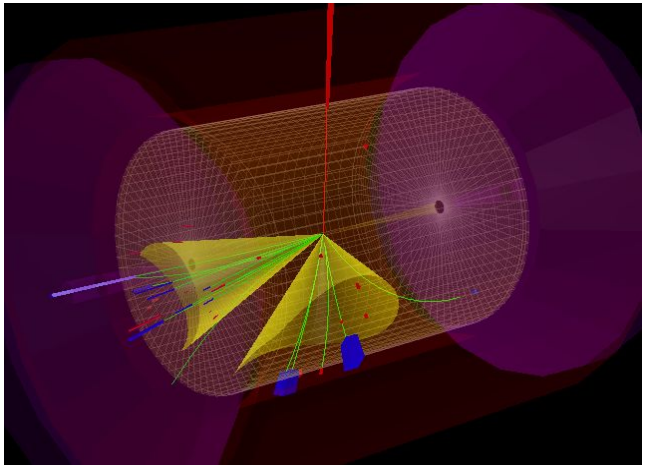


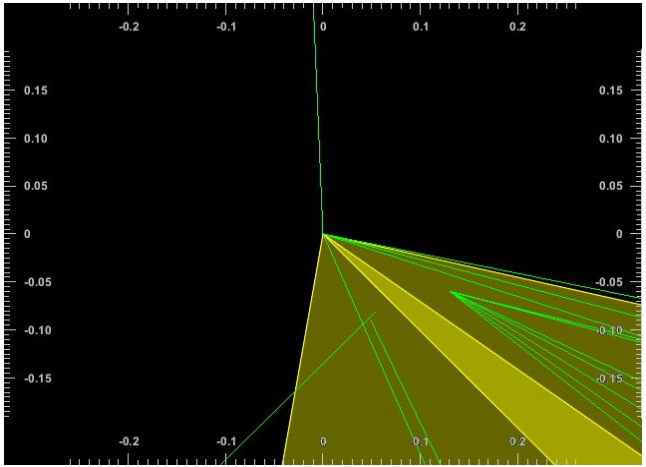
Heavy flavour

Via vertexing and PID



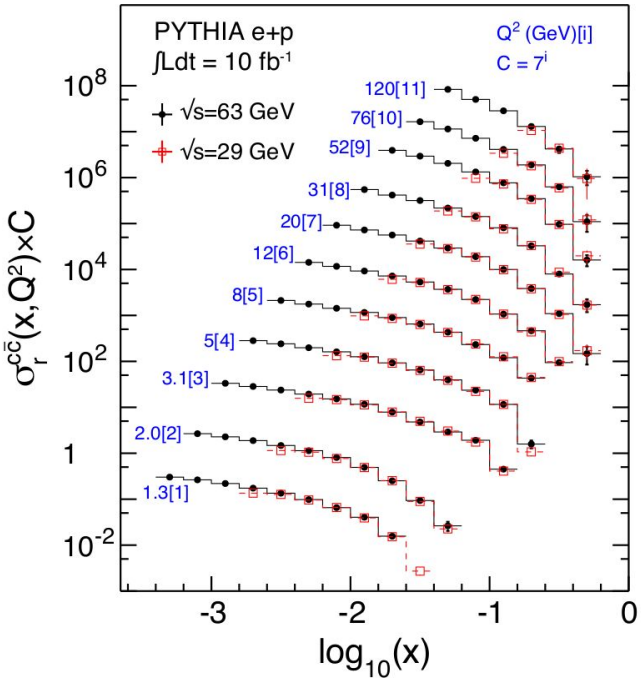






To explore:
gluon PDFs (very poorly known in nuclei)
and gluon TMDs (essentially unknown)

