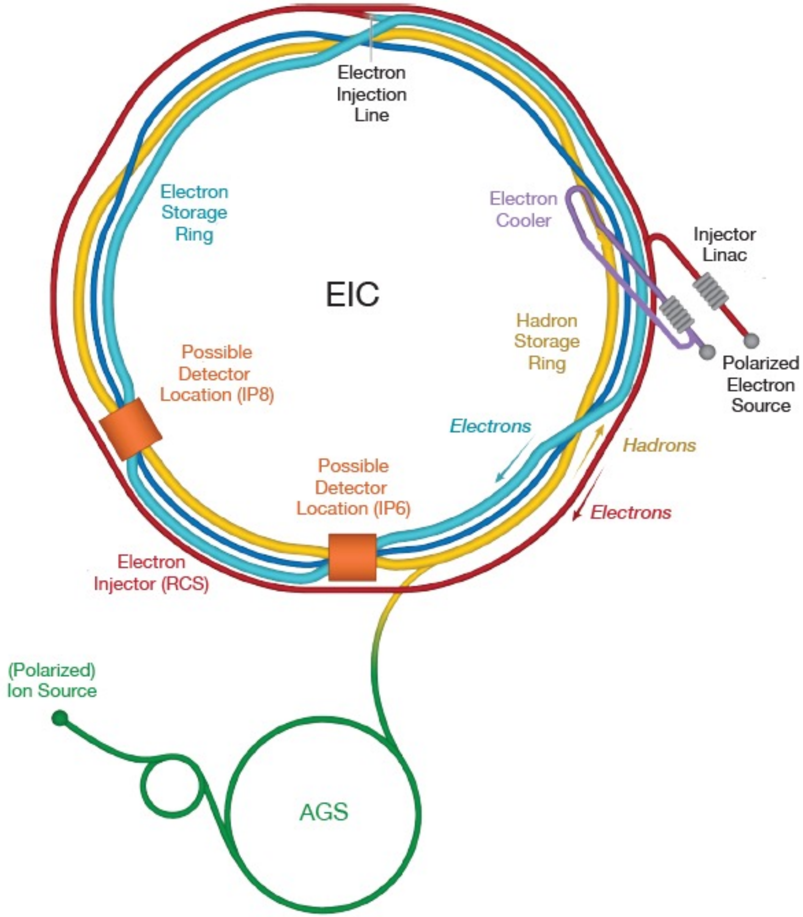
^{3}He at the EIC: Neutron spin study using Double spectator tagging

Dien Nguyen

Exploring QCD with Tagged Processes
October 21, 2021

The EIC: Next generation QCD machine

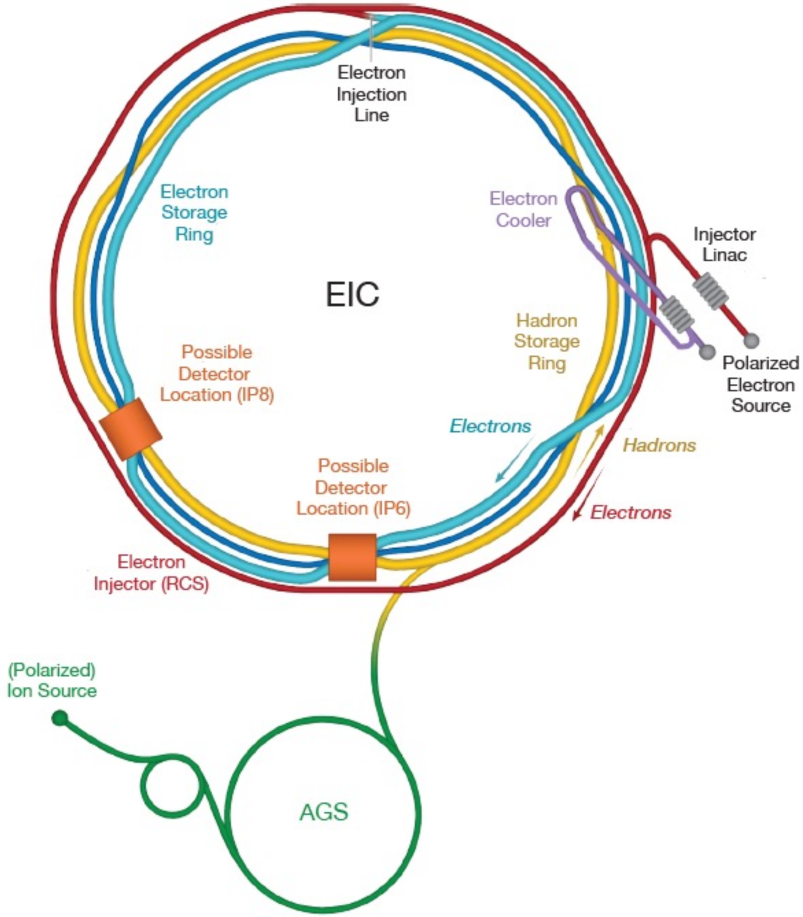


Versatility and high Luminosity are key:

