Jefferson Lab
Exploring the Nature of Matter

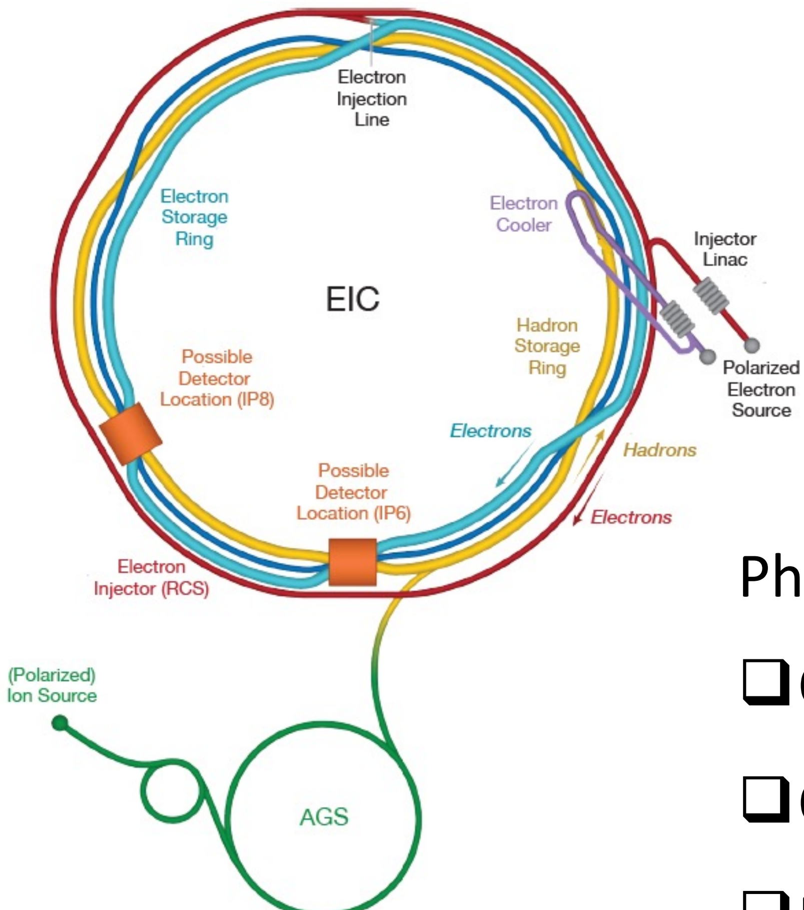
JSA

Studying Neutron Spin Structure in Polarized e+He3 Collisions at the EIC

Dien Nguyen
(Nathan Isgur Fellow at JLab)

RHIC/AGS Annual User's Meeting
June 7 – 10, 2022

The EIC: Next generation QCD machine



Versatility and high Luminosity are key:

- ❑ $\sqrt{S}$ (ep): 20 – 140 GeV
- ❑ Ion beam: Proton to Uranium
- ❑ $\mathcal{L}_{max}$ = 10^{34} cm^{-2} s^{-1}
- ❑ High polarization $P_e = P_p \sim 70\%$

Physics Goals:

- ❑ Origin of nucleon spin?
- ❑ Origin of nucleon mass?
- ❑ Properties of a dense system of gluon?

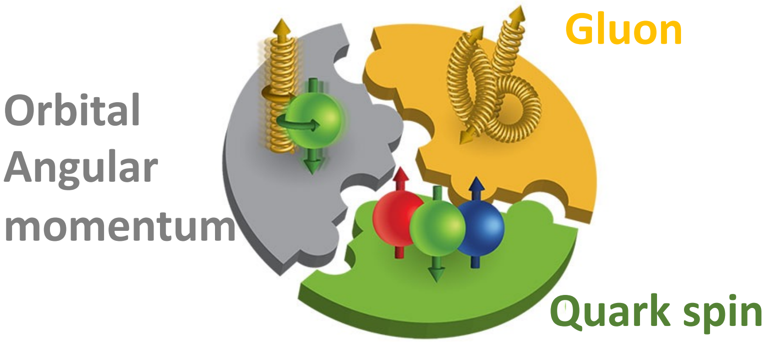
EIC YELLOW REPORT
Volume II: Physics

EIC Comprehensive Chromodynamics Experiment

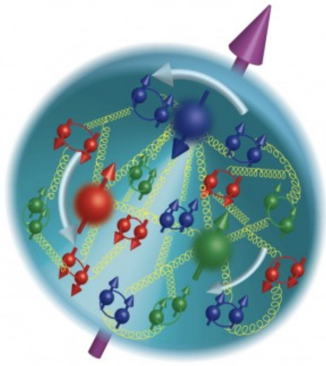
ATHENA
A Totally Hermetic Electron-Nucleus Apparatus

Nucleon spin question

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

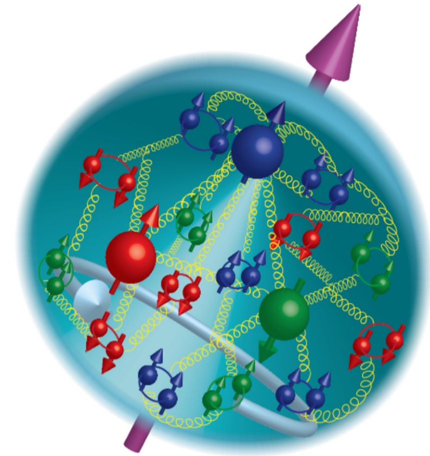


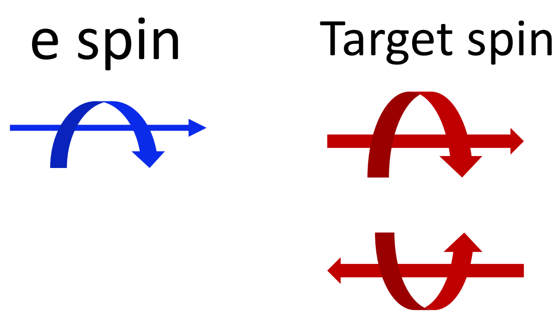
- Only ~20% due to quark spin
- Rest due to gluons and orbital angular momentum



Spin polarization measurements

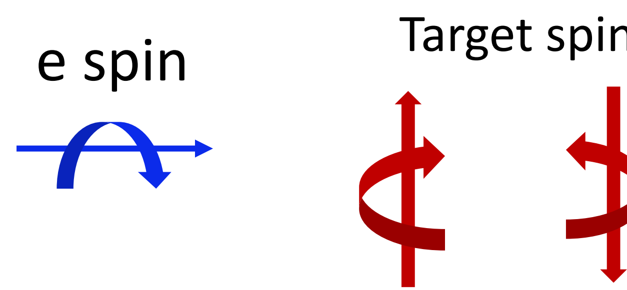
- Particles are polarized if their spins are aligned
- Using polarized beams / targets provides access to spin structure





Longitudinal asymmetry

$$\frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$$



Transverse asymmetry

$$\frac{\sigma_{\uparrow\rightarrow} - \sigma_{\uparrow\leftarrow}}{\sigma_{\uparrow\rightarrow} + \sigma_{\uparrow\leftarrow}}$$

Nucleon Spin

- How do quark and gluon carry nucleon spin?

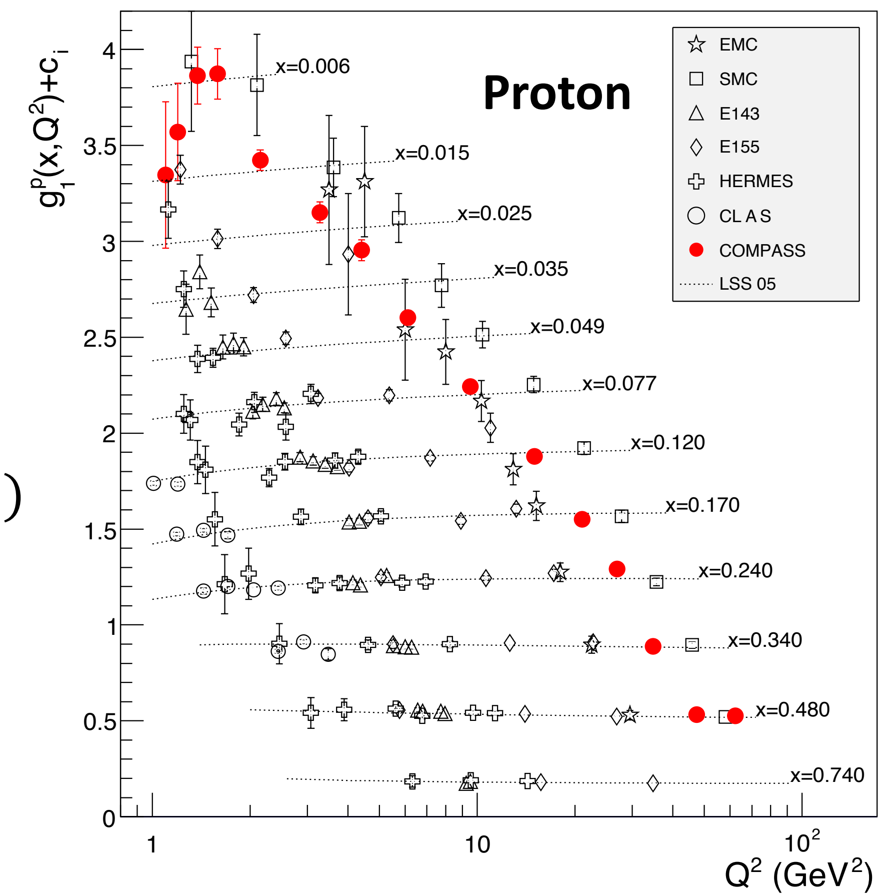
$$S_z^N = S_z^q + S_z^g + L_z^{q,g} = \frac{1}{2}$$

