THE UNIVERSITY OF TENNESSEE KNOXVILLE

Jefferson Lab
Exploring the Nature of Matter

Tagging measurements: Opportunities for Nucleon Spin Physics at the EIC

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FIU, Miami, Feb 24-28 , 2025

Physics Opportunities at an Electron-Ion Collider XI

Physics motivation

Nucleon spin question:

$$S_z^N = S_z^q + L_z^q + J_z^g = \frac{1}{2}$$

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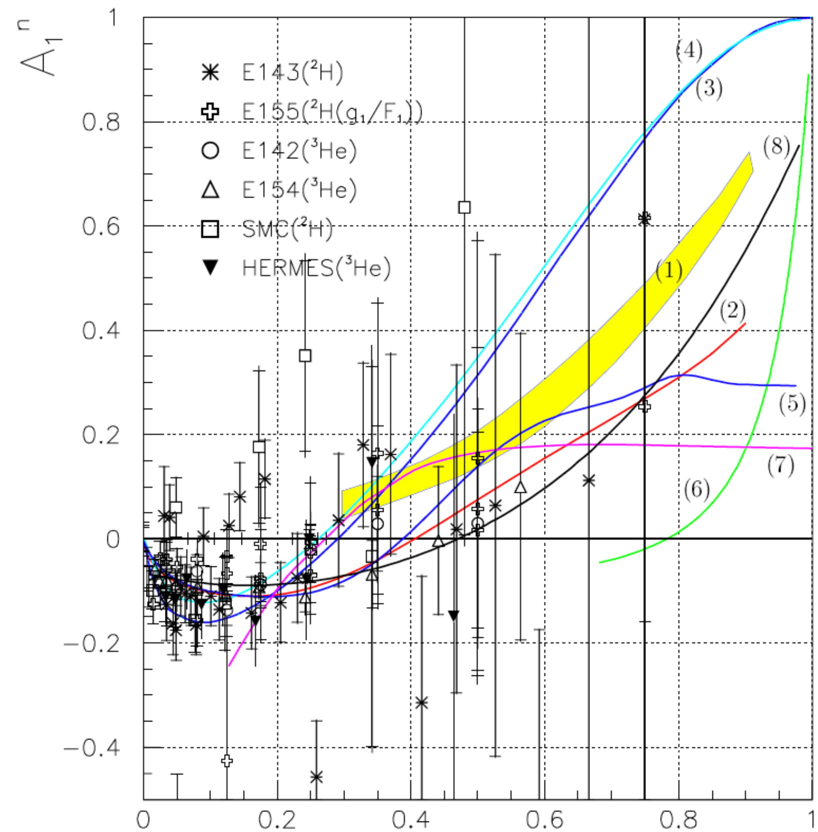
Asymmetry A1 measurement:

$$A_1(x, Q^2) = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \approx \frac{g_1(x, Q^2)}{F_1(x, Q^2)}$$

A1n measurement



JLab's E12-06-112 proposal

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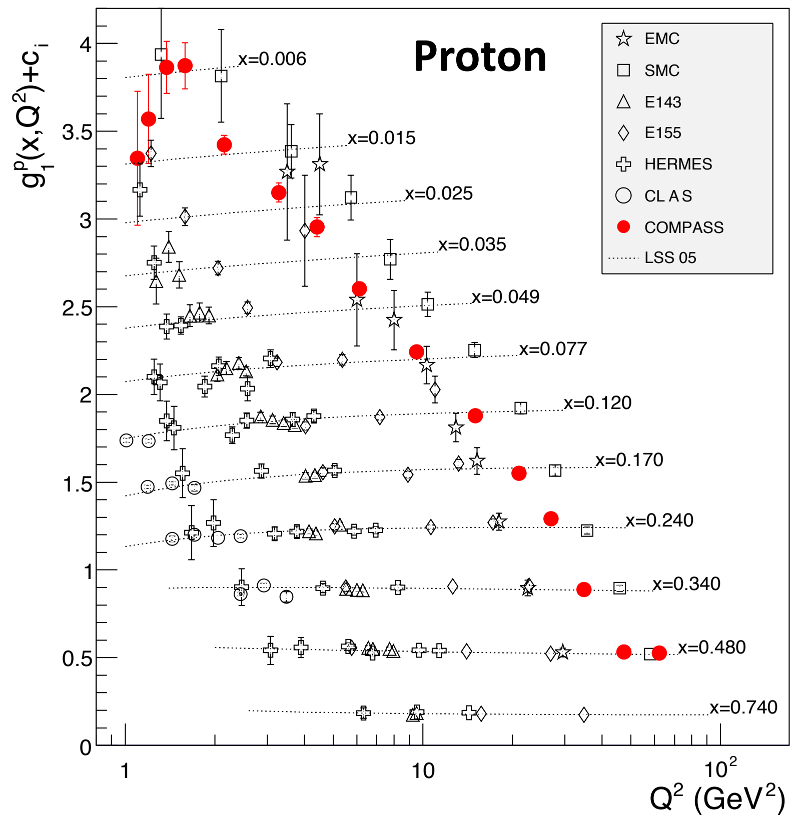
Proton polarized structure world's data



Christine A. Aidala RMP (2013)

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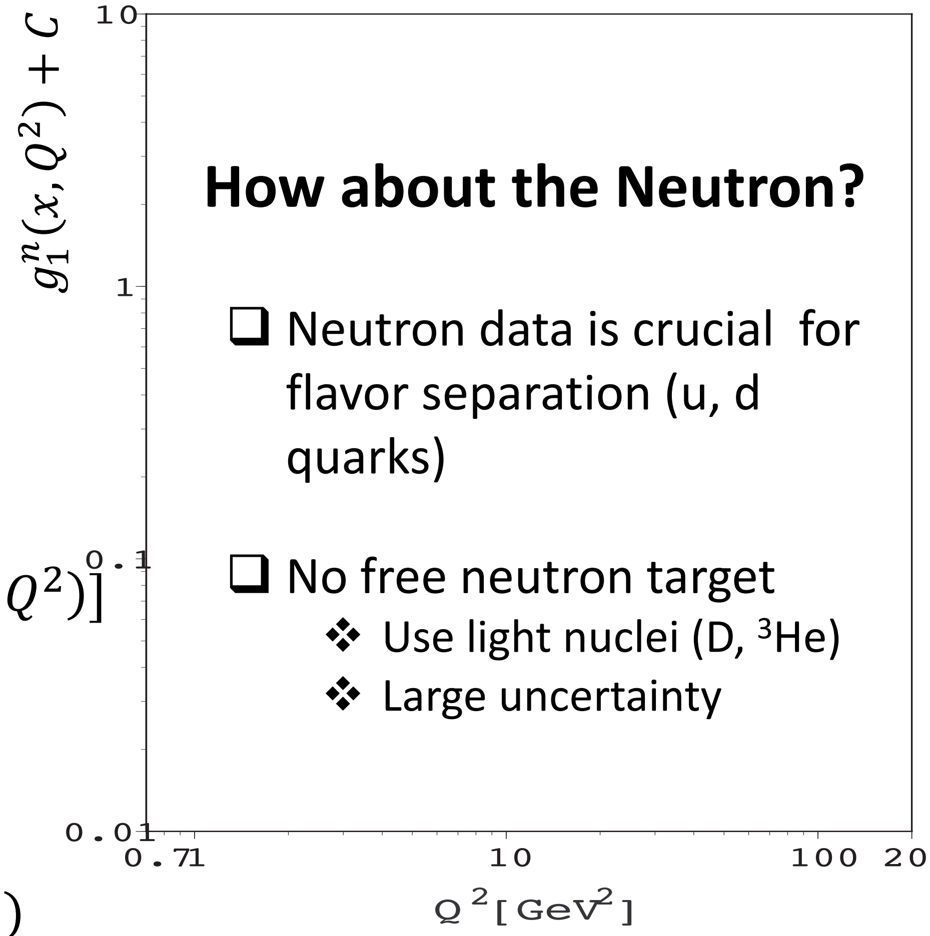

How about the Neutron?

- Neutron data is crucial for flavor separation (u, d quarks)
- No free neutron target
  - Use light nuclei (D, ^{3}He)
  - Large uncertainty

Physics motivation

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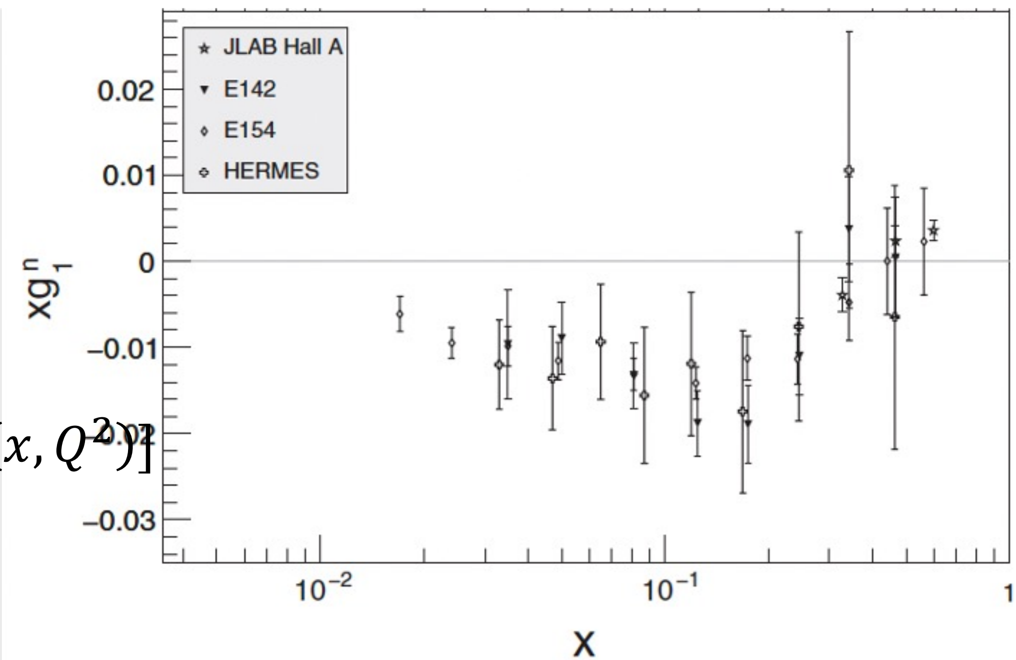
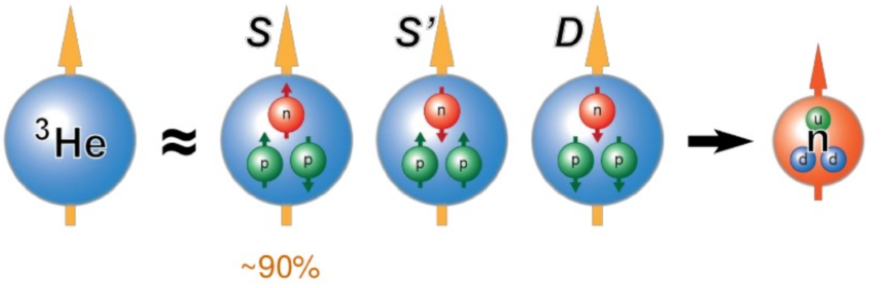
Neutron polarized structure world's data