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

arXiv: 2103.05419

The EIC: Next generation QCD machine



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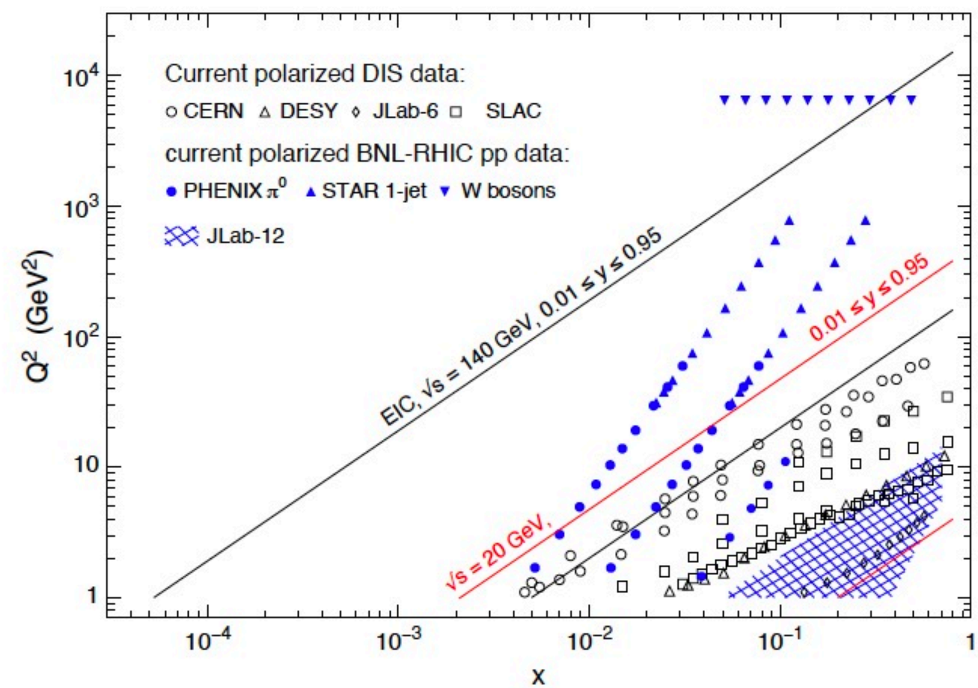

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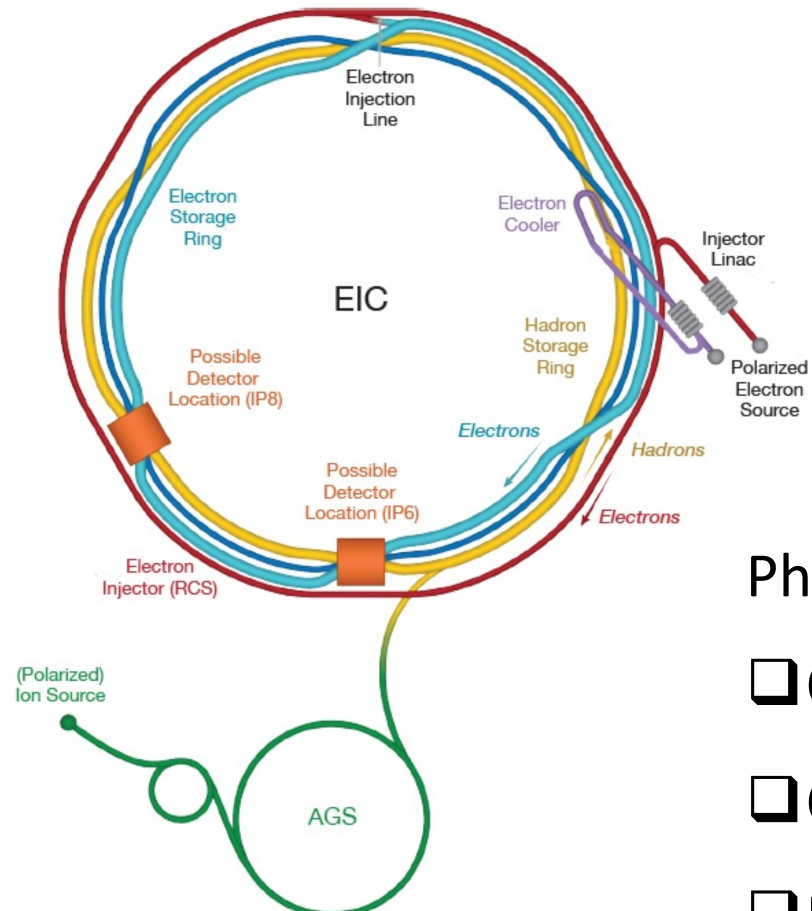
The EIC: Next generation QCD machine