Cross-section for gluon PDFs



Transverse-spin asymmetry for gluon TMD

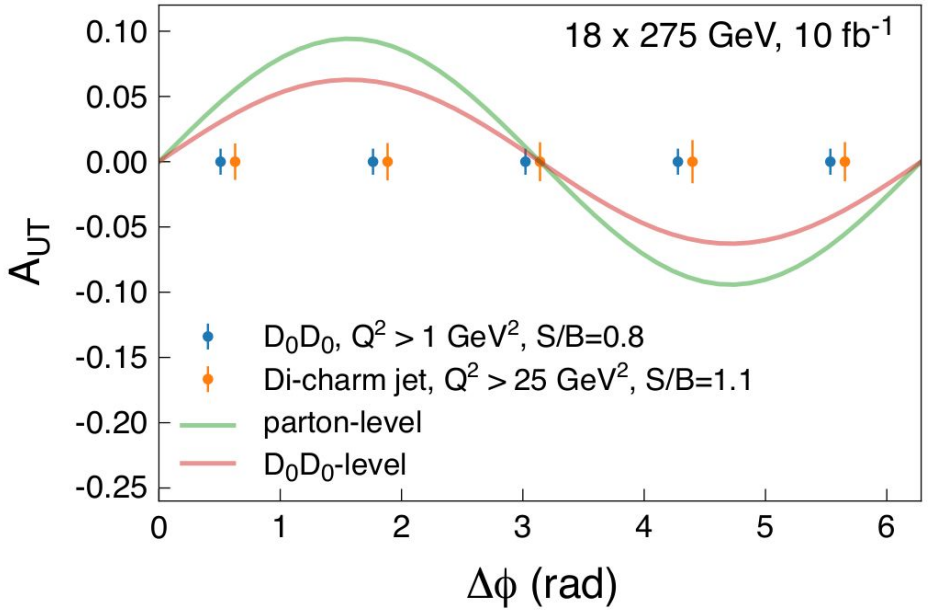
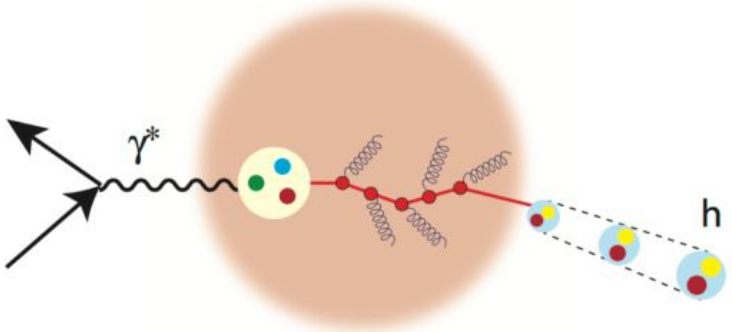
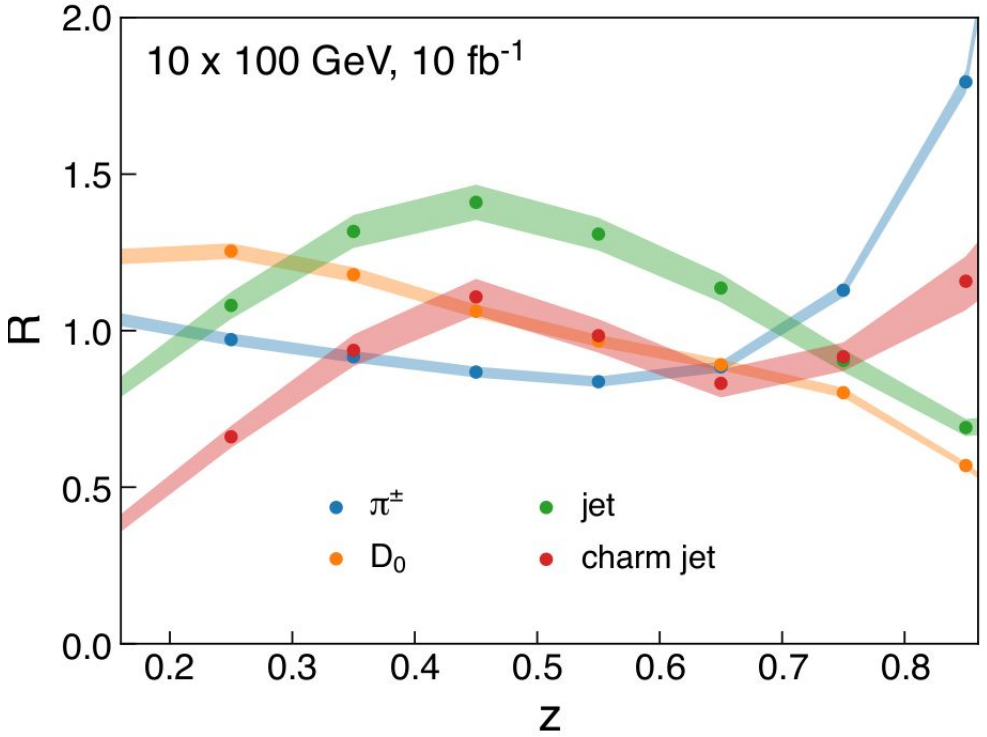


Image source: ATHENA proposal

To answer: How does the nucleus react to a fast quark?





Fraction of energy carried by hadron

Exclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$, which require the measurement of *all* particles in the event with high precision.

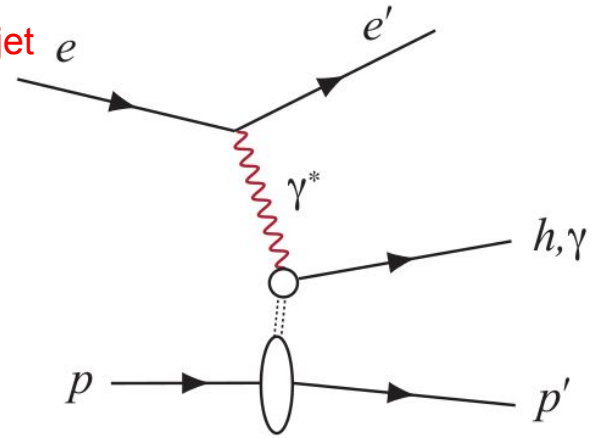
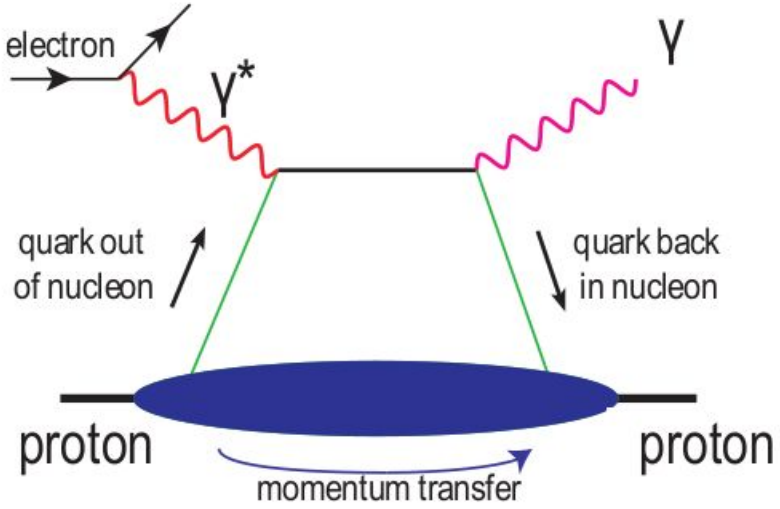