- Spin Structure function

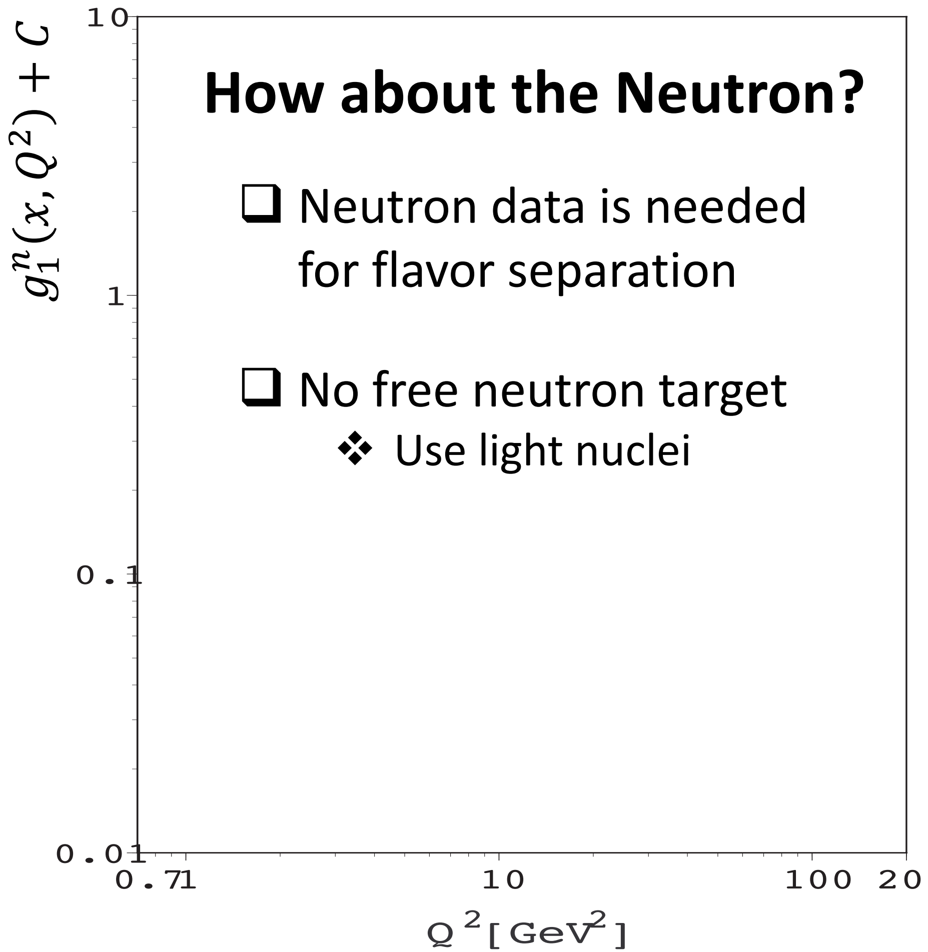
$$g_1(x,Q^2) = \frac{1}{2}\sum_i e_i^2[q_i^{\uparrow}(x,Q^2) - q_i^{\downarrow}(x,Q^2)]$$

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

Christine A. Aidala RMP (2013)



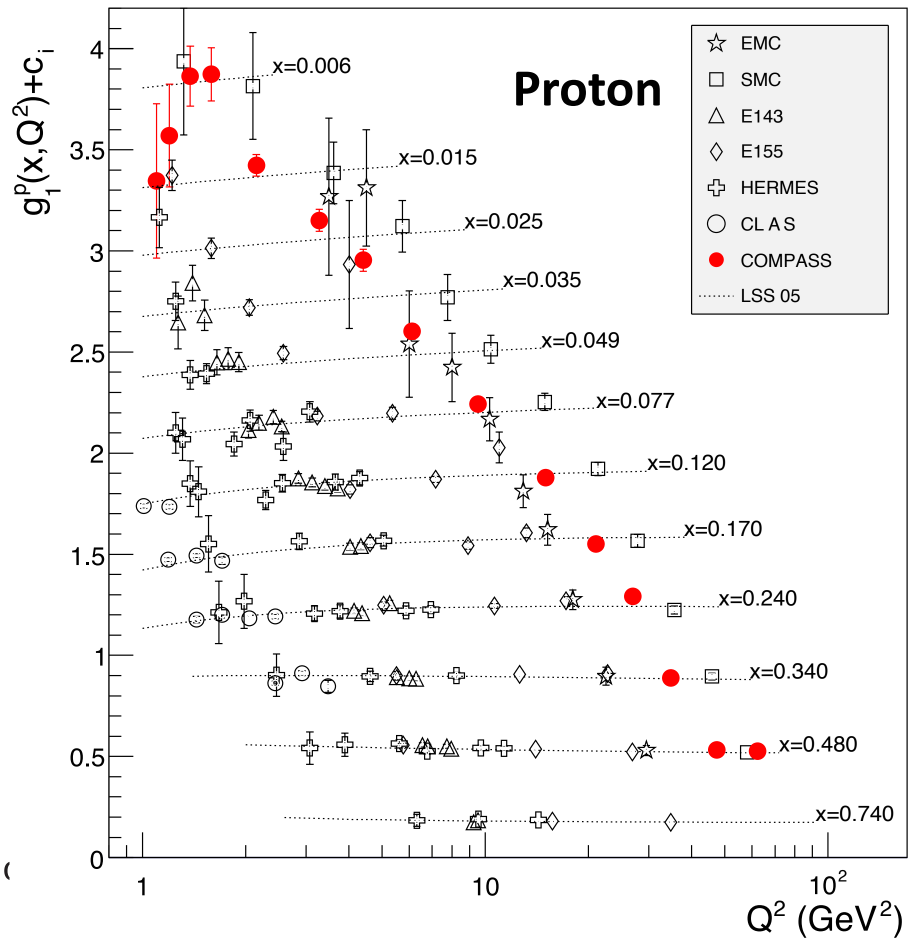
Nucleon Spin



How about the Neutron?

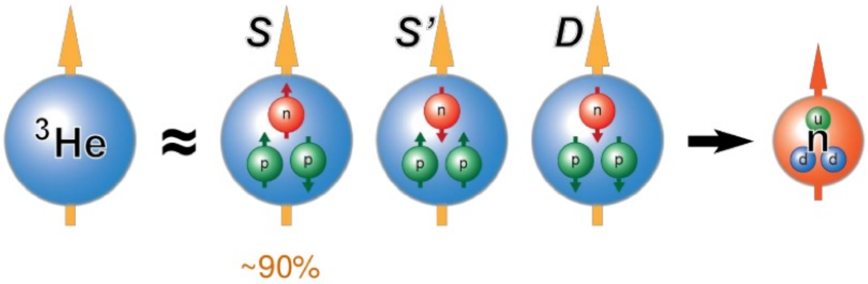
- ❑ Neutron data is needed for flavor separation
- ❑ No free neutron target
  - ❖ Use light nuclei

Christine A. Aidala RMP (2013)



^{3}He as polarized neutron target

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



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

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

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

A_1^n is extracted from inclusive DIS e-^{3}He

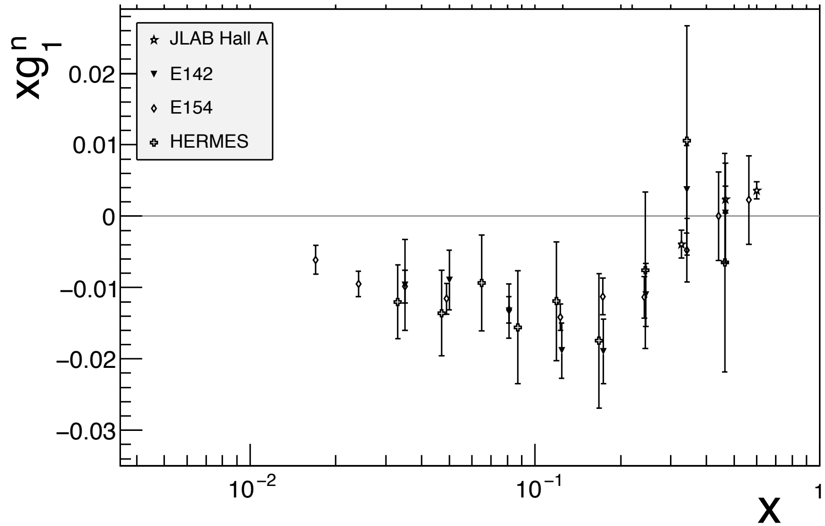
$$A_1^n \approx \frac{1}{P_n}\frac{F_2^{^3\mathrm{He}}}{F_2^n}\left(A_1^{^3\mathrm{He}} - 2P_p\frac{F_2^p}{F_2^{^3\mathrm{He}}}A_1^p\right)$$

