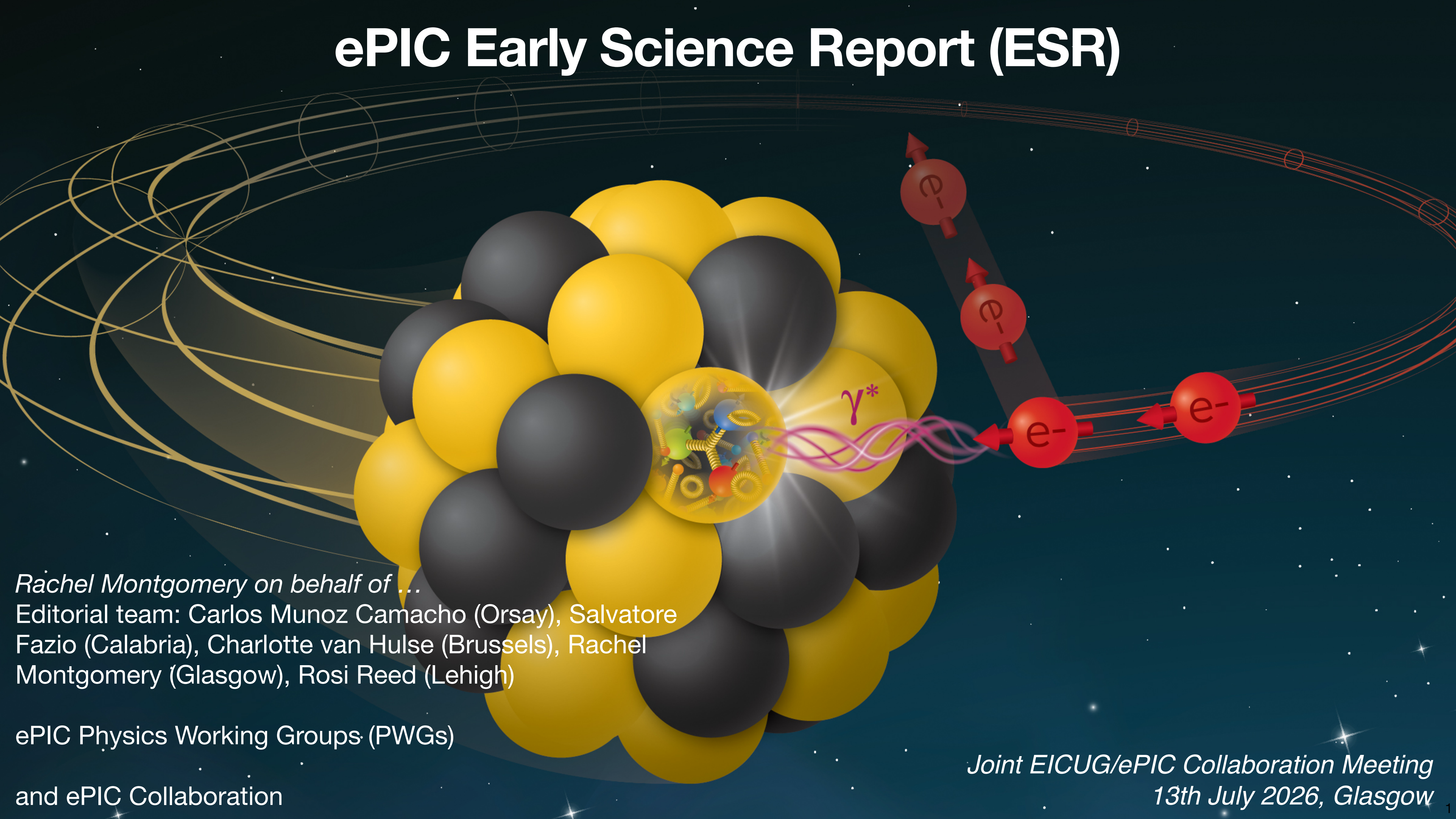


ePIC Early Science Report (ESR)



Rachel Montgomery on behalf of ...
Editorial team: Carlos Munoz Camacho (Orsay), Salvatore Fazio (Calabria), Charlotte van Hulse (Brussels), Rachel Montgomery (Glasgow), Rosi Reed (Lehigh)

ePIC Physics Working Groups (PWGs)
and ePIC Collaboration

*Joint EICUG/ePIC Collaboration Meeting
13th July 2026, Glasgow*



Context

- EIC will approach full design specs over a multi-year period, in terms of:
 - instantaneous luminosity and beam energies/species/polarization
- ePIC will be operational during this period
- June 2025: ePIC received a charge from JLab & BNL ALD's
 - Produce a report summarizing what exciting scientific results would be possible with early data
 - Results should be based on latest ePIC full simulations and reconstruction
 - (Original deadline May 1st 2026 - but we extended it to July 2026)
- Overall Goal:
 - Highlight meaningful and impactful science achievable within initial years of operation, without undermining the importance of measurements with full EIC capabilities



Early Running Configurations

9 GeV electron beam (10 nC bunch charge) collides with staged sequence of hadron and ion beams

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 ³He ions will be available

Note: e + A luminosity is per nucleon

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

Based on EIC Project’s most recent assessment for early running [[link to Elke’s Slides](#)]

Assumptions: Running 30 weeks/year; 2.5 hour turn around time; 80% facility availability

Other configs technically possible: e + p 5 x 100 (0.5 fb⁻¹/yr); e + Au 5 x 110 (2 fb⁻¹/yr); e + Ag 5 x 110 (2 fb⁻¹/yr);

Compare with HERA - delivered 0.5fb⁻¹ to each of H1 and ZEUS in its lifetime!

The Path



Collaboration Discussions

- Early science has been discussed since before the charge
- July 2024 - E.C. Aschenauer's talk, collaboration meeting (Lehigh) [\[link\]](#)
- Series of discussions, followed by focussed early science/physics readiness workshops
- Sep 2024 - online workshop [\[link\]](#)
- Jan 2025 - collaboration meeting (Frascati) [\[link\]](#)
- Apr 2025 - CFNS workshop (Stony Brook) [\[link\]](#)
- Jun 2025 - charge from ALDs
- Sep 2025 - Institute of Physics workshop (London) [\[link\]](#)

Discussions laid the foundation for an ESR shaped by the collaboration

ESR Development

- Editorial team formed (PACs plus Carlos and Charlotte)
- Reviewers identified
- PWG analyses/appendices progressed
- Development of ESR document
- Feb 2026 - v1 to reviewers
- Mar 2026 - University of Calabria/INFN Cosenza workshop [\[link\]](#)
- Apr 2026 - production campaign by S&C for ALD version
- End May 2026 - v2 to reviewers
- Jun 2026 - v2.1 to collaboration - [\[link\]](#)
- Jul 2026, v3 to spokespeople and CC chairs for final comments
- CC office, membership & publication committees & SPs worked on author list

Iterative process between reviewers, editors, PWGs, S&C, collaboration, theorists

Submission and Next Steps

- Jul 10th 2026 - v3.2 sent to ALDs for comments and feedback; v3.2 posted on zenodo [\[link\]](#)
- Next:
- Implement any final fixes, post on arXiv at end of Jul 2026
- Convert ESR into article for ePIC NIM A Special Issue (submission ~ end Oct 2026)
- Each PWG will publish a NIM A article, with more details on their results (and more)
- BSM/EW paper will focus on full EIC capabilities
- Note: July S&C production campaign will be used for NIM A articles

Culmination of >1 year targeted effort by collaboration and a major milestone!



The Path

Collaboration Discussions

- Discussions on early science have took place since before the charge
- July 2024 - E.C. Aschenauer's talk, collaboration
- Then, by focusing on reading
- Sep 2024 - ...
- Jan 2025 (Frascati)
- Apr 2025 Brookhaven
- Jun 2025 - charge from ALDs
- Sep 2025 - Institute of Physics workshop (London) [\[link\]](#)

Discussions laid the foundation for an ESR shaped by the collaboration

ESR Development

- Editorial team formed (PACs plus Carlos and Charlotte)
- Reviewers identified (see back up slide)
- Charge specified that results should be based on latest ePIC full simulations and reconstruction
- Demanded close collaboration with software and computing team for large-scale production campaigns
- Many core-house of computing have gone into generating this report!
- We are grateful for their help with these campaigns
- Note: v3.2 uses 10 GeV electrons, 250 GeV protons, but NIM A articles will use 9 GeV electrons, 275 GeV protons (July campaign)
- Jun 2026 - v2.1 to collaboration - [\[link\]](#)
- Jul 2026, v3 to spokespeople and CC chairs for final comments
- CC office, membership & publication committees & SPs worked on author list

Iterative process between reviewers, ESR editors, PWGs, S&C, and collaboration

Submission and Next Steps

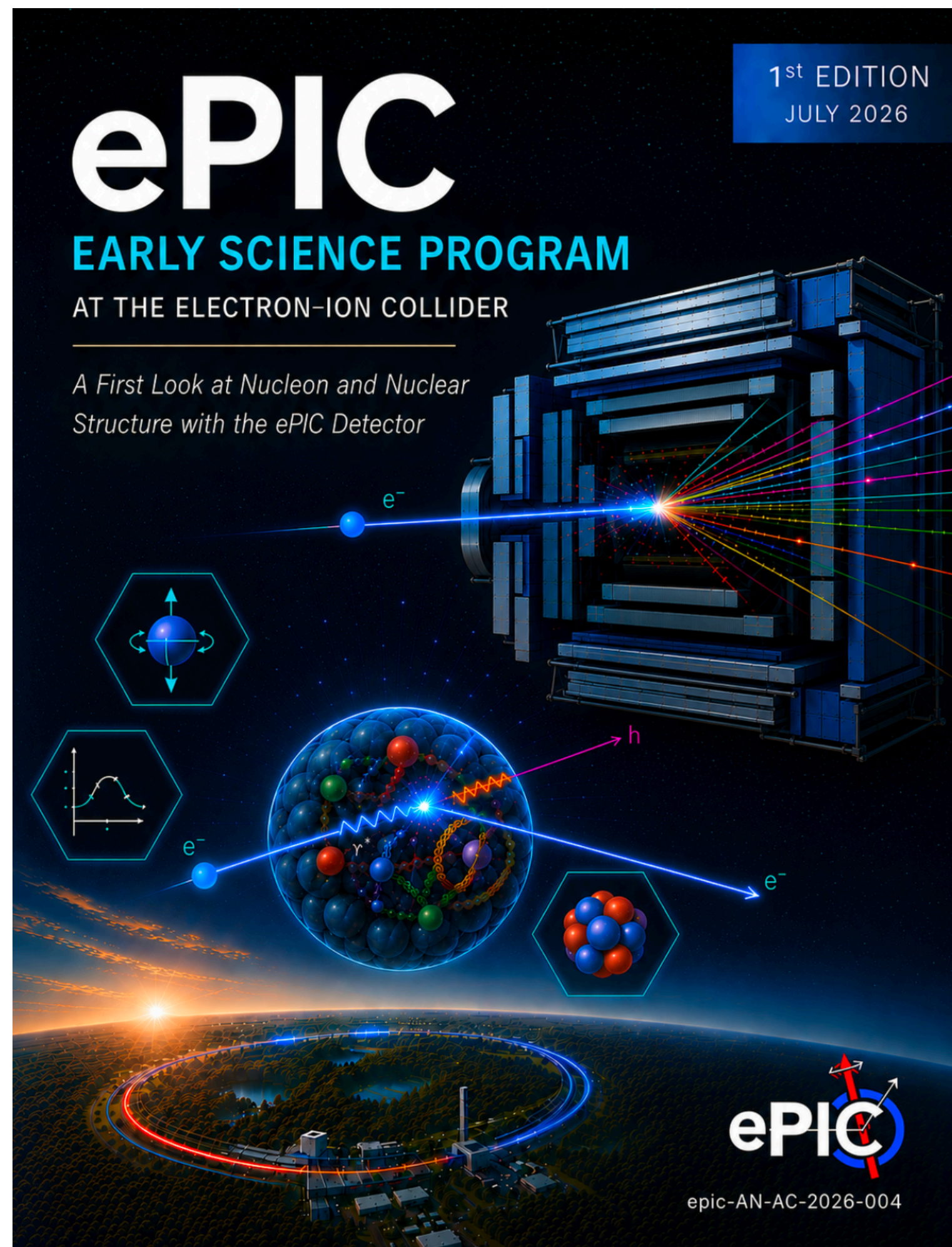
- July 10th 2026 - v3.2 sent to ALDs on posted on zenodo [\[link\]](#)
- Next:
- Note: July S&C production campaign will be used for NIM A articles



Culmination of >1 year targeted effort by collaboration and a major milestone!



ESR Structure



The ePIC Collaboration

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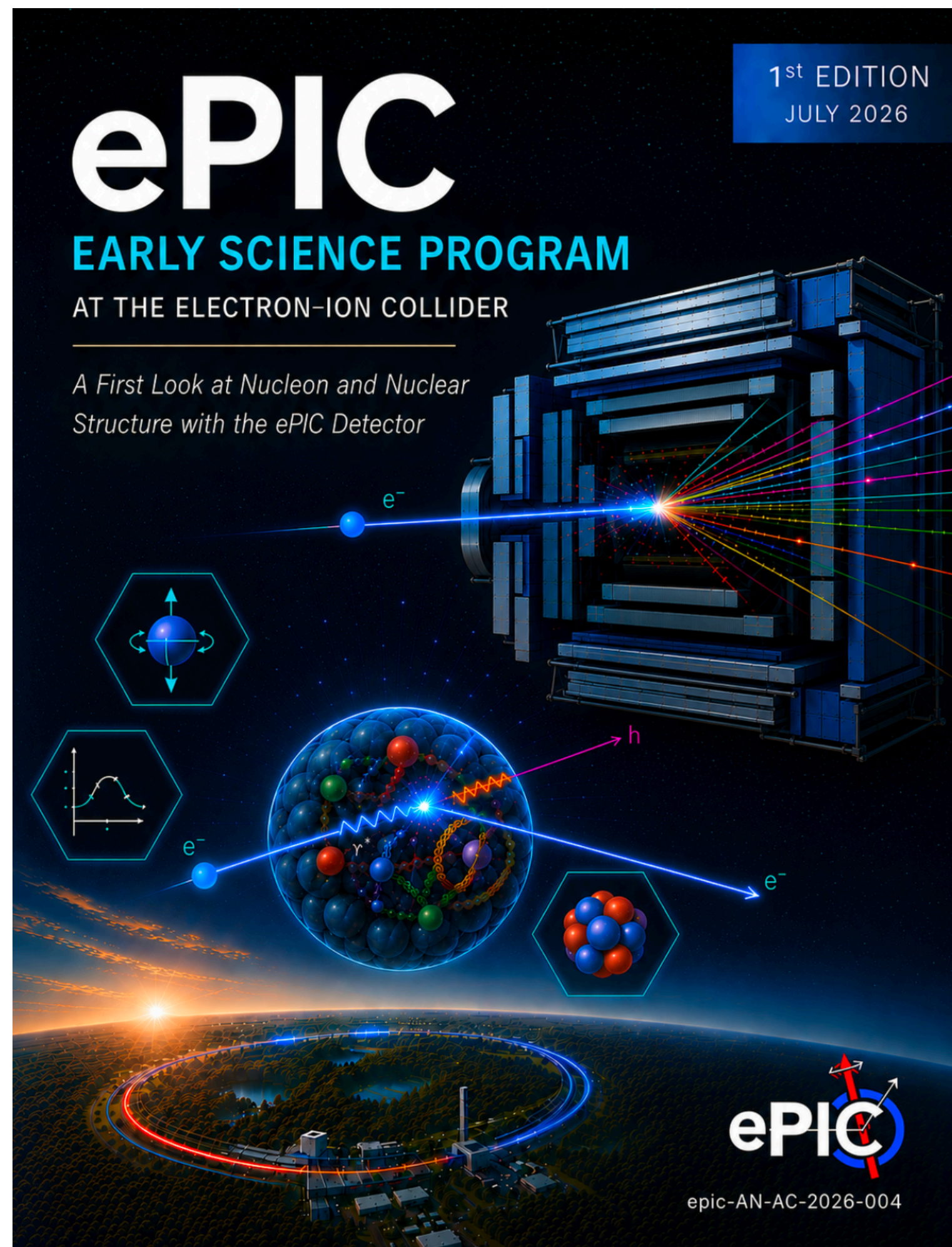
Example snapshot
- not full/final list!