Image source: EIC YR

Real photon or meson production to measure density profile of quarks and gluons in momentum space



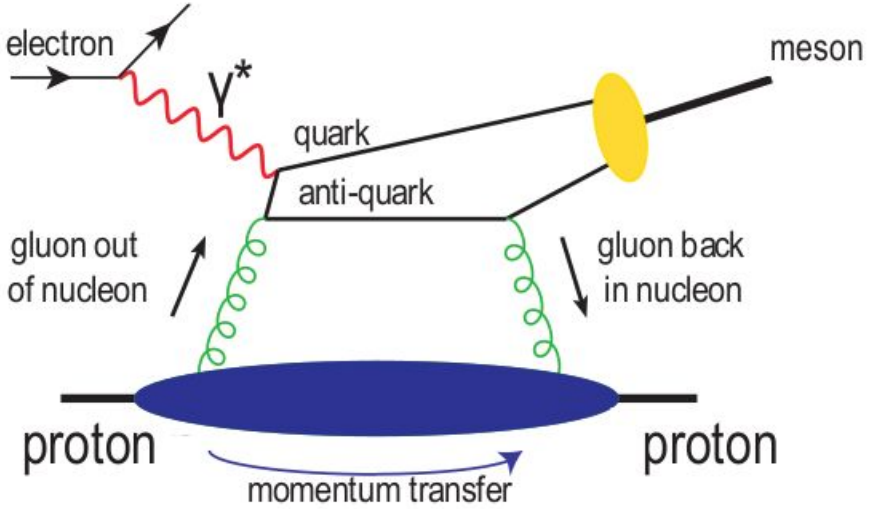
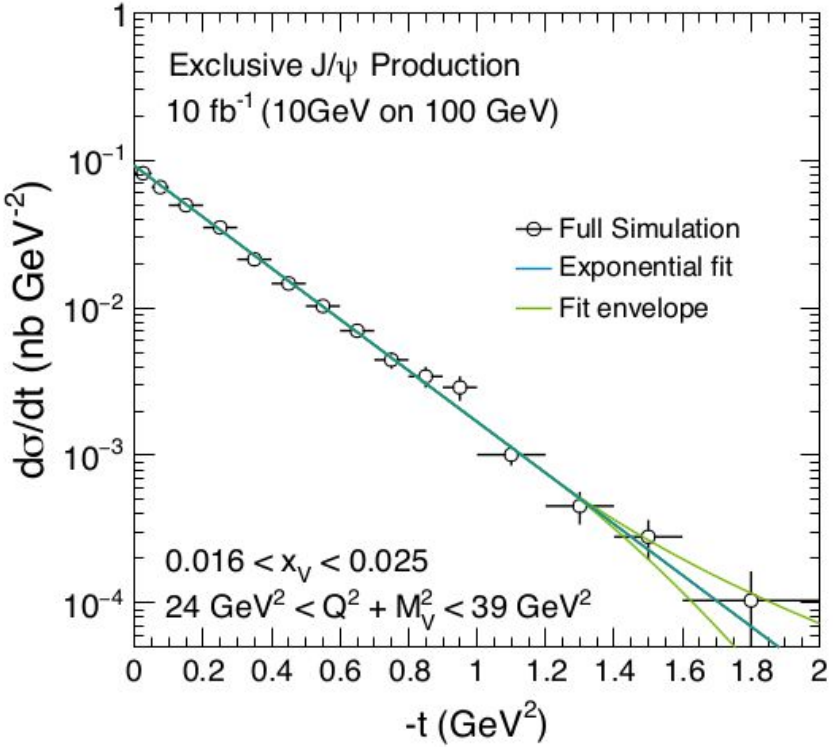


Image source: NAS

Photon (meson) detected in coincidence with far-forward proton

From Fourier transform to momentum-transfer distribution yields density profile in impact parameter