The need of improving the precision on Neutron spin measurement

^{3}He as polarized neutron target

- Neutron carries most of the spin in polarized ^{3}He



- Precise calculation

Neutron pol: Pn ~ 87%
Proton pol: Pp ~ 2.7%

- A_1^n is extracted from inclusive DIS e-He3, A_1^{He}

$$A_1^n \approx \frac{1}{P_n}\frac{F_2^{^3\mathrm{He}}}{F_2^n}\left(A_1^{^3\mathrm{H}e} - 2P_p\frac{F_2^p}{F_2^{^3\mathrm{H}e}}A_1^p\right)$$

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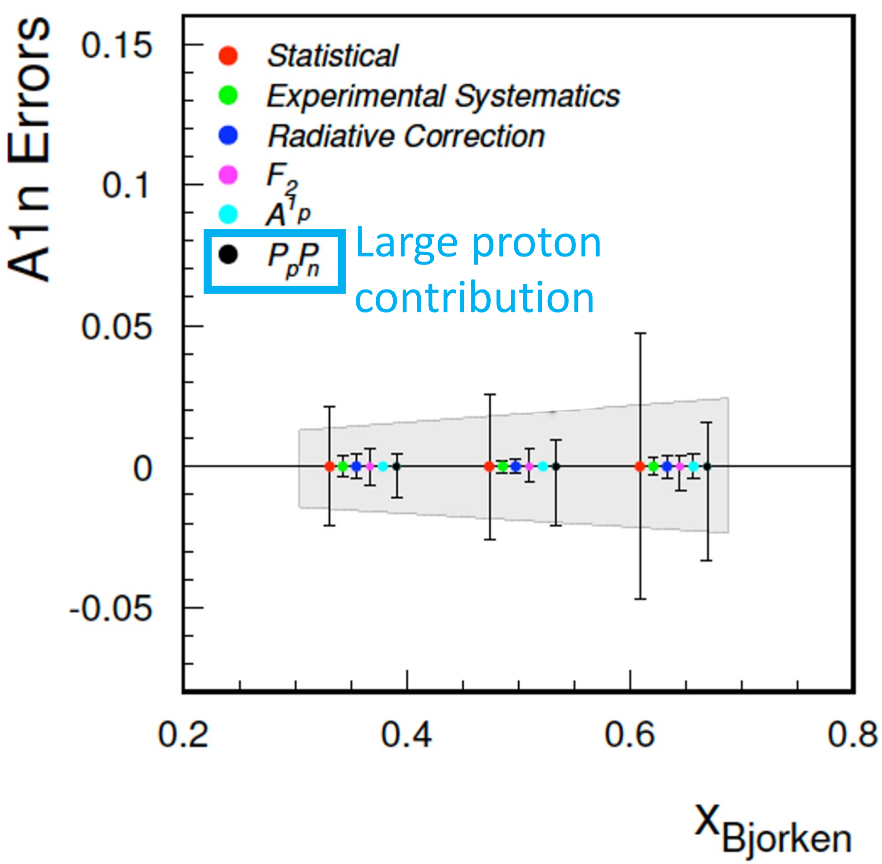
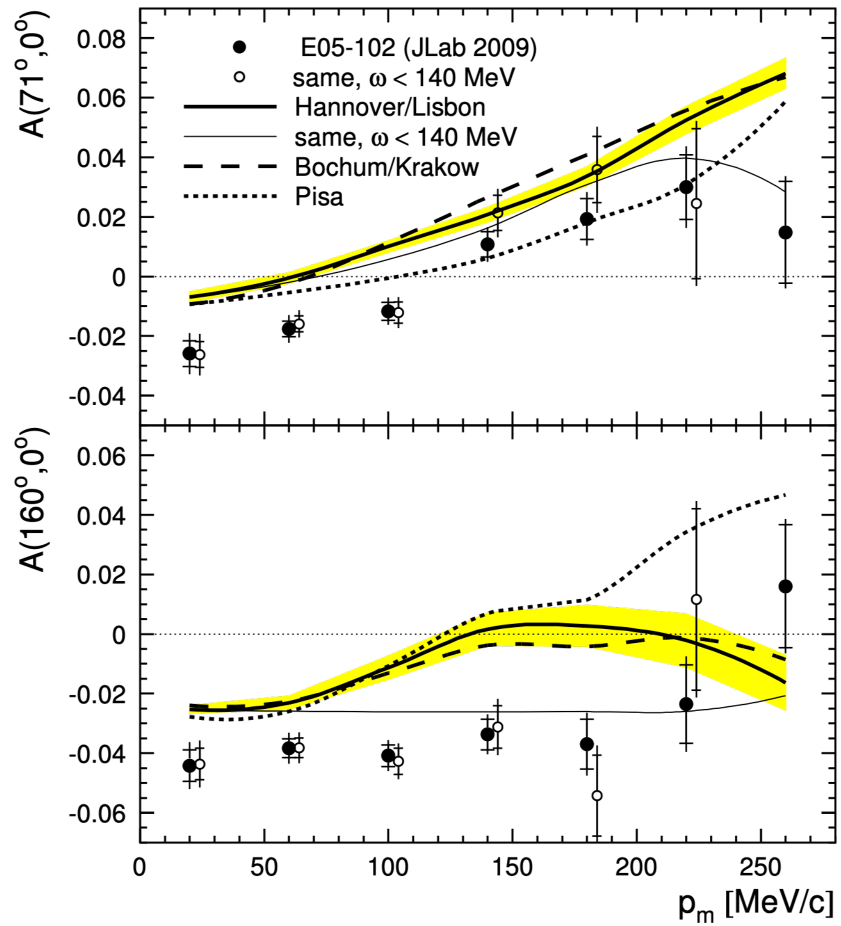
Large model dependence

- ❑ Effective neutron and proton polarization
- ❑ Structure functions F_2
- ❑ A1p uncertainty.

Inclusive extraction has large systematic uncertainties



PRL 113, 232505 (2014)



What do we need?

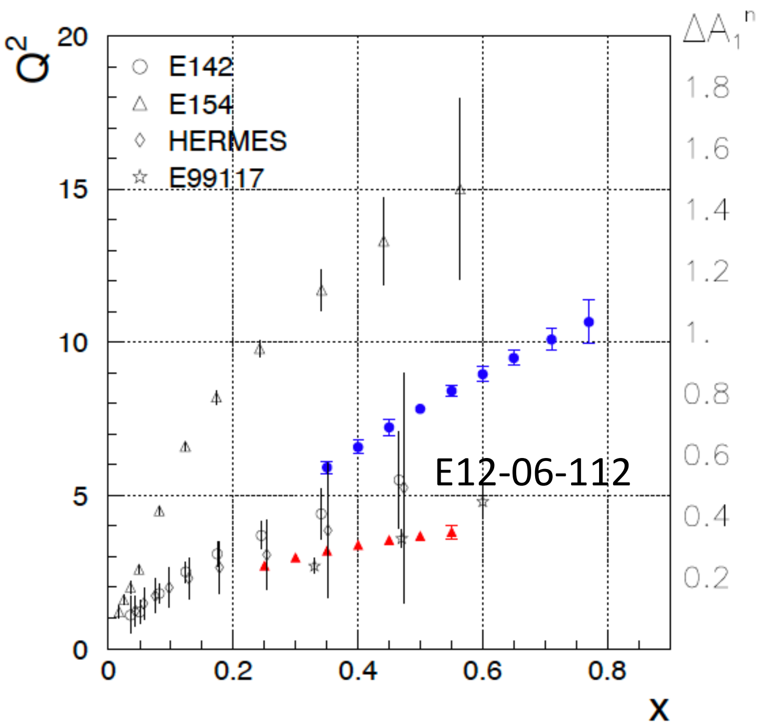
- High precision neutron spin measurement
- Large coverage of x and Q^2
- New measurement that minimize nuclear correction