- First time putting together author list according to ePIC publication policy
- Big thanks to CC chairs, membership and publication committees and spokespeople for this
- Still a **draft** author list - pending CC feedback and will be discussed at CC meeting this Thursday
- Any oversights can be fixed before future upload to arXiv and NIM A
- Please contact CC chairs directly (Thomas and Renee) wrt oversights

Current cover for v3.2 on Zenedo - will be updated by BNL artistic team for arXiv



ESR Structure



Current cover for v3.2 on Zenedo - will be updated by BNL artistic team for arXiv upload

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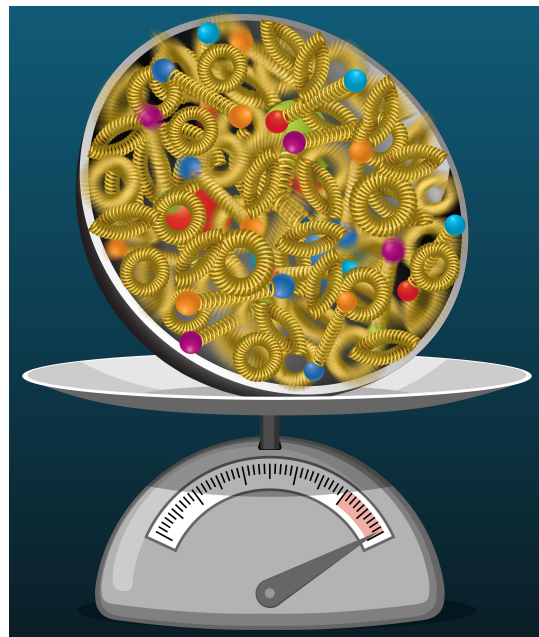
Outline:

- Introductory material, connection between NAS pillars and physics processes we will measure
- 4 sections corresponding to physics working groups (PWGs)
- Discussion on limitations and why we need full EIC
- Conclusions
- Please note - measurements are representative (i.e. not exhaustive) based on several factors

ESR Connection to NAS Science Pillars

- Laid out in 2018 National Academy of Sciences (NAS) assessments of the EIC science case [[link](#)]
- Early science program coherently begins to address NAS pillars, with every early science measurement mapped to one or more of the pillars

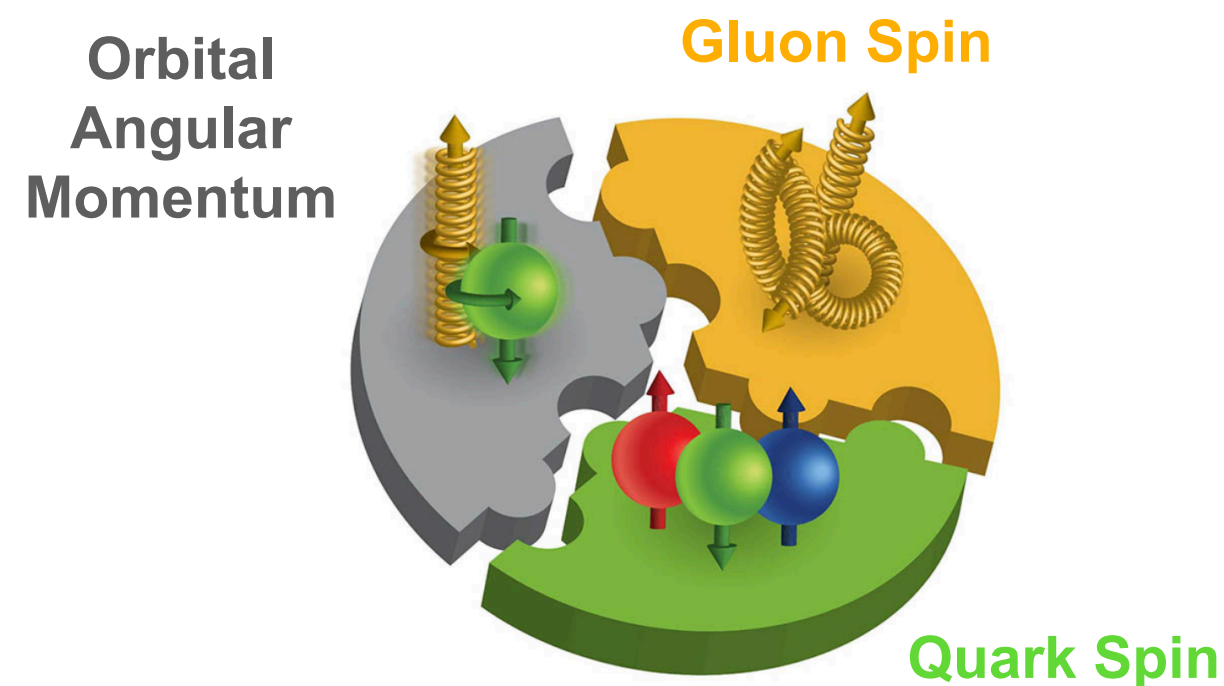
Origin of Nucleon Mass



How does the mass of the nucleon arise?

Gluon dynamics, gravitational form factors, and the QCD mechanisms behind visible mass

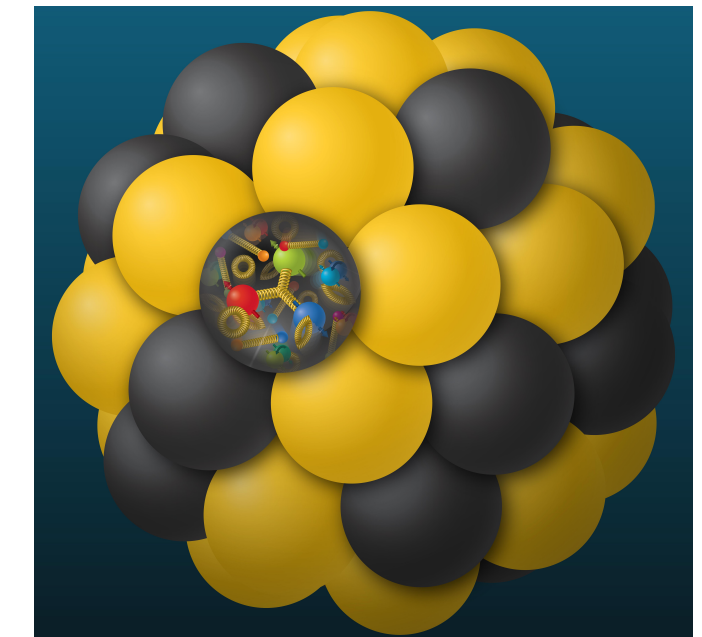
Origin of Nucleon Spin



How does the spin of the nucleon arise?

Quark and gluon helicity, transversity, and orbital angular momentum via polarized beams

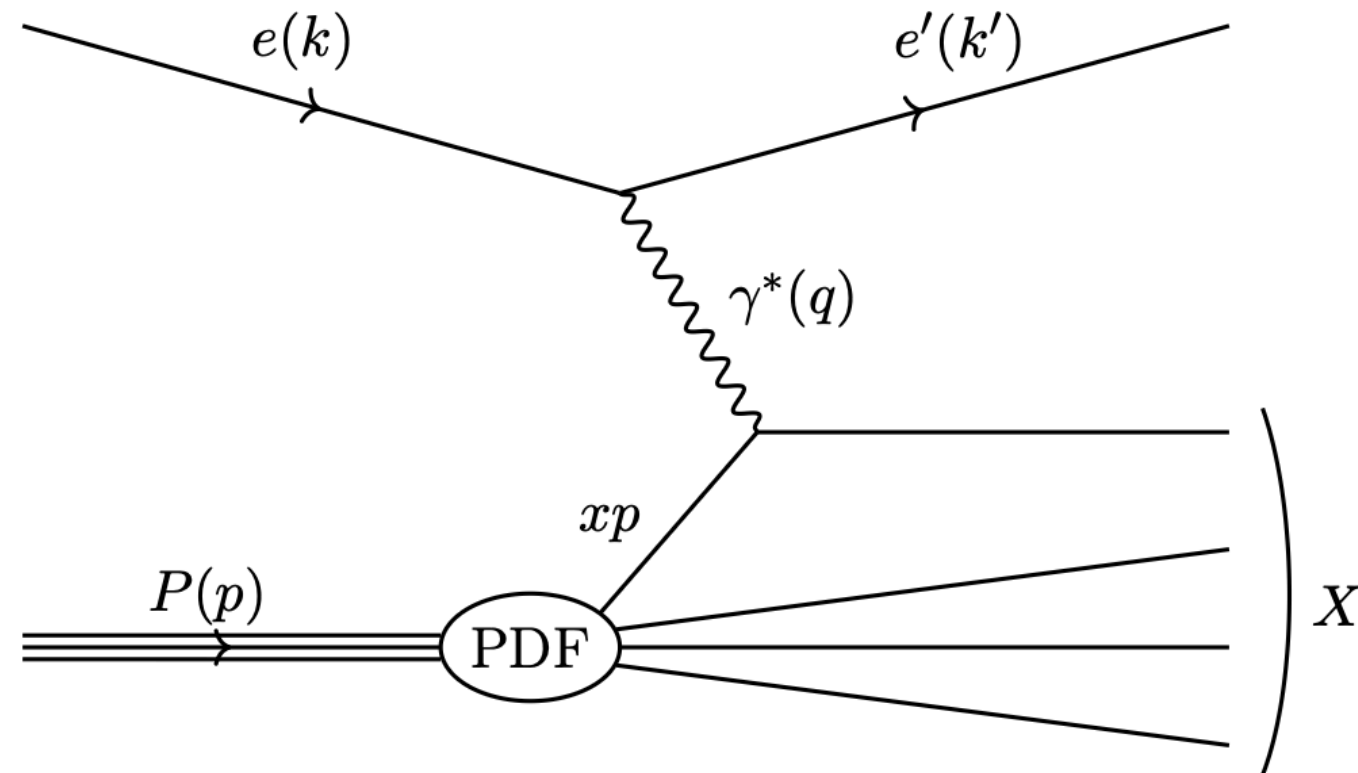
Dense Gluonic Matter



What are the emergent properties of dense systems of gluons?

Nuclear gluon densities, nuclear structure, and the search for the onset of gluon saturation

Inclusive Measurements

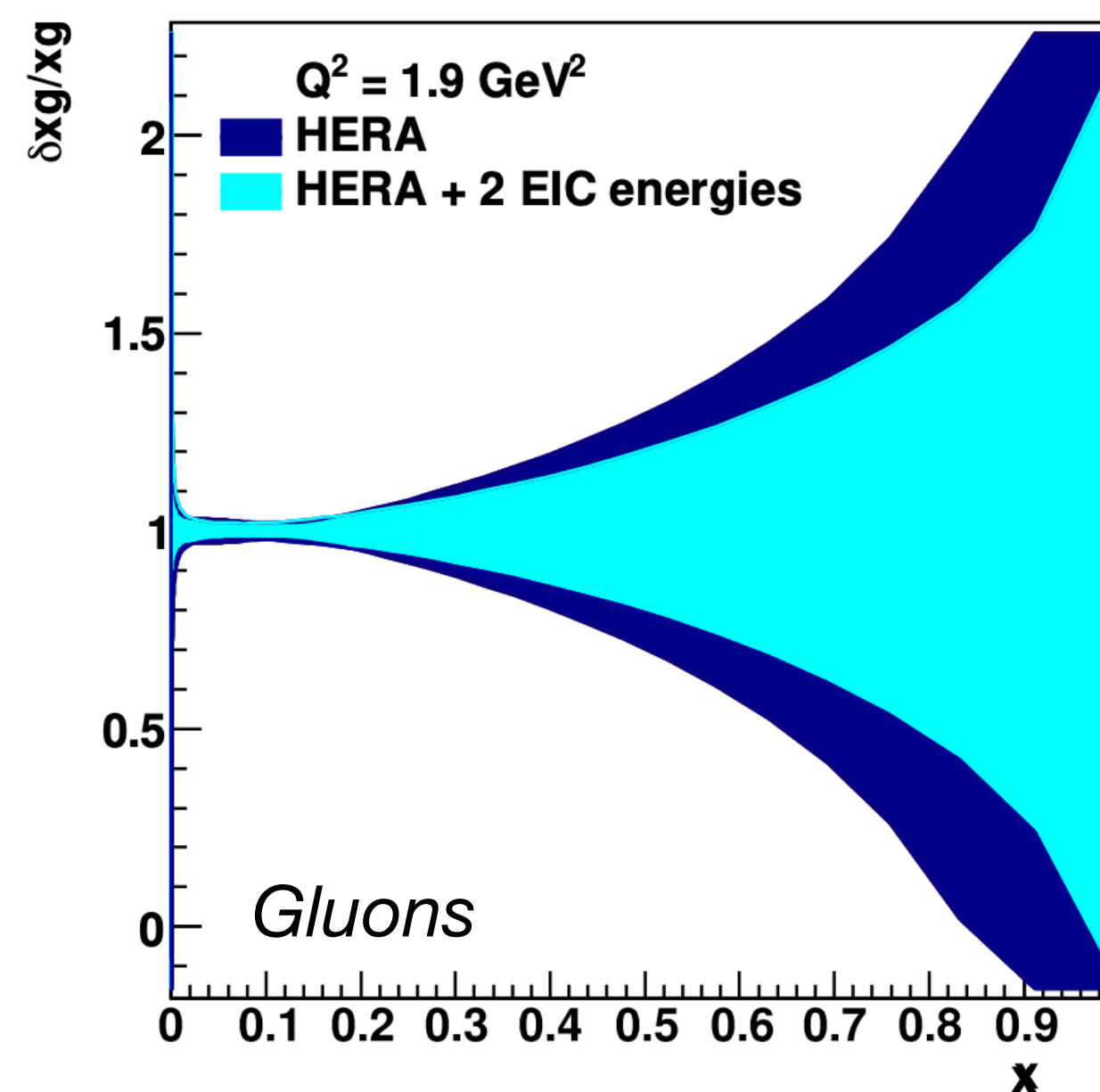
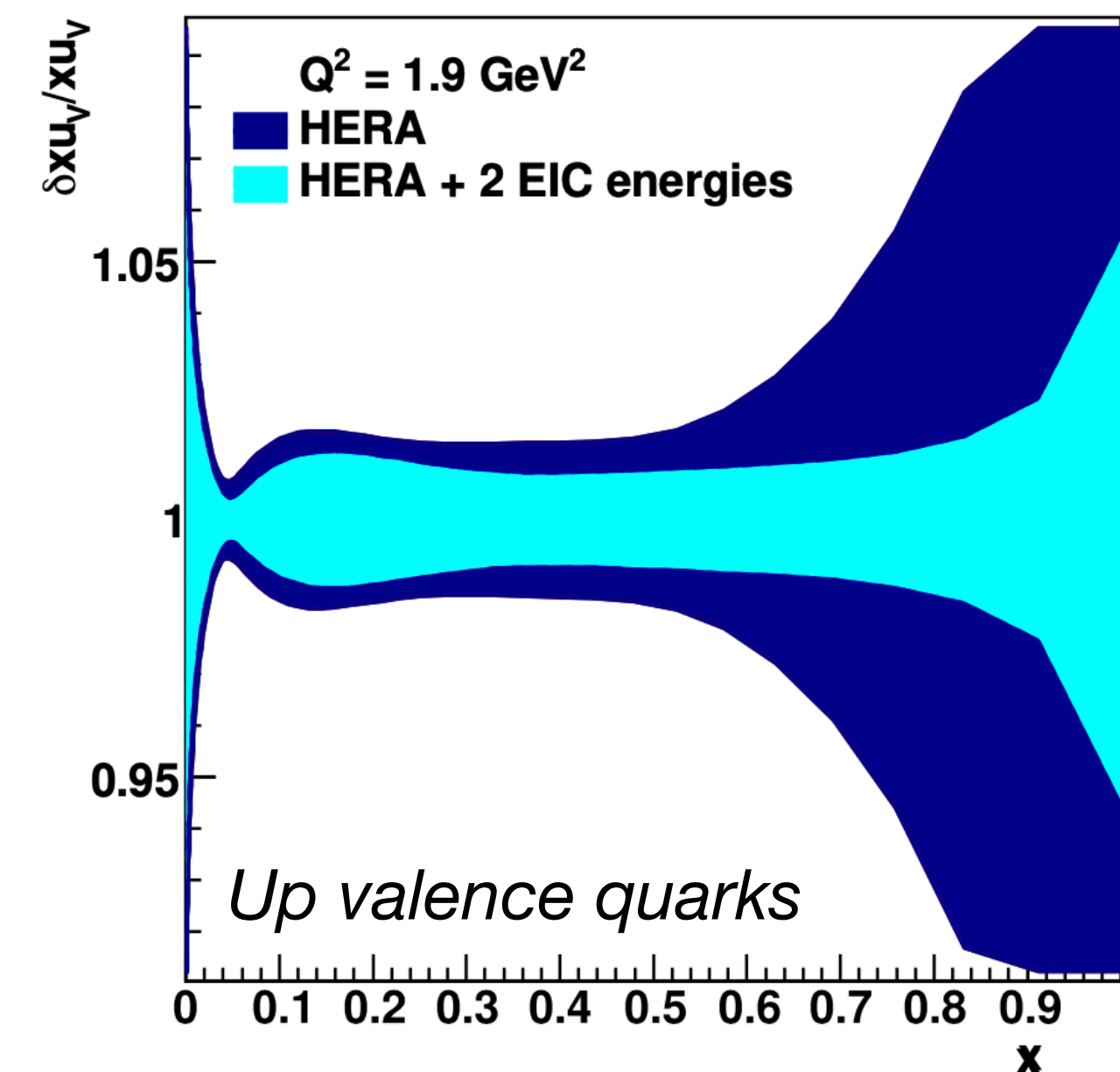
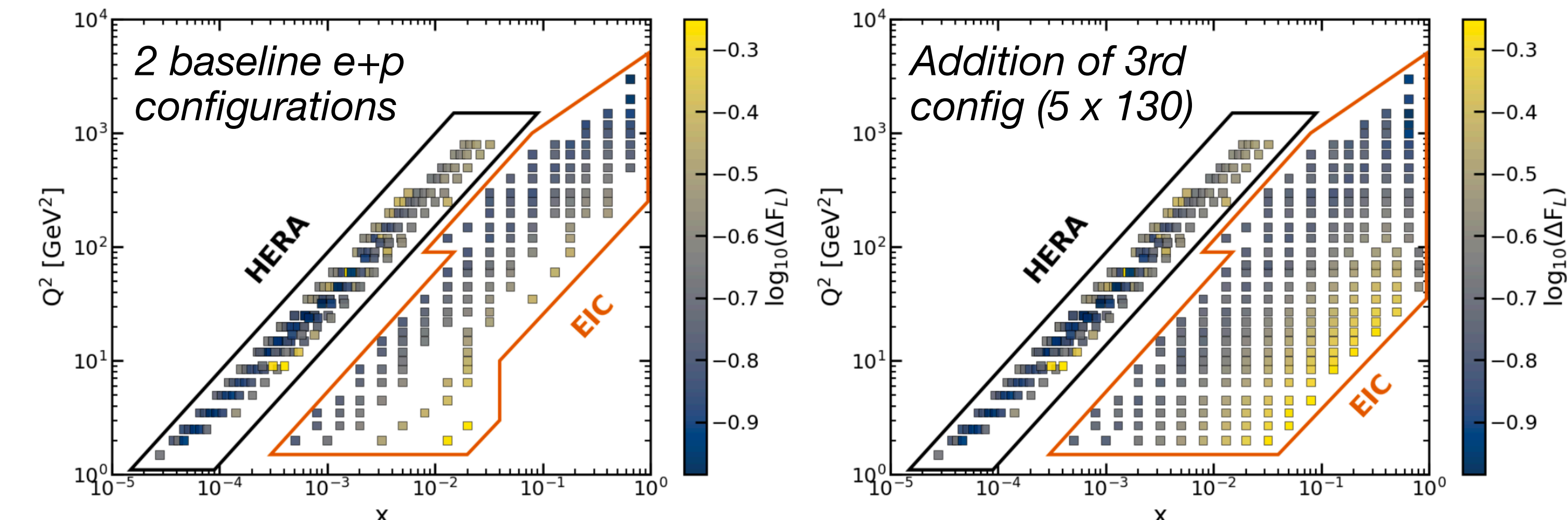


