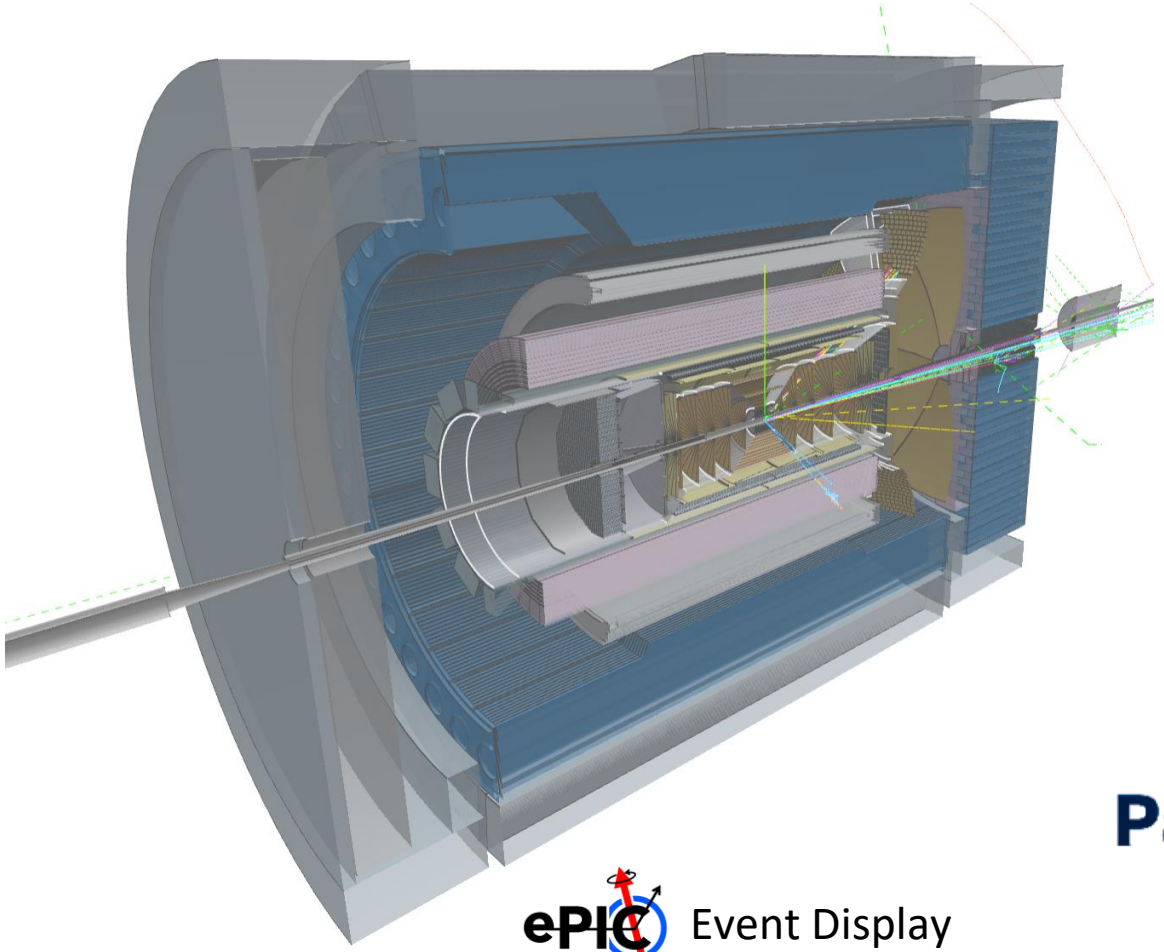


ePIC Event Display

Early Science Opportunities with ePIC at the Electron-Ion Collider

Carlos Muñoz Camacho
IJCLab, CNRS/IN2P3 (France)

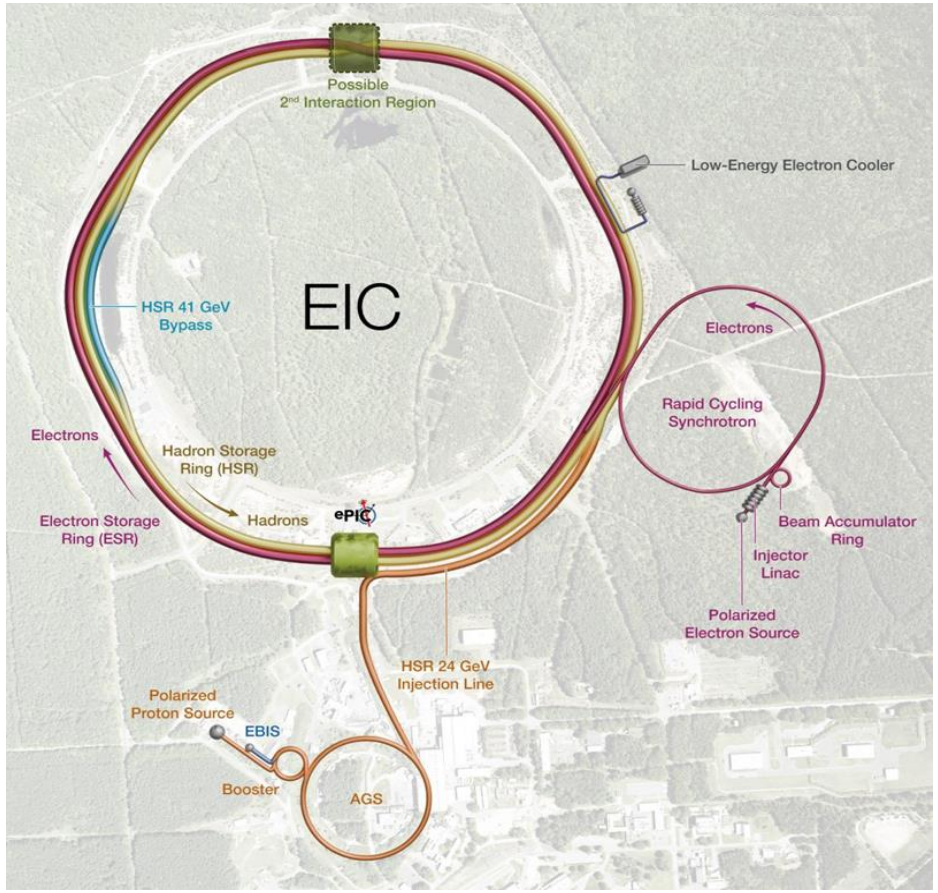
on behalf of the ePIC Collaboration

30 October 2026

PacificSPIN 2026

The 13th Circum-Pan-Pacific Symposium on High Energy Spin Physics

The EIC facility



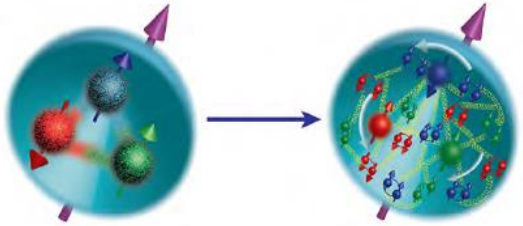
- Highly polarized electron / Highly polarized proton and light ions /Unpolarized heavy ions
- CME: ~ 20–140 GeV
- Luminosity: ~ $10^{33\text{-}34}$ $cm^{-2}s^{-1}$

- Polarized electron source and 400 MeV injector linac to feed a rapid cycling synchrotron design to avoid depolarizing resonances up to the maximum e-beam energy of 18 GeV
- Polarized proton beams and ion beams based on existing RHIC facility
- 2 detector interaction points capability in the design

Motivation – the EIC science program

Origin of spin:

How does the spin-1/2 of the nucleon arise from the spin of quarks, gluons and their orbital angular momenta?