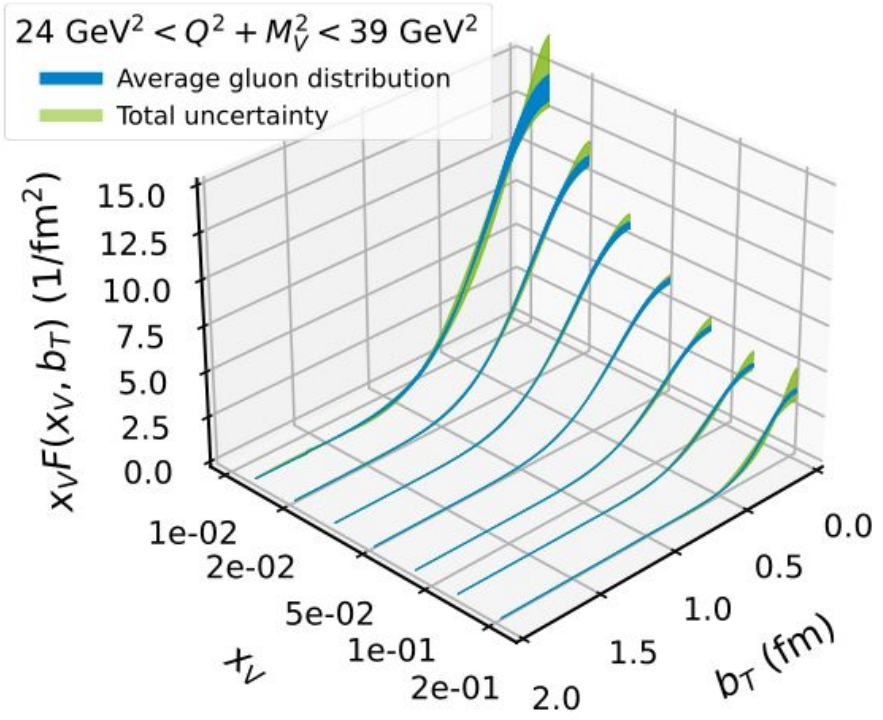
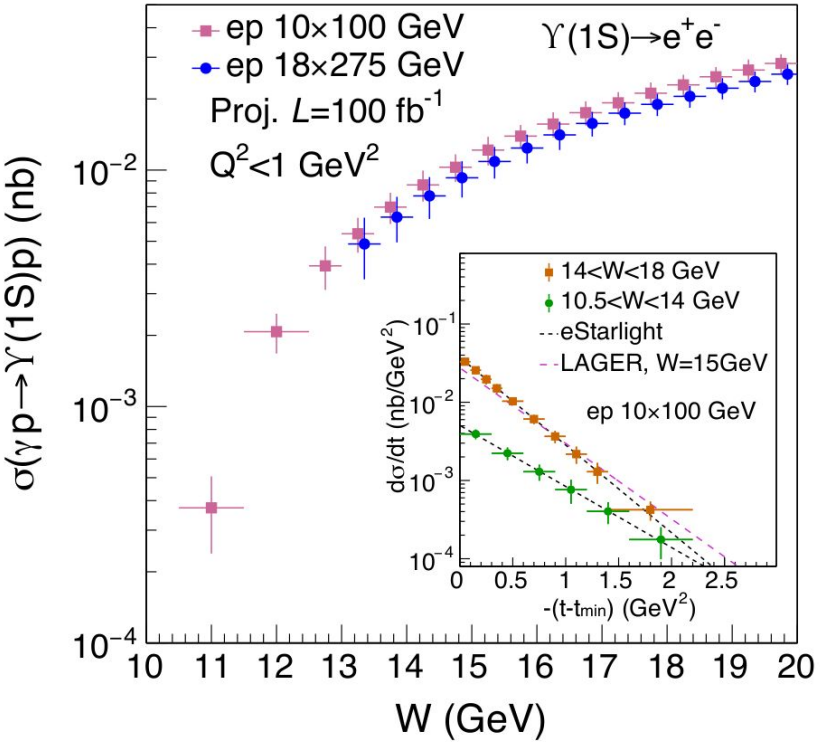


Image ATHENA proposal

Quarkonia measurements at threshold sensitive to “trace anomaly”



Which might be linked to
“Gravitational form factors”
And thus “origin of mass”

Image ATHENA proposal

Exclusive meson production on nuclei to probe gluon density and its fluctuations (key for saturation searches)

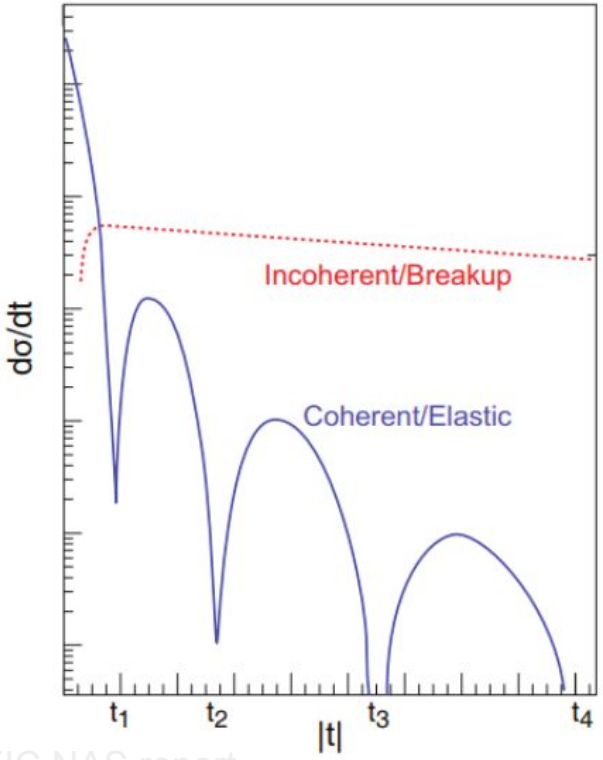
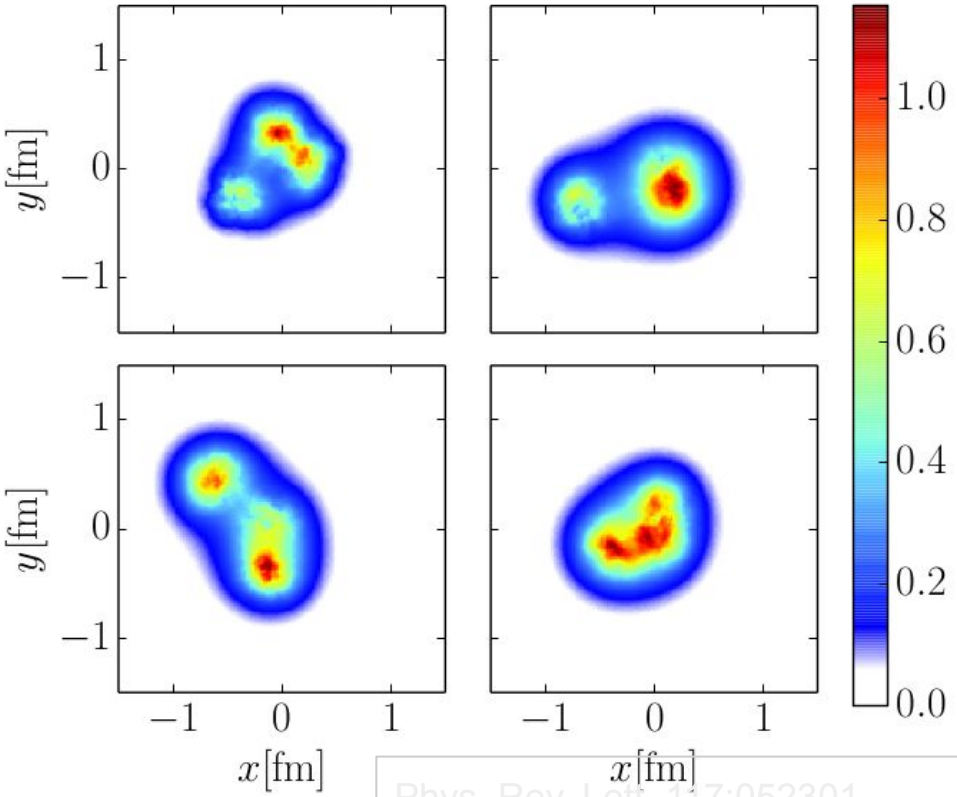