Configuration	Representative Measurement
$e + A$ running with medium and light mass nuclei	Reduced cross sections for nuclear F_2 ; A-dependence of nuclear effects; nPDFs; diffractive nPDFs
$e + p$ running at multiple energies with polarization	Reduced cross sections for F_2 and F_L ; collinear and diffractive PDFs; strong coupling constant α_s ; spin asymmetries for proton spin SF and polarized PDFs
$e + A$ running with heavy nuclei	Reduced cross sections for nuclear modifications of F_2 ; A dependence of nuclear effects in SF, nPDFs and diffractive nPDFs
$e + A$ running with polarized ^3He	Spin asymmetries for neutron spin SF and polarized PDFs

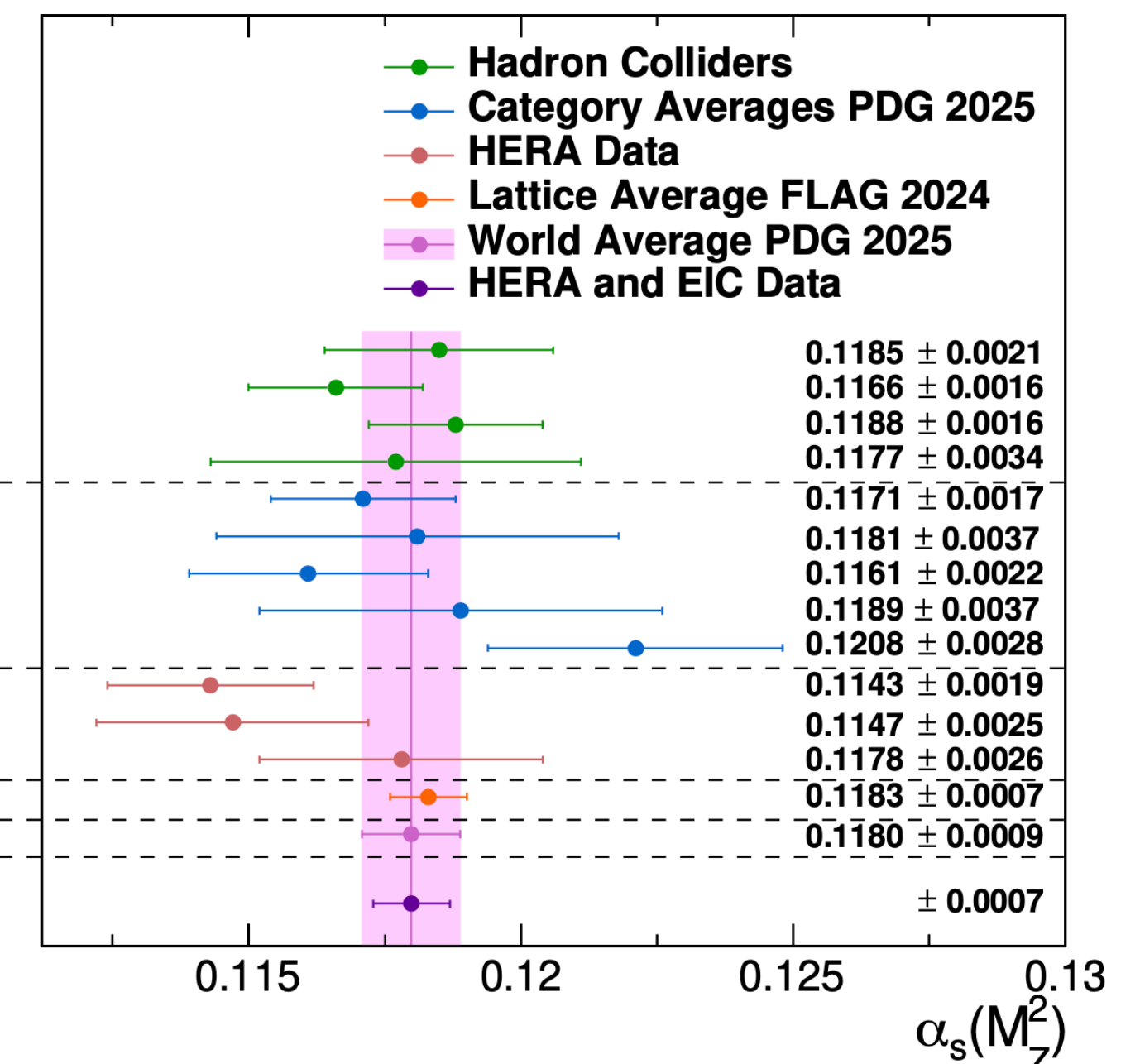
- Central role in determining **collinear quark-gluon structure of nucleons and nuclei, and nucleon spin structure**
- **One of earliest and potentially most impactful components of early science program**
- Modest luminosities well-suited to high cross-sections for precision measurements in $e+p/e+A$
- Reliance on precision e' reconstruction, without explicit need for advanced hadron PID or far-forward system
- (Far-forward enables spectator tagging with ^3He)
- Polarized beams to access decomposition of nucleon spin

Inclusive Measurements

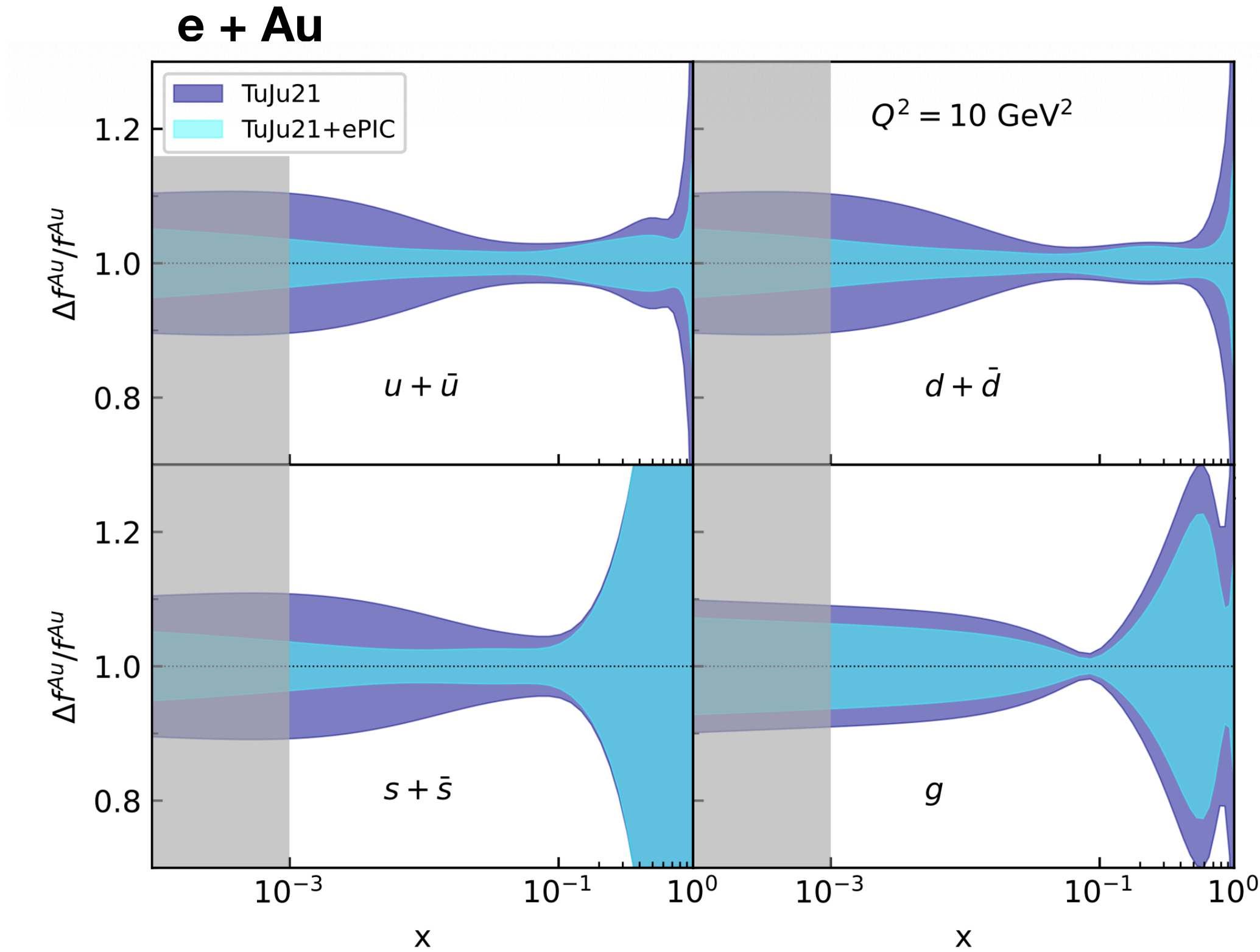
- Important constraints on proton F_2 and F_L
- Improve determinations of proton PDFs, especially at mid to high- x
- Sensitivity to strong coupling constant
- World-competitive precision and complementary determination of α_s within global QCD analysis framework



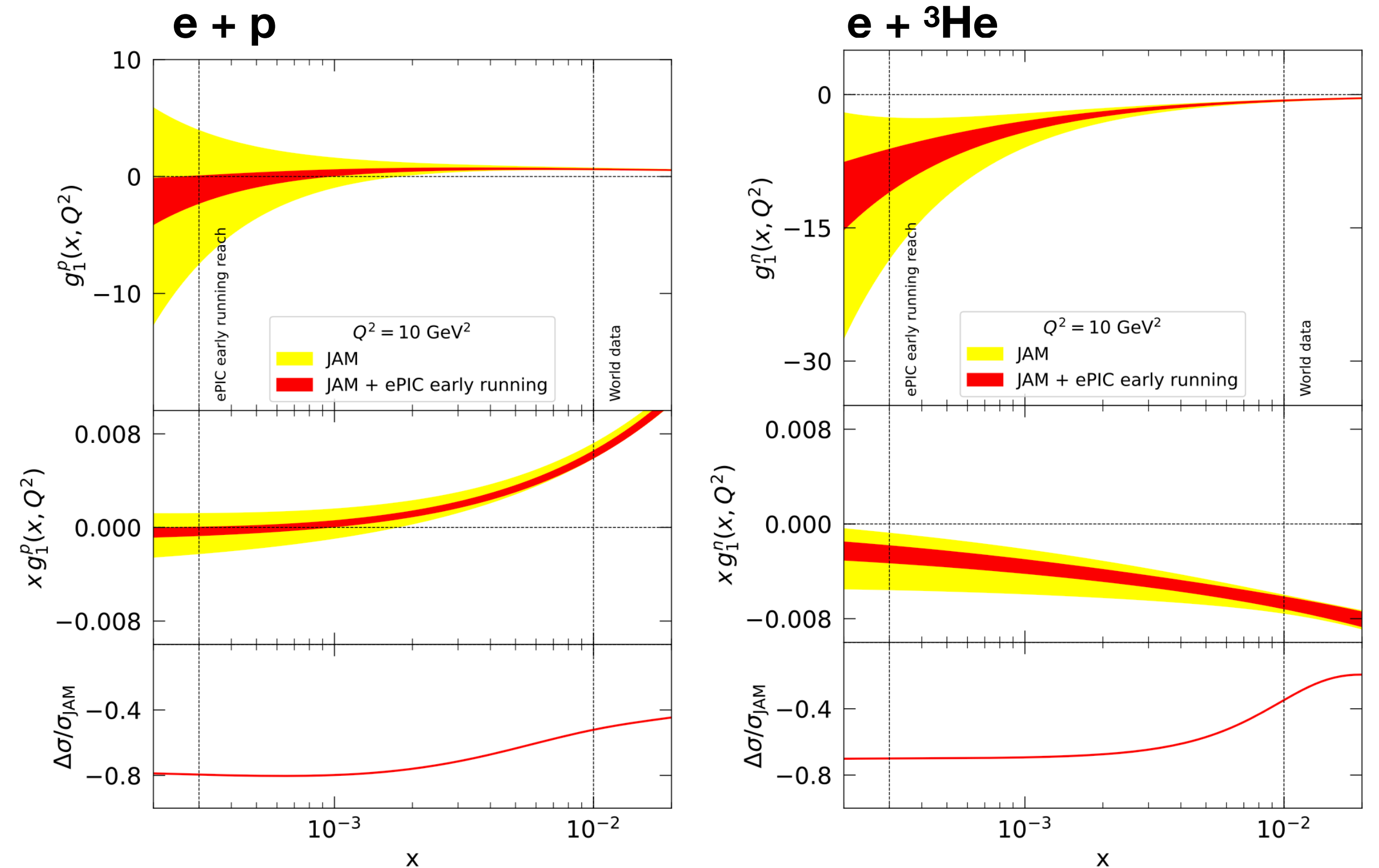
ATLAS ATEEC
CMS Jets
W, Z Inclusive
tt Inclusive
 τ Decays
QQ Bound States
PDF Fits
 e^+e^- Jets and Shapes
Electroweak Fit
ZEUS Inclusive + Jet Data
H1 Inclusive + Jet Data
H1 and ZEUS Jet Data
Lattice Average
World Average
HERA and EIC Early Science
Inclusive Data (exp)



Inclusive Measurements

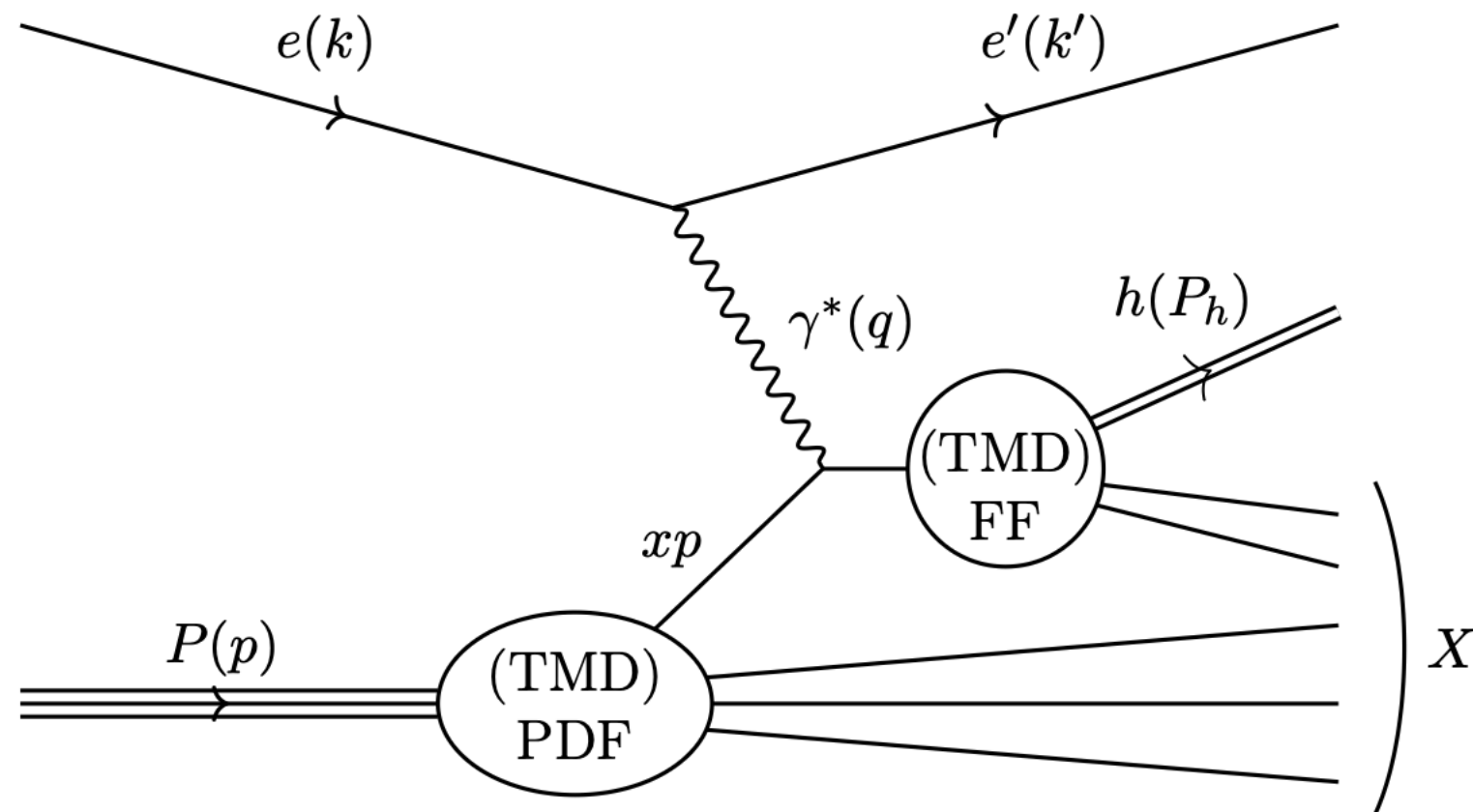


- Heavy ions running → F_2^A for ions at low- x for first time in heavy nuclei → explore partonic structure of nuclei with unprecedented detail
- Reach of e + A DIS data in low- x region extended by order of magnitude, down to $x \sim 10^{-3}$
- **Significant improvements in nPDF uncertainties for all parton species at low- x** (obtained using re-weighting of TUJU21 nPDFs)