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Physics Goals:

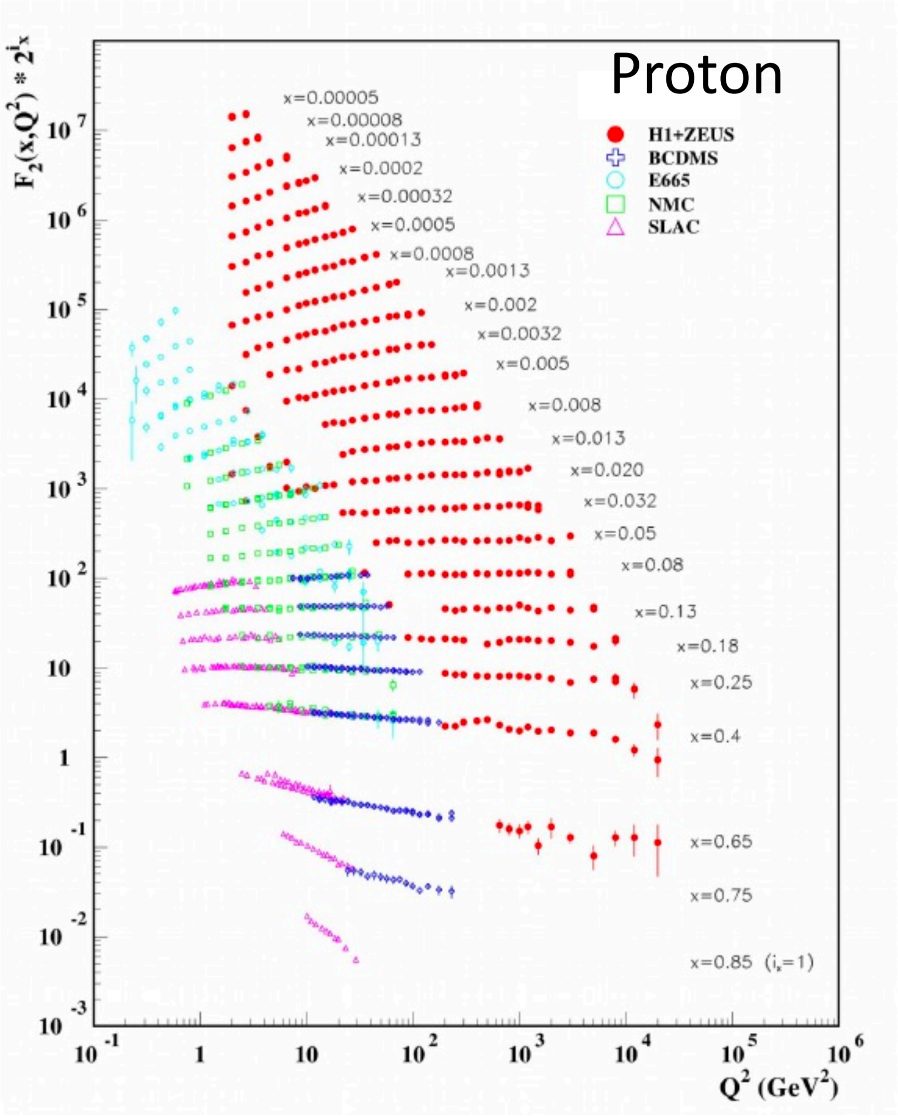
- ❑ Origin of nucleon spin?
- ❑ Origin of nucleon mass?
- ❑ Properties of dense system of gluon?