Large model dependence

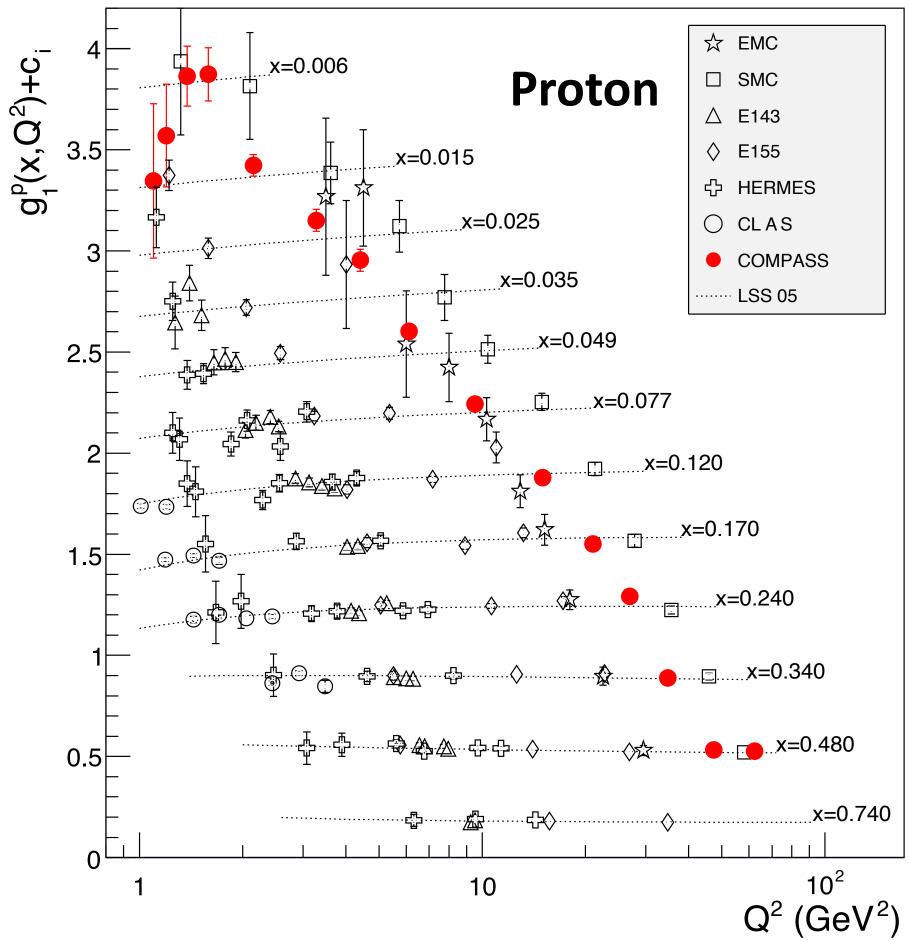
- ❑ Effective neutron and proton polarization
- ❑ Structure functions F_2
- ❑ A1p uncertainty.

Nucleon Spin

How about the Neutron?



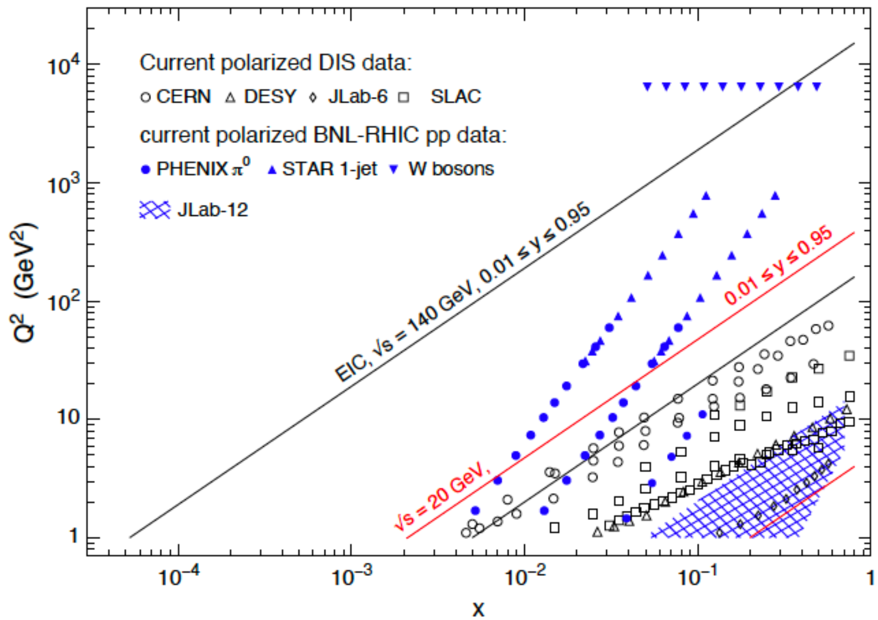
Christine A. Aidala RMP (2013)



Need a novel measurement what minimize the nuclear correction

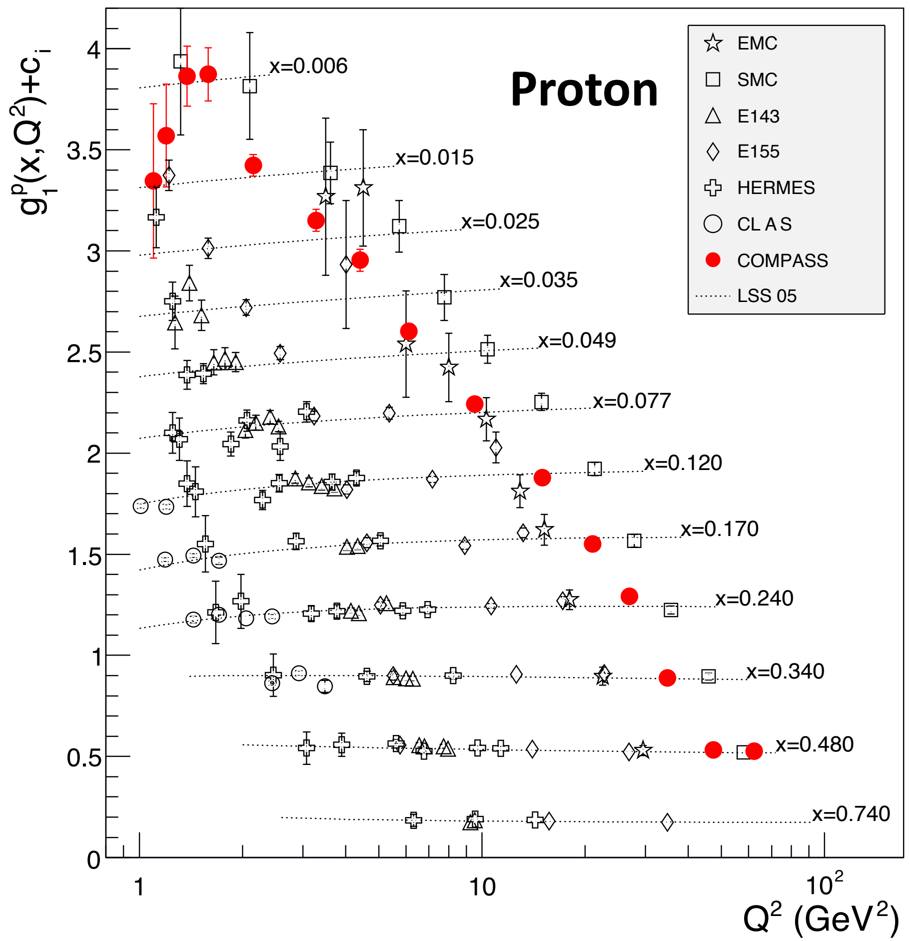
Nucleon Spin

How about the Neutron?

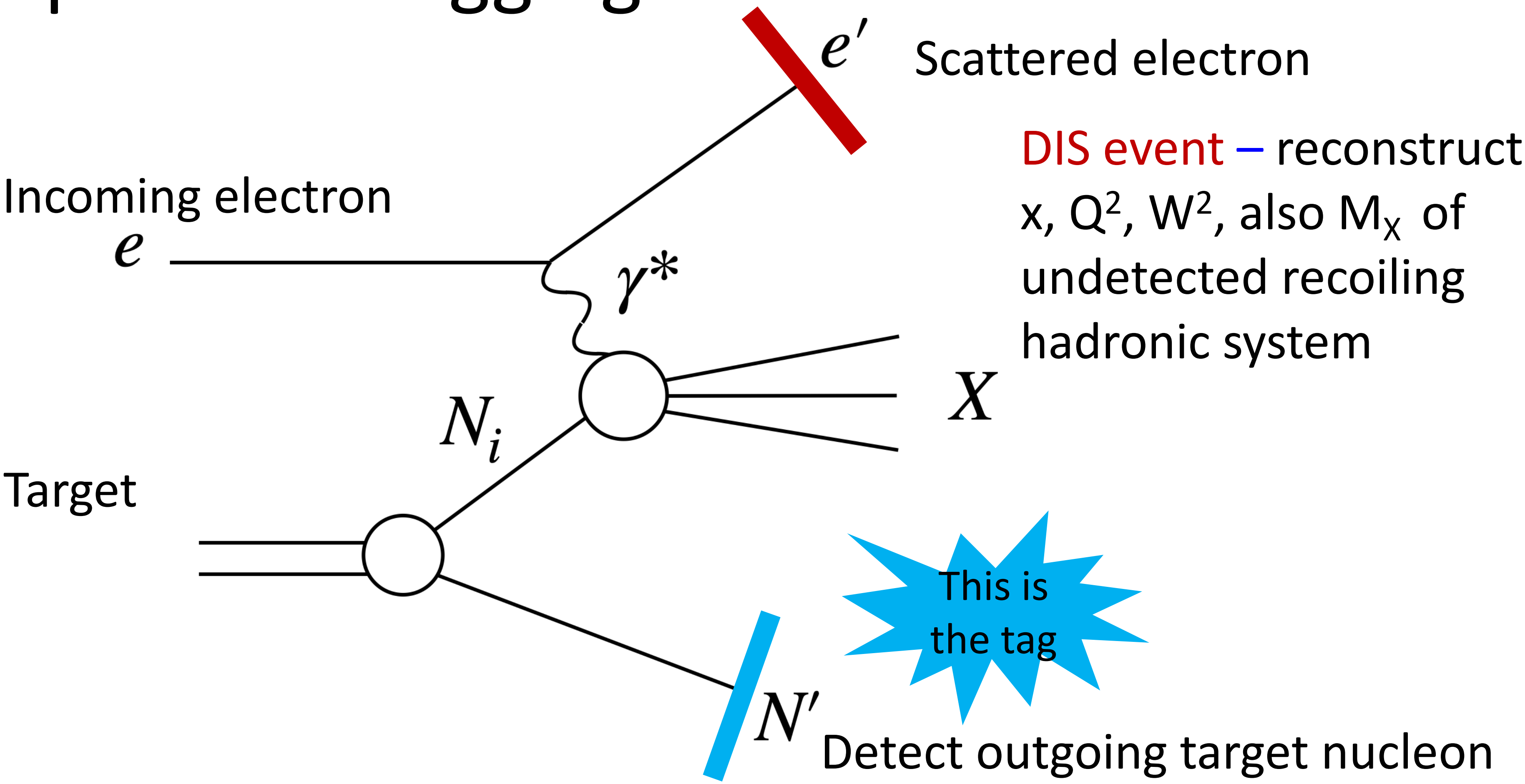


Need a novel measurement what minimizes the nuclear correction

Christine A. Aidala RMP (2013)