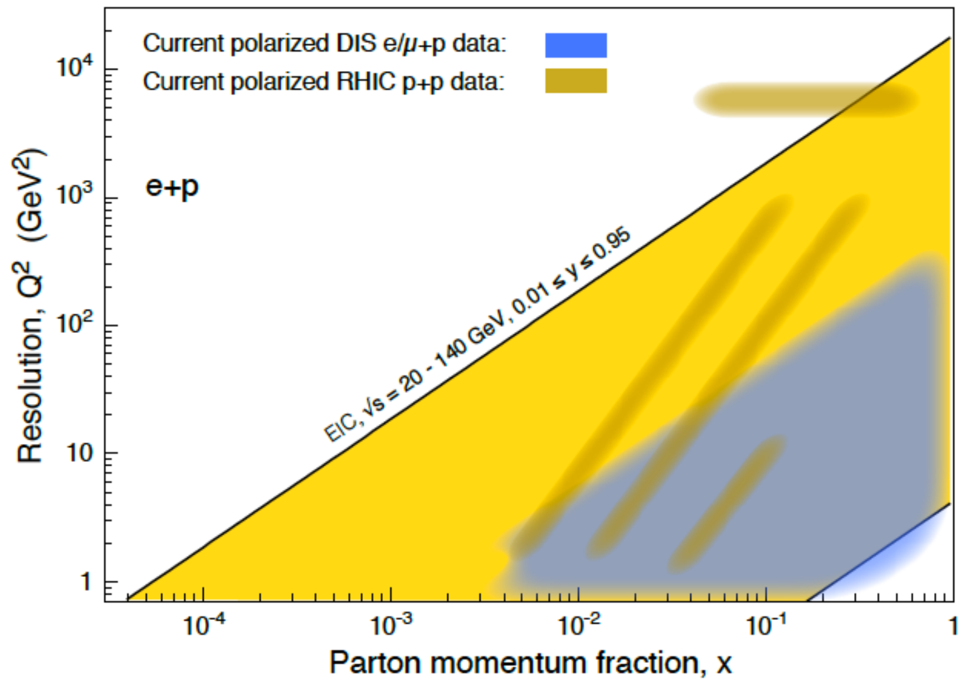
The EIC: New opportunities

EIC x:Q2 coverage

A1n world's data

Nucl. Phys. A 1026, 122447

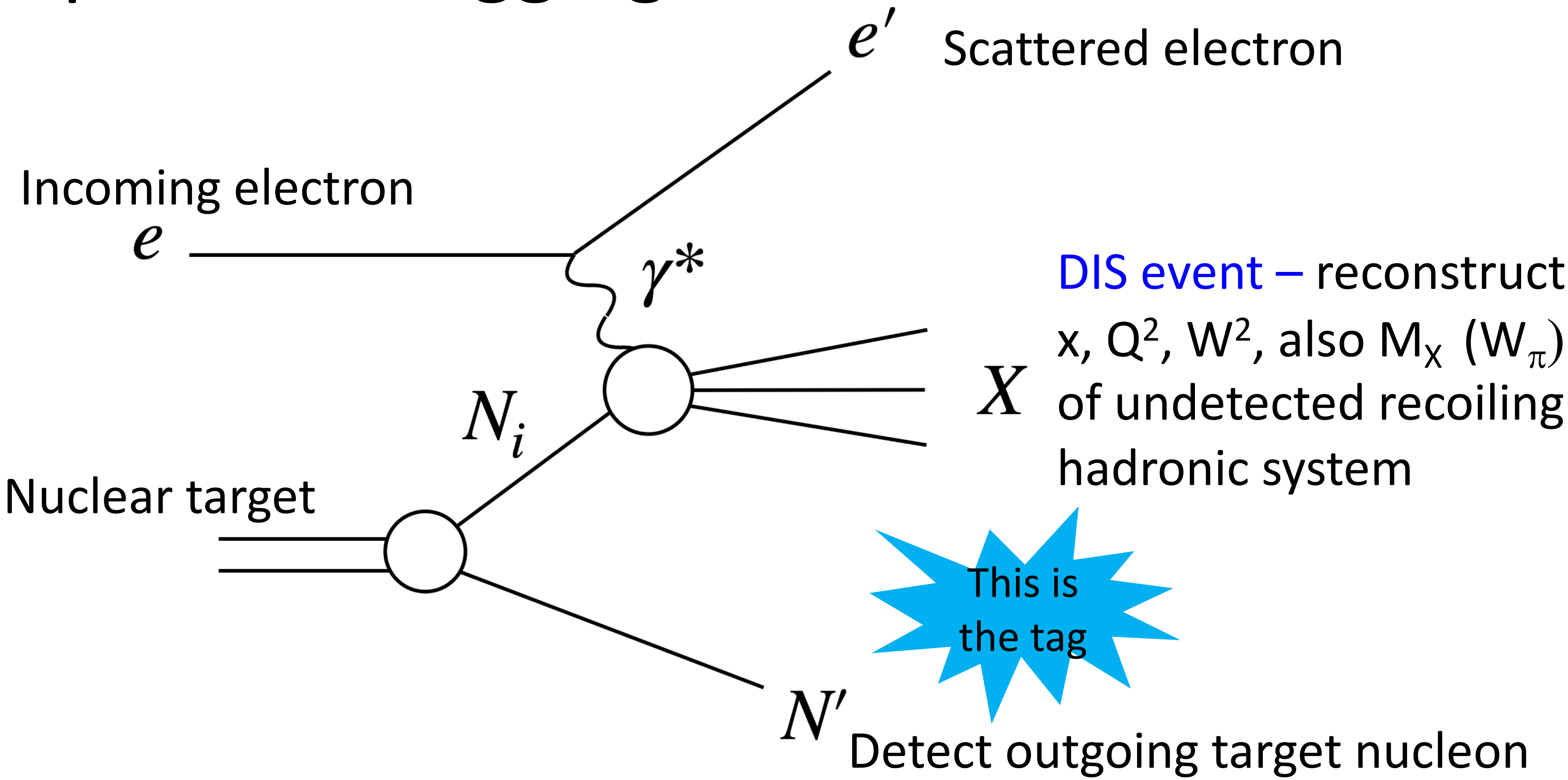




<u>EIC gives:</u>

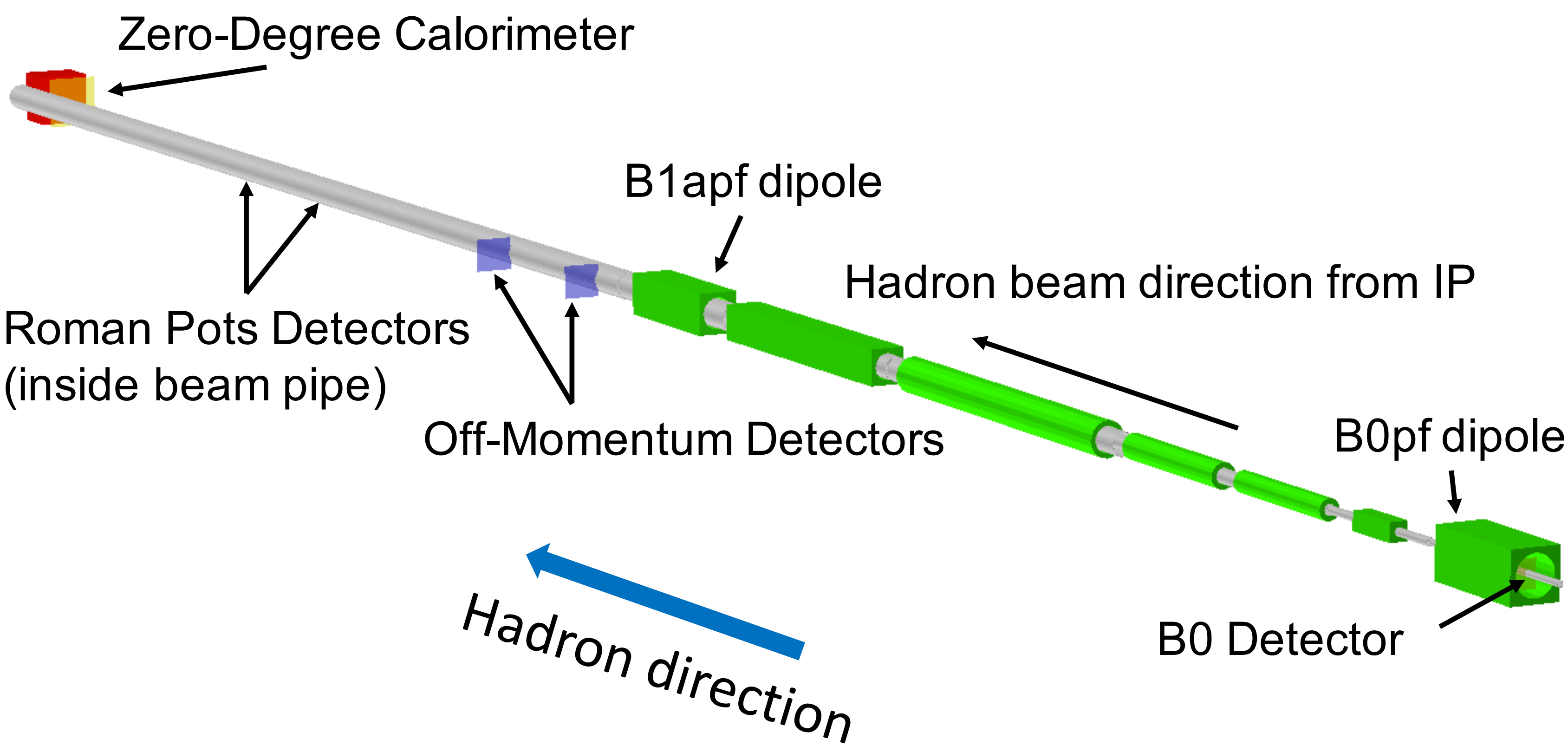
- Large coverage in x and Q^2:
- Unique opportunity for new measurements: Tagging
- Polarized ^{3}He Ion should be ready for the first EIC beam

Spectator Tagging DIS measurement



- ❑ Facilitates effective targets not readily found in nature
- ❑ Novel probes of partonic structure function

Forward Tagging possible @ EIC Far forward region

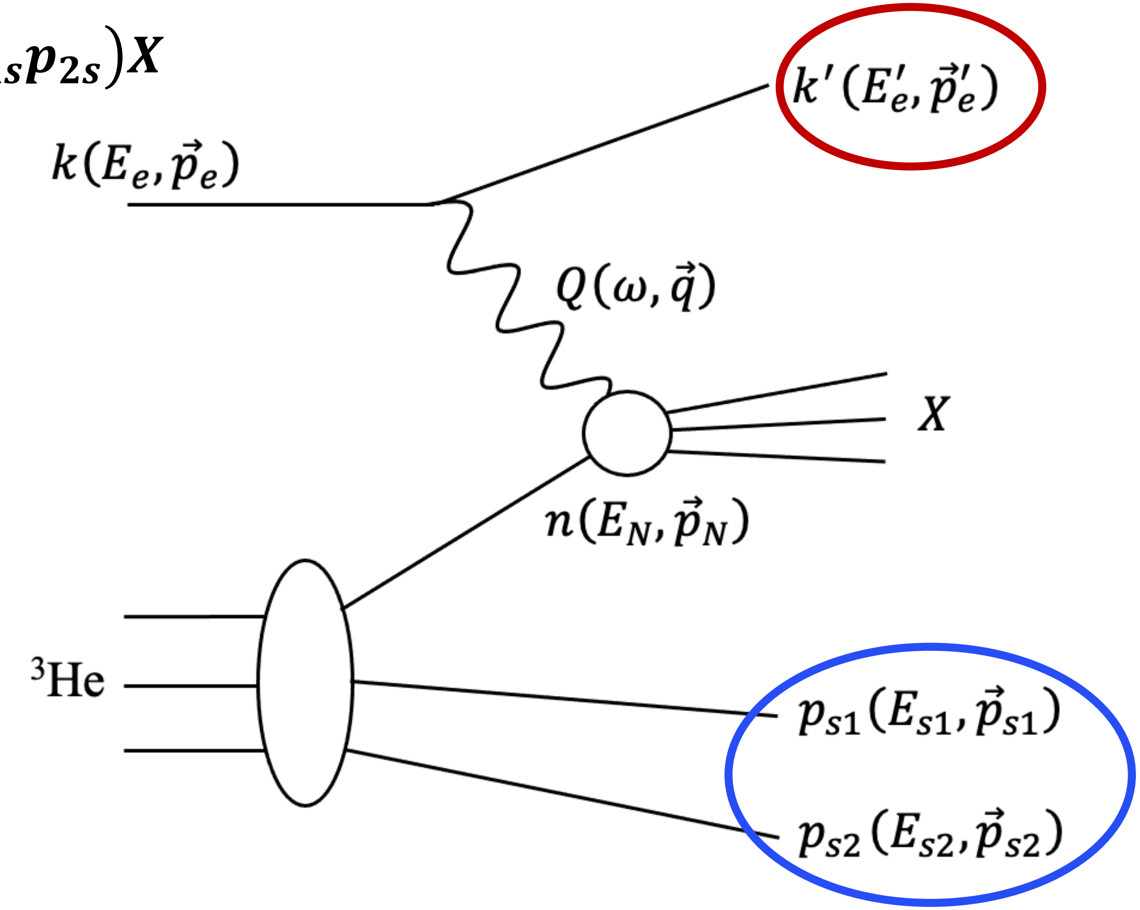


- ❑ Protons: B0, Off-momentum detectors and Roman Pots
- ❑ Neutron: Zero-Degree calorimeter