EIC YELLOW REPORT
Volume II: Physics

ECCE
EIC Comprehensive Chromodynamics Experiment

Nucleon structure functions

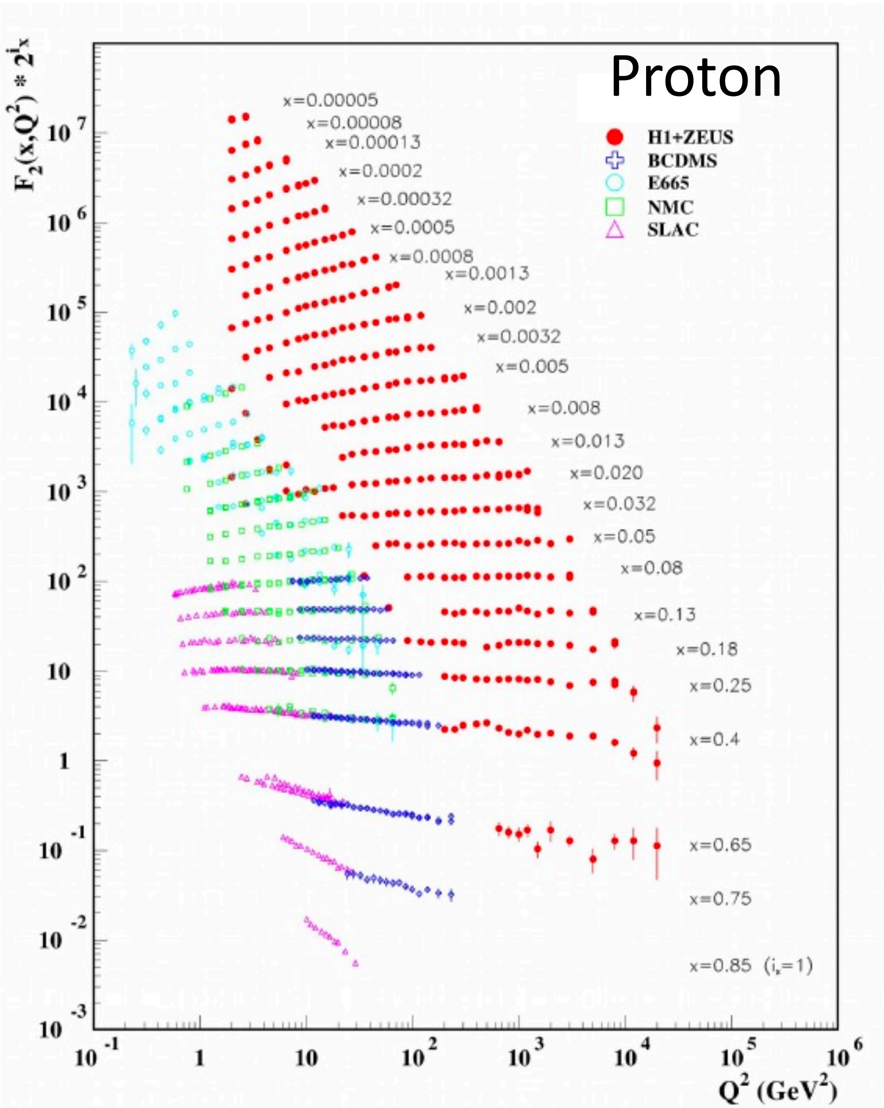
- ❑ Fundamental for understanding strong interaction in QCD