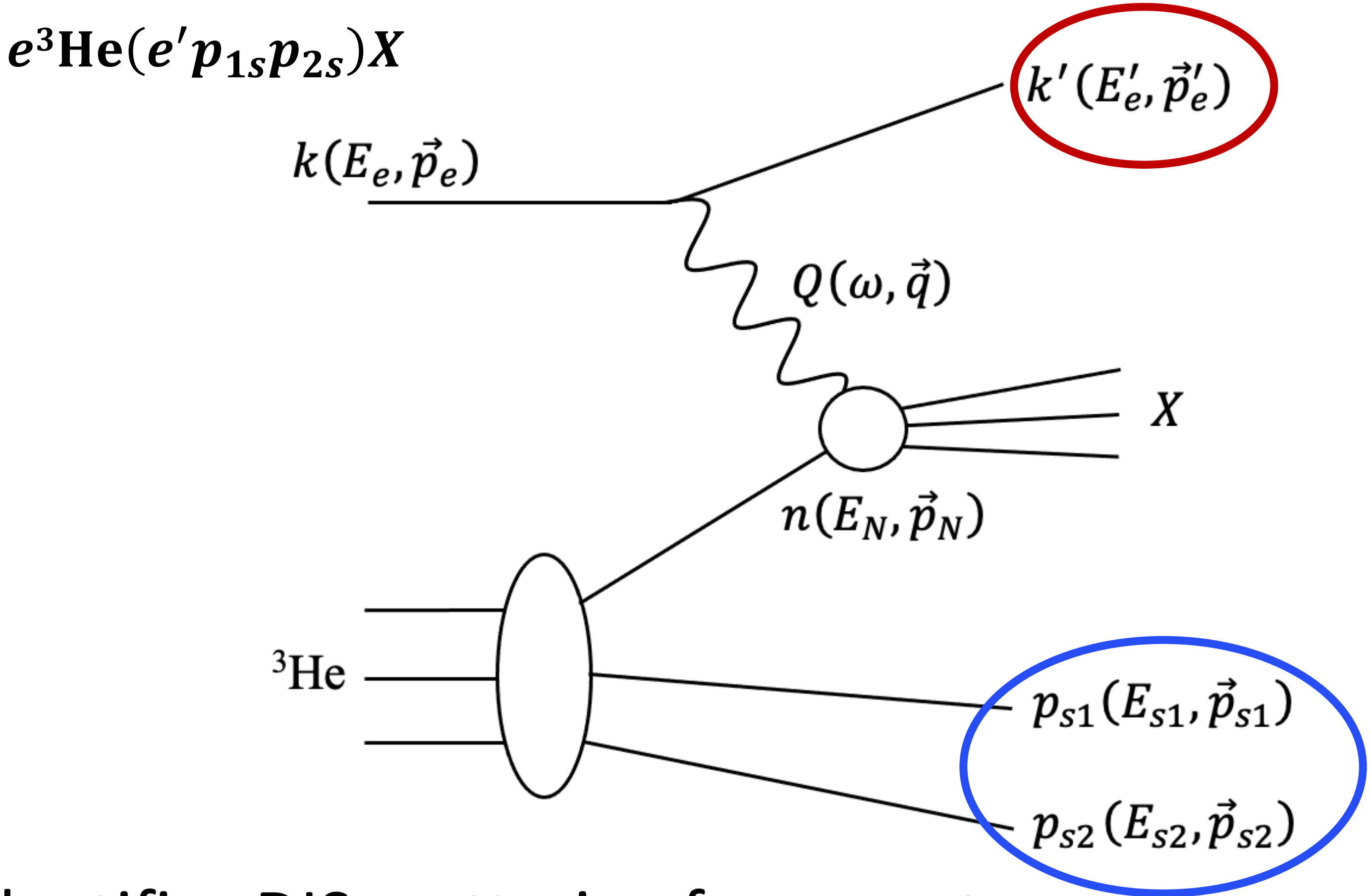


Spectator Tagging DIS measurement



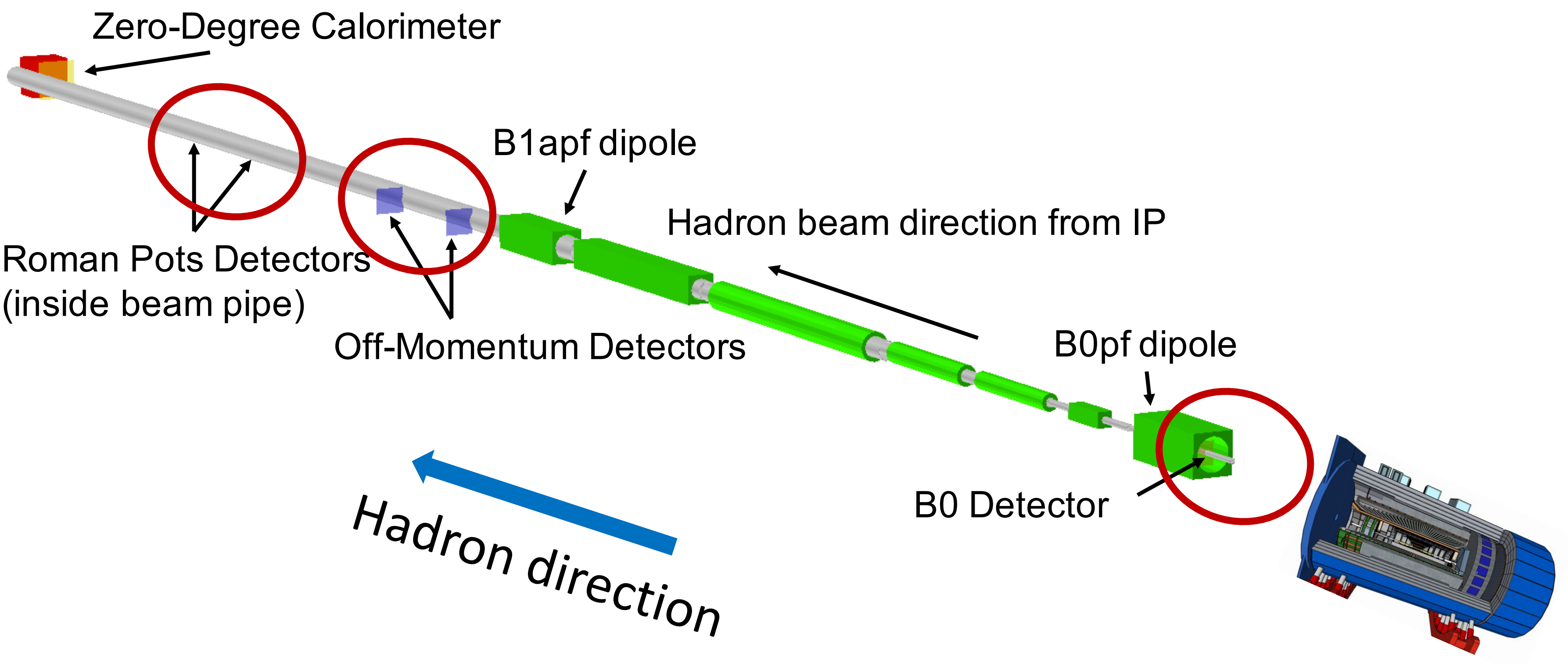
- Facilitates effective targets not readily found in nature
- Novel probes of partonic structure function

3He Double proton spectator tagging suppress model dependence



- Identifies DIS scattering from neutron
  - Low neutron momentum => "Effective" free neutron target

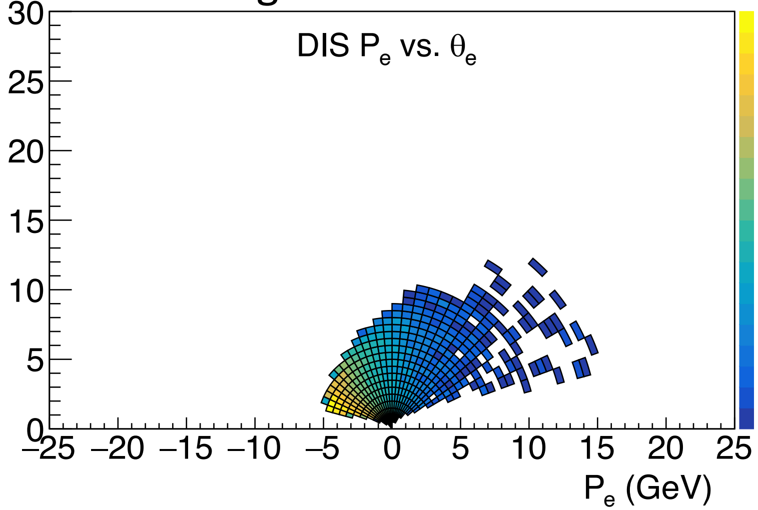
Spectator tagging at EIC Far forward detector region