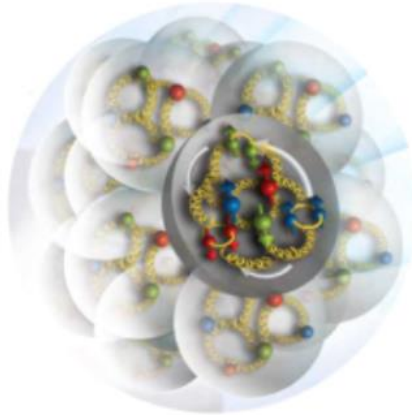


Origin of mass:

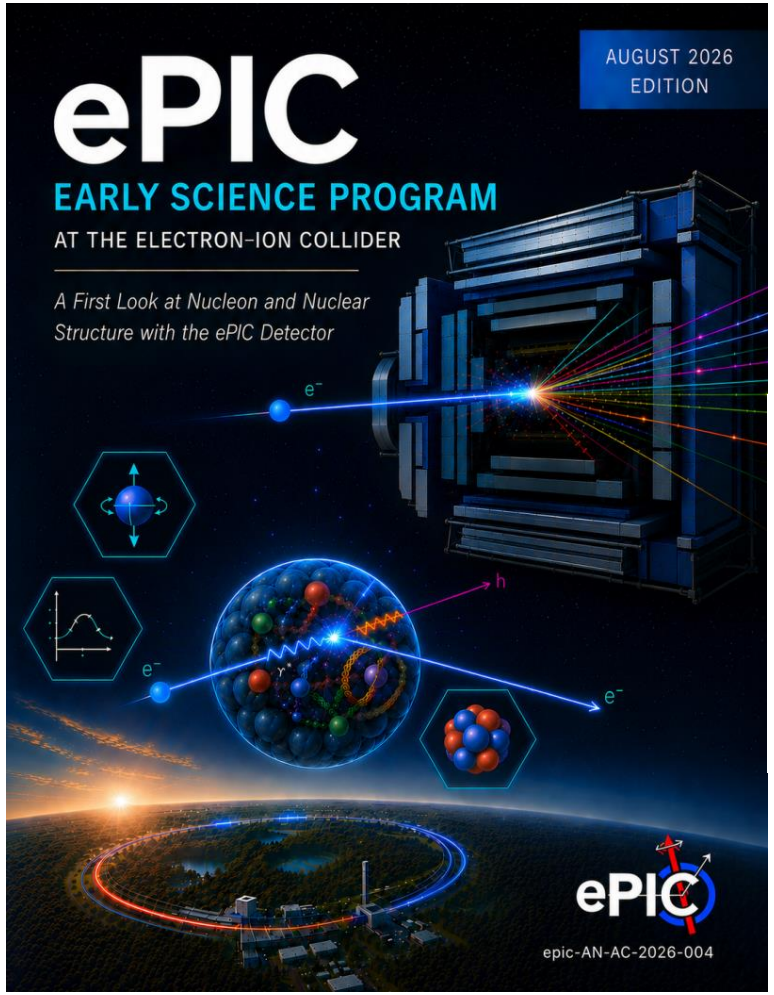
How do massless gluons make up for most of the nucleon mass?

Gluons in nuclei:

Does gluon density saturate at high energy giving rise to a new regime of matter?



ePIC Early Science Report



- Prepared in response to a BNL/JLab charge: identify science possible before the ramp-up to full EIC capability.
- Uses realistic early-running beam configurations and full ePIC detector simulations.

Stage 1: Commissioning

Unpolarized mid and light-weight ions for technical stability in RHIC → EIC transition

Stage 2: e^- Polarization

Longitudinal electron polarization via spin rotators; far-forward system become operational; transversely polarized hadron beams become available

Stage 3: Hadron Polarization

Hadron spin rotators enable longitudinal proton polarization

Heavy ion run (Au, unpolarized)

Eventually polarized ^{3}He ions will be available

ePIC science and the NAS pillars

NAS Science Pillars and ePIC early science Measurements

Examples inside each cell indicate how ePIC early physics measurements connect to the three NAS pillars

ePIC early science measurement type	Origin of nucleon mass	Origin of nucleon spin	Emergent properties of dense gluon matter
Inclusive DIS	**Supporting** • F_2 and F_L structure functions • Proton PDFs and α_S	**Strong** • $A_1^{p,n}$ and $g_1^{p,n}$ • Gluon helicity PDFs	**Important** • Nuclear F_2 ratios • Nuclear PDF constraints
Semi-inclusive DIS	**Supporting** • Unpolarized TMD PDFs • Nuclear fragmentation functions	**Strong** • Sivers A_{UT} • Collins asymmetries • Quark helicity PDFs	**Strong** • Di-hadron correlations • Nuclear hadronization / fragmentation
Exclusive / Diffractive / Tagged	**Strong** • DVCS / GPD imaging • Quarkonium production • Meson form factors / structure functions	**Important** • Spectator-tagged $A_1(n)$ • GPD constraints on OAM	**Strong** • Coherent/incoherent VM in eA
Jets & Heavy Flavor	**Important** • Open charm production • Λ_c/D^0 ratio	**Supporting** • Δg from charm/jets • Hadron-in-jet Collins FF	**Important** • Charged-jet R_{eA} • D^0-in-jet R_{eA}

Origin of mass
DVCS/GPD imaging, vector mesons, meson form factors and meson structure functions.

Origin of spin
Spectator-tagged neutron observables and GPD constraints relevant to orbital angular momentum.

Dense gluonic matter
Coherent/incoherent vector-meson production in e + A accesses average gluon density and fluctuations.

Early running assumptions

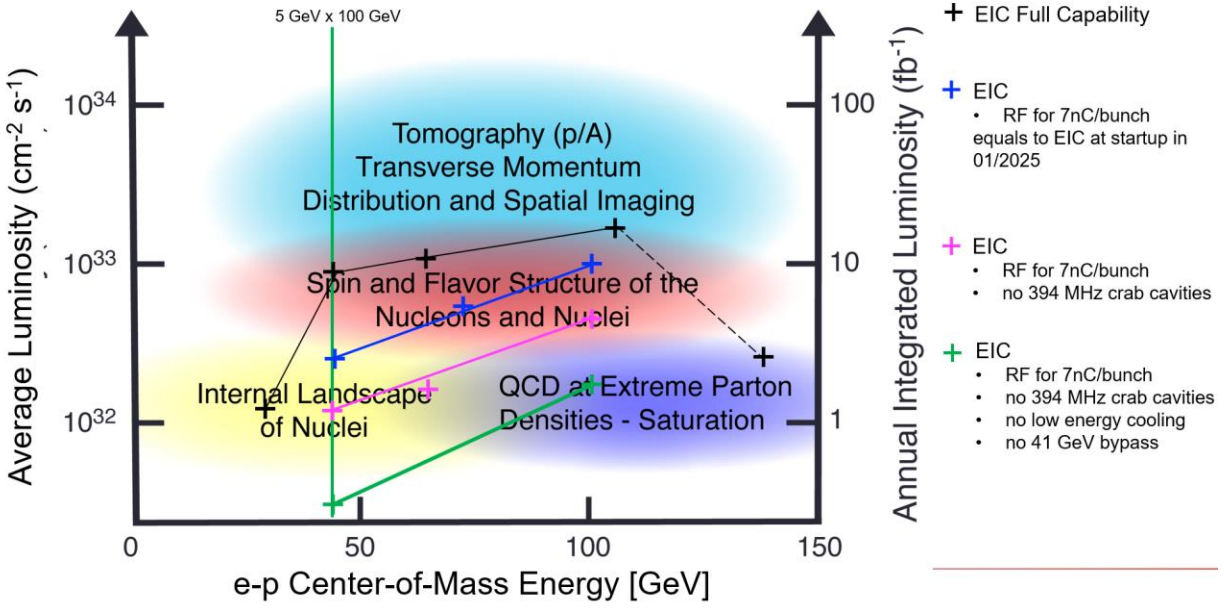
Species	Beam energy (GeV)	Integrated luminosity (fb^{-1})	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	1.0	NO	N/A
e+D	9×130	1.5	LONG	NO
$e + p$	9×130	1.0	LONG	TRANS and/or LONG
$e + p$	9×275	2.5	LONG	TRANS and/or LONG
e+Au	9×100	1.0	LONG	N/A
$e + {}^3$He	9×166	1.5	LONG	TRANS and/or LONG

Table 2: EIC early science matrix. The $e + A$ energy and luminosity are per nucleon.