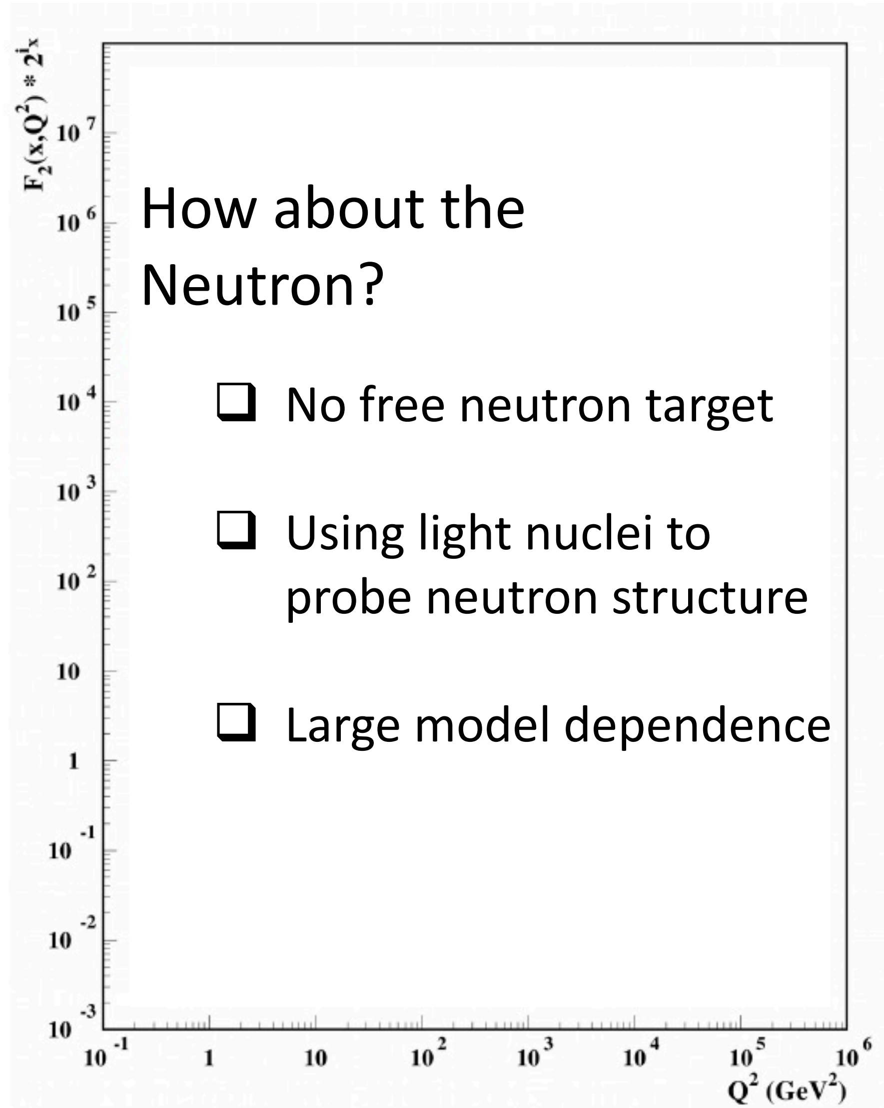


- ❑ Well measured: over 5 orders of magnitude in x, Q^2
- ❑ High precision data

Nucleon structure functions

- Fundamental for understanding strong interaction in QCD

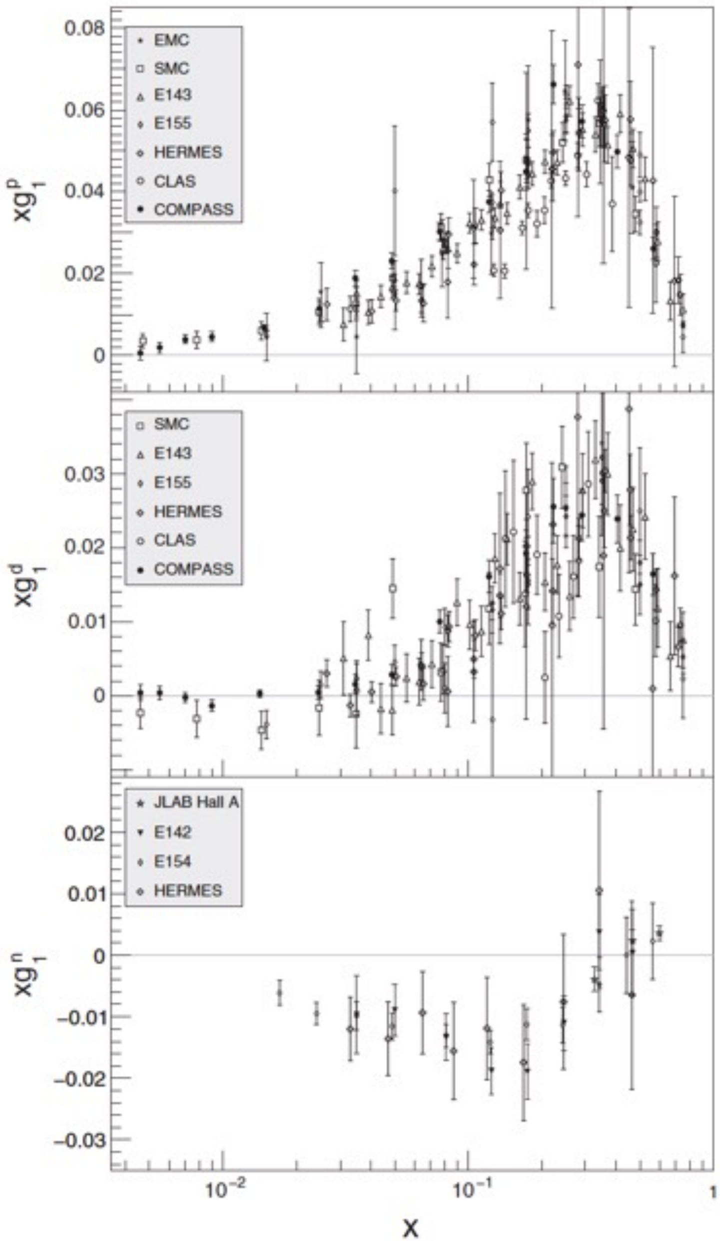




How about the Neutron?

- No free neutron target
- Using light nuclei to probe neutron structure
- Large model dependence