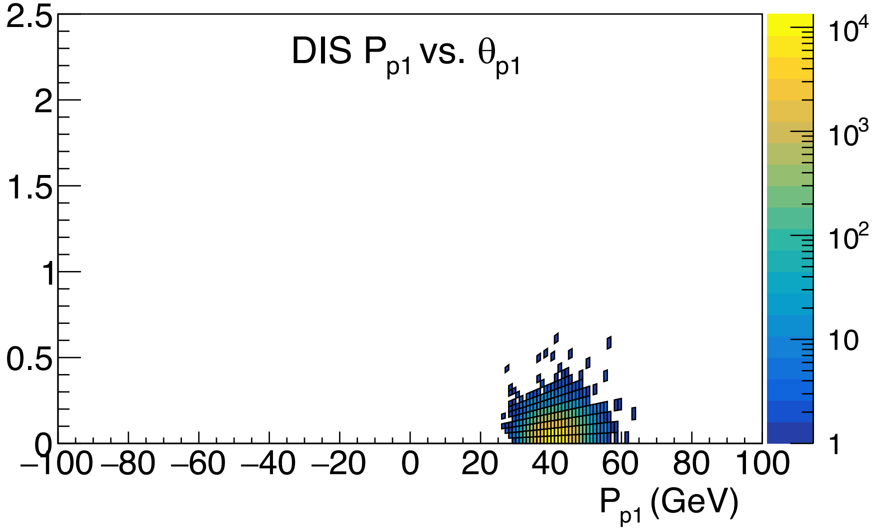
Yellow report section: 11.6, arXiv: 2103.05419v2

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

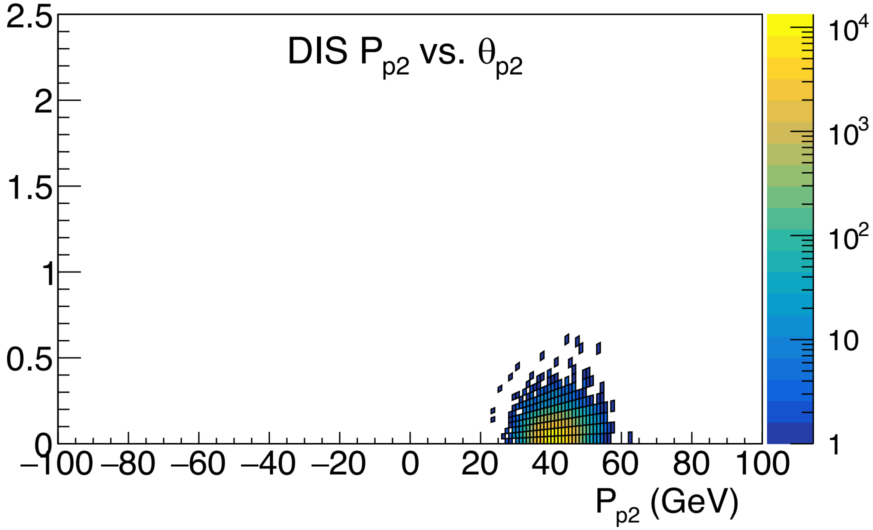
Scattering electron



Spectator proton p1s



Spectator proton p2s



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

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 (EIC smear and EIC root)

CLASDIS Event Generator

↓

Fermi motion correction

J. Pybus
MIT & JLab-EIC

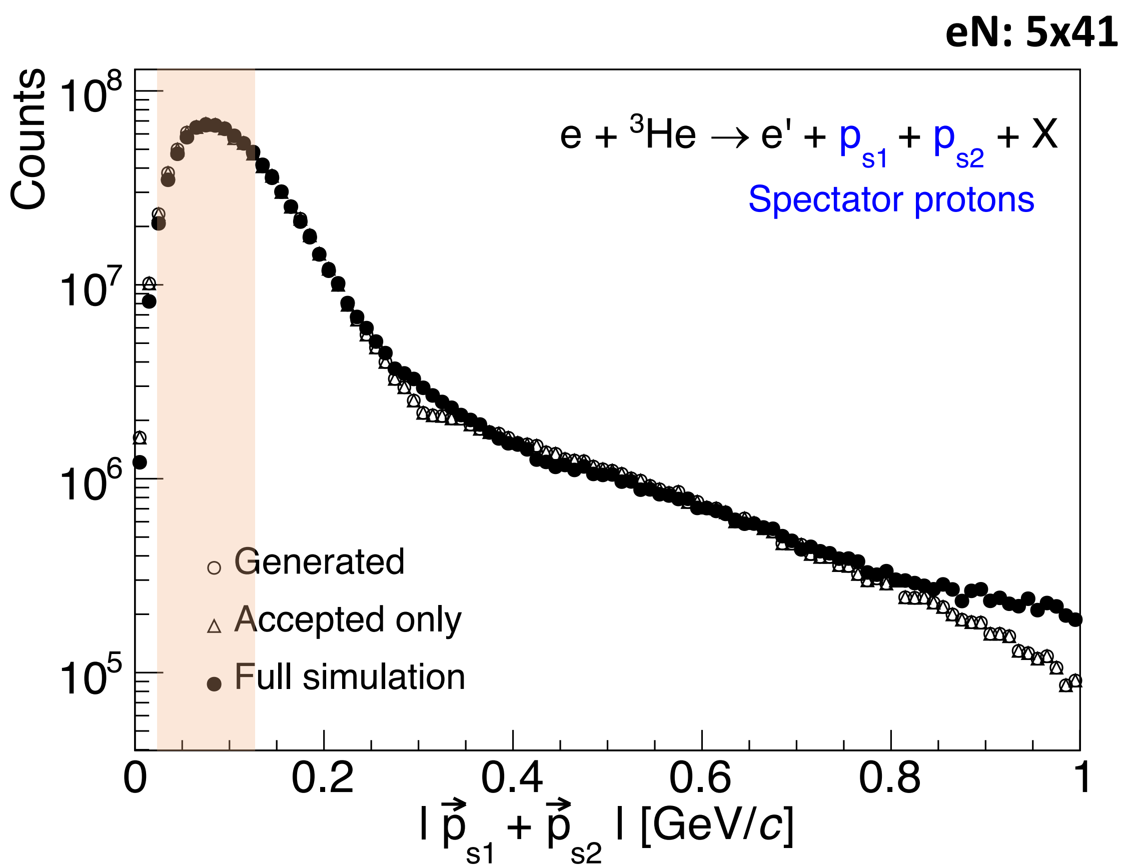
↓

EIC simulation
I. Friscic and A. Jentsch

Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

Spectator momentum at the Ion Rest Frame

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



I. Friscic, **D. Nguyen**, Pybus, et al., Phys. Lett. B 823 (2021)13672

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

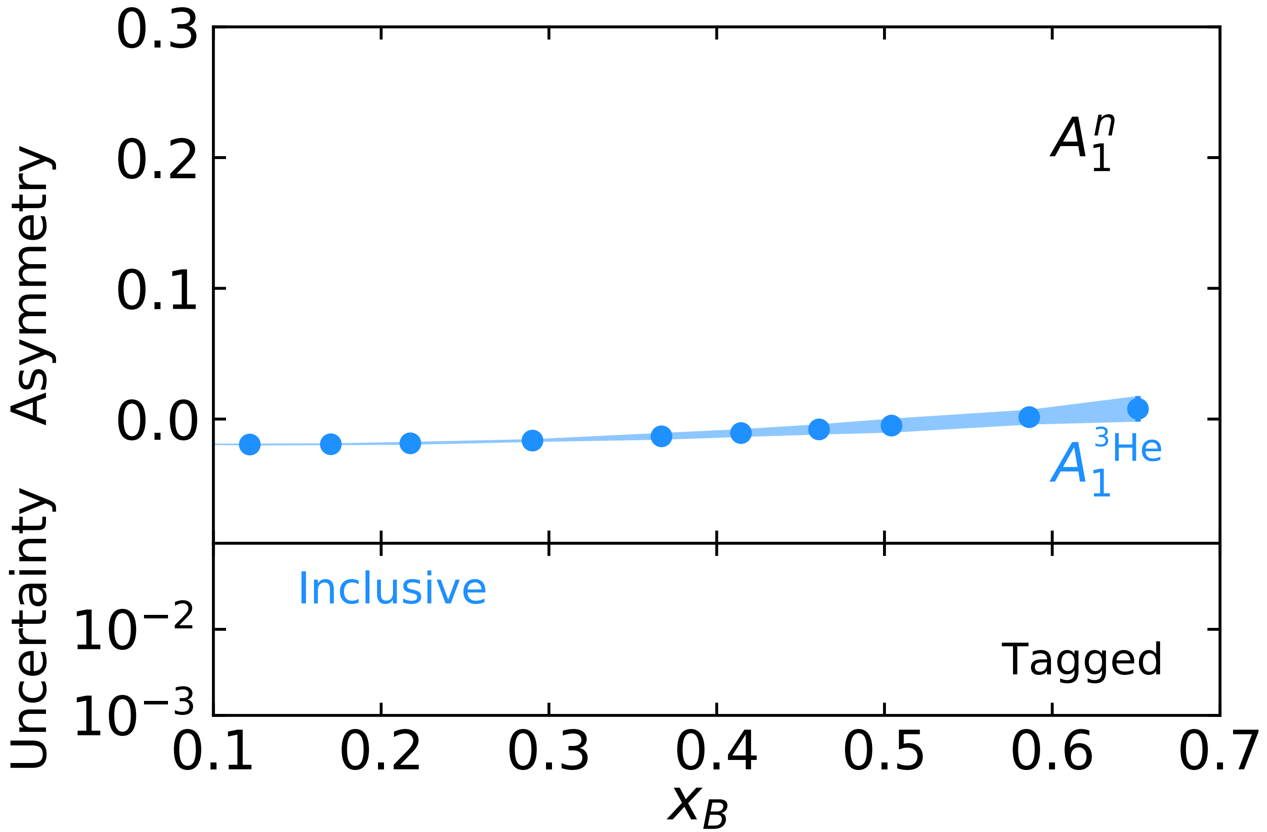
Projections:

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

Compare uncertainties of extracted *vs* double tag A1n

Friscic, Nguyen, Pybus, et al., Phys. Lett. B, In-Print (2021)

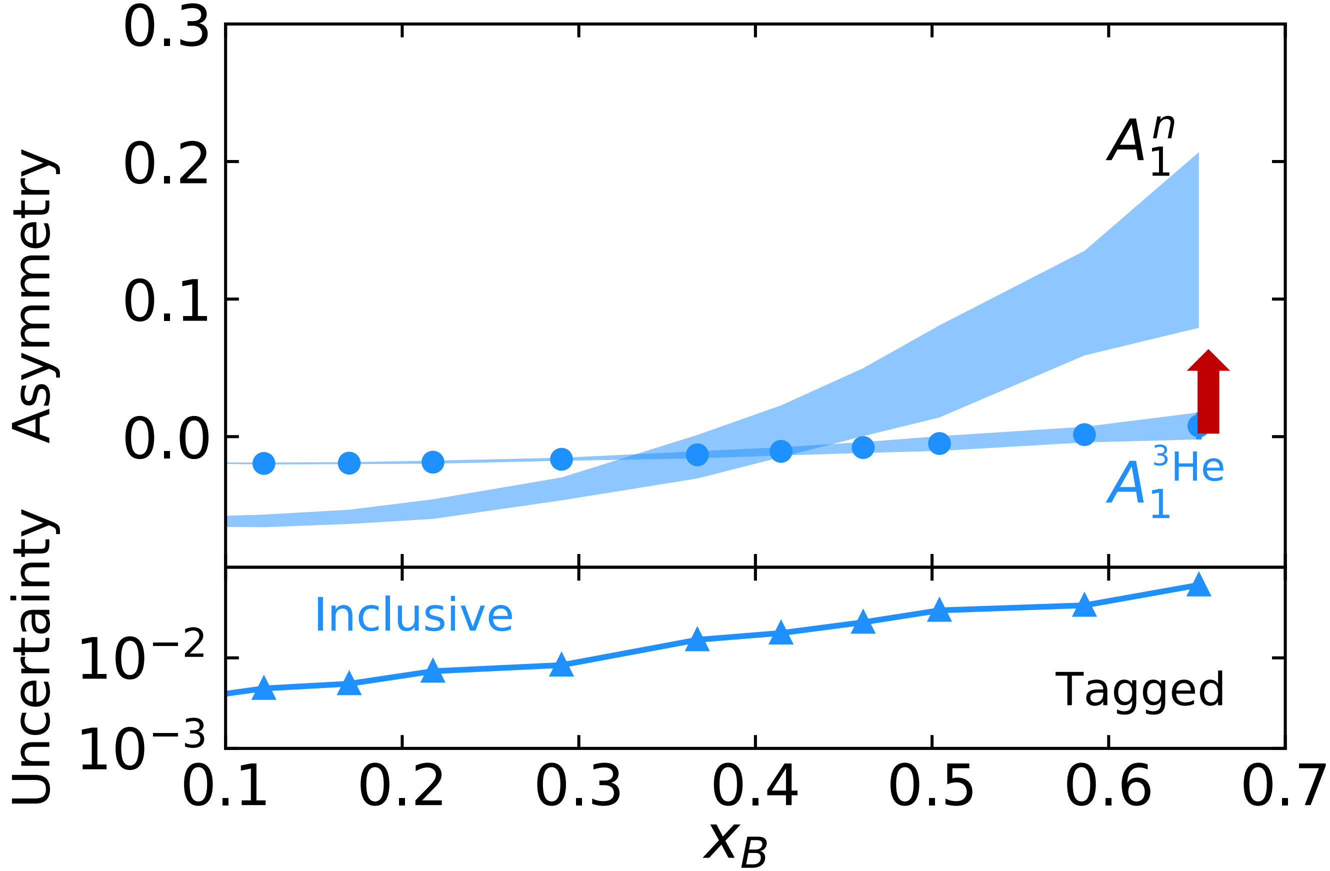
$A_1^{^3\mathrm{He}}$ from 3He(e, e′)



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

Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

A_1^n from 3He(e, e′)