- Polarized beams enable precision measurements of spin dependent nucleon structure functions and polarized PDFs
- Extend reach to unexplored low- x region
- **Improve constraints on quark/gluon contributions to nucleon spin**
- Unique tagging capabilities with ^3He enable neutron measurements with minimal nuclear corrections

Semi-Inclusive Measurements

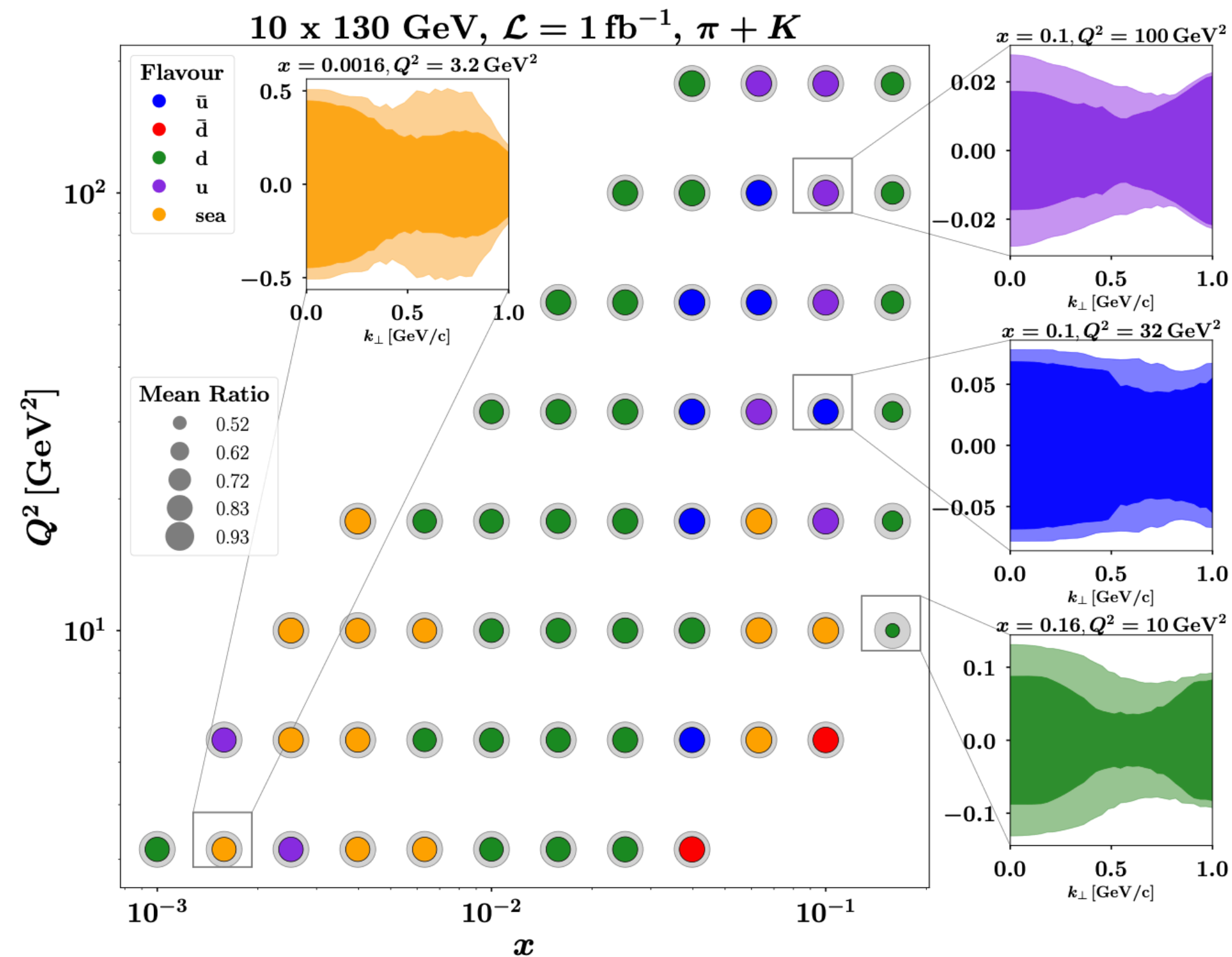


Configuration	Representative Measurement
$e + p$ running	Multiplicities (M_h) for FFs, multifold differential cross sections for unpolarized TMD PDFs
$e + p$ running with polarization	Azimuthal single spin asymmetries for Sivers TMD PDF and Collins TMD FF, double spin asymmetries for sea quark helicities
$e + A$ running with polarized ^3He	TMD and helicity measurements on the neutron
$e + A$ running with polarized heavy nuclei	Di-hadron correlations for onset of gluon saturation and non-linear QCD effects

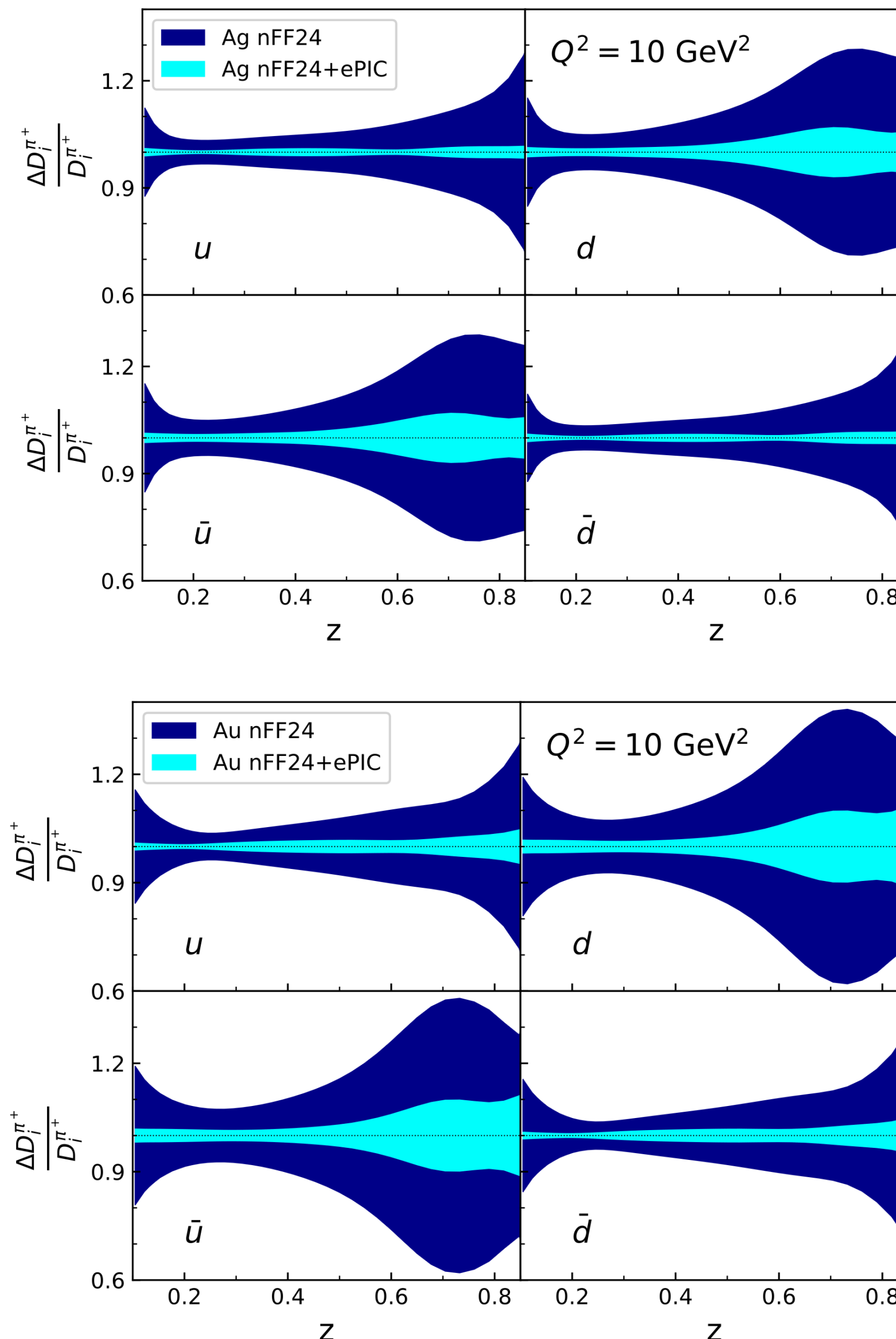
- Expand beyond collinear picture to 3D mapping of internal dynamics, as hadron reconstruction and hadron PID matures
- Polarized beams grant sensitivity to transverse degrees of freedom and 3D momentum structure via TMD PDFs, and fragmentation process via FFs, providing sensitivity to flavor, spin and momentum
- Early running enables us to start forming a more complete dynamical 3D picture of nucleon
- Early data paves the way for a more complete SIDIS program to be completed with full EIC

Semi-Inclusive Measurements

Access to unpolarized TMD PDFs for 3D quark distributions and nuclear FFs for emergence of hadrons from quarks and gluons

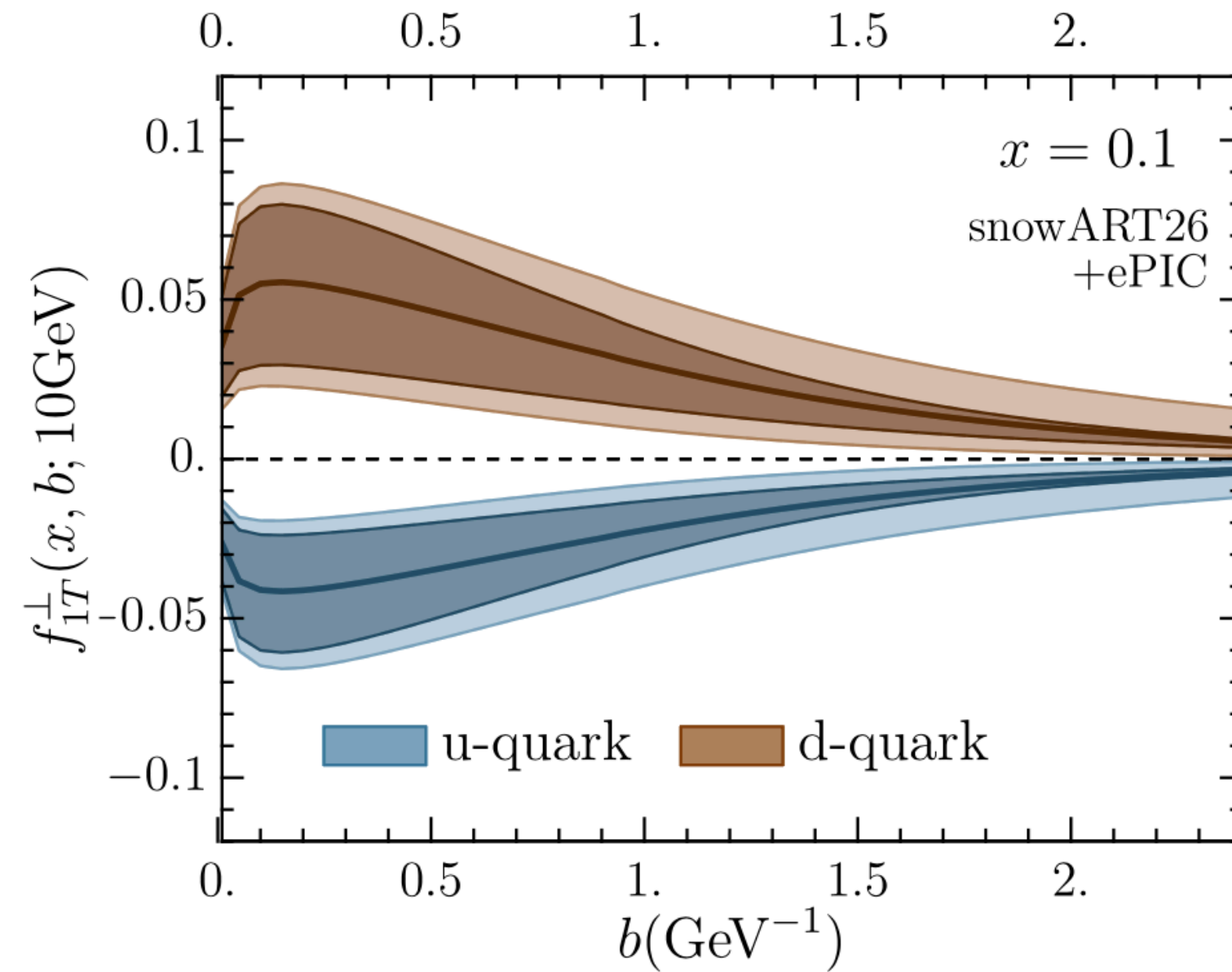


- MAPTMD24 extraction of definitive flavor-separated unpolarized TMD PDFs mapped across wide (x, Q^2) phase space
- Early science data significantly reduces extraction uncertainties for valence and sea quarks
- Essential also as baseline for polarized TMD observables and spin physics extractions

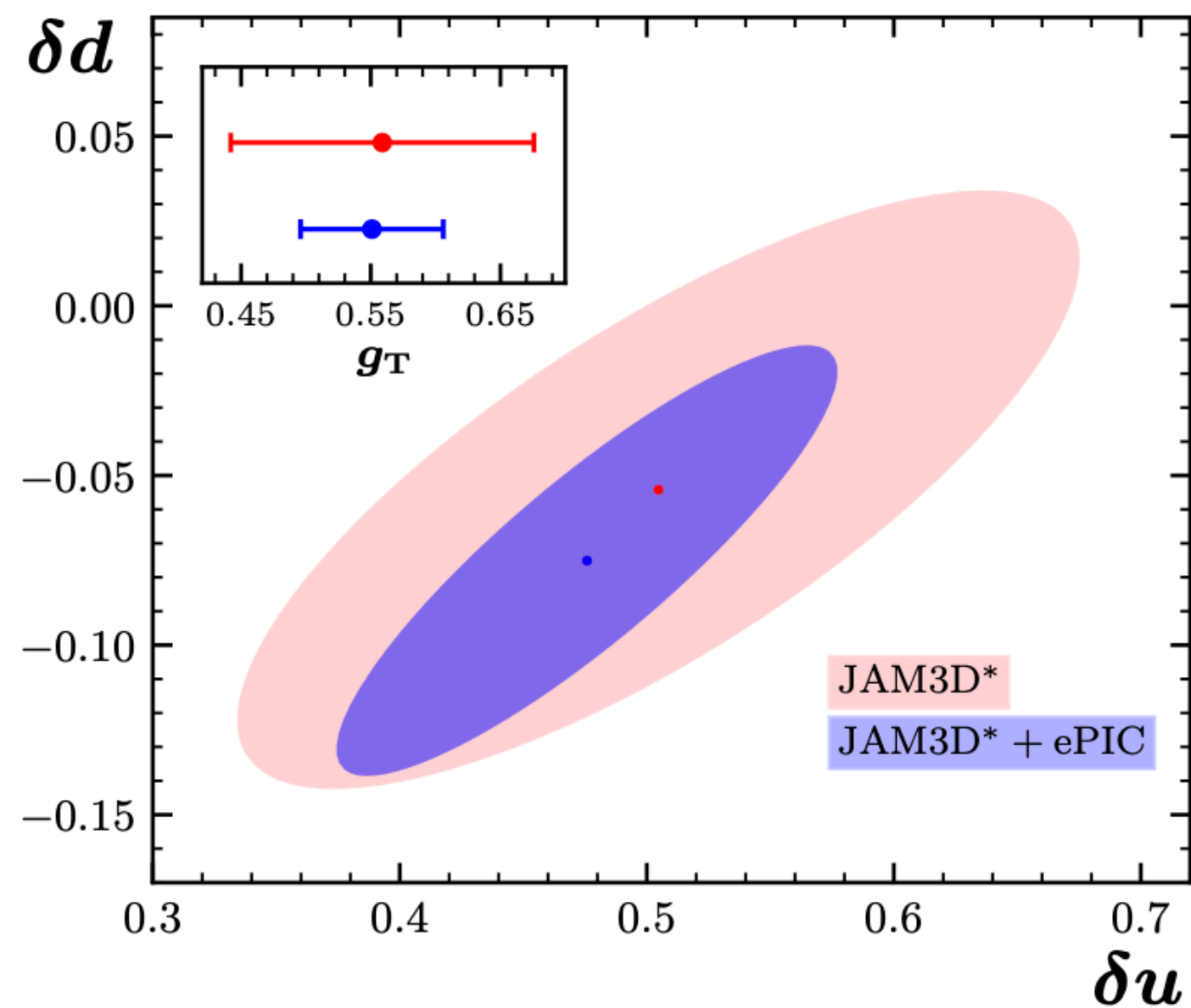


- nFFs currently poorly constrained
- ePIC early science data shows large reduction in relative uncertainties
- Re-weighting technique using new set of nFF24 based on A-dependent parameterization of available nuclear data
- 5% of bins from π^+ simulation data (1fb^{-1}) $\rightarrow$ further improvements expected with full data and global fit