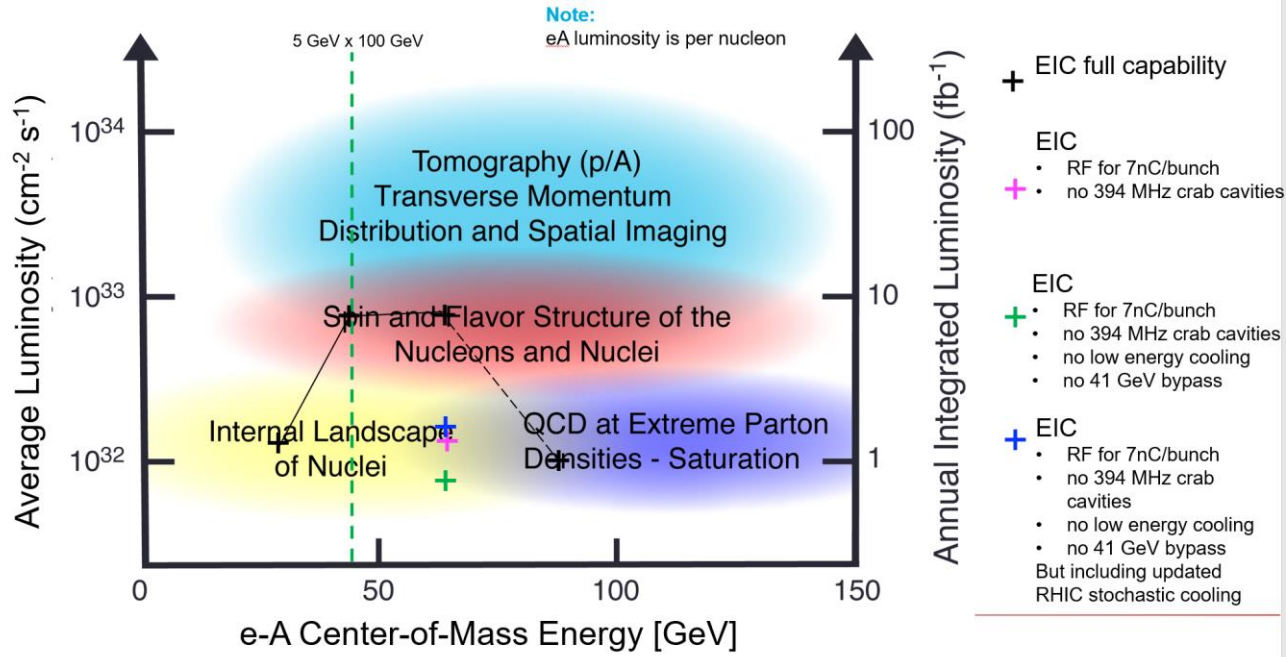
- Baseline electron beam: 9 GeV, with an upgrade path to 18 GeV.
- Initial e + A running supports early diffractive and low-multiplicity nuclear measurements.
- Polarized e + p and e + ^{3}He enables spin and tagged-neutron observables.
- Far-forward commissioning required for exclusive and spectator tagging measurements.

Luminosity: early science

ep



eA



E. Aschenauer (U. of Calabria, March 2026)

The EIC detector: ePIC

Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:
- Backward pfRICH
- Barrel hpDIRC
- Forward dRICH
- Barrel & Forward TOF

Calorimetry:
- Backward HCal (Steel+scint)
- $PbWO_4$ EMCal in backward direction
- Sampling & Imaging Barrel EMCal
- Outer HCal (sPHENIX re-use)
- Finely segmented EMCal +HCal in forward direction