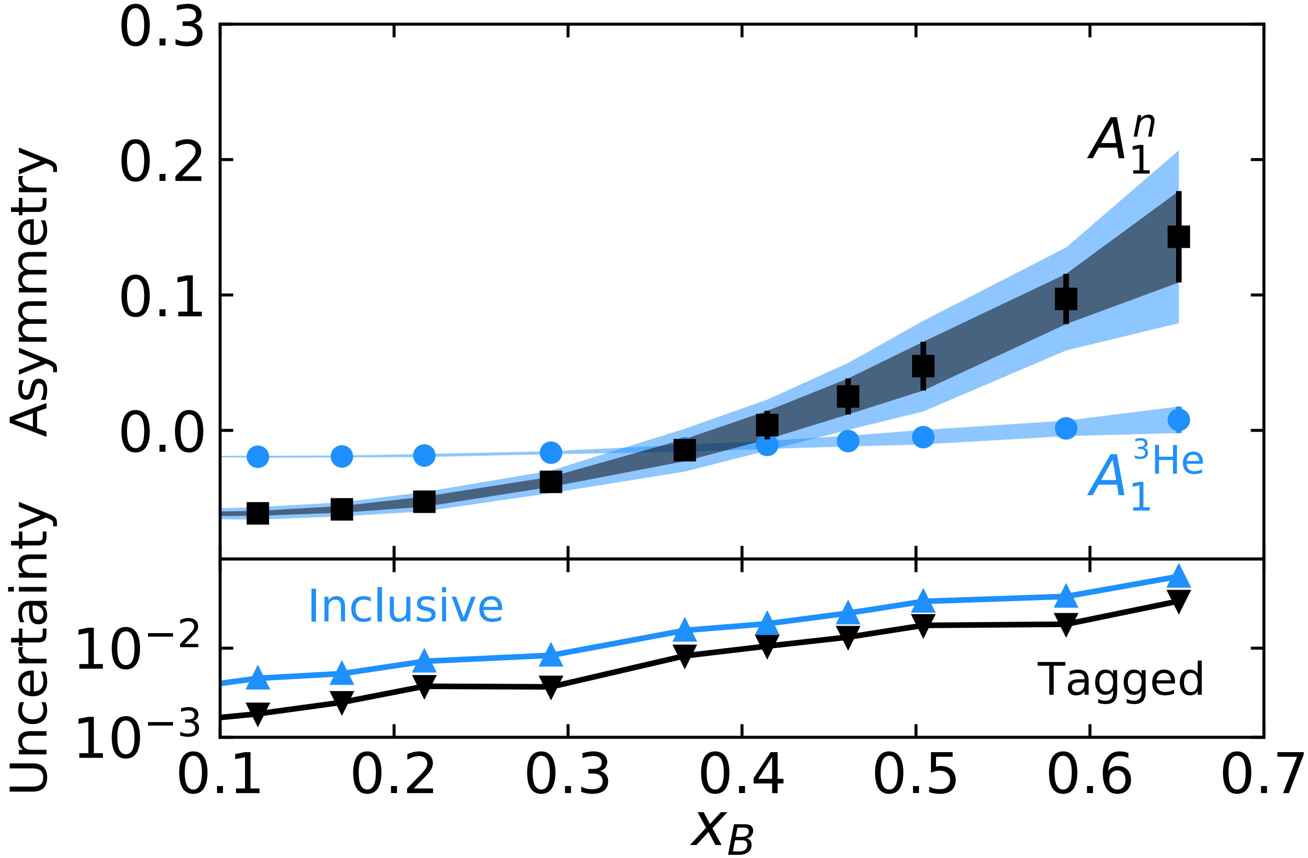


- Extraction introduce a large systematic uncertainty

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

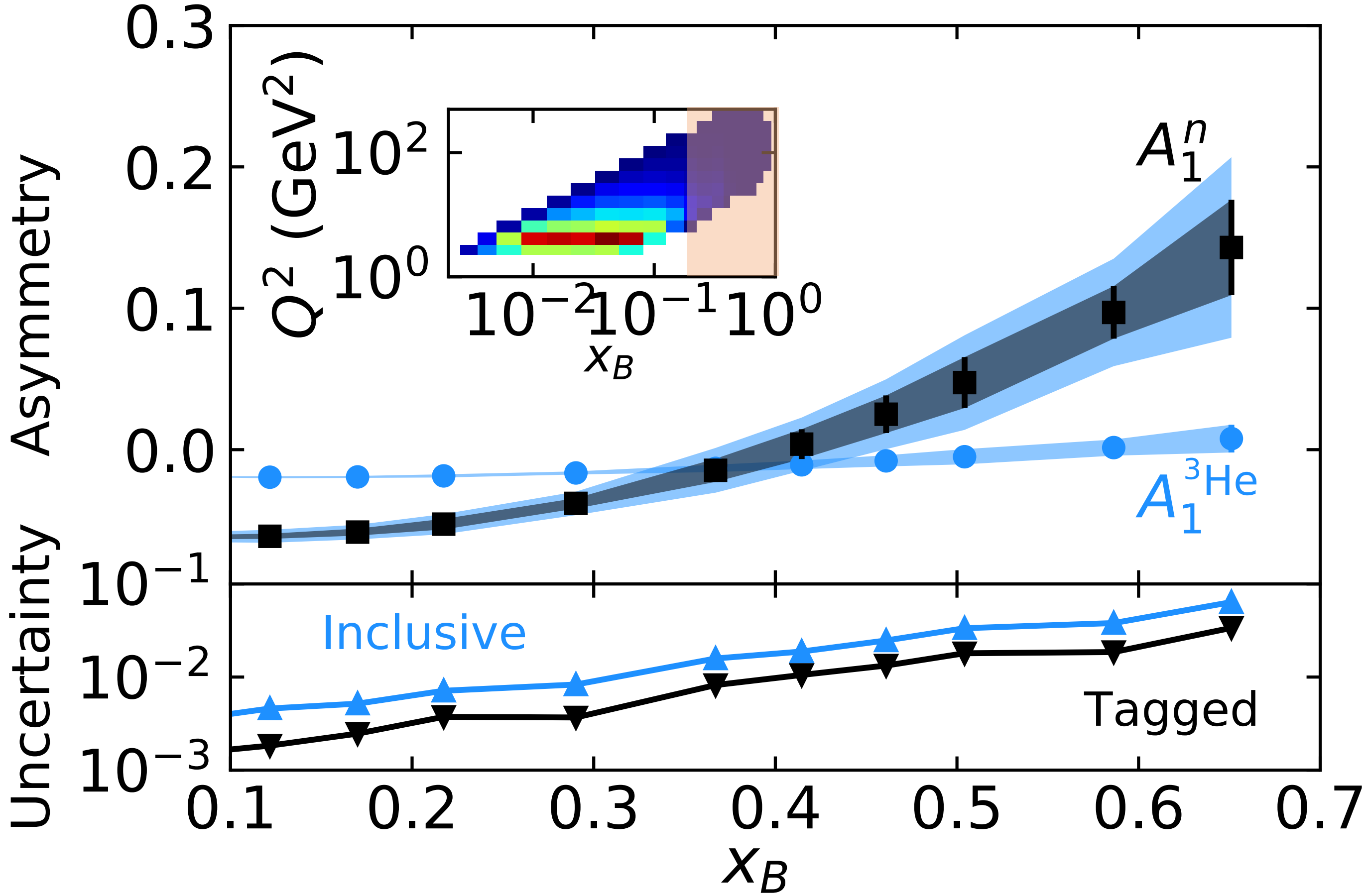
Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

Double Tagging Reduce A_1^n Uncertianty



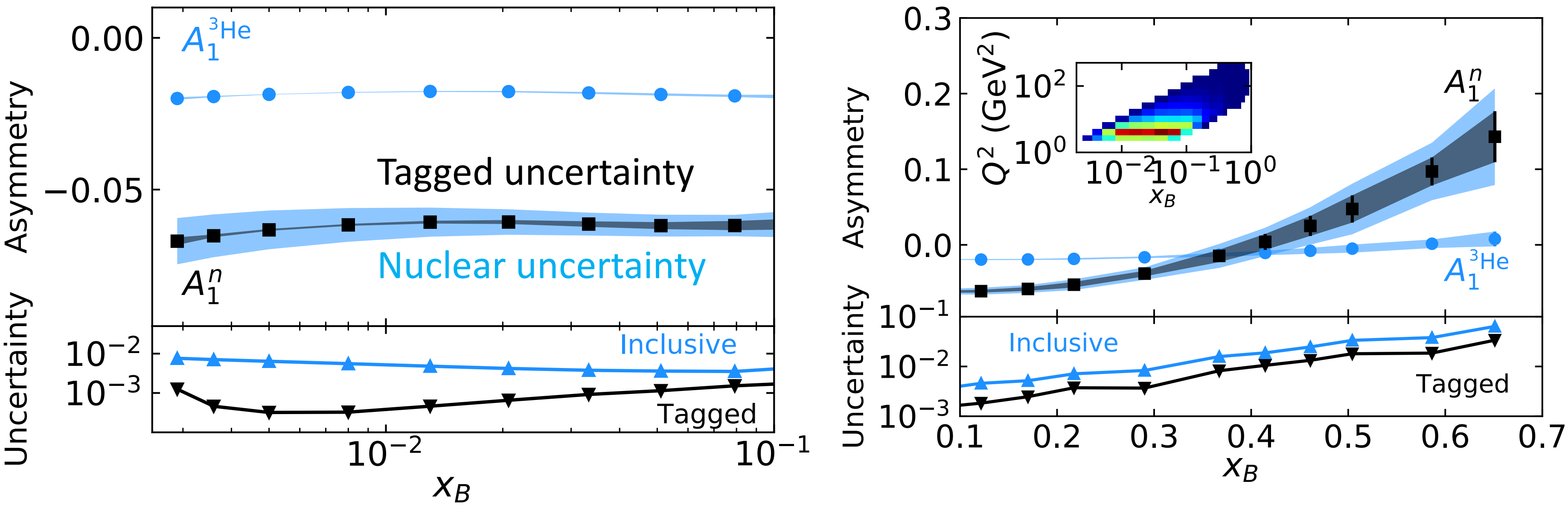
Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

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



Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

Double tagging vs Inclusive A_1^n

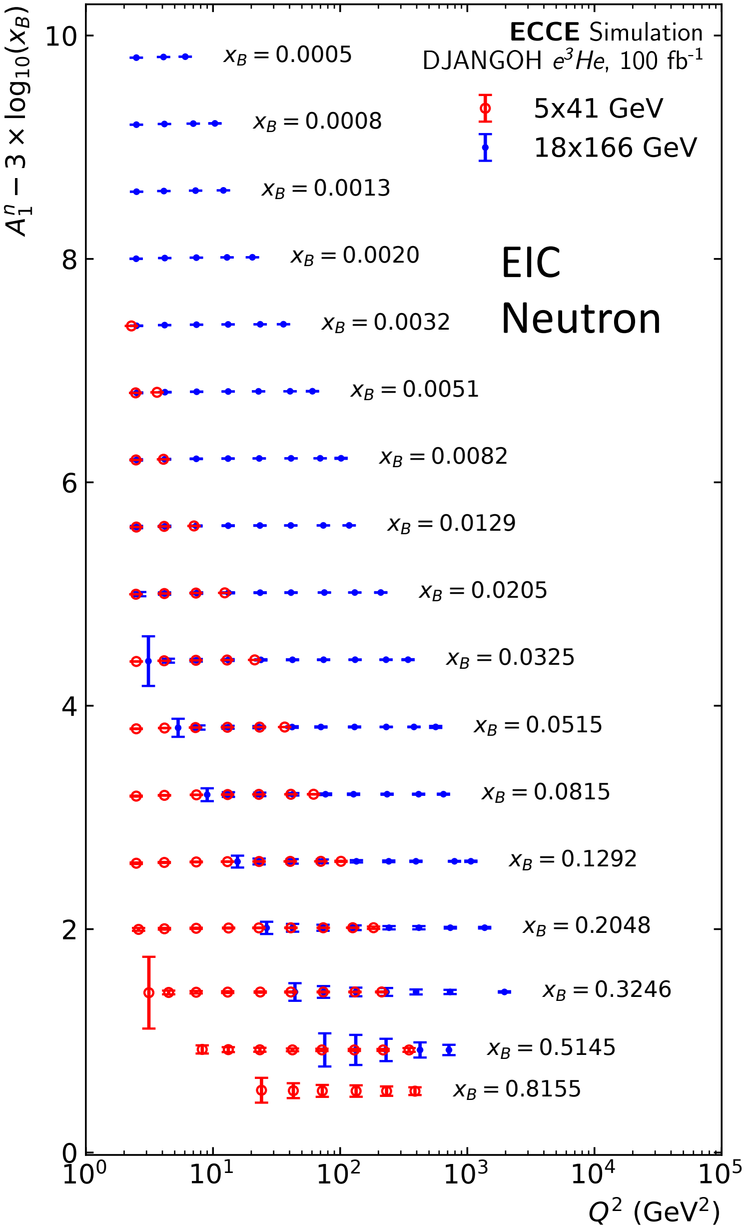


- ❑ EIC covers $0.003 < x < 0.651$
- ❑ Significantly reduced uncertainty

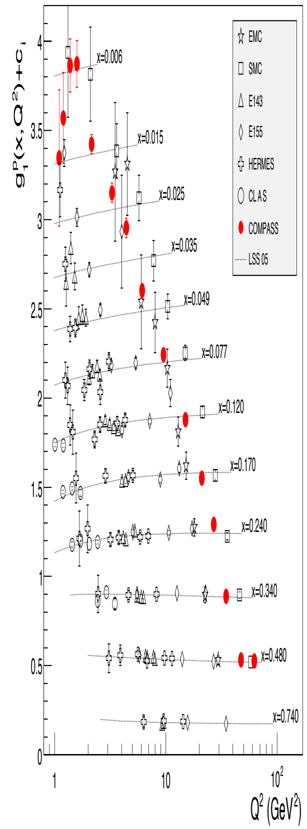
➢ Much better understanding of quark spin and orbital angular momentum in the nucleon