Semi-Inclusive Measurements

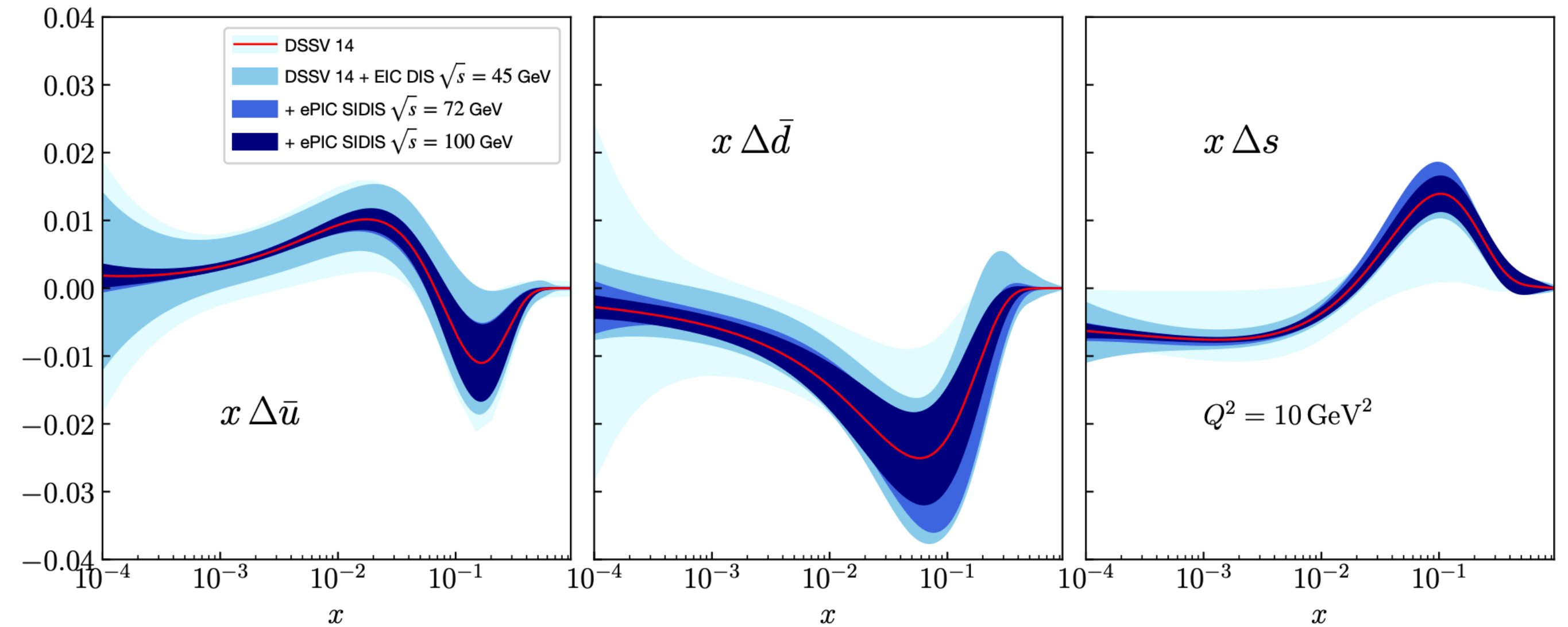


Reduction on uncertainties for u and d quark Sivers function (e+p)



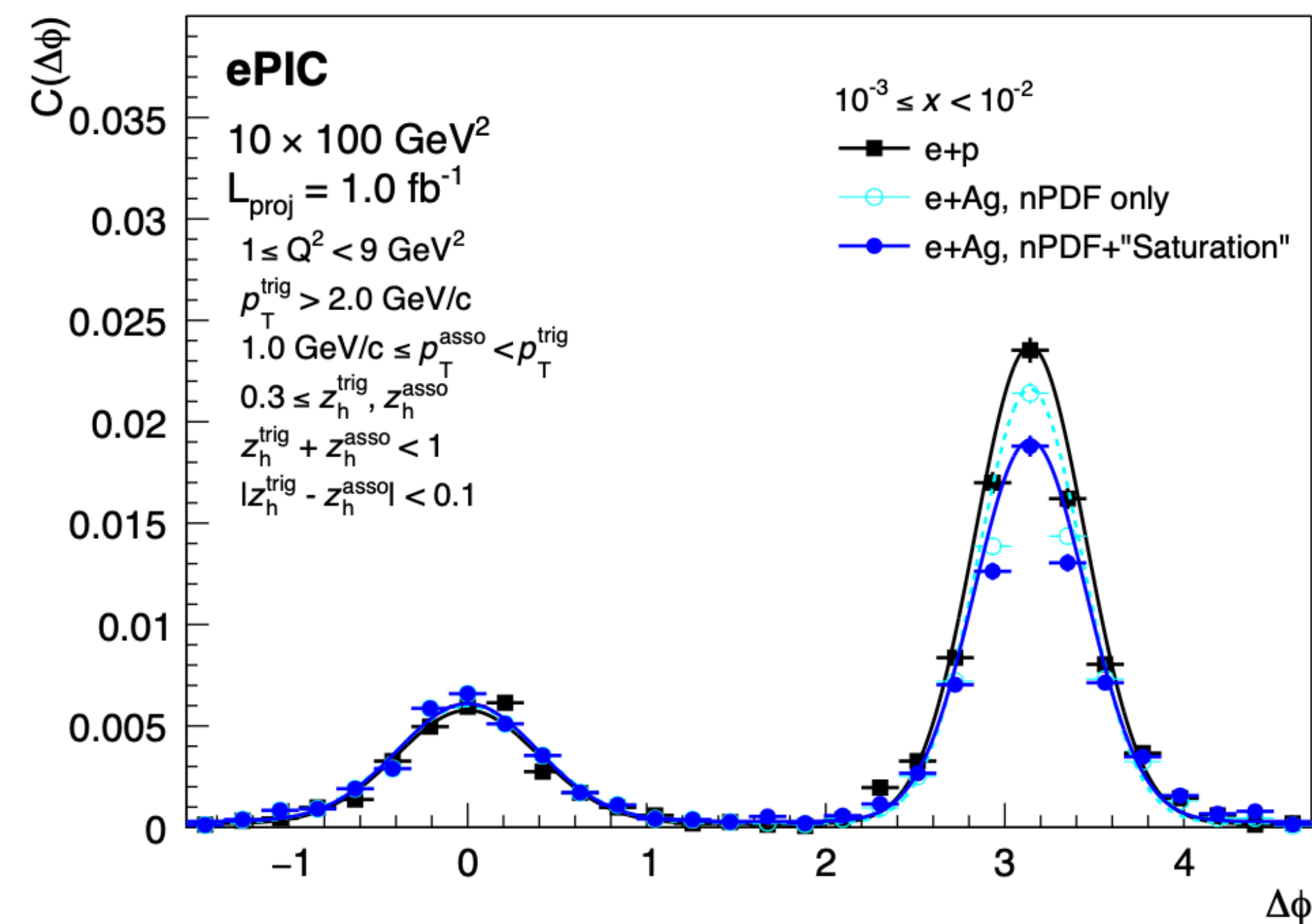
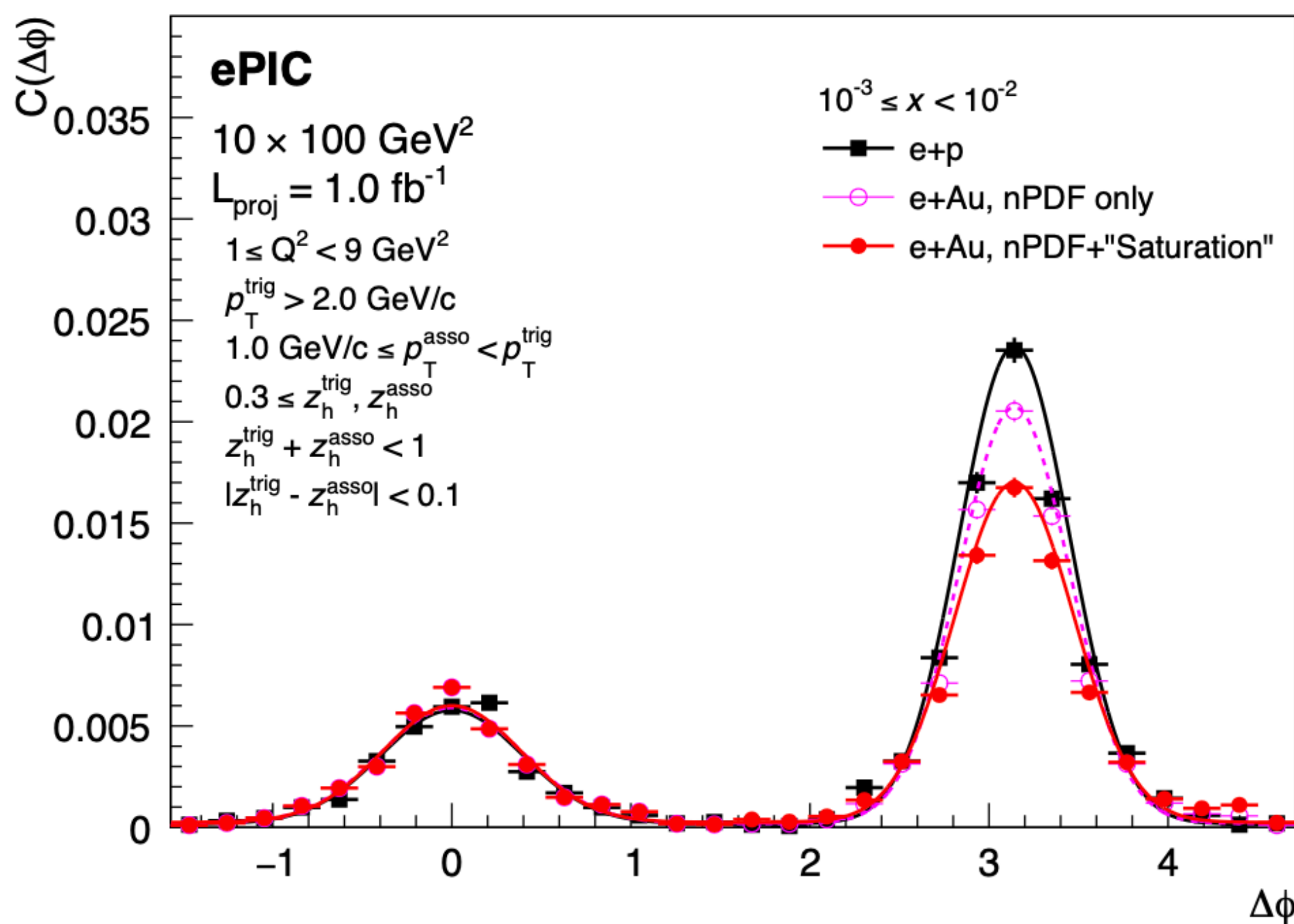
Reduction on uncertainties for u and d quark tensor charges (using e+p and e+³He)

- **Transversely polarized hadron beams** and SIDIS measurements of Sivers and Collins single-spin asymmetries with **multi-dimensional binning** will access spin-orbit and spin-spin correlations, providing **insights into quark transversity and spin structure of nucleon**
- Reduction on uncertainties already achieved with early running configurations



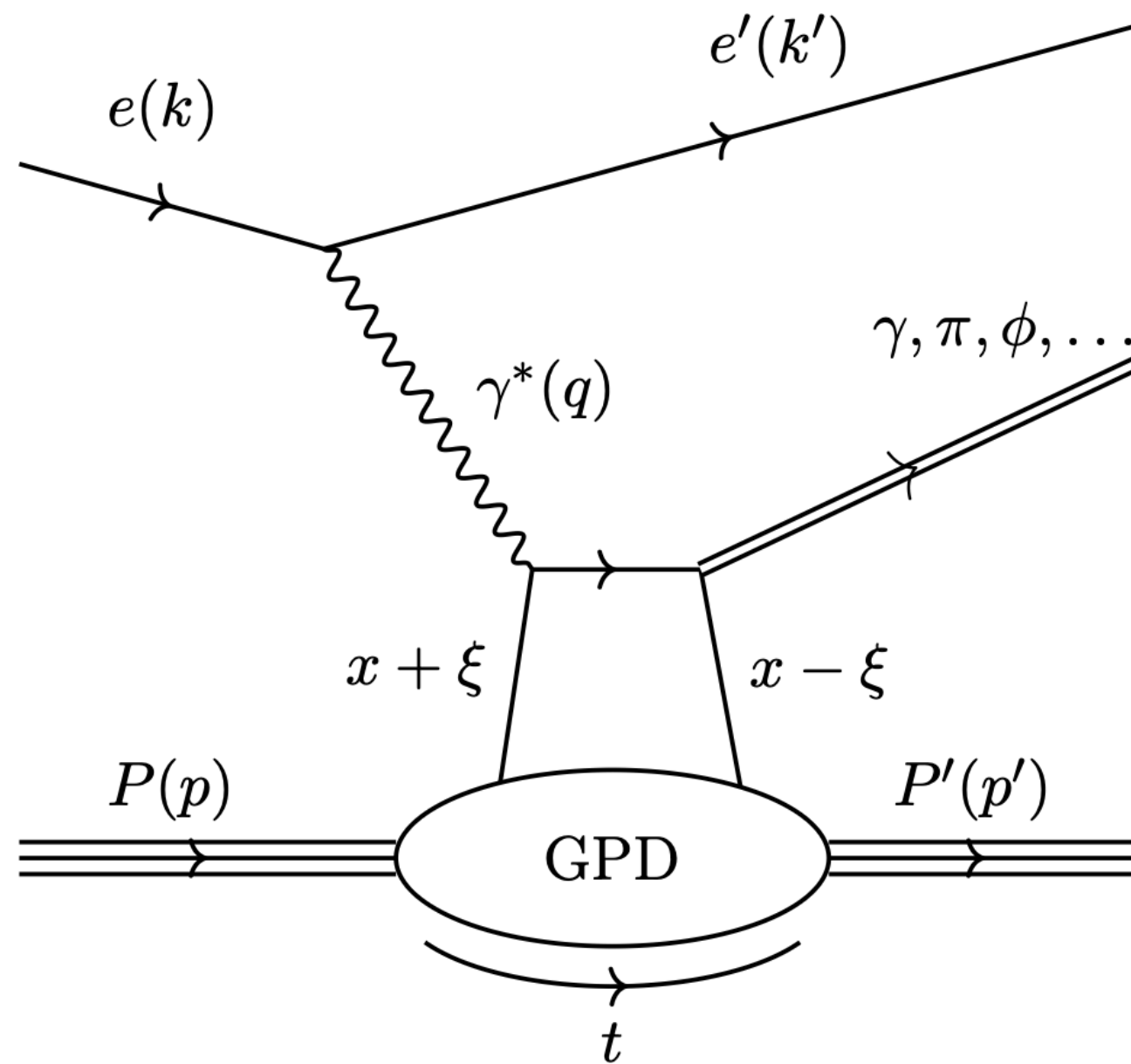
- Flavor sensitivity of SIDIS valuable for flavor-separation of sea quark helicity distributions
- Early data: extensive kinematic coverage can be achieved in which uncertainties of all helicities can be determined precisely
- **Early data particularly relevant for strange quark distributions**

Semi-Inclusive Measurements



- Production of back-to-back, high-transverse momentum, charged hadrons in SIDIS in $e + A \rightarrow$ sensitivity to non-linear QCD effects arising from high gluon densities in nuclear medium and insights on transition into gluon saturation
- Studies of azimuthal angular correlations between near- and away-side peaks in di-hadrons show with early data we can expect to probe non-linear QCD effects
- Note: currently not using full ePIC simulations or reconstruction - will be updated for NIM A
- However, no significant changes expected due to high efficiency and resolution of ePIC tracking system