hadronic calorimeters

Solenoidal Magnet

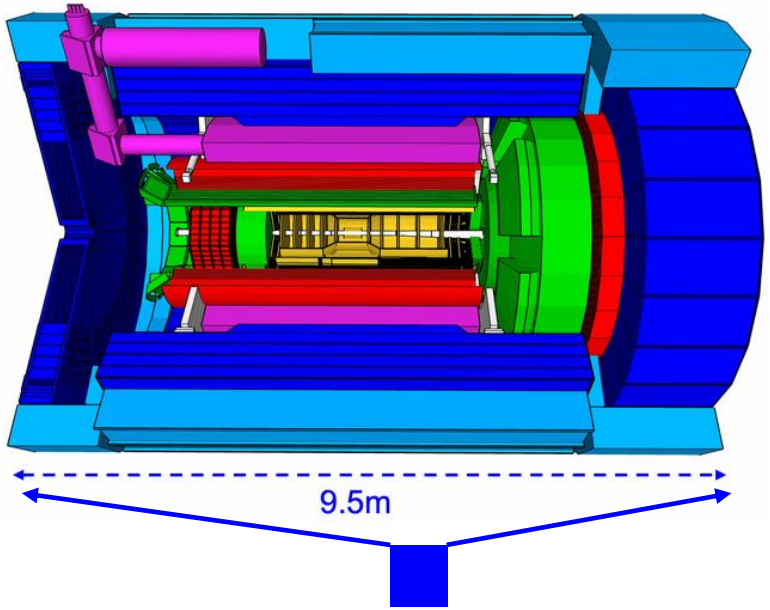
e/m calorimeters

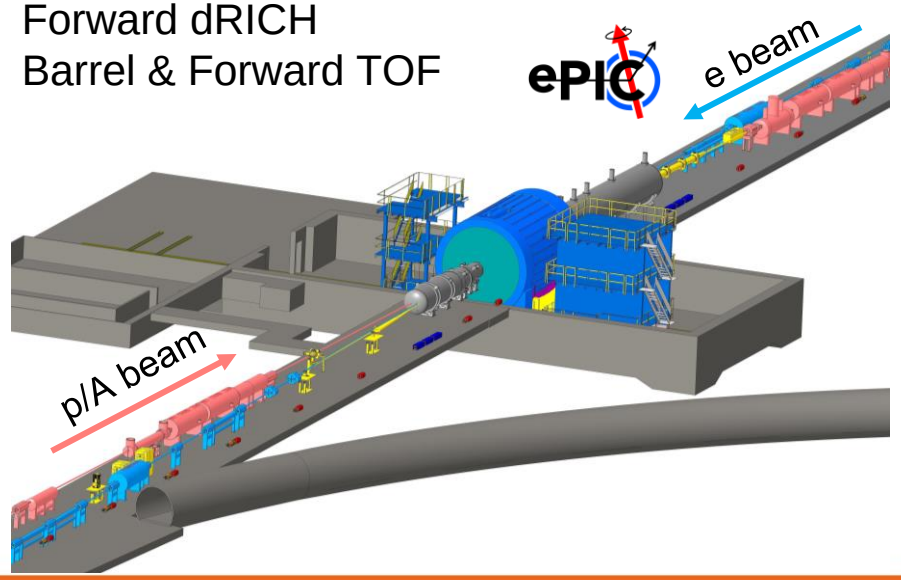
ToF, DIRC, RICH detectors

MPG trackers

MAPS tracker

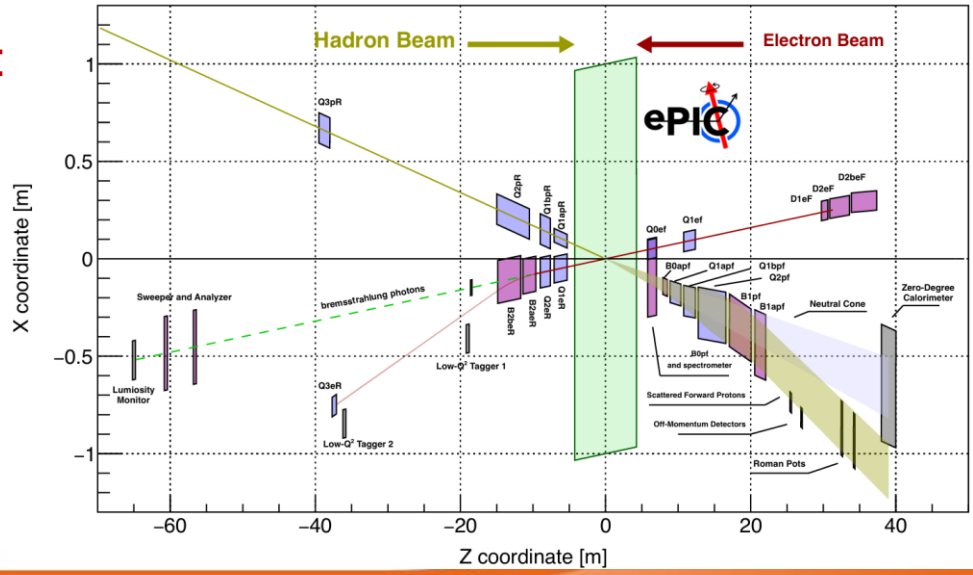
25 subdetectors incl. polarimeters



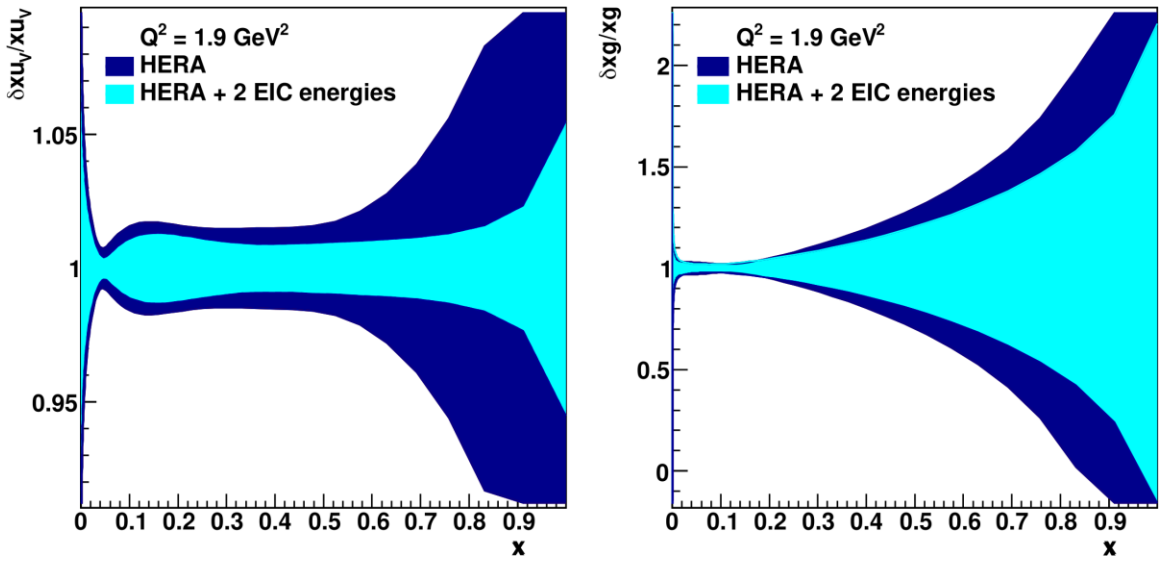


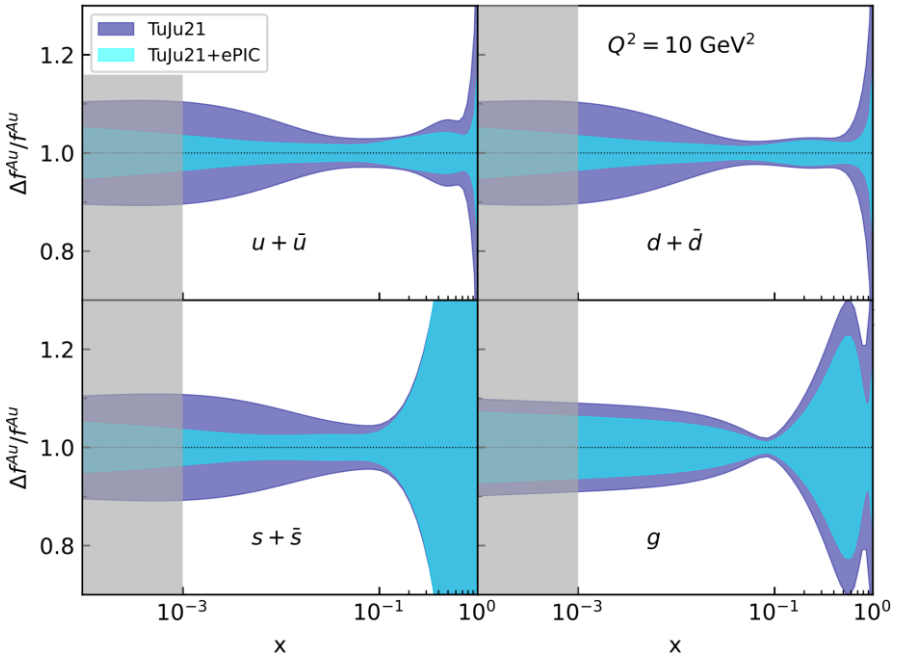
Far-Backward Detectors:
- Luminosity monitor.
- Low-Q^2 Tagger

Far-Forward Detectors:
- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors.
- Zero-Degree Calorimeter



Inclusive DIS measurements





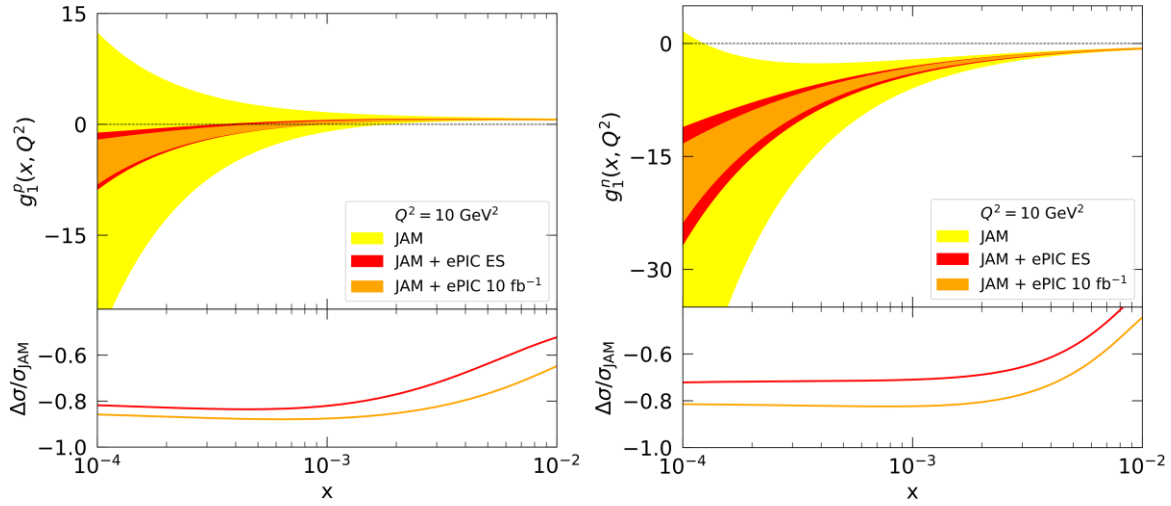
Proton PDFs

Early e+p DIS reduces uncertainty for up-valence and gluon PDFs, especially at intermediate and high x.

Nuclear PDFs

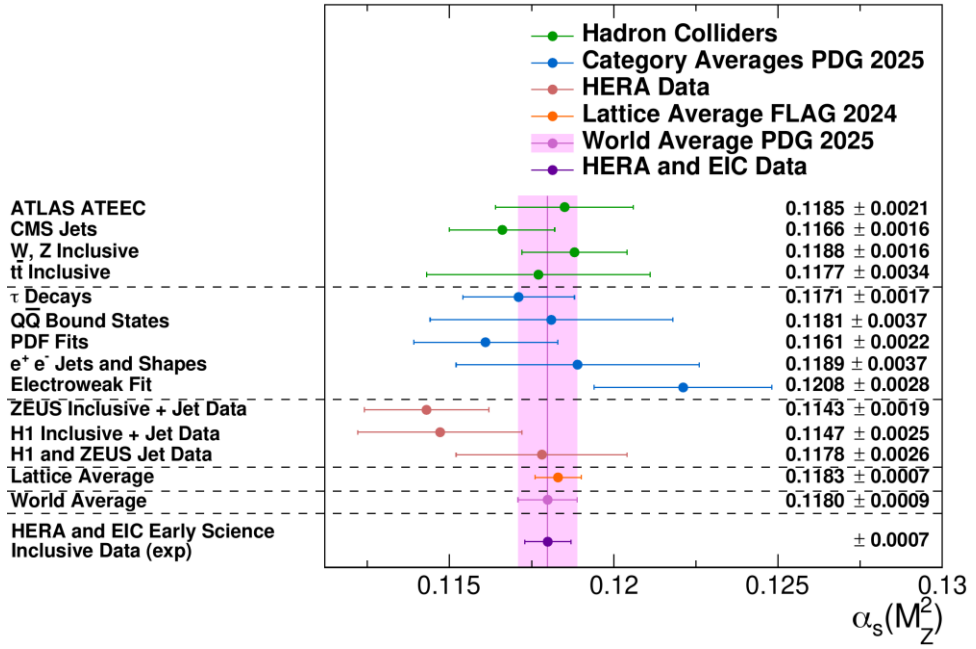
Early e+Au data extend nuclear DIS reach toward x ~ 10^-3 and constrain sea, valence and gluon nPDFs.