Image: EIC NAS report



Phys. Rev. Lett. 117:052301

Summary

The EIC experimental program will be enabled by 4π general-purpose detectors to measure nearly all particles measured in various types of reactions.

The program will begin centred on to key thrusts:

- Quantum tomography
- Searches for saturated-gluon matter

With a multipronged effort with various
- observables
- beam species
- reaction types

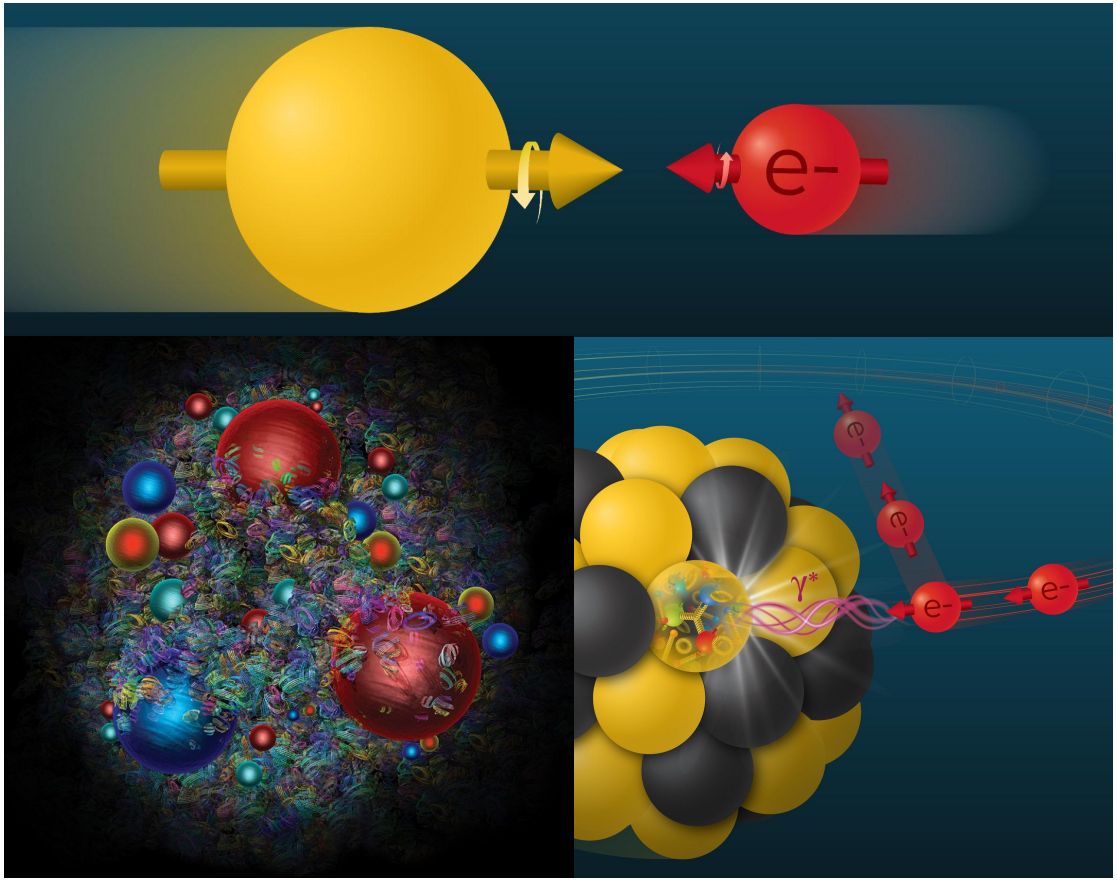
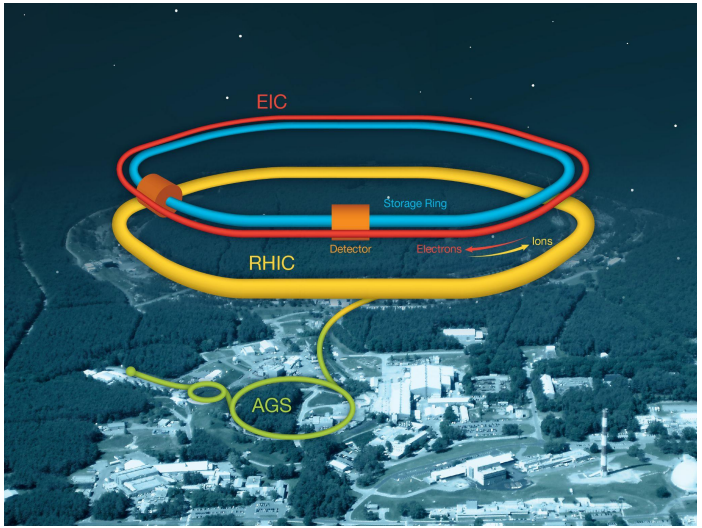