Nucl. Phys. A 1026, 122447

Double spectator tagging suppress model dependence

$e^3\mathrm{He}(e' p_{1s} p_{2s})X$



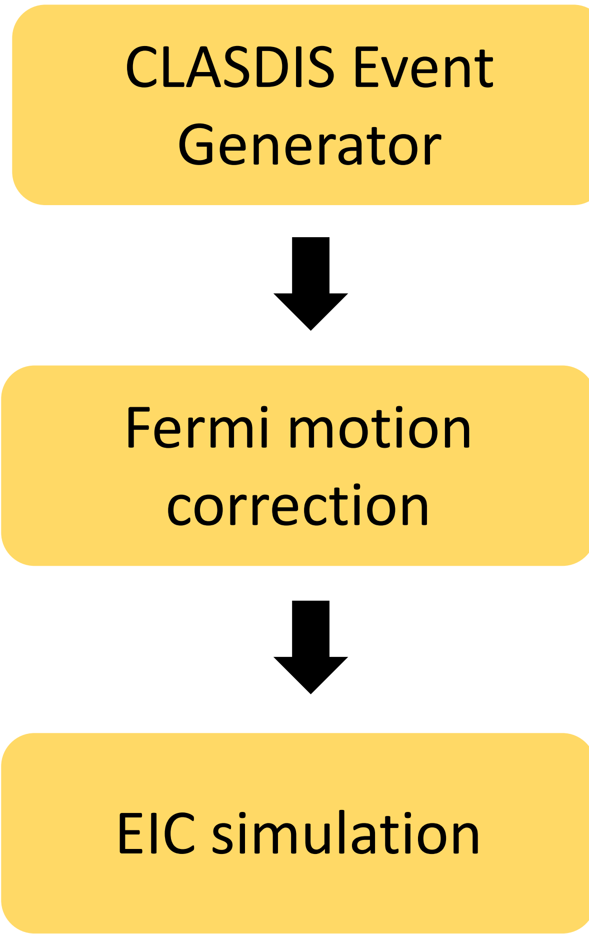
- ❑ Select the active nucleon in the reaction and break up channel
- ❑ Suppress the contribution of non-nucleonic degree of freedom
- ❑ Low total momentum => “Effective” free neutron target

Event generator and processing

Existing code assumes standing nucleons.

Add ^{3}He light-front wave function effects (fermi motion)

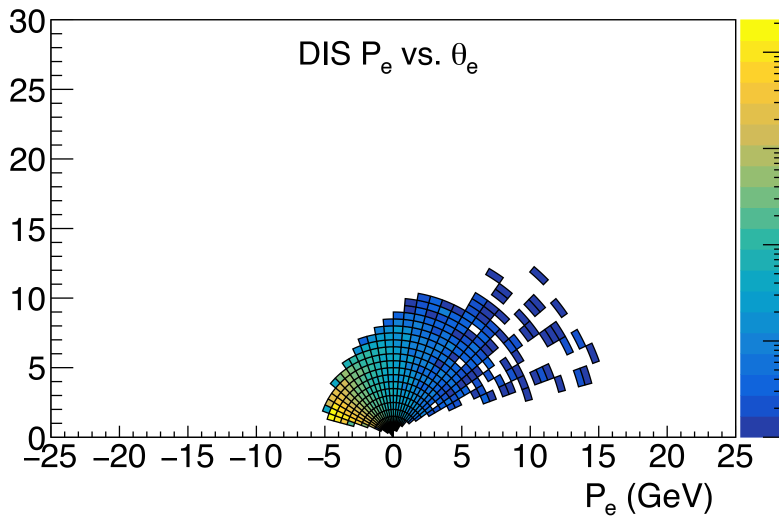
Produce pseudo-data and run via EIC Simulation



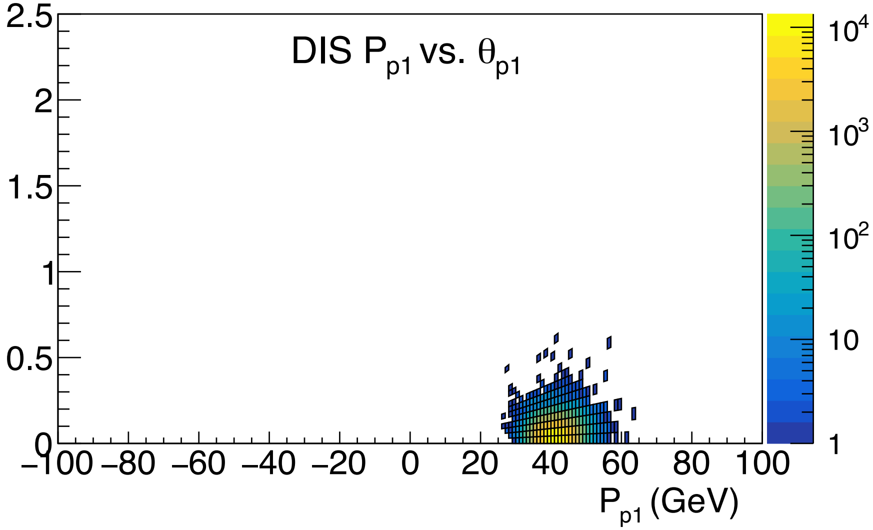
Nucl. Phys. A 1026, 122447

$^3He(e, e'pp)X$: kinematic

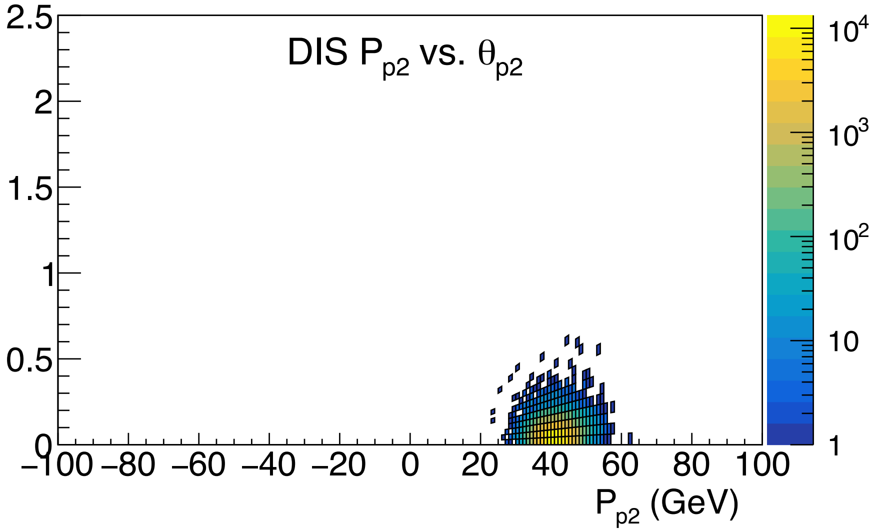
Scattering electron



Spectator proton p1s

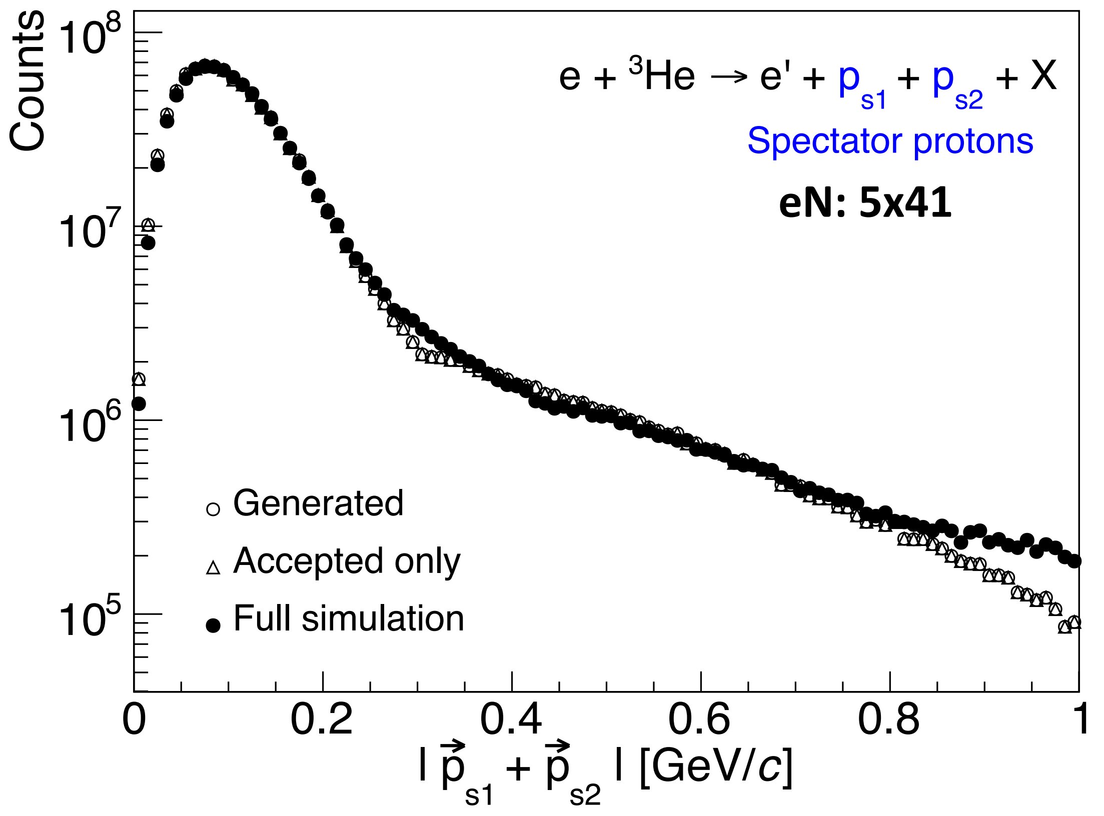


Spectator proton p2s



- ❑ Scattered electron: detected at central detector
- ❑ Spectator protons: Detected at far forward detector

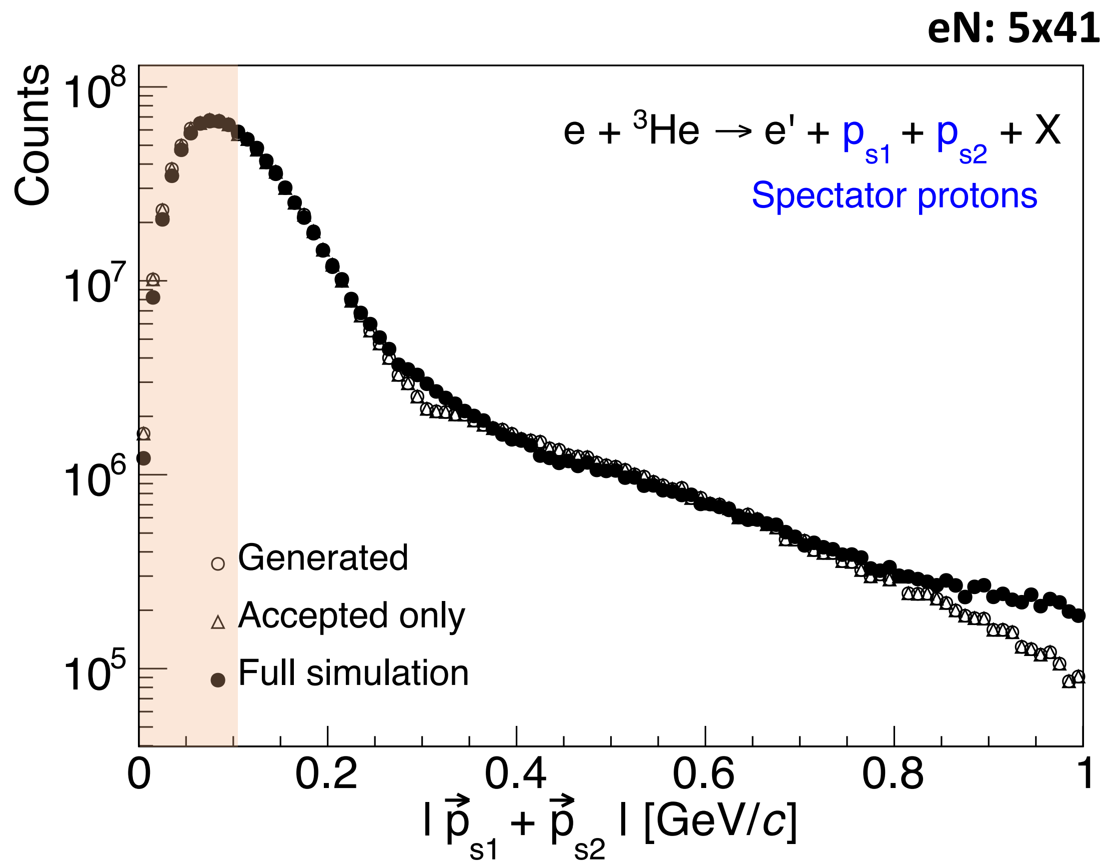
Spectator momentum at the Ion Rest Frame