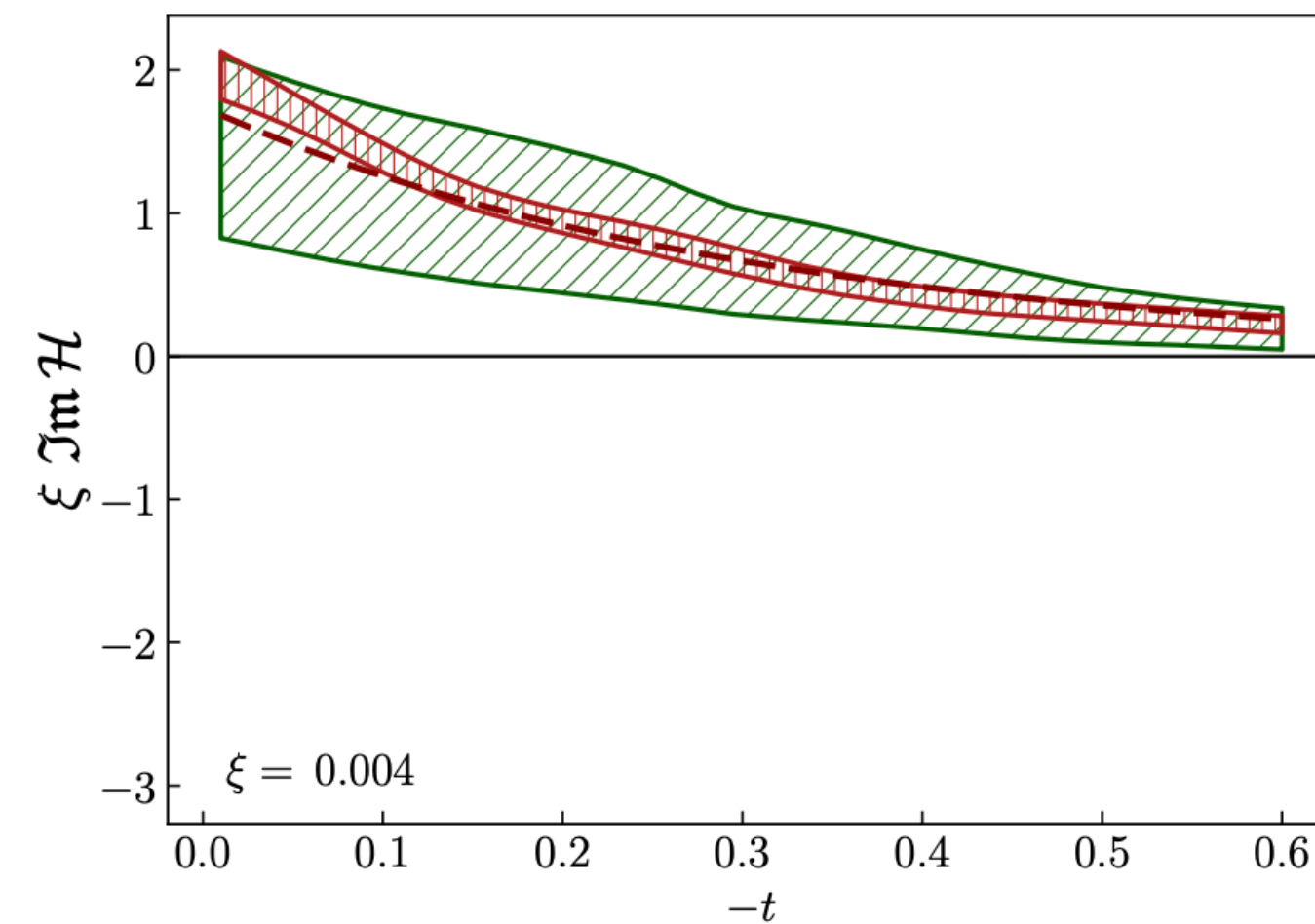
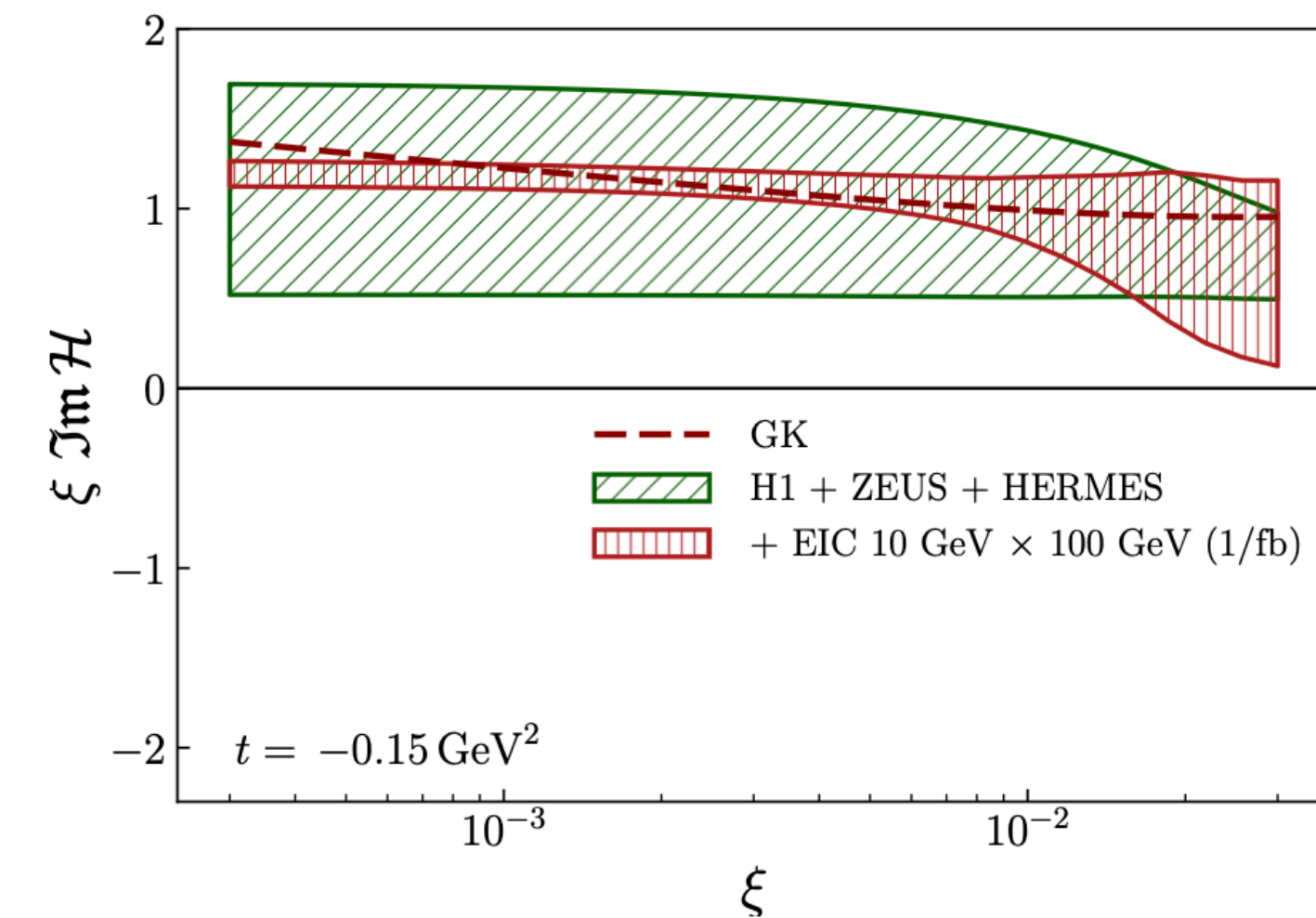
Exclusive, Diffractive and Tagging Measurements



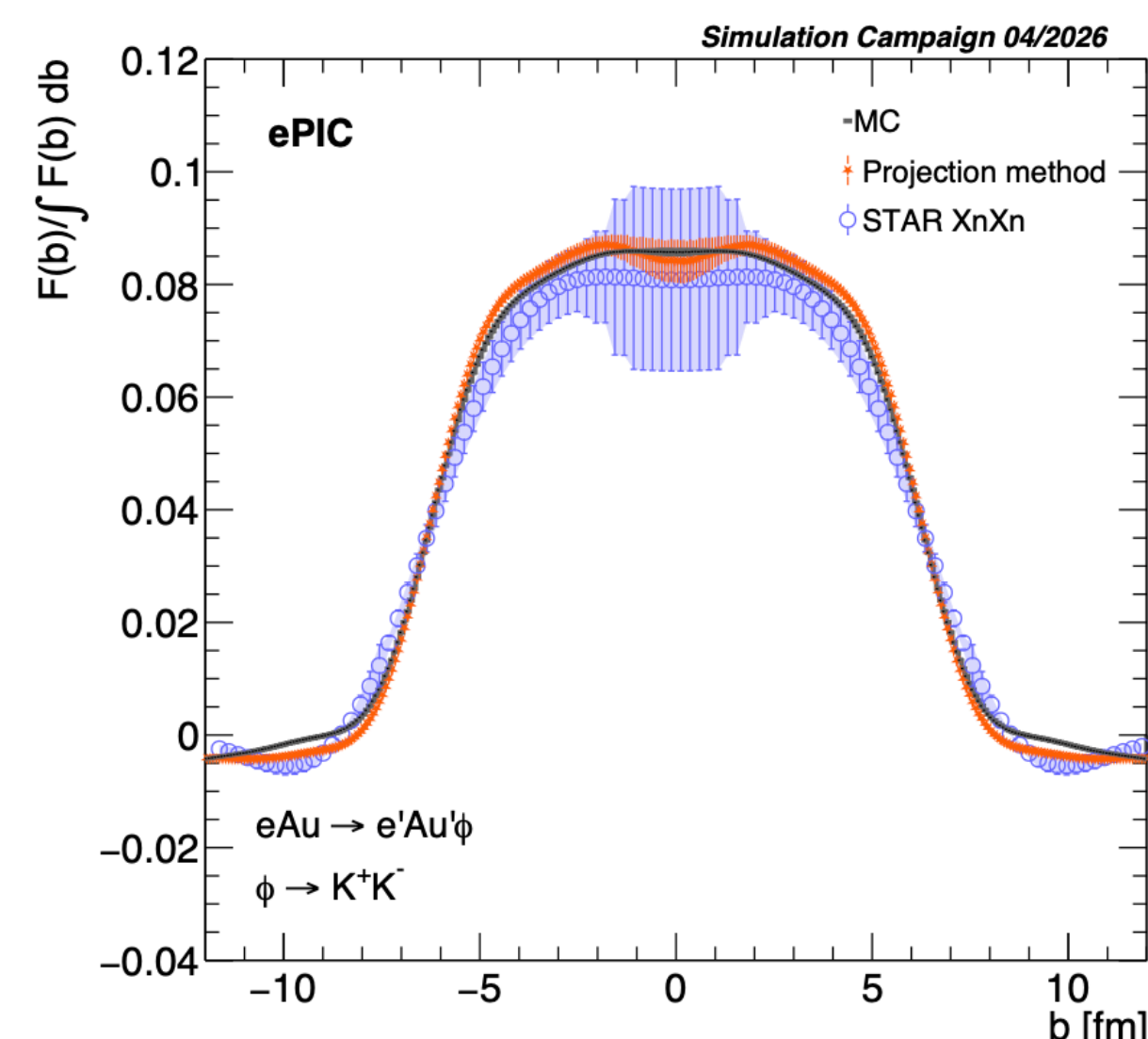
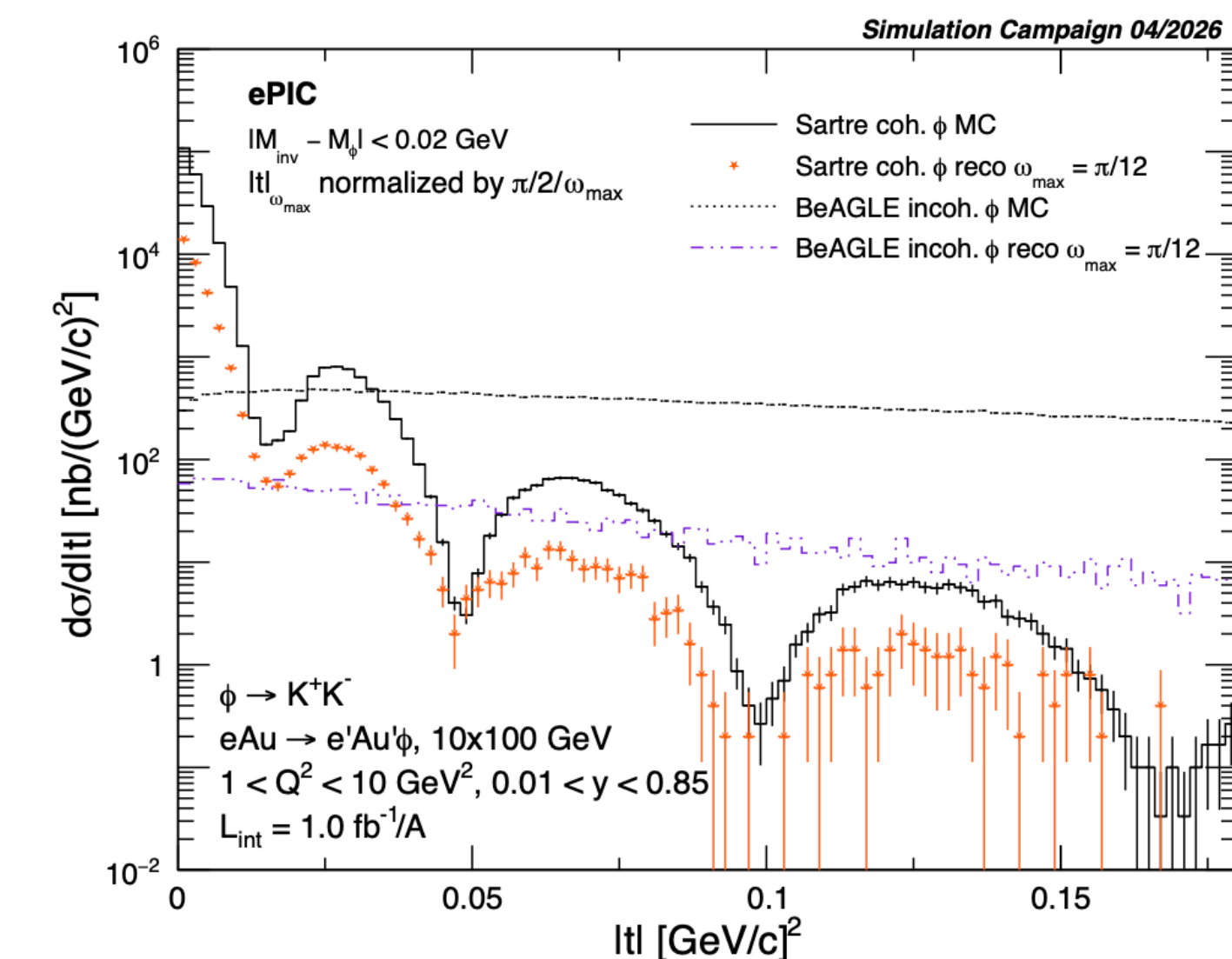
Configuration	Representative Measurement
$e + A$ running with medium mass nuclei and light nuclei	Rapidity-gap diffraction; coherent enhanced exclusive ρ/ϕ samples; initial $J/\psi \rightarrow \ell^+ \ell^-$ exclusive studies
$e + D$	Spectator tagged DIS with D; tagged neutron structure; tagged studies of nuclear binding and off-shell effects
$e+p$ running	DVCS; Υ electro-production; exclusive VM production ($\rho/\phi/J/\psi$); diffractive DIS w/ leading-proton or rapidity-gap selection
$e+p$ running with polarization	Spin asymmetries in DVCS and exclusive VM production; spin-dependent GPD observables
$e + A$ running with heavy nuclei	Coherent and incoherent VM production; coherent to incoherent ratios; nuclear diffractive DIS
$e + A$ running with polarized ^3He	Double spectator tagging; spin-dependent tagged neutron measurements

- Instrumental for advancing modern QCD description of hadron structure, including:
 - quark and gluon dynamics, quark and gluon spatial imaging of nucleon/nuclei, spin decomposition of nucleon
- Enabled by polarized beams, high acceptances, full reconstruction of final states
 - Maturation of hadron reconstruction and hadron PID, as well as commissioning of far-forward detectors essential
- Far-forward system also provides spectator tagging capabilities unique to EIC