Polarized structure functions

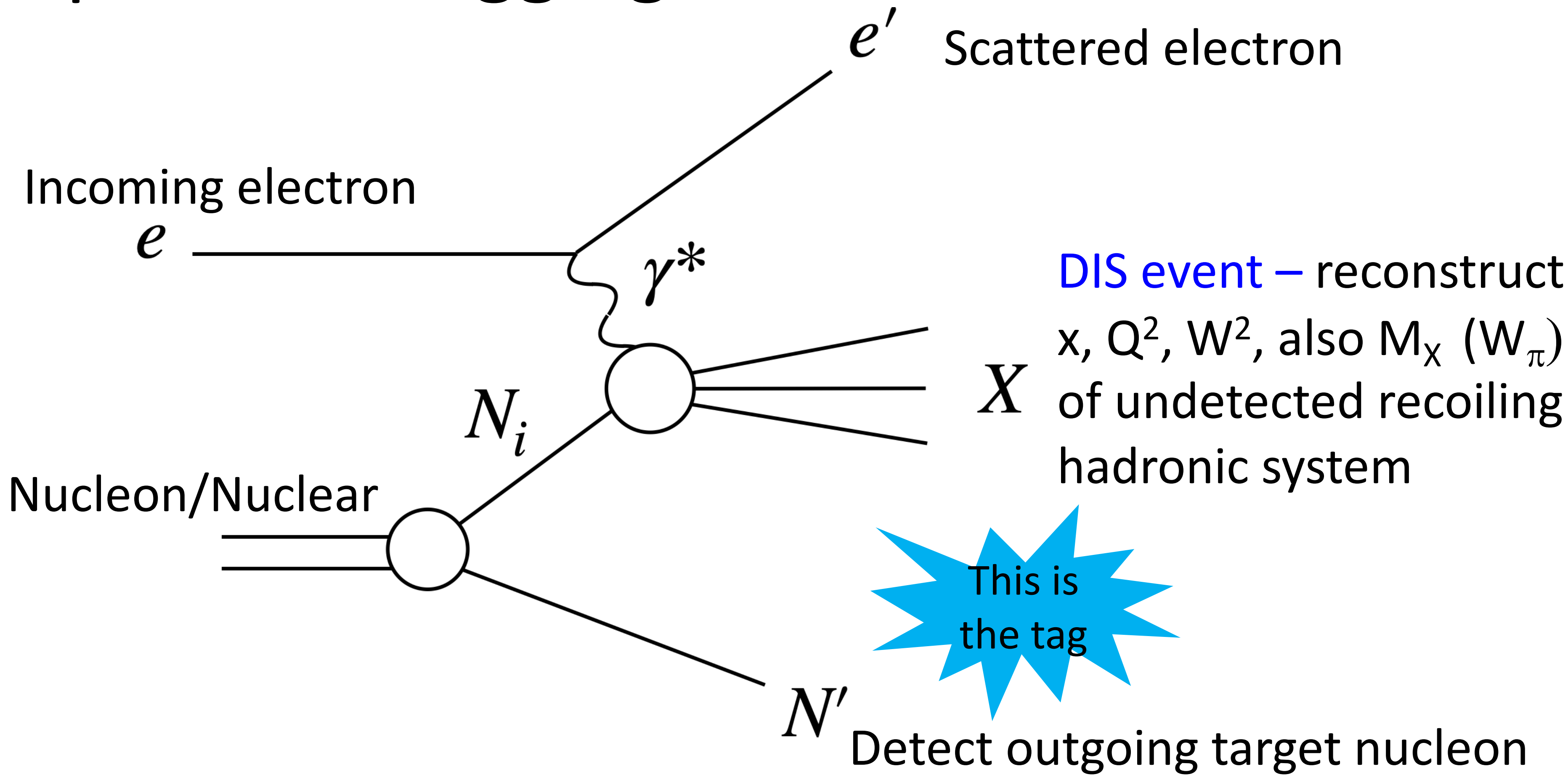


C. Aidala et al., Rev. Mod. Phys. 85, 655 (2013)

- ❑ Probing Spin in QCD
  - ❑ Understanding the spin structure of nucleon