Inclusive DIS measurements



Spin structure

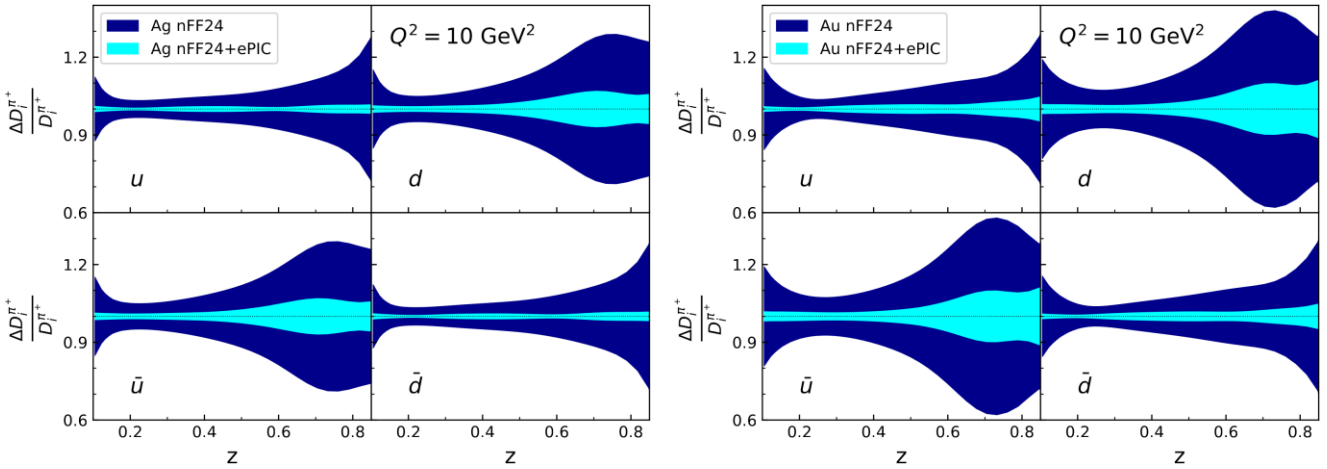
Polarized DIS expands g1 constraints into the low-x region for proton and neutron spin studies.



Strong coupling constant α_s

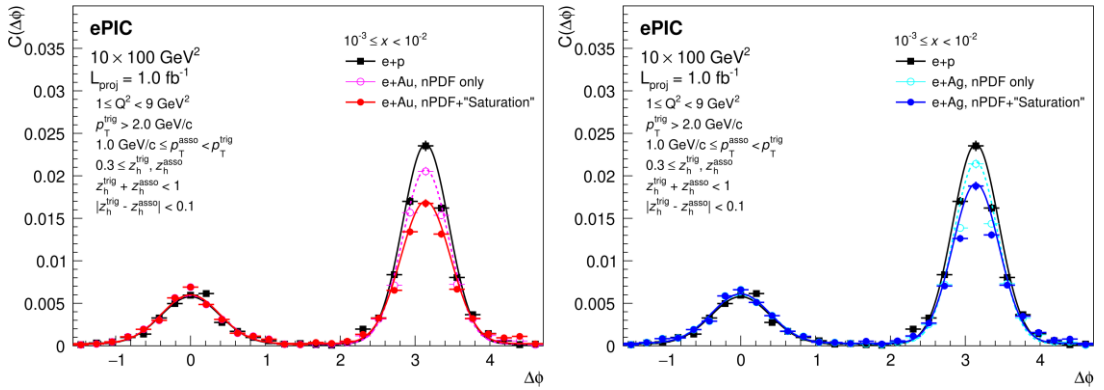
- Fit early e+p reduced cross sections together with HERA data in an NNLO DGLAP framework.
- PDFs and the strong coupling are determined simultaneously, giving a precision test of QCD from clean DIS data.

Semi-inclusive DIS



Nuclear fragmentation functions

e+Ag and e+Au SIDIS multiplicities sharply reduce nFF uncertainties, improving cold-nuclear-matter baselines.