Exclusive, Diffractive and Tagging Measurements



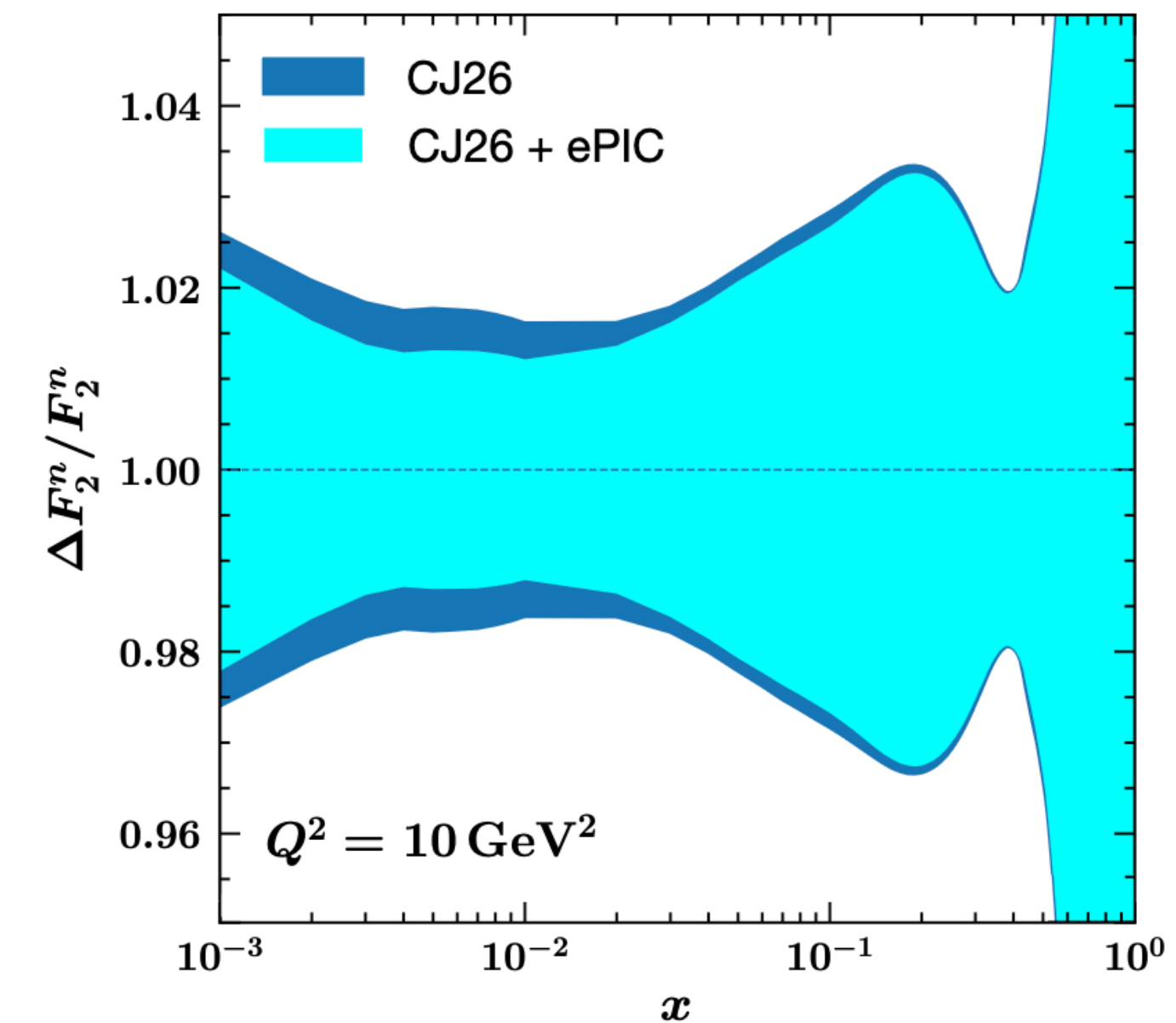
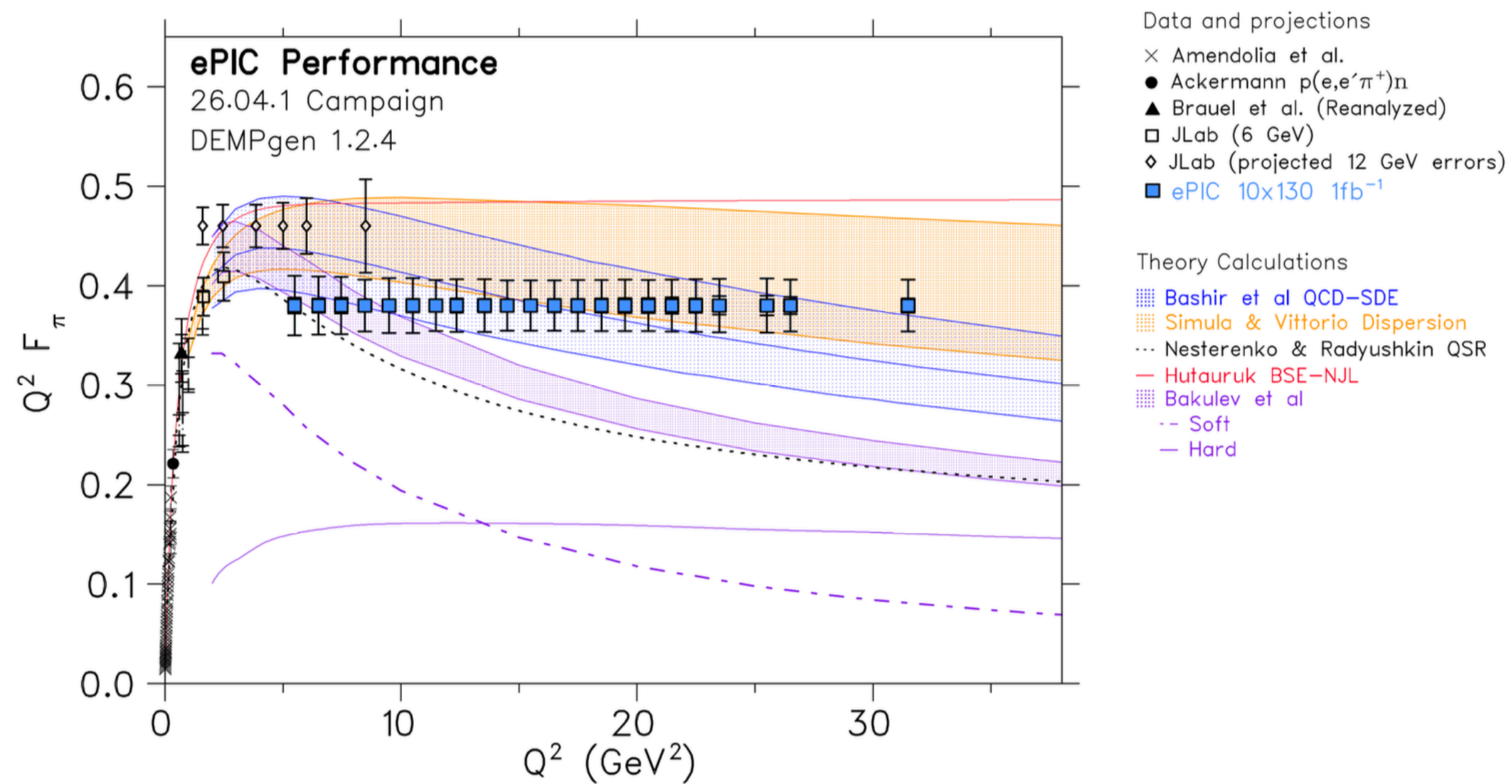
- DVCS - access tomographic imaging of proton
- Beam spin asymmetries provide quantitative constraints for improving extraction of Compton form factors connected to proton imaging and quark contributions to proton spin and OAM
- Starts to pave the way for full EIC GPD program



- Coherent diffractive VM production - direct sensitivity to transverse spatial distributions of gluon in nuclei
- Diffractive pattern can be reconstructed, provided adequate control of incoherent background demonstrated
- Then, Fourier-Bessel transform of differential cross section can reproduce transverse gluon profiles with high accuracy compared to previous data

Exclusive, Diffractive and Tagging Measurements

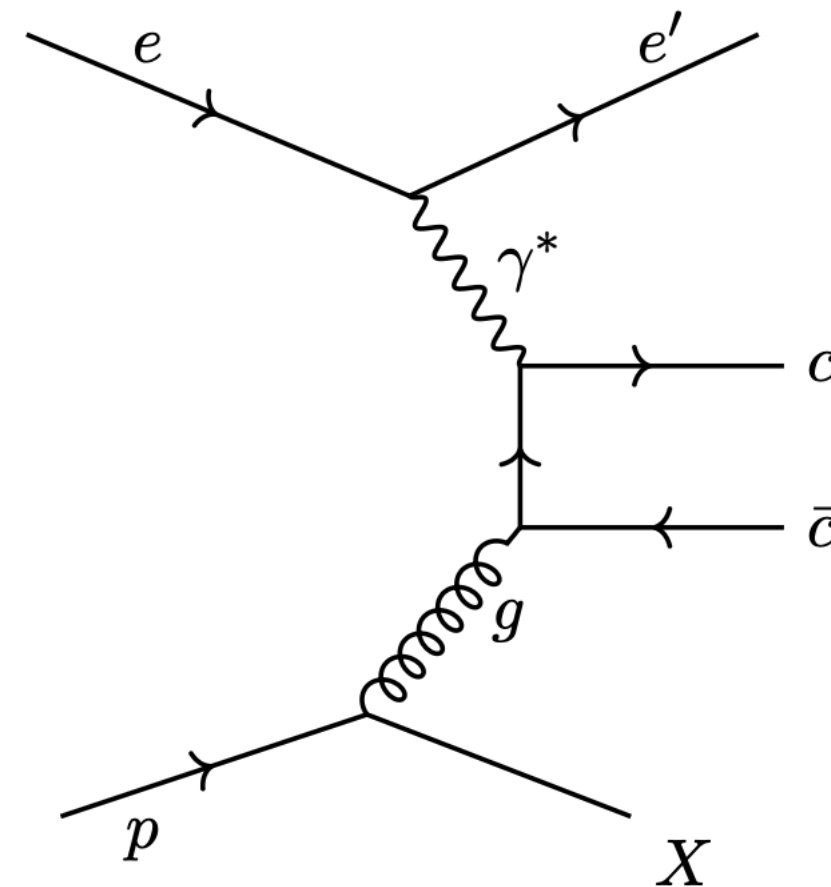
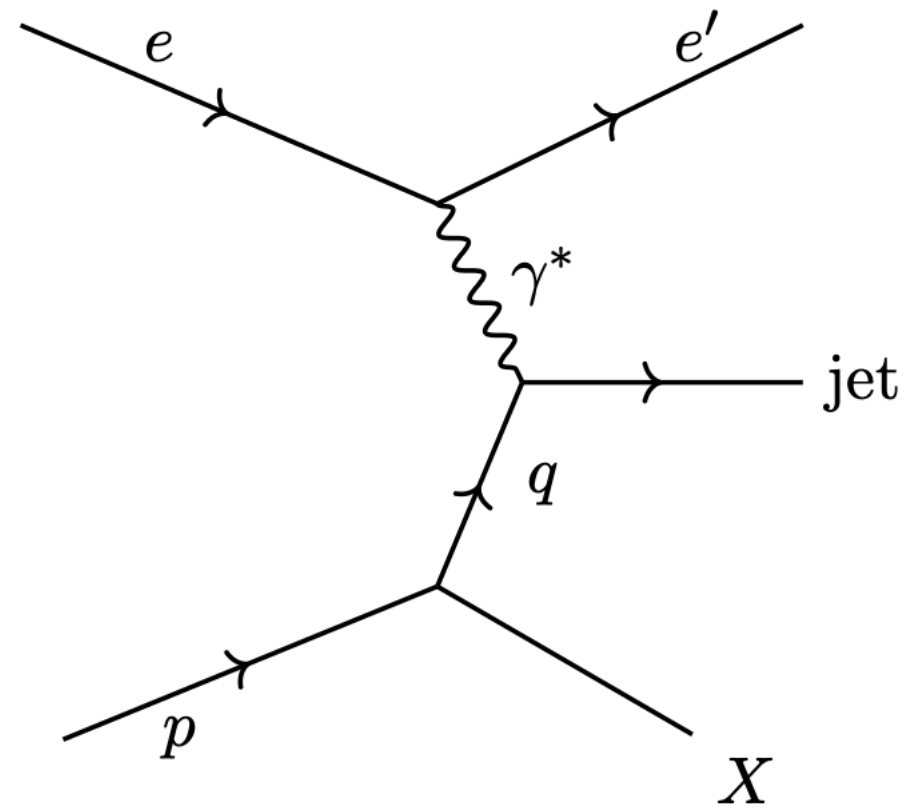
Establishment of far-forward detectors unlocks unique tagging capabilities in early running years



- Access to meson structure via $ep \rightarrow e'\pi^+n$, relevant for:
 - nucleon mass enigma; transition between perturbative and non-perturbative QCD regimes; complementary info for GPDs
- Early science data greatly extends kinematic reach of meson FF world data, allowing for better model discrimination and tests of hadron structure models

- Tagging recoil protons in ^3He isolates scattering from nearly on-shell neutrons → access to free neutron structure with minimal nuclear corrections
- Also helps constrain isospin decomposition of nucleon structure
- Early data will impact neutron SF, with ~25-30% reduction at around low x observed - benefits studies of nuclear shadowing and constraints for flavor-separated global PDFs

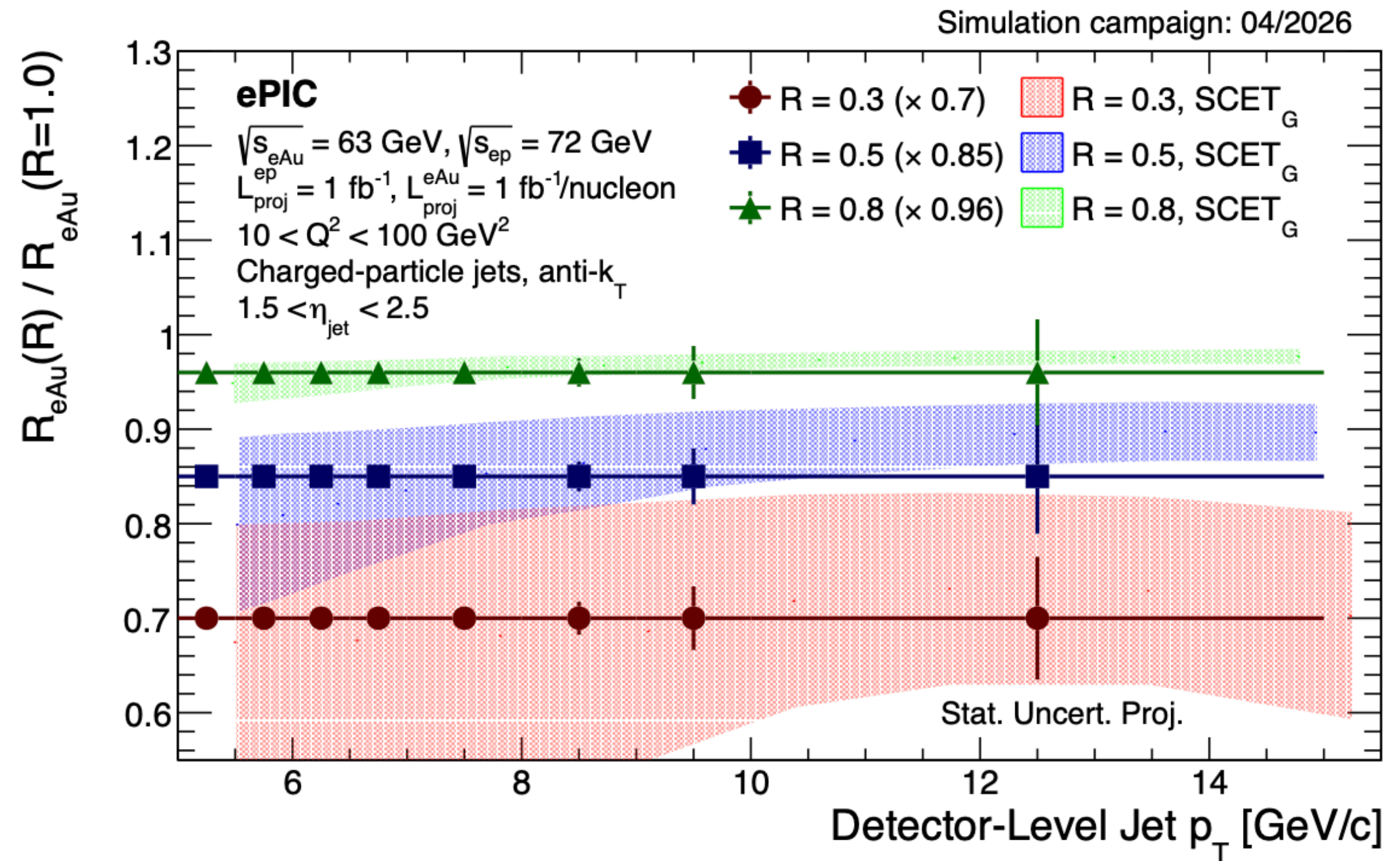
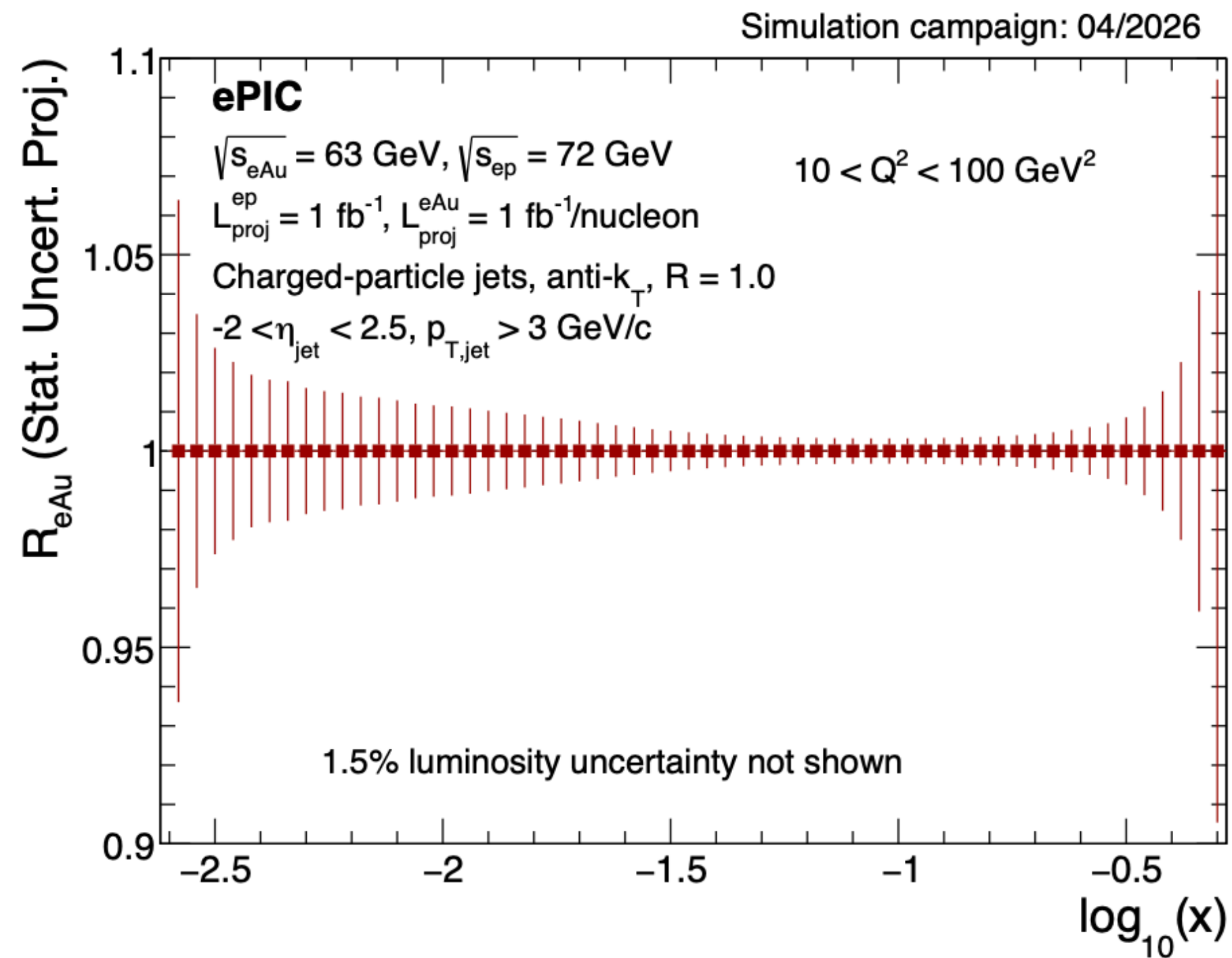
Jets and HF Measurements