  - ❑ Neutron data is needed for flavor separation
  - ❑ Again, neutron extraction model dependent due to nuclear corrections

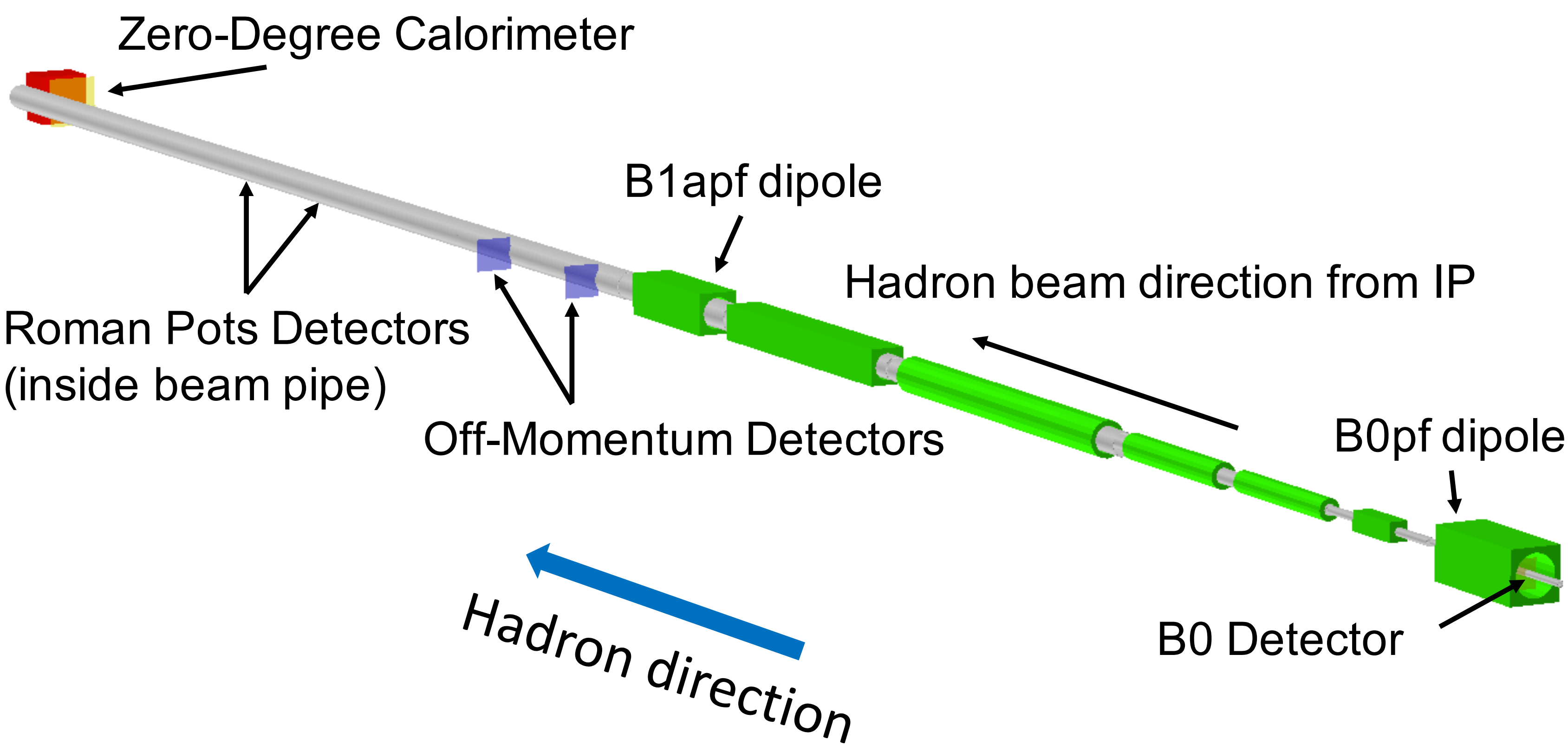
Need a novel measurement what minimize the nuclear correction