Phys. Lett. B 823 (2021)13672, NIMA 167238 (2023)

Spectator momentum at the Ion Rest Frame

- Spectator protons = DIS off neutron
- low total spectator momentum = Effective "free neutron" target
- Minimal nuclear effects



Phys. Lett. B 823 (2021)13672, NIMA 167238 (2023)

Event selection

DIS Selection:

- $Q^2 > 2\ (GeV/c)^2$
- $W^2 > 4\ (GeV/c)^2$
- $0.05 < y < 0.95$

+Tagging :

- Both spectator protons detected.
- $|p1 + p2| < 0.1$ GeV

Projections:

- ❑ Bin in x & Q^2
- ❑ Scale to 1 EIC year (100 fb^{-1})

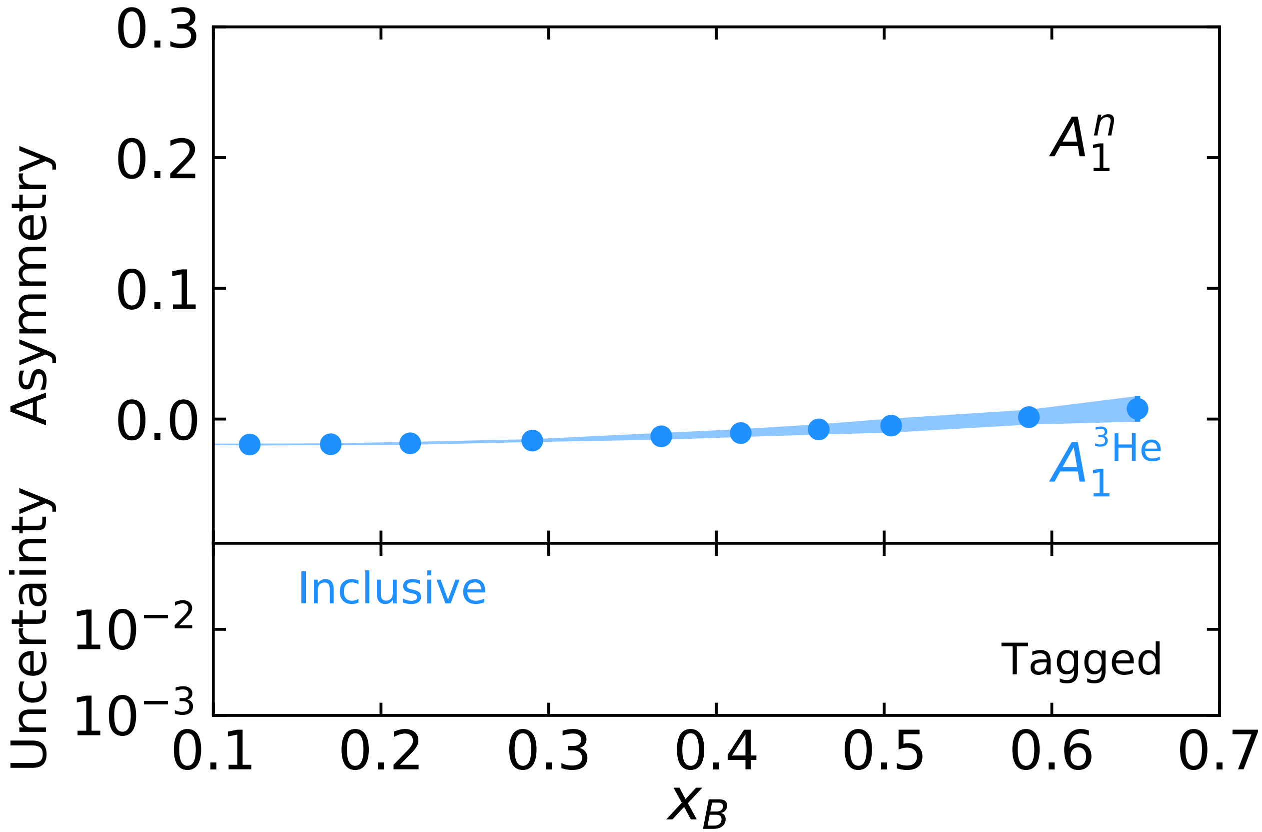
Compare uncertainties of extracted *vs* double tag A1n

$A_1^{^3\mathrm{He}}$ prediction

$$A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$$

- A_1^n, A_1^p : E99117 fit
- F_2^p, F_2^D : E155 fit
- $F_2^n = F_2^D - F_2^p$; $F_2^{3\mathrm{He}} = F_2^D + F_2^p$
- $P_n = 0.86 \pm 0.02$; $P_p = -0.028 \pm 0.004$

$A_1^{^3\mathrm{He}}$ from 3He(e, e′)



- $A_1^{^3\mathrm{He}}$: Only includes the statistic uncertainty

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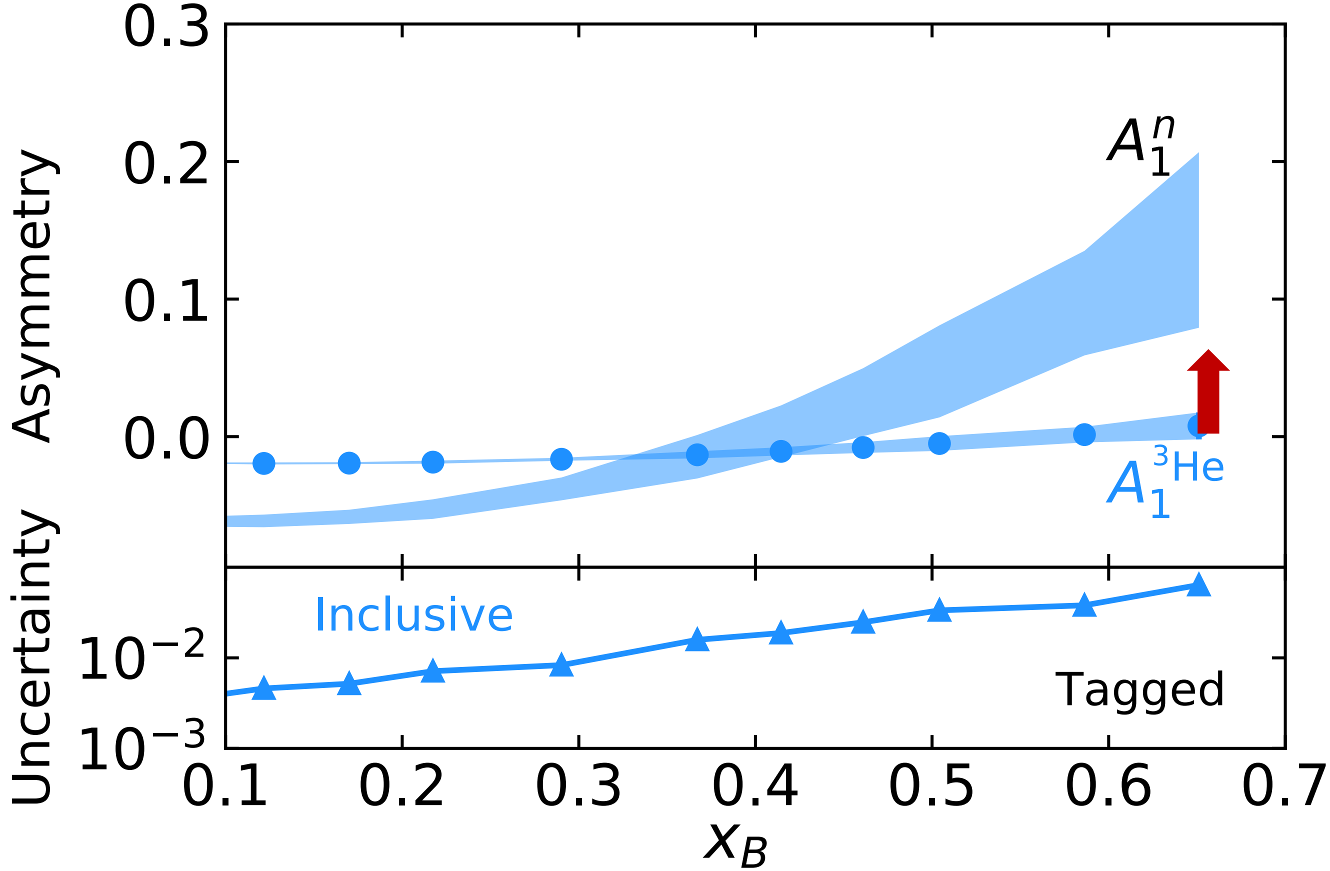
A_1^n from 3He(e, e′)