Image source: BNL and CERN

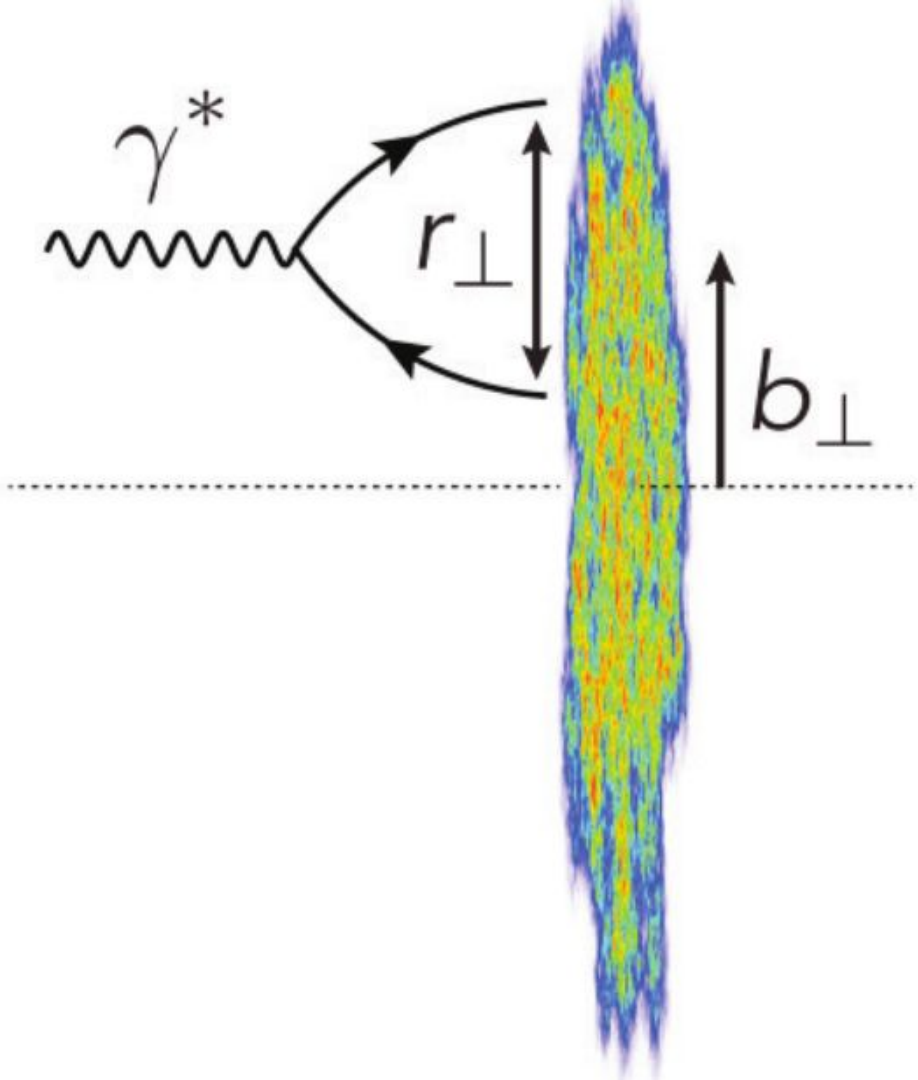
Final words

EIC: a new collider in American soil, with great discovery potential, which will run at least until the 2050s

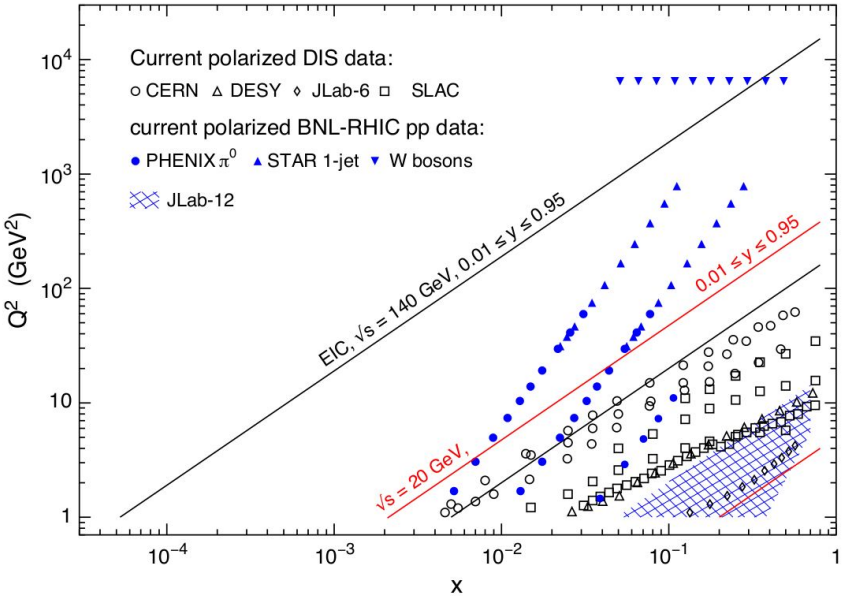
Plenty of opportunities for HEP people to migrate to EIC!
Come join us, the future is bright