Configuration	Representative Measurement
$e+p$ running	Jets FFs; Λ_c^+/D^0 ratio
$e+p$ running with polarization	Hadron-in-jet Collins FF
$e+A$ running with heavy nuclei	Charged-jet R_{eA} ; D^0 -in-jet R_{eA}

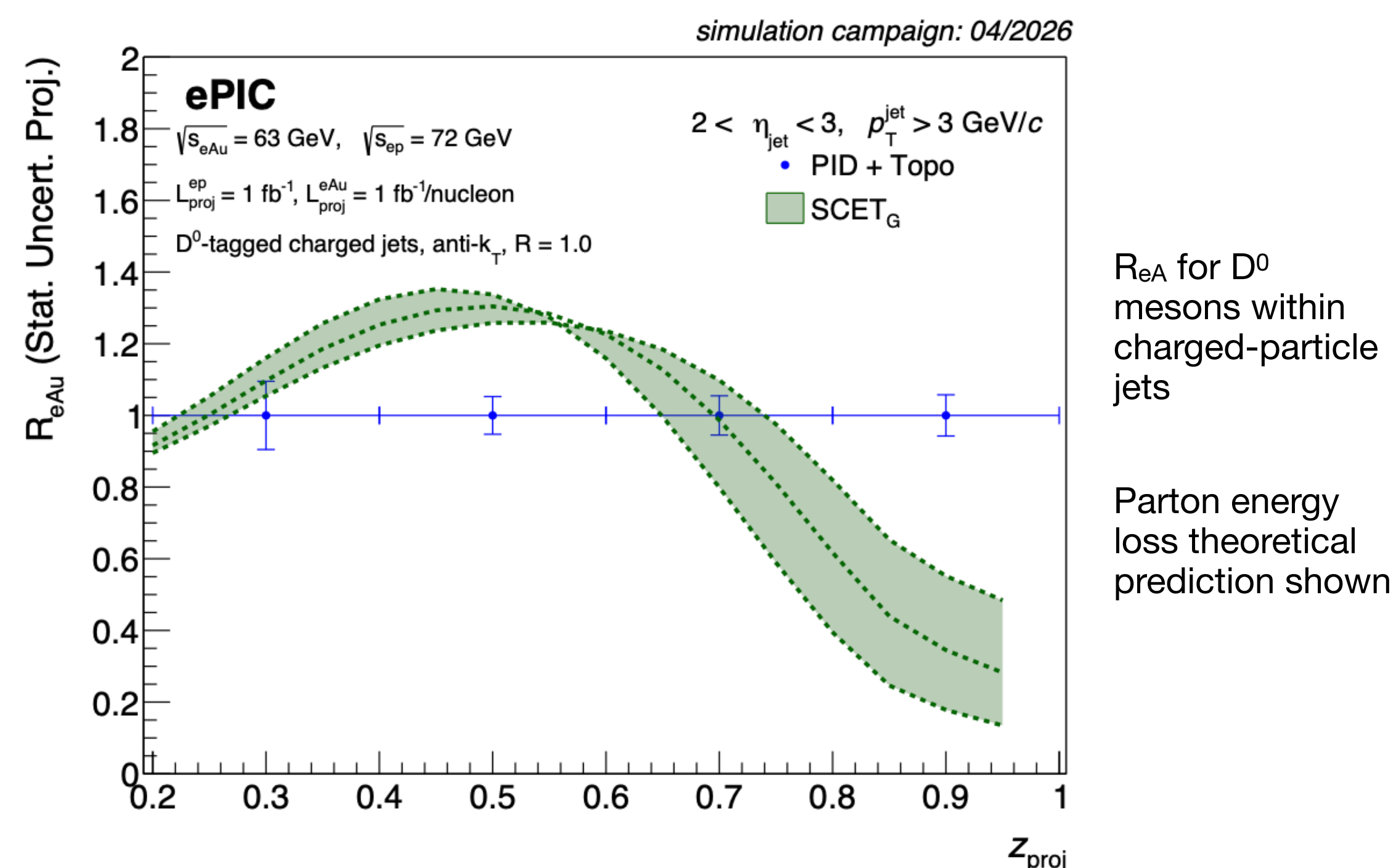
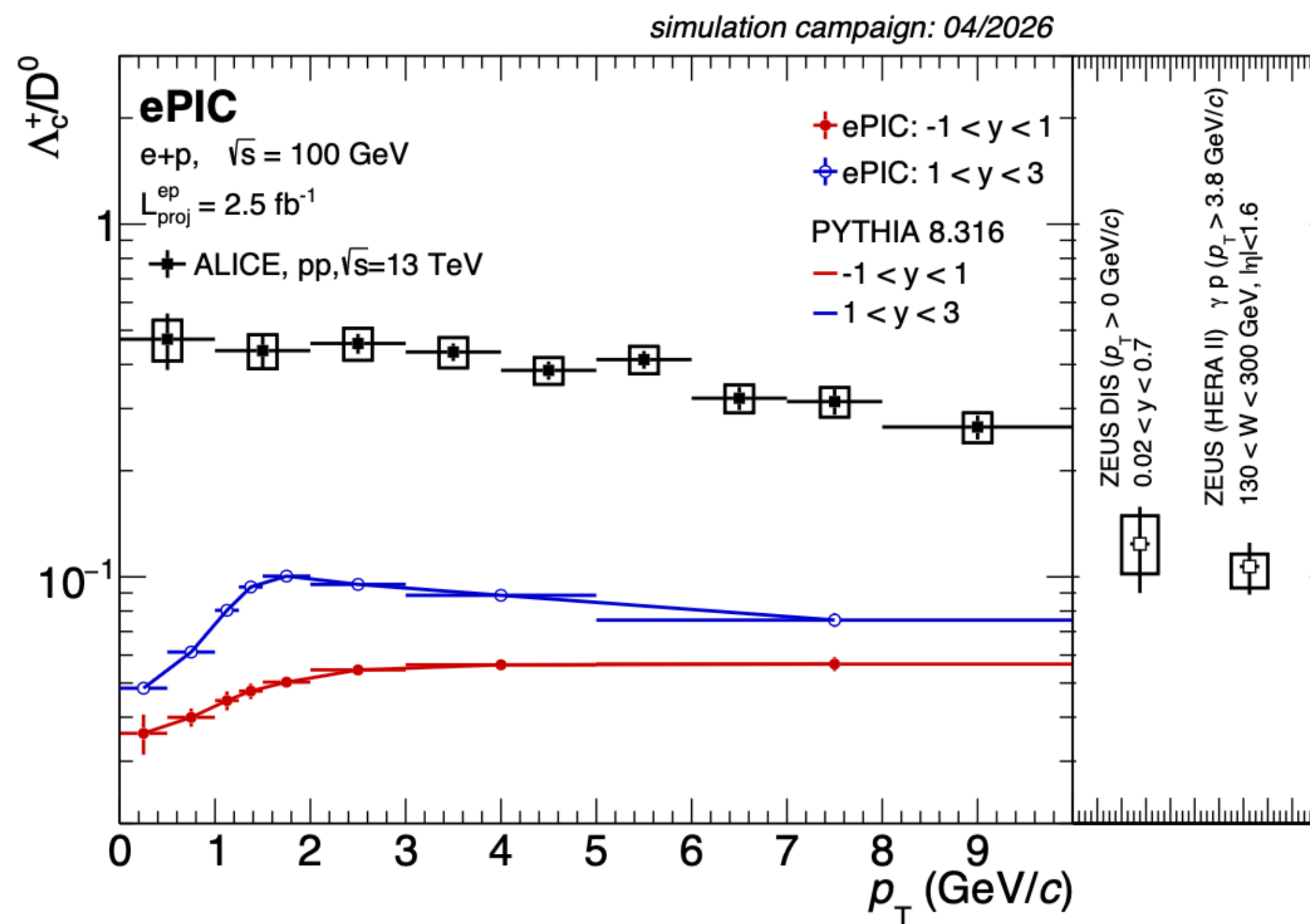
- Jets and HF measurements expand early science program as hadron reconstruction and hadron PID mature
- Already in early running Jets and HF observables can be linked to all three NAS pillars
- Complimentary tool with direct sensitivity to gluons, gluon dynamics, hard parton propagation and heavy-quark hadronization in vacuum and cold nuclear matter
 - Observables with clean reconstruction signatures and robust theoretical interpretations can be measured with sufficient statistical precision in early running

Jets and HF Measurements



- Inclusive charged jet measurements provides a direct probe of QCD dynamics in nuclear matter with sensitivity to initial and final state effects (eg modifications of nPDFs or parton energy loss)
- Large jet radii: ratio between e+A and e+p (R_{eA}) for $R=1$ jets offers enhanced sensitivity to nPDF effects
 - High statistical precision (generally $<2\%$) $\rightarrow$ enables robust theoretical interpretation
- Smaller jet radii: ratio of R_{eA} to $R=1$ directly probes cold nuclear matter effects on jet propagation and shower dynamics, with enhanced sensitivity to modifications from final-state effects
 - High statistical precision $\rightarrow$ enables constraints on final-state nuclear effects and discrimination of different theoretical predictions incorporating parton energy loss in cold nuclear matter

Jets and HF Measurements



- Charm observables are a powerful tool for constraining gluon distributions, and studying hadronization mechanisms
- Early running luminosities facilitate multi-differential measurement of inclusive Λ_c^+/D^0 production vs p_T , shedding light on dynamics of charm hadronization and testing whether fragmentation and baryon formation in clean DIS environment of EIC differ from previous hadron-hadron collision results
- D^0 -in-jet nuclear modification measurements will offer enough statistical precision (5-10%) to probe parton shower, heavy quark propagation and hadronization modifications in nuclei



Mapping Example Measurements to 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}

A coherent cross-cutting program linked to all NAS pillars is achievable in the early years of running !

Strength of label indicates directness of connection between measurement and pillar:

Strong → direct
Important → substantial but less direct

Supporting → complimentary/ more indirect



We Still Need the Full EIC Capabilities

- Early running will deliver world-class measurements addressing all three NAS science pillars
- First stage of EIC physics only - science case can only be fully realized with eventual design capabilities

Kinematic Reach

Reduced collision energy: $\sqrt{s} = 100$ GeV Vs final upgraded 140 GeV

Reduced Q^2 range at fixed x : limits lever arm for PDF/ α_s extractions

Low- x reach limited: very low- x frontier in $e+p$ and $e+A$ collisions reachable only with full energy EIC

Luminosity

Reduced luminosities: 1.0 - 2.5 fb⁻¹ per species Vs eventual ≥ 10 fb⁻¹

Restricts multi dimensional binning (x , Q^2 , z , $P_{h\perp}$, t) for GPDs/TMDs. Initial studies will pave the way but need full EIC for completion of program

Several measurements need high statistics (e.g. spin asymmetries at $x \lesssim 10^{-3}$, or rare exclusive channels like near-threshold quarkonium)

Saturation Scale

Reduced collision energy: kinematic reach does not reach far enough to low- x , perturbative Q^2 phase space region where saturation regime is expected to open up, even with Au ions

Early measurements (e.g. di-hadron correlations, diffractive gluon imaging) will characterize approach towards onset of saturated regime, but **definitive measurements require full EIC**

Hard Probes and CC DIS

Limited jet p_T reach: Full EIC needed to extend reach for jet substructure studies, improved separation of initial and final state nuclear effects, and access to domain where higher order QCD calculations are more robust

Limited luminosities and energies for CC DIS: needs full EIC, where it will provide unique flavor separation and a complimentary probe of nucleon sea



Summary

- 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
- Diverse set of measurements take the first decisive steps towards addressing the three NAS pillars
- Staged program of measurements mapping to early EIC running configurations
 - 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 maturation of far-forward instrumentation
- Fully answering NAS pillars requires the ultimate design EIC luminosity, energy, beams and detector instrumentation
- In addition to producing world-leading measurements, early years of ePIC running will pave the way for final EIC - developing complex techniques needed for full program (e.g. reconstruction, calibration, global analysis tools, unfolding)
- ESR is culmination of >1year targeted efforts - this is a huge milestone for the collaboration and well done to everyone!

Team Effort

- ESR has been a massive team effort from the entire ePIC Collaboration. Huge thanks to you all.
- ePIC Collaboration
- ePIC leadership
- PACs and Editing Team (thank you to Carlos and Charlotte for joining the efforts)
- PWGs - conveners and analysers
- ePIC Software and Computing
- Teams of reviewers (internal and external) - see next slide
- EIC Project leadership
- ePIC CC office, membership and publication committees
- Physics readiness workshop attendees
- Theorists/collaborators supporting impact plots: A. Accardi; I. Borsa; M. Cerutti; C. Cocuzza; K. Kumericki; R. Martinez; M. Radici; L. Rossi; R. Sassot; P. Sznajder; A. Vladimirov; K. Wichmann; S. Yadav; P. Zurita

THANK
YOU!

NB: please check ESR v3.2 on Zenodo for more details on plots and citations for theory inputs in studies shown



List of Reviewers

- **General Overview**
 - Thomas Ulrich; Taku Gunji; John Lajoie; Wim Cosyn
- **Inclusive**
 - Katarzyna Wichmann; Pia Zurita; Paul Newman; Enrico Tassi; Andy Buckley
- **Exclusive, Diffractive, Tagging**
 - Kresimir Kumericki; Nicole D'Hose; Alex Jentsch
- **Semi-Inclusive**
 - Marco Mirazita; Marco Radici; Marco Contalbrigo; Charlotte Van Hulse
- **Jets/HF**
 - Olga Evdokimov; Deepa Thomas; Brian Page; Rithya Kunnawalkam Elayavalli; Cameron Dean



Thanks



Back up

Inclusive Staging

Configuration	Representative measurements	Enabling capabilities
$e + A$ running with medium- and light- mass nuclei	Reduced cross sections for nuclear F_2 extraction; A dependence of nuclear effects; nPDFs; diffractive nPDFs	No polarization needed, moderate luminosity; tracking, calorimetry, PID; rapidity gap selections for diffractive nPDFs
$e + p$ running at multiple energies, with polarization	Reduced cross sections for F_2 and F_L extractions, collinear and diffractive PDFs and α_S extractions; spin asymmetries for proton spin SFs and polarized PDFs	Lever arm in center of mass energies; proton polarization; electron polarization; far forward instrumentation; and previous capabilities
$e + A$ running with heavy-nuclei	Reduced cross sections for nuclear modifications of F_2 , A dependence of nuclear effects in SF and nPDFs, diffractive nPDFs	Only needs previous capabilities
$e + A$ running with polarized ^3He	Spin asymmetries for neutron spin SFs and polarized PDFs	Spectator tagging and previous capabilities



Semi-Inclusive Staging

Configuration	Representative measurements	Enabling capabilities
$e + p$ running	Multiplicities (M_h) for FFs	Hadron ID (π, K, p) and z coverage
$e + p$ running	Multifold differential cross sections for unpolarized TMD PDFs	Needs previous capabilities + higher collected luminosity than in previous case
$e + p$ running with polarization	Azimuthal single-spin asymmetries for Sivers TMD PDF and Collins TMD FF	Needs previous capabilities + transversely polarized proton beam
$e + p$ running with polarization	Double spin asymmetry measurements for sea quark helicities	Needs previous capabilities + longitudinally polarized proton beam
$e + {}^3\text{He}$ beam with polarization	TMD and helicity measurements on the neutron	Spectator tagging capabilities
$e + A$ running with heavy nuclei	Di-hadron correlations for the onset of gluon saturation and non-linear QCD effects	Large acceptance (4π) tracking; and previous capabilities



Exclusive, Diffractive and Tagging Staging

Configuration	Representative measurements	Enabling capabilities
$e + A$ with medium-mass nuclei	Rapidity-gap diffraction; coherent-enhanced exclusive ρ/ϕ samples; initial exclusive $J/\psi \rightarrow \ell^+ \ell^-$ candidate studies	Unpolarized eA beams; central electron tracking and PID; low-multiplicity and rapidity-gap selections
$e + p$ running	DVCS, $e + p \rightarrow e' p' \gamma$; exclusive vector-meson production, including J/ψ , ρ , and ϕ ; diffractive DIS with leading-proton or rapidity-gap selection	Higher luminosity; proton beams; initial far-forward proton detection; broad central and forward acceptance
$e + D$	Spectator-tagged DIS on deuterium; tagged neutron structure; tagged studies of nuclear binding and off-shell effects	Deuteron beams; far-forward proton and neutron tagging; control of spectator kinematics
$e + p$ running with polarization	Beam-spin and target-spin asymmetries in DVCS and exclusive meson production; spin-dependent GPD observables	Longitudinal and/or transverse proton polarization; polarized electron beam; good azimuthal acceptance
$e + \text{Au}$ running	Coherent and incoherent vector-meson production in gold; coherent-to-incoherent ratios; nuclear diffractive DIS	Heavy-ion beams; improved luminosity; robust nuclear-breakup vetoes; precision t reconstruction and unfolding
$e + {}^3\text{He}$ with polarization	Double spectator tagging in ${}^3\text{He}$; spin-dependent tagged neutron measurements	Polarized ${}^3\text{He}$ beams; forward spectator detection; mature light-ion reconstruction



Jets and Heavy Flavor and Tagging Staging

Configuration	Representative measurements	Enabling capabilities
$e + p$ running	Jet FFs; Λ_c^+ / D^0	Particle ID (π, K, p), primary and secondary vertexing, tracking and calorimetry, high luminosity
$e + p$ running with polarization	Hadron-in-jet Collins FF	Same as above with transversely polarized proton beam
$e + A$ running with heavy nuclei	Charged-jet R_{eA} ; D^0 -in-jet R_{eA}	Same as above