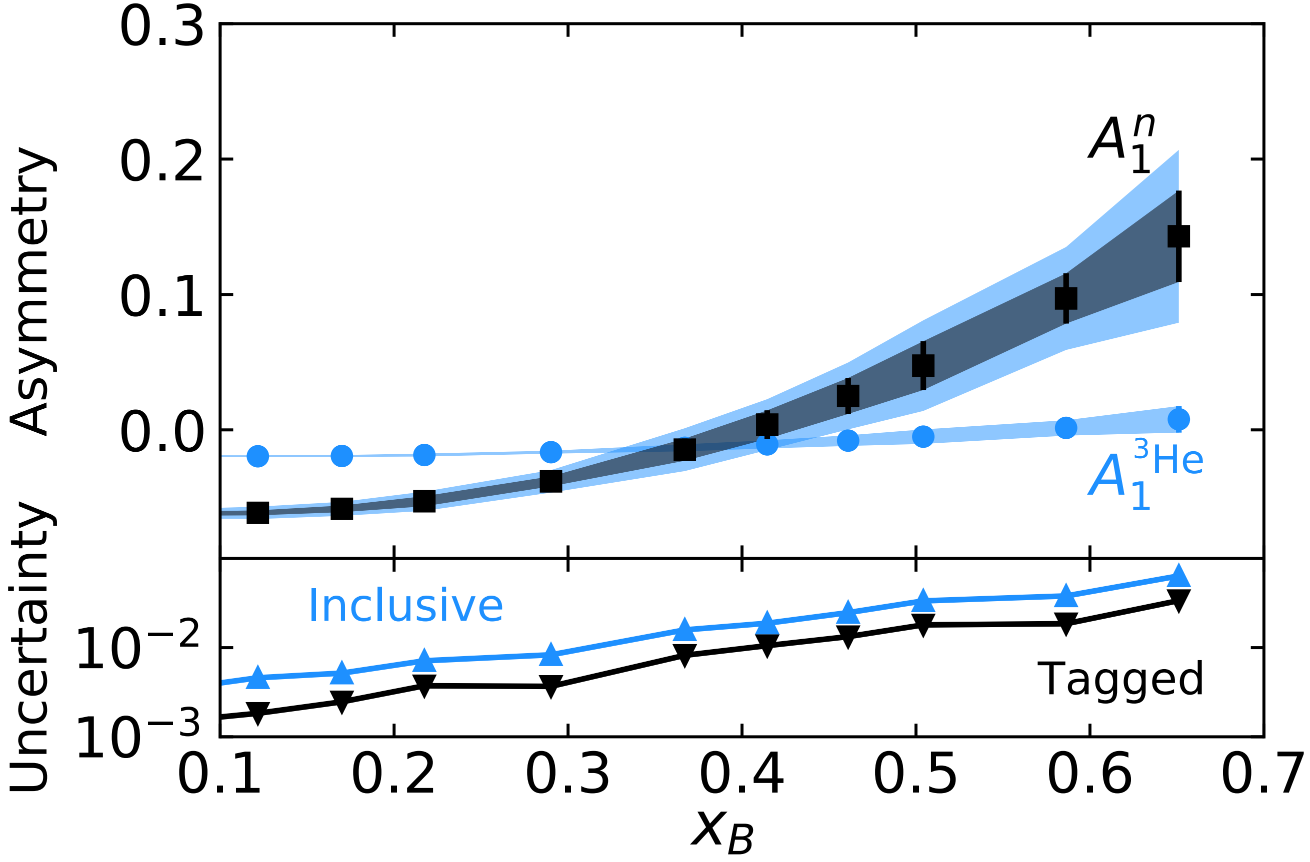


- ❑ Extraction introduce a large systematic uncertainty

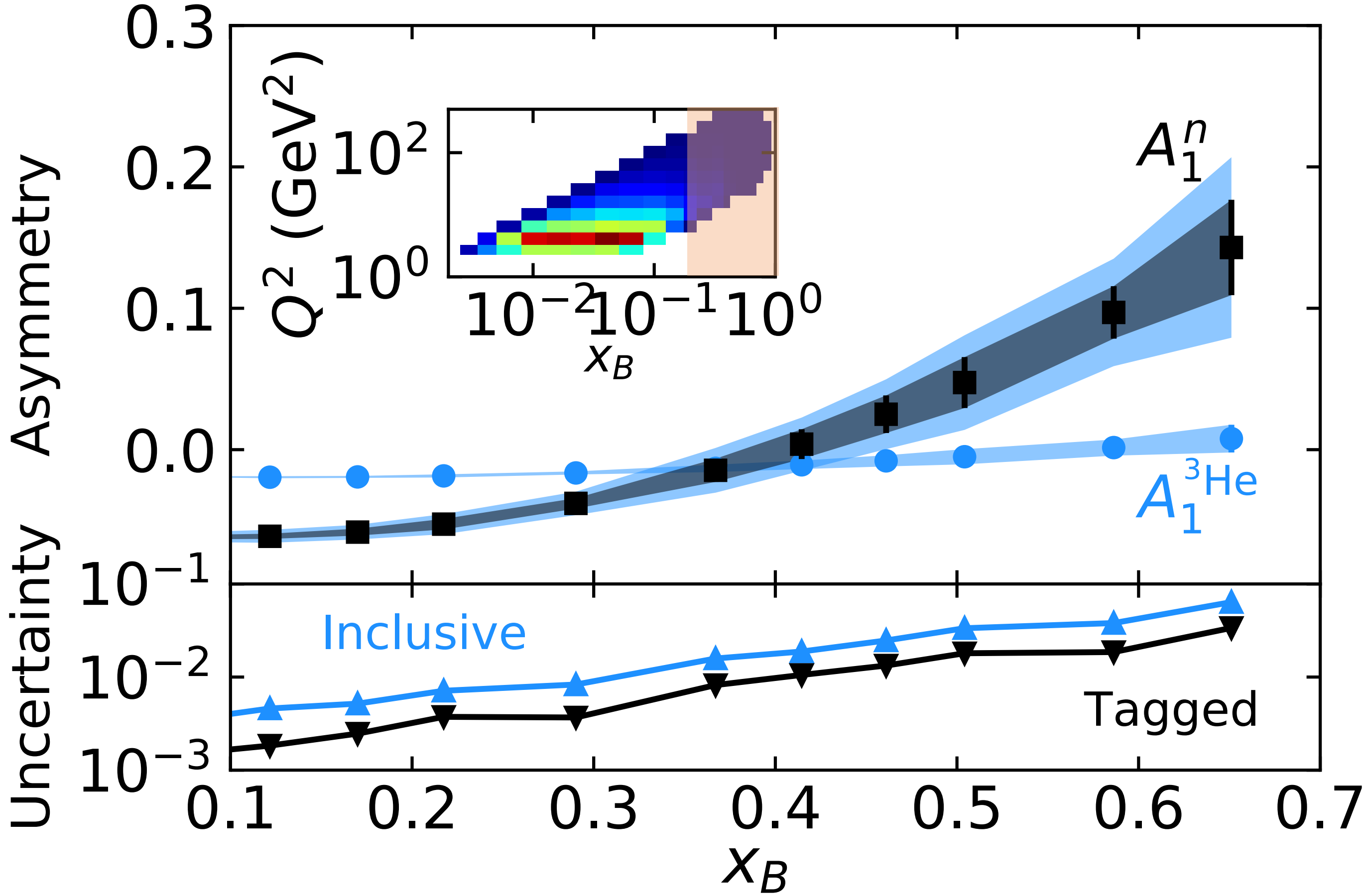
$$A_1^n \approx \frac{1}{P_n} \frac{F_2^{^3\mathrm{He}}}{F_2^n} (A_1^{^3\mathrm{He}} - 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p)$$

Phys. Lett. B 823 (2021)13672, NIMA 167238 (2023)

Double Tagging Reduce A_1^n Uncertianty



+ Valence-region Overlap \w JLab12 @ higher-Q^2



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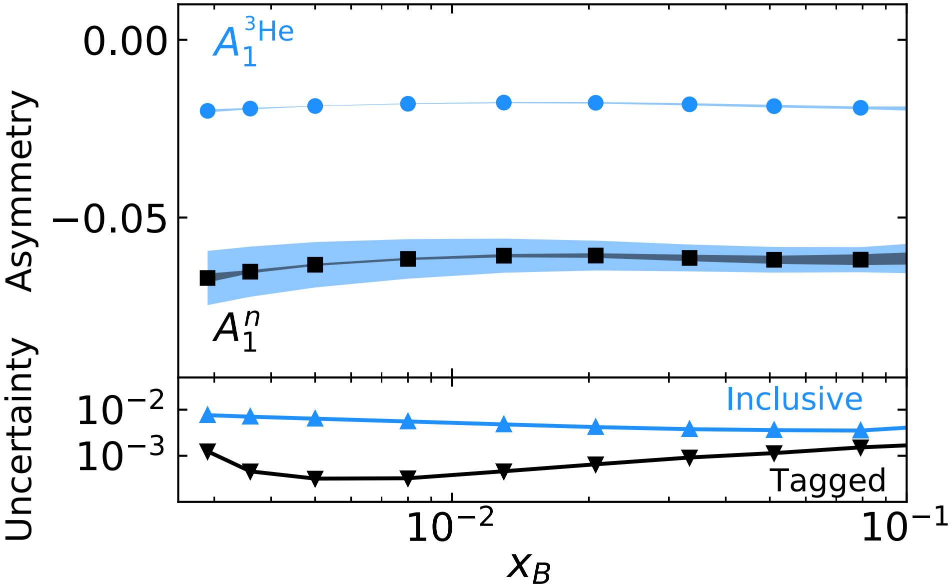
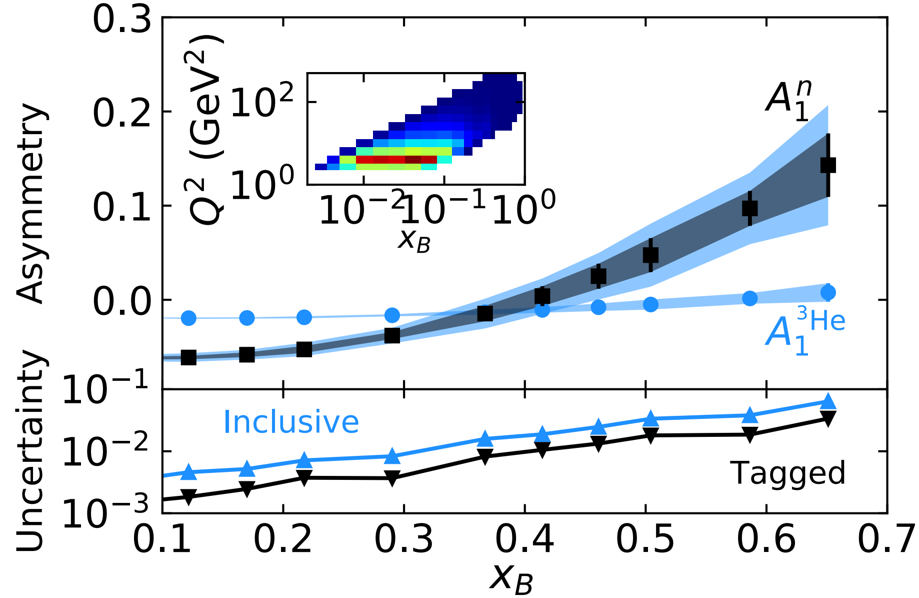
A_1^n: Also cover low-x