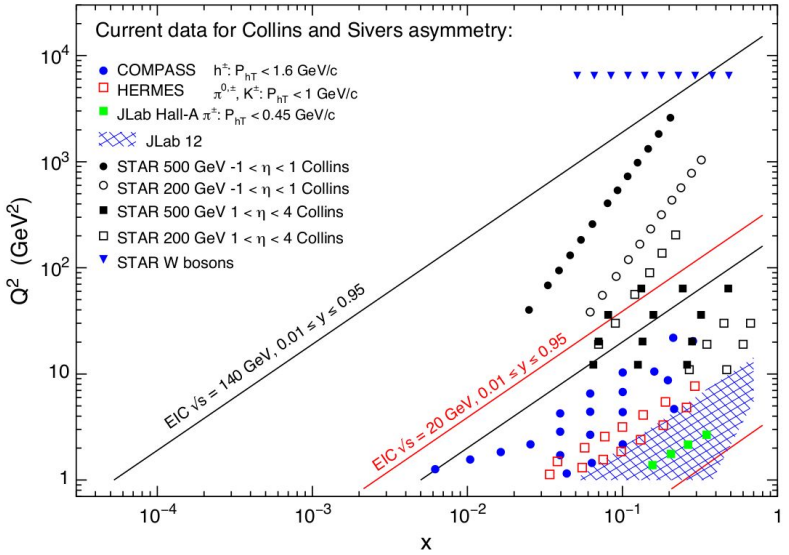


Backup

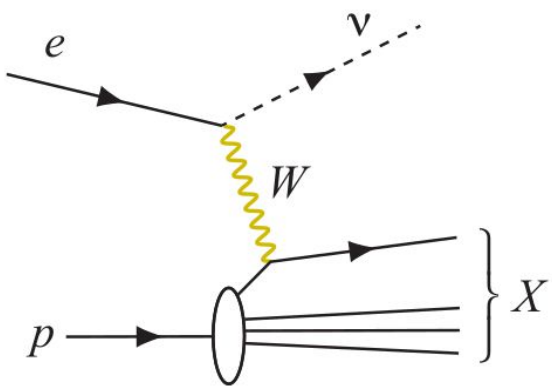

γ^*
$r_\perp$
$b_\perp$

Pushing the envelope in polarized deep-inelastic scattering

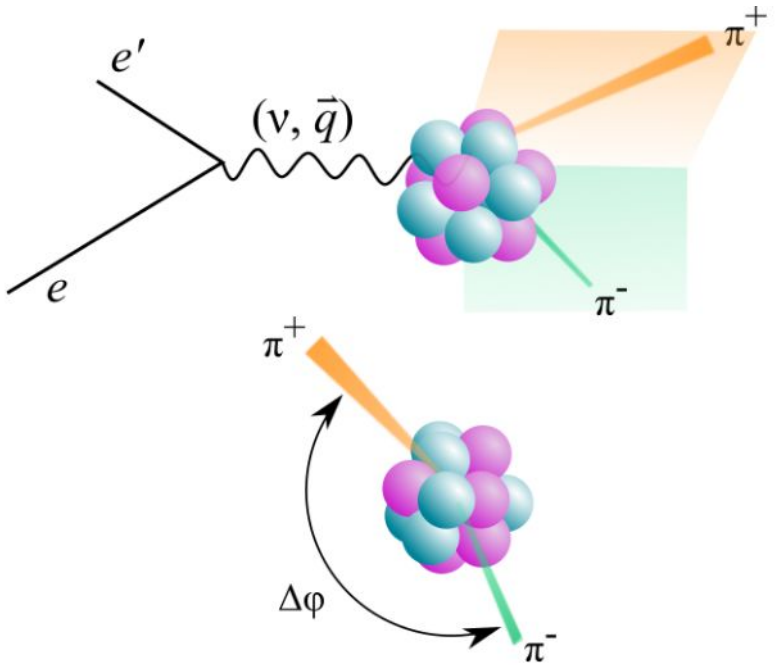




Charged-current Inclusive DIS: $e + p/\mathrm{A} \longrightarrow \nu + X$; at high enough momentum transfer Q^2, the electron-quark interaction is mediated by the exchange of a $W^{\pm}$ gauge boson instead of the virtual photon. In this case the event kinematic cannot be reconstructed from the scattered electron, but needs to be reconstructed from the final state particles.