Friscic, **D. Nguyen**, Pybus, et al., Phys. Lett. B 823 (2021)13672

A_1^n: coverage in x and Q^2



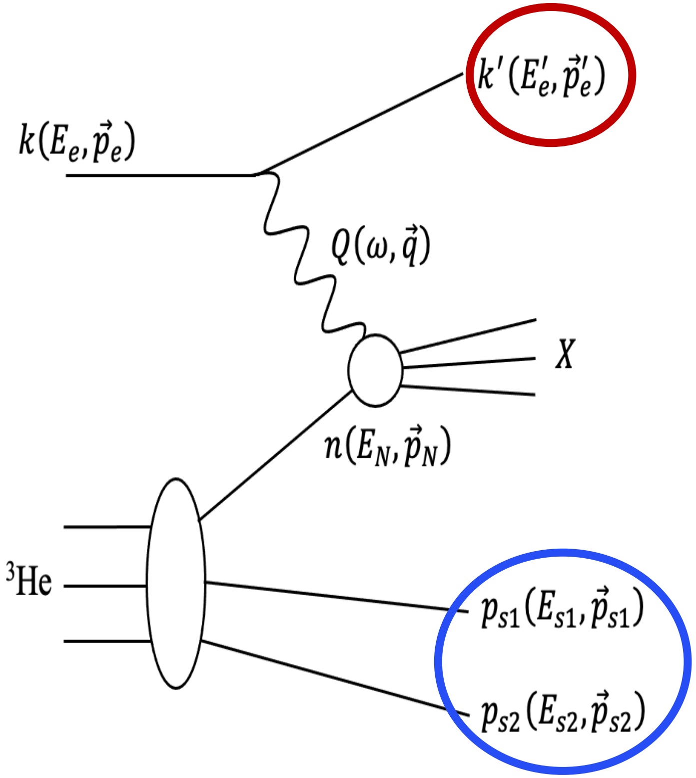
Proton



- ❑ Providing high precision data for global fitting
- ❑ Valuable insight into the spin and flavor structure of nucleons

e^3He at EIC: Other spin physics studies

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

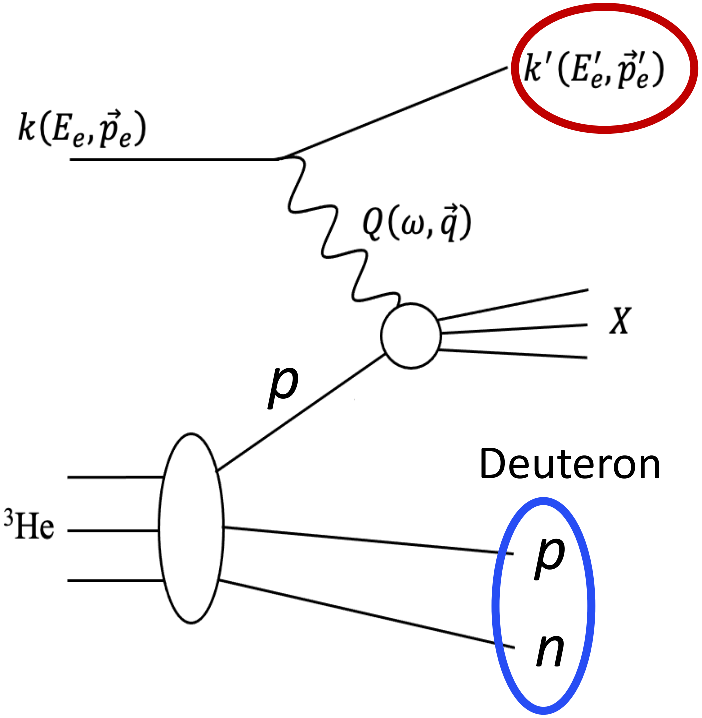


- Spin dependent EMC effect

- Extracting the g_1^n as a function of virtuality

e^{3}He at EIC: Other Spin Physics Study

$e^3\mathrm{He}(e'D)X$

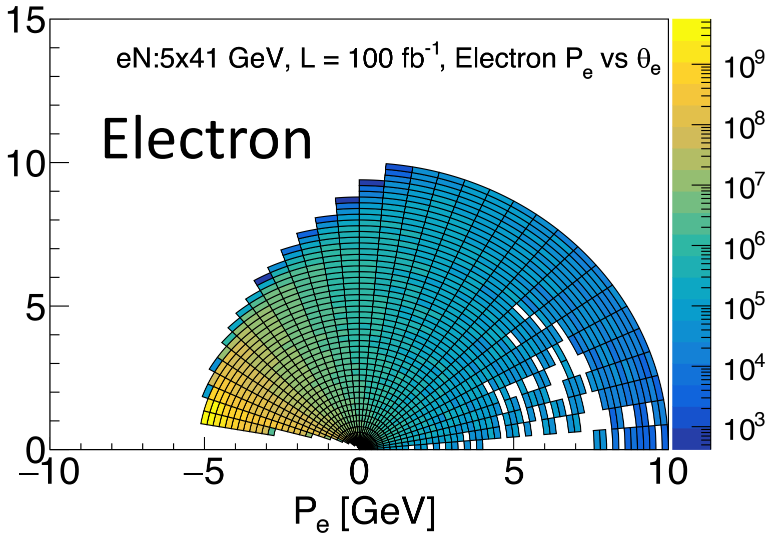


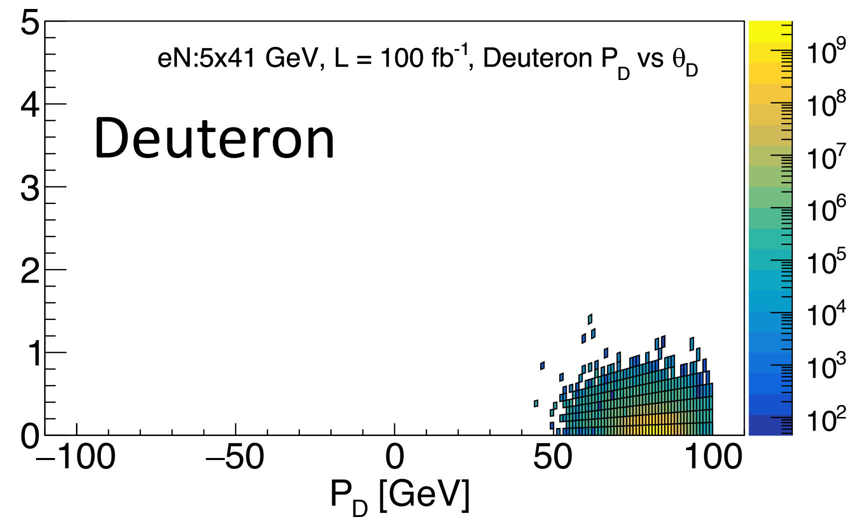
- Spin dependent EMC effects
  - Tagging deuteron: $A_1^p \rightarrow \; g_1^p$
  - Comparing g_1^p from free to bound proton
  - Study feasibility for this measurement at EIC is on going
  - Possibility to do this measurement at CLAS12?

[R. Milner arXiv:1809.05626](arXiv:1809.05626)

Tag ^2D from ^3He at EIC at Far-Forward detector

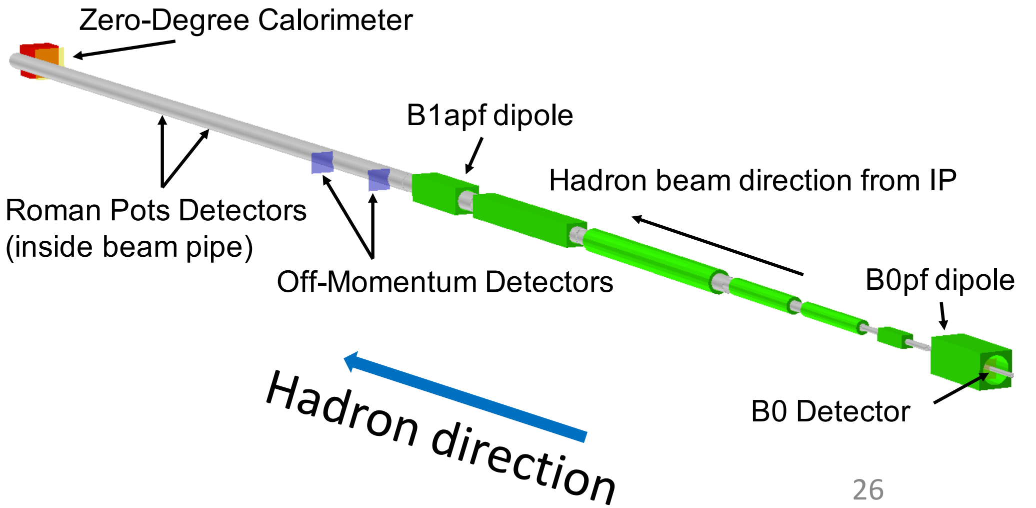
➢ Collide experiment, Using ECCE simulation for feasible studies





❖ Electron: Large angles, detected at central detector

❖ Deuteron: Small-angle, large-momentum, detected at Far-forward detector



Summary

- ❑ EIC capable of spectator tagging measurement
- ❑ Minimize the model dependence for neutron spin structure
- ❑ Provide high precision data with a Large coverage range of x and Q^2
- ❑ Open many other potential spin physics measurements at EIC

e^3He Tagging measurement at EIC:

Providing – novel probes – many potential physics to explore