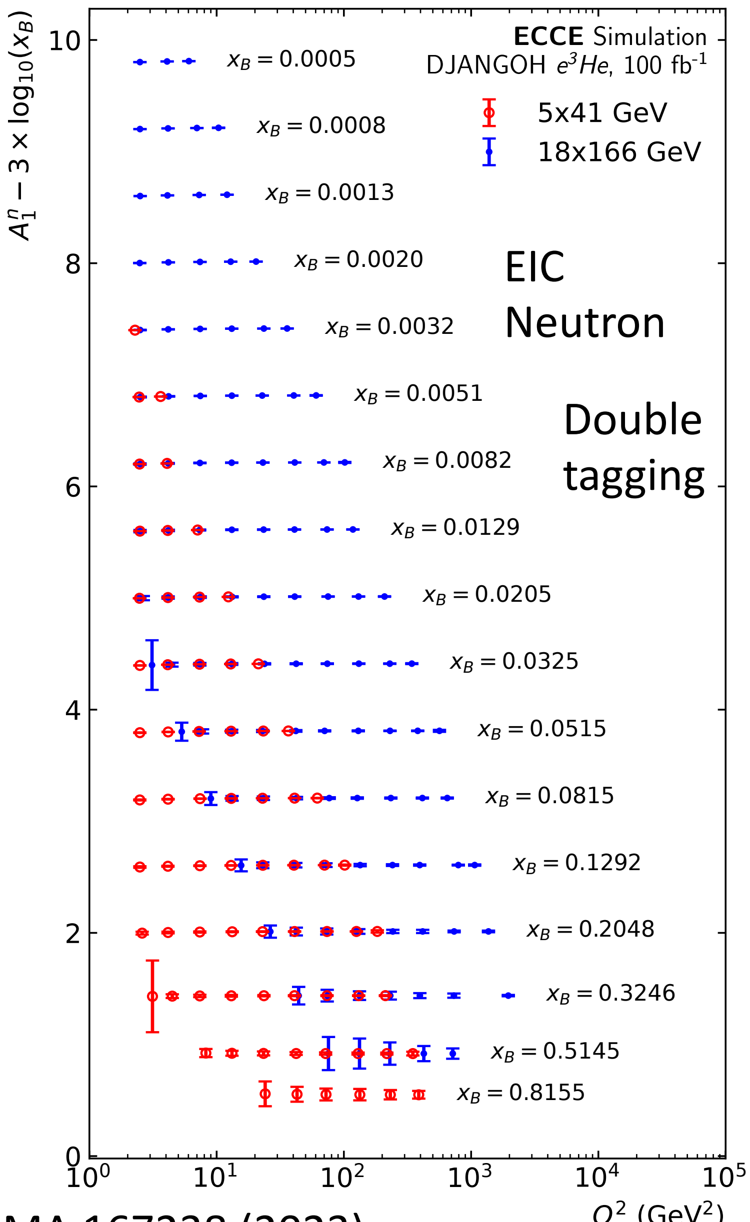




- ❑ Double tagging @ EIC cover $0.003 < x < 0.651$,
- ❑ Significantly reduced model dependent uncertainty compare \w (e,e'):
  x10 @ x < 0.1 ; x2 @ x > 0.1

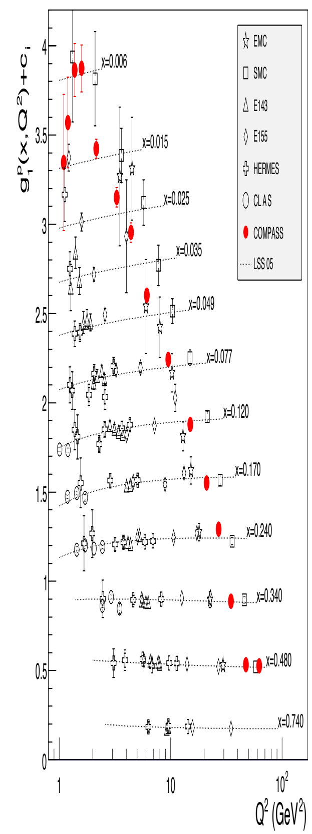
Phys. Lett. B 823 (2021)13672, NIMA 167238 (2023)

A_1^n: The EIC new coverage in x and Q^2



NIMA 167238 (2023)

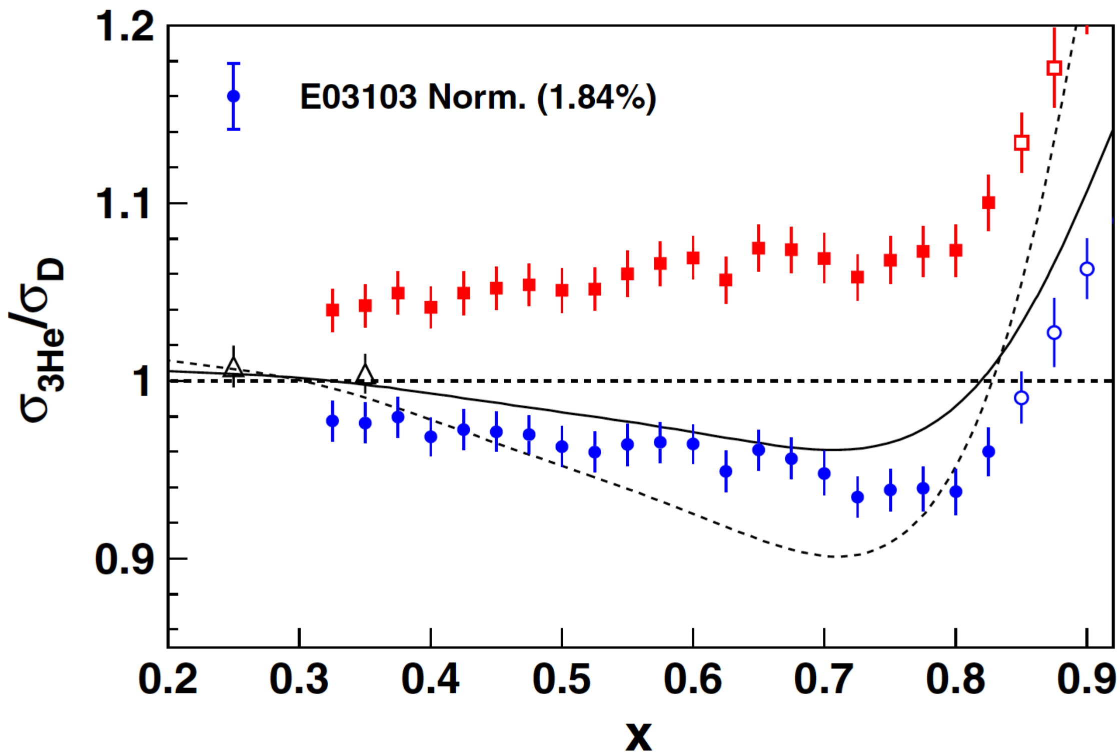
Current Proton data



What are other opportunities with e-^3He at the EIC?

The unpolarized EMC effect in ^{3}He

J. Seely et al. PRL 103 202301 (2009)



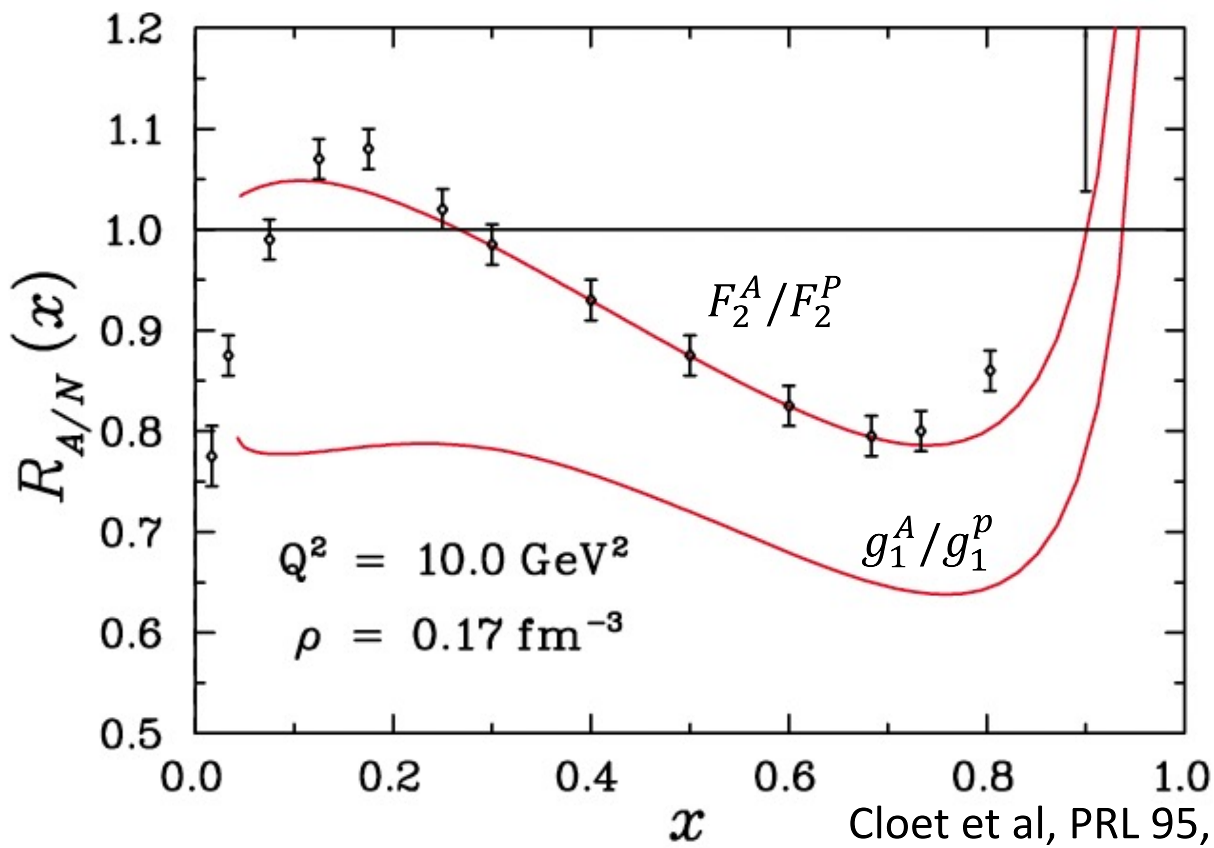
Questions:

❑Whether polarized structure function modify in nuclear medium?

❑What is the size of it?

Polarized EMC effect?