“Gluon saturation” searches at low x



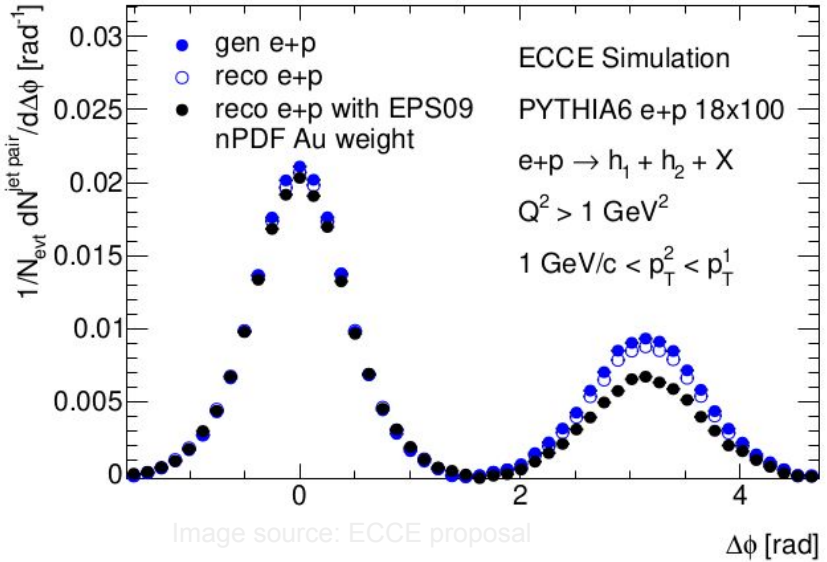


Image source: ECCE proposal

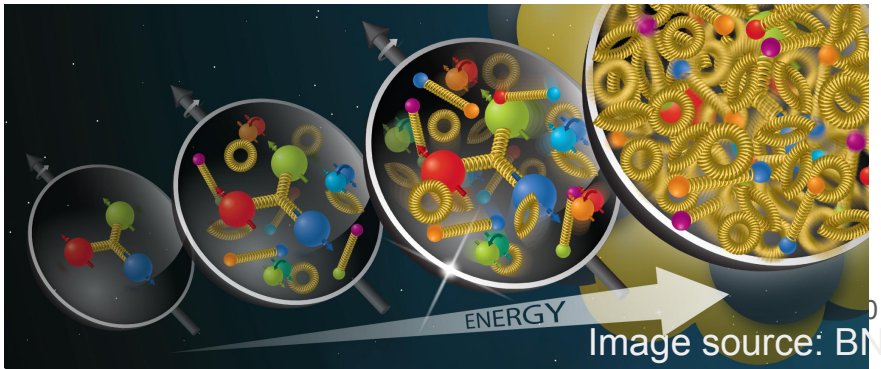
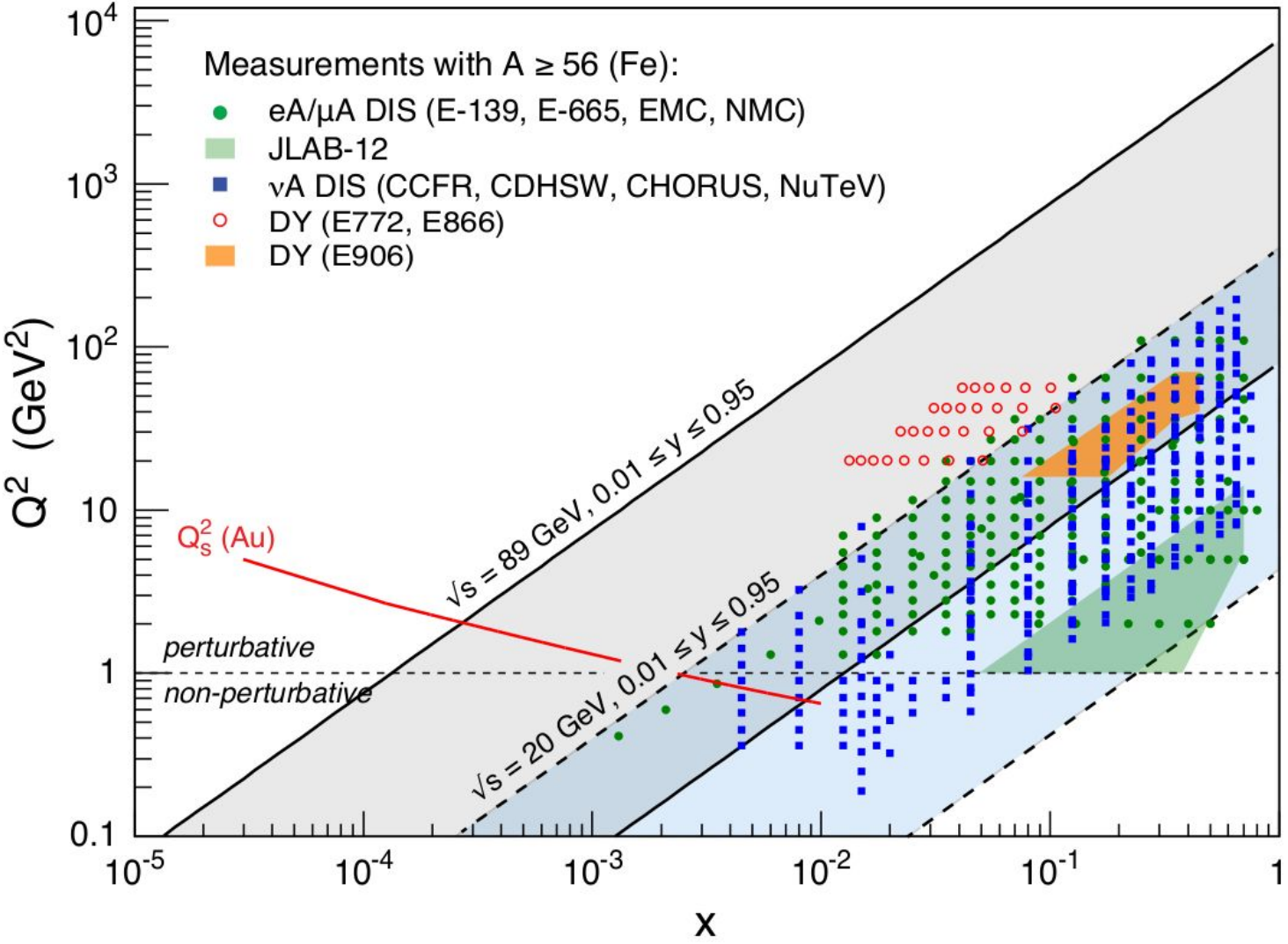


Image source: BNL


Measurements with A ≥ 56 (Fe):
eA/μA DIS (E-139, E-665, EMC, NMC)
JLAB-12
νA DIS (CCFR, CDHSW, CHORUS, NuTeV)
DY (E772, E866)
DY (E906)
Q_s^2 (Au)
√s = 89 GeV, 0.01 ≤ y ≤ 0.95
√s = 20 GeV, 0.01 ≤ y ≤ 0.95
perturbative
non-perturbative
Q^2 (GeV^2)
x
10^4
10^3
10^2
10
1
0.1
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1