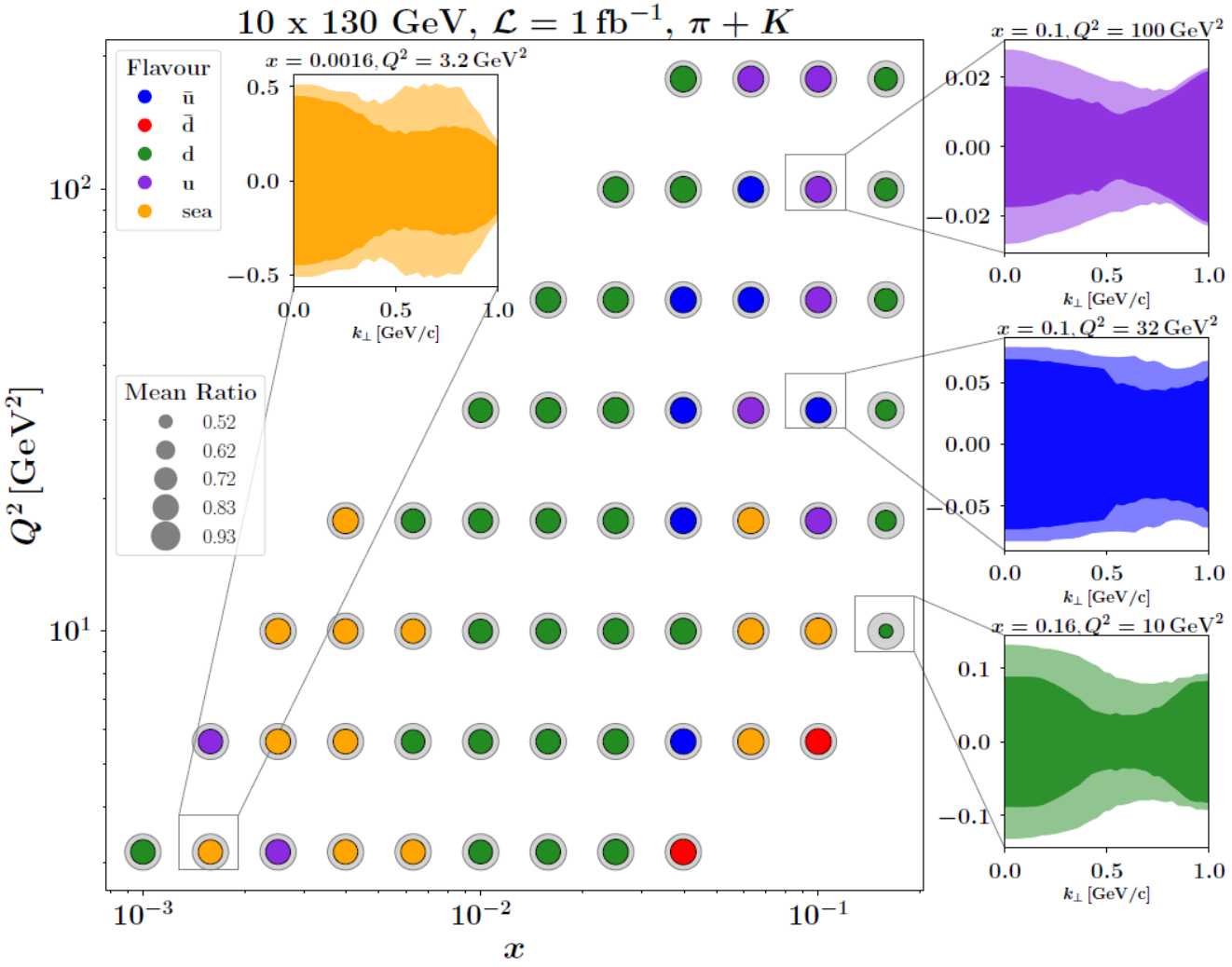


Di-hadron correlations

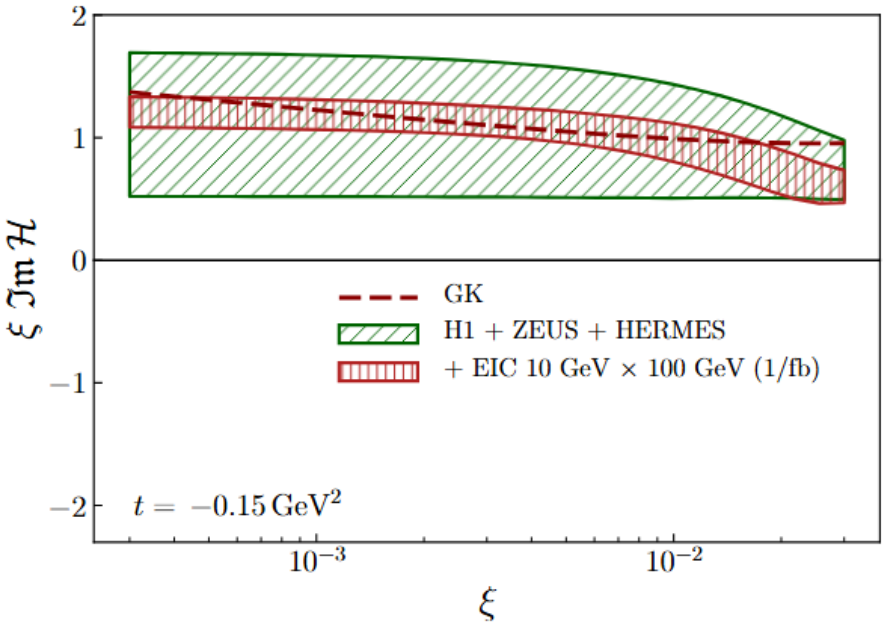
Away-side peak suppression in e+A relative to e+p provides an early saturation-sensitive observable.

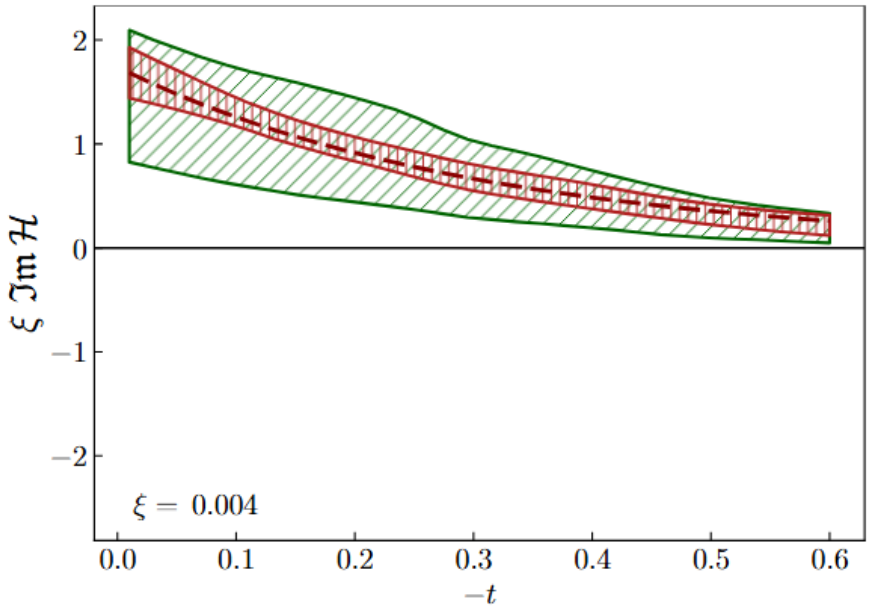
Semi-inclusive DIS: TMDs

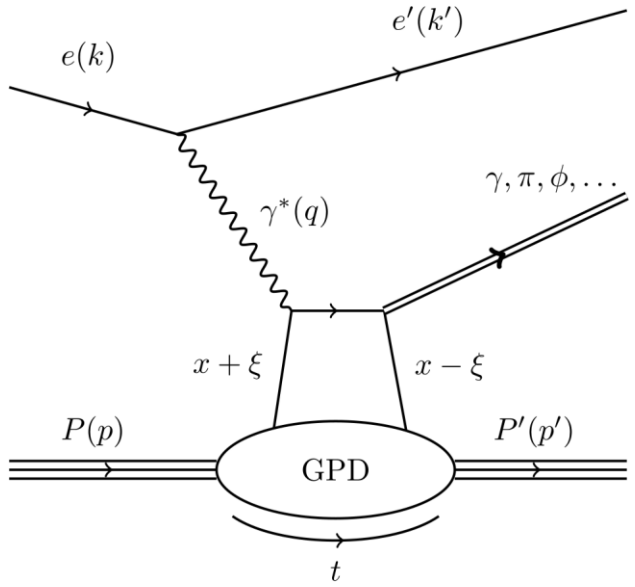
- Identified hadrons add flavor sensitivity and access to fragmentation.
- Unpolarized TMD PDFs establish the baseline for all polarized TMD extractions.
- Sivers and Collins observables probe spin-orbit correlations, transversity, and tensor charges.



Exclusive measurements: DVCS





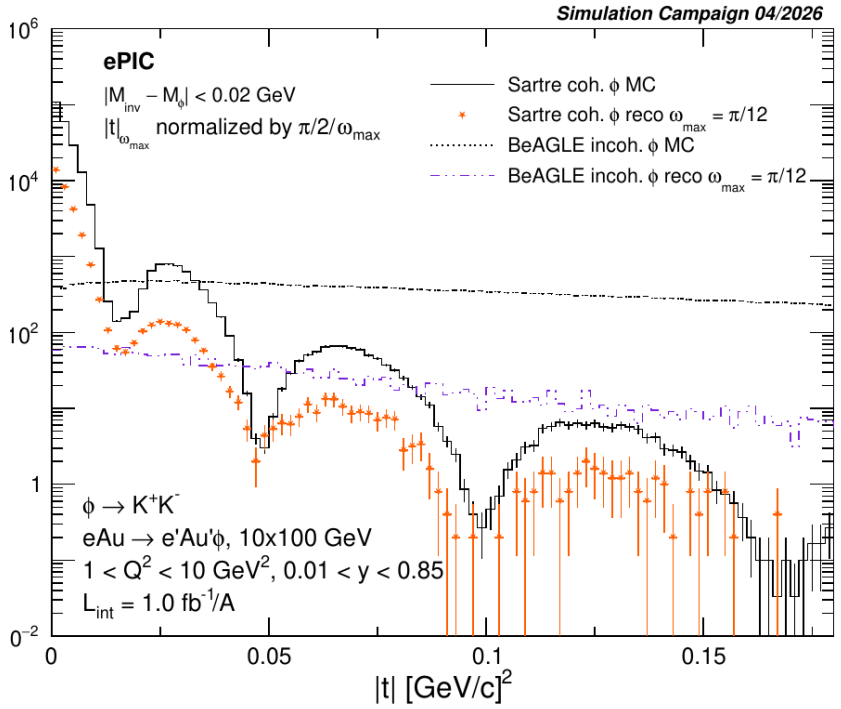


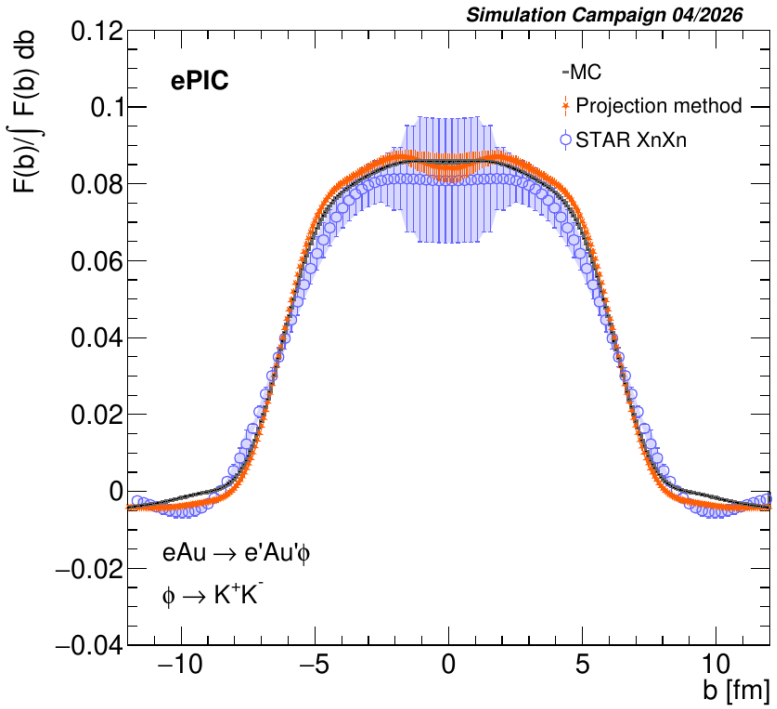
Early Physics Impact:

Projected DVCS data narrow uncertainty bands on Im H, one of the Compton form factors entering the DVCS amplitude.