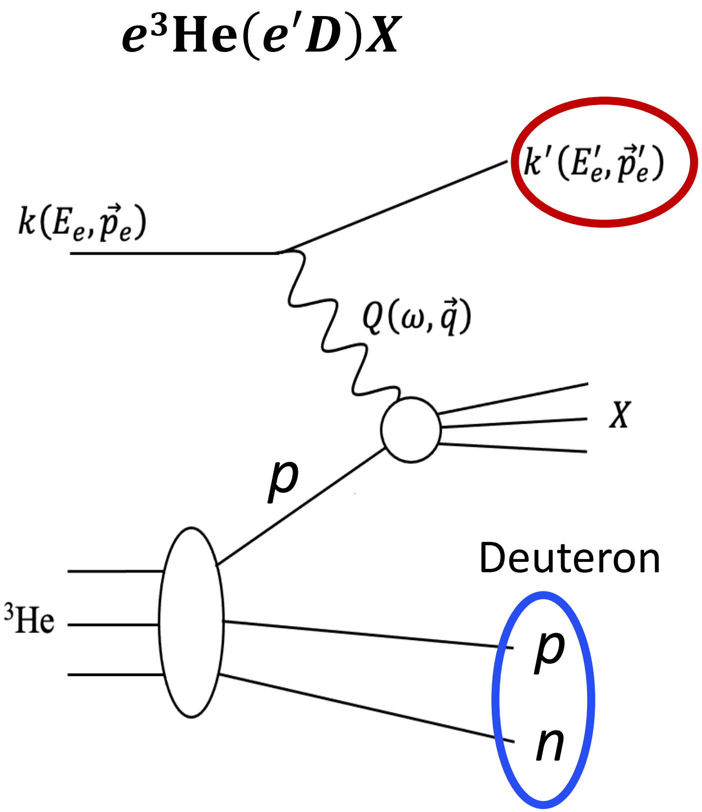
EMC ratio at nuclear matter density



Cloet et al, PRL 95, 052302 (2005)

- Polarized EMC ratio was predicted to be significantly different from unity
- Can we experimentally confirmed this?

e^3He at EIC for Polarized EMC



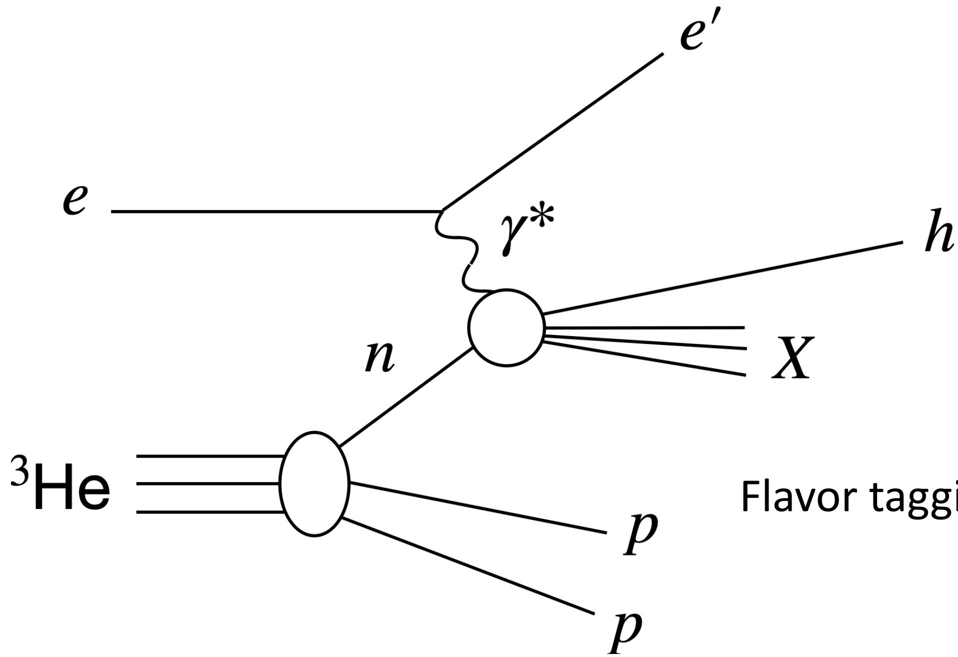
Spin dependent EMC effects

- Tagging deuteron: $A_1^p \rightarrow g_1^p$
- Comparing g_1^p in ^{3}He to free to bound proton
- Need feasibility study for this measurement at EIC
- Possibility to do this measurement at CLAS12?

R. Milner arXiv:1809.05626

e^3He at EIC: Other Physics measurements

SIDIS and Tagging SIDIS:

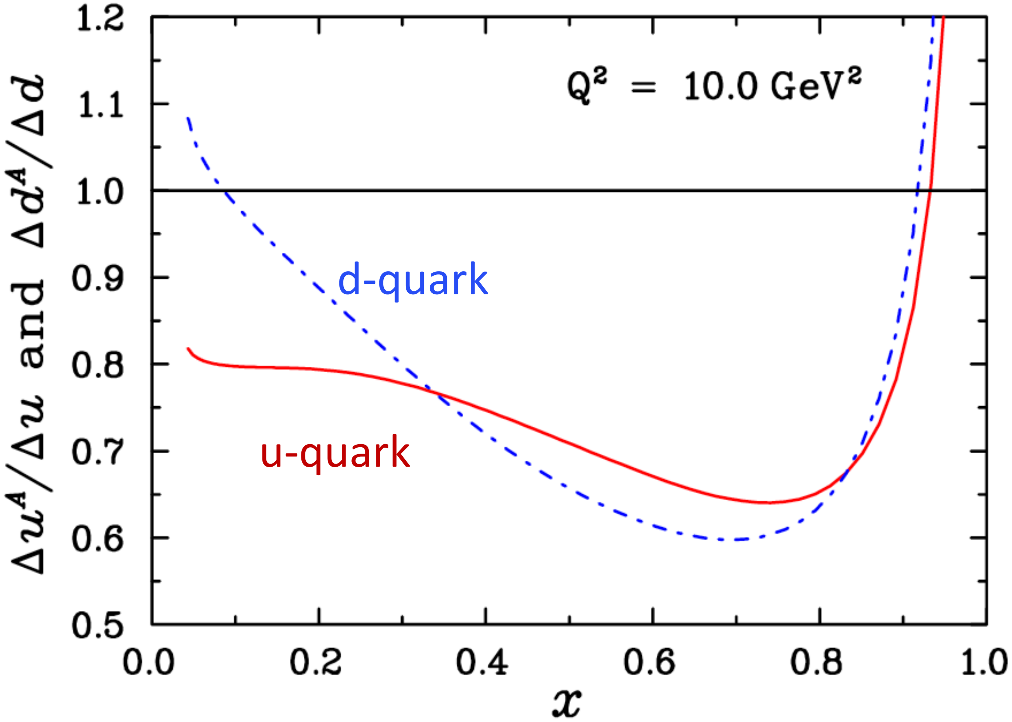


Flavor tagging

- ❑ Suppress the nuclear correction
- ❑ Study for feasibility of this process is on going for the EIC

Quark polarization

Polarized quark ratio at nuclear matter density



Cloet et al, PRL 95, 052302 (2005)

See Harut's talk

Summary

- ❑ Inclusive DIS: $g_1^n(x, Q^2)$. With large coverage in x and Q2
- ❑ Tagging DIS: Minimize the model dependence
  - ❑ Double protons tagging for High precision $g_1^n(x, Q^2)$
  - ❑ Deuteron tagging: $g_1^p(x, Q^2)$. Polarized EMC effect
- ❑ SIDIS and Tagging SIDIS
  - ❑ Flavor tagging: $\Delta u, \Delta d$ and more
- ❑ Feasibility study for other potential measurements

Tagging measurements:

Providing – novel probes – rich physics to explore

Backup slides

- **Tagged deuteron:** Scattering from the $|0,0>$ state cannot contribute. Thus, measurement of $\overrightarrow{{}^3\mathrm{He}}(\overrightarrow{e}, e' d_{\mathrm{spectator}})$ in DIS kinematics is equivalent to scattering from a negatively polarized proton 66% of the time and 33% of the time from a positively polarized proton. This is equivalent to scattering from the polarized proton in ^{3}He with -33% polarization. This makes polarized ^{3}He an effective polarized proton target.

- **Tagged proton:** 50% of the time, the scattering arises from the $|1,1>$ state, 25% from the $|1,0>$ state and 25% from the $|0,0>$ state. In forming the spin-asymmetry A in the DIS process $\overrightarrow{{}^3\mathrm{He}}(\overrightarrow{e}, e' p_{\mathrm{spectator}})$ there will be a contribution from scattering from the deuteron A_{ed}, the contribution arising from the $|1,0>$ state will cancel and there will a correction arising from a contribution A_{corr} from scattering from the np pair in the $|0,0>$ state, i.e.

$$A \sim \frac{2}{3} A_{ed} + \frac{1}{3} A_{corr} \ . \tag{29}$$

How large is A_{corr}?

R.B. Wiringa *et al.*, Phys. Rev. C **89**, 024305 (2014)

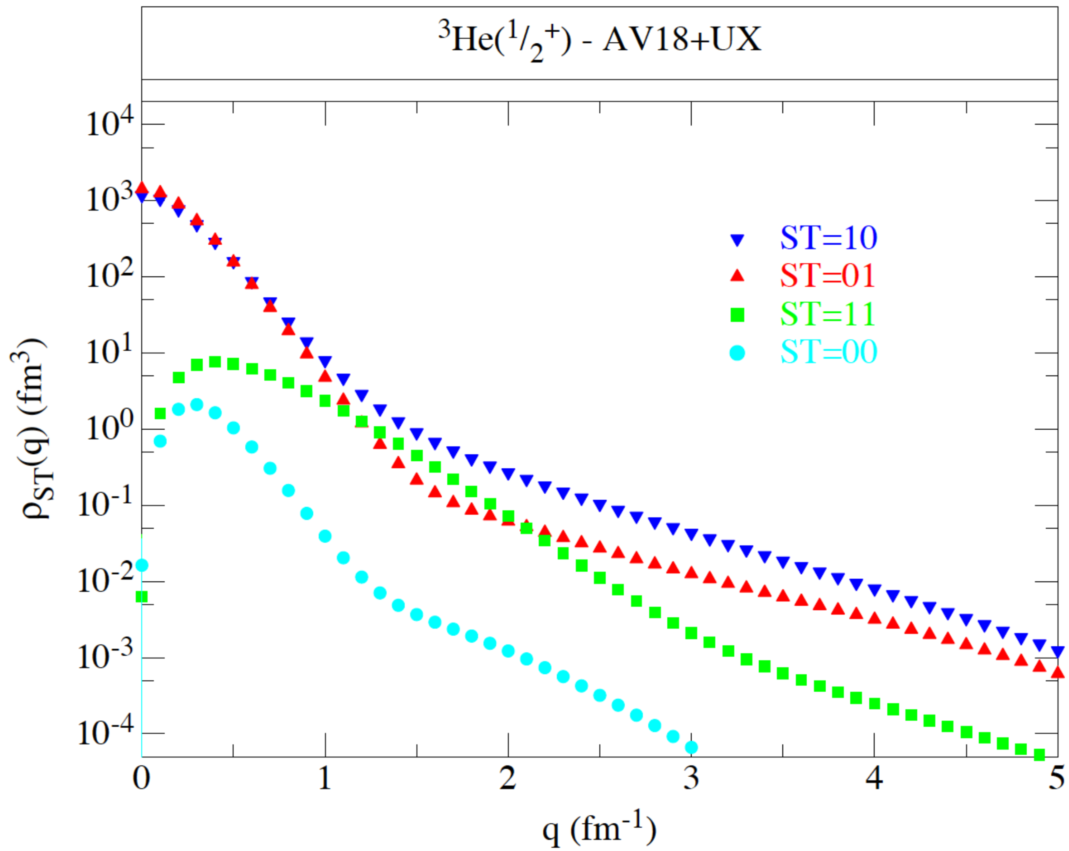


FIG. 8. Momentum distributions of nucleon-nucleon pairs by spin (S) and isospin (T) in ^{3}He in fm^3 calculated using variational Monte-Carlo techniques from [9].