- DVCS is the clean benchmark for Compton Form Factors and GPD-based proton imaging.

Coherent φ in e+Au: diffraction & *g* imaging





Key detectors:

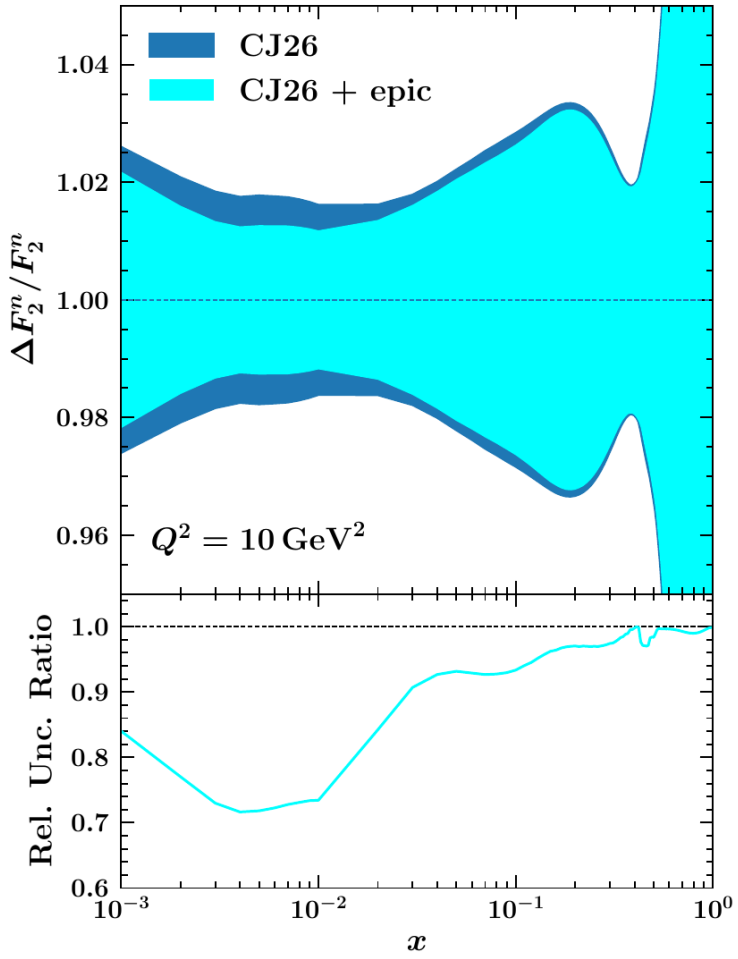
OMD/RP/ZDC vetoes and tags control coherent vs incoherent breakup; electron and kaon reconstruction controls exclusivity

Projection-method |t| reconstruction resolves the diffractive structure and follows the MC truth more closely than the standard method.

The Fourier–Bessel transform converts the measured |t| distribution into the transverse gluon spatial profile.

Spectator-tagged deuteron data: F_2^n

CJ26 baseline uncertainty on F_2^n at Q^2 = 10 GeV², compared with CJ26 + ePIC spectator-tagged pseudo-data.

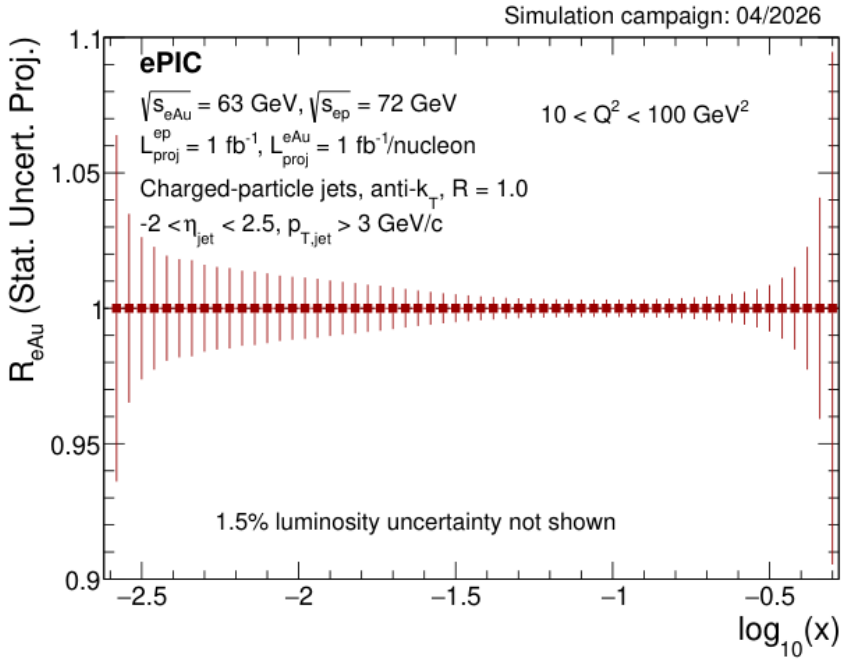


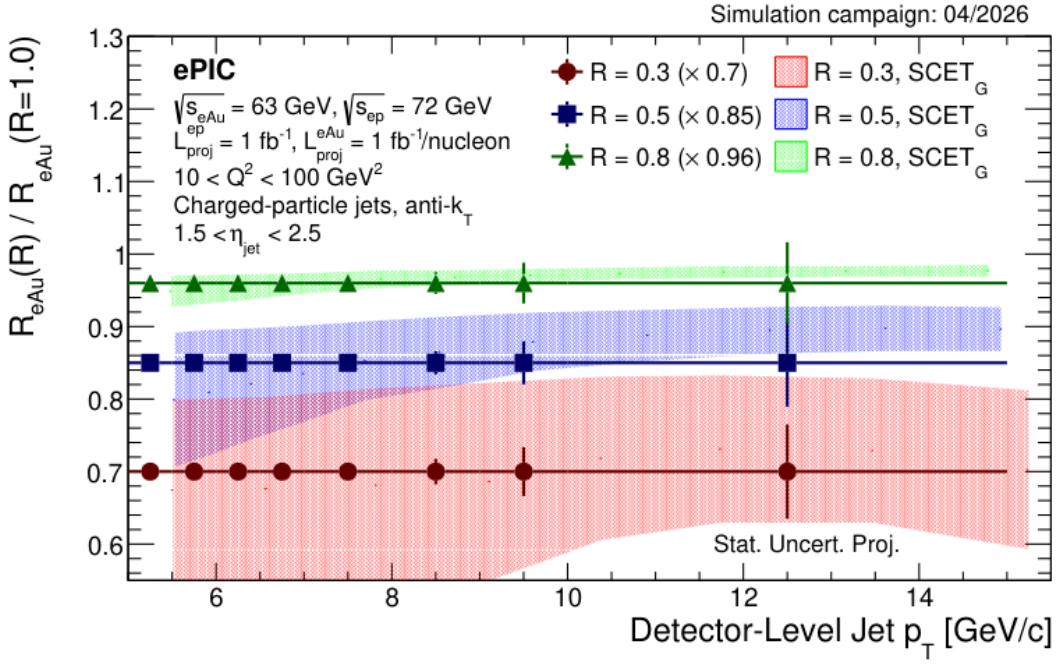
- Use deuterium as an effective neutron target: e+d → e' + X + p_{spec}
- A low-momentum spectator proton tags DIS on the neutron and fixes the initial p/n configuration.
- Extrapolation to the deuteron pole selects the large-separation p+n limit, where the struck neutron is effectively free.
- This minimizes nuclear binding and final-state-interaction corrections, enabling a clean extraction of the free-neutron structure function F_2^n.

- The relative uncertainty is reduced over a broad x range; around x ≃ 5×10⁻³, about 2% → 1.5% (≈25–30% reduction)
- This brings neutron-structure uncertainties closer to the scale required for deuteron shadowing tests and robust flavor-separated PDF constraints

Jets and heavy flavor

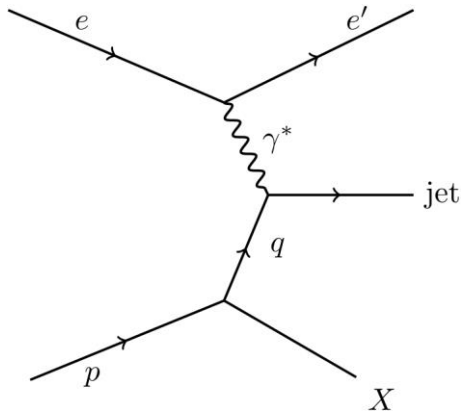
Inclusive charged-jet nuclear modification in e+Au

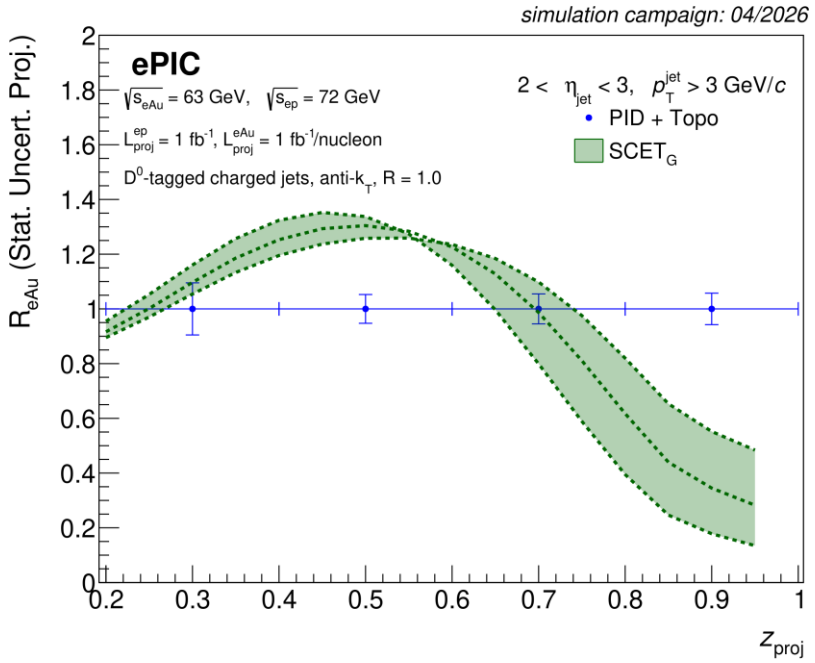


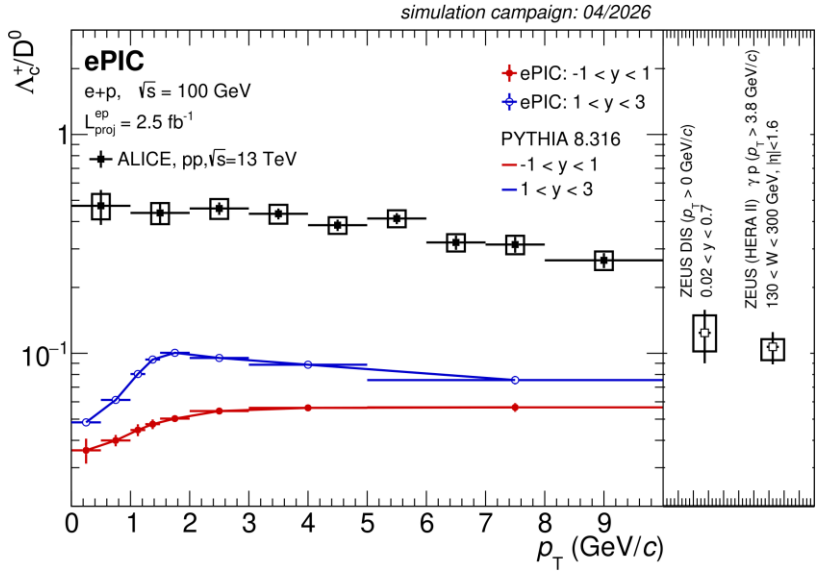


- Large-radius jets (R = 1.0): R_{eA} mainly probes initial-state nuclear effects / nPDFs while minimizing final-state shower effects; projected statistical precision is generally below 2%.
- Jet-radius ratio $R_{eA}(R)/R_{eA}(R = 1.0)$: initial-state effects largely cancel, enhancing sensitivity to final-state cold-nuclear-matter energy loss and shower broadening.
- Early e+Au and e+p running at 1 fb^{-1} already provides quantitative constraints on parton propagation in cold nuclear matter.

Jets and heavy flavor







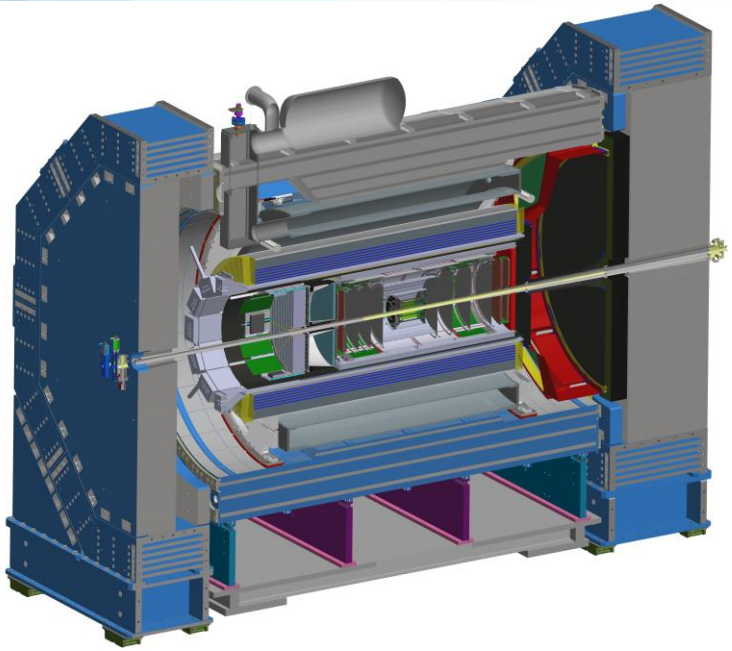
- Inclusive charged-jet ReA separates nPDF effects from final-state energy loss using jet-radius dependence.
- Charm production is a clean photon-gluon-fusion probe of gluon dynamics.
- Λ_c/D^0 and D^0-in-jet measurements test charm hadronization and cold nuclear matter modification.

EIC early running: limitations

Kinematic reach	9 GeV electrons limit the low-x frontier; fully entering saturation requires the 18 GeV upgrade path.
Luminosity	Early luminosities are powerful for benchmarks but limit fine multidimensional binning in x, Q^2 and t.
GPD tomography	DVCS can initiate the CFF/GPD program; quantitative model-independent tomography needs full luminosity.
Saturation	Coherent VM imaging in e + A provides early constraints; discovery-level saturation studies need full energy and luminosity.
Rare channels	Near-threshold quarkonium and some hard-probe channels are deferred beyond the early configuration.

Early ePIC validates and begins the program; full EIC capability completes the NAS science case

Summary



- The ePIC detector at the EIC will address fundamental questions on the structure and dynamics of nucleons and nuclei in terms of quarks and gluons, including
  - Parton distributions in nuclei/QCD at extreme parton densities – saturation
  - Spin and flavor structure of the nucleon and nuclei
  - Tomography (p/A) Transverse Momentum Distributions and Spatial Imaging
  - Synergies with pA and AA (PDFs, nPDF, FFs…)
- Early years of running not purely for commissioning: configurations enable a rich physics program!
- ePIC will make world-leading and competitive measurements on QCD science in early years of running
- Staged program of measurements mapping to early EIC running configuration:
  - Inclusive DIS provides early high statistics and impactful measurements
  - SIDIS and jets/HF channels expand the program as hadron reconstruction and hadron PID mature
  - Exclusive, diffractive and tagged measurements fully exploit the far-forward instrumentation
- Fully answering NAS pillars requires the ultimate design EIC luminosity, energy, beams and detector instrumentation