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



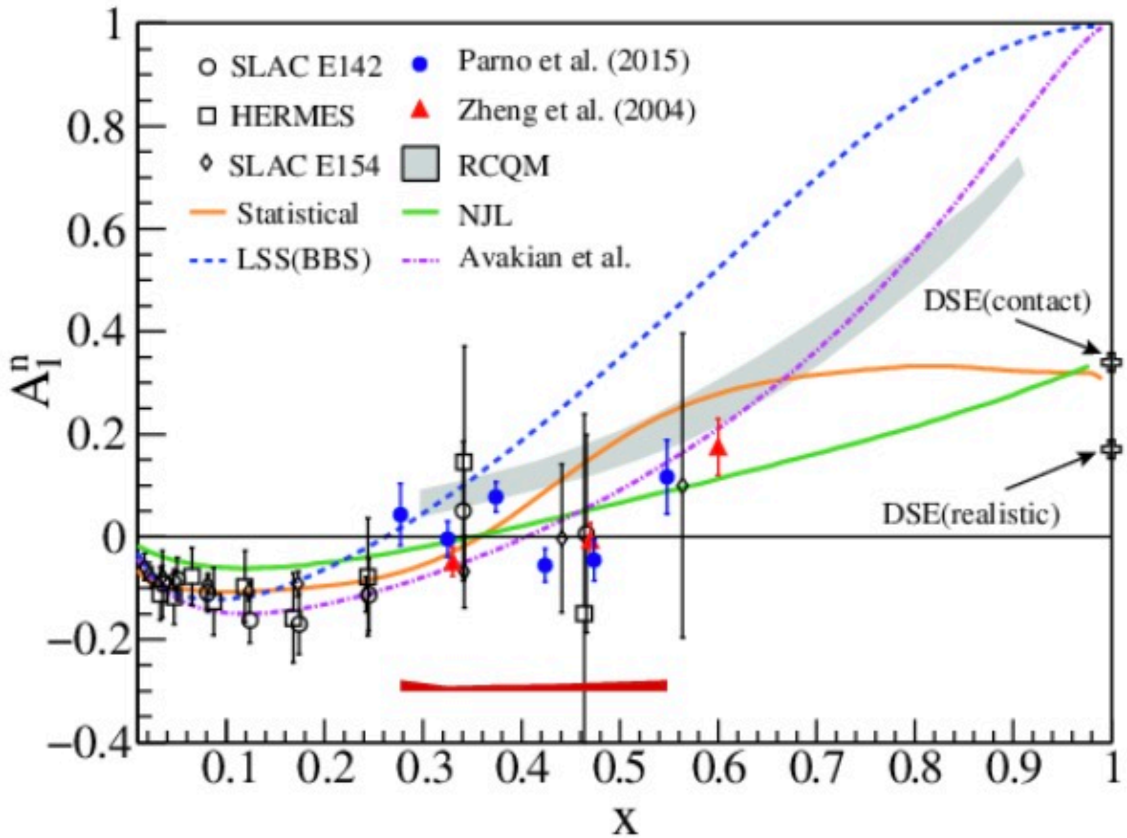
- ❑ Protons: B0, Off-momentum detectors and Roman Pots
- ❑ Neutron: Zero-Degree calorimeter

arXiv: 2103.05419

See talk by A. Jentsch

Spin structure from asymmetry data

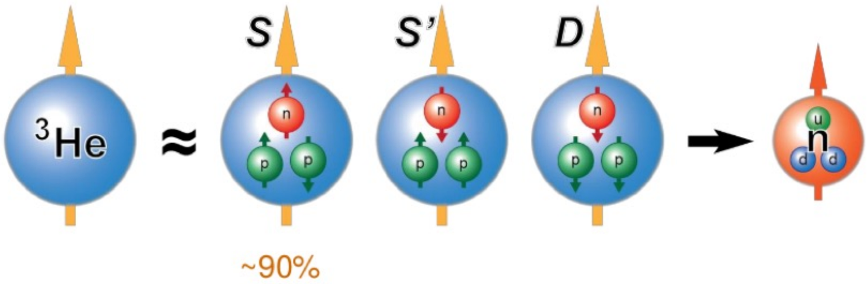
$$A_1(x, Q^2) = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \approx \frac{g_1(x, Q^2)}{F_1(x, Q^2)}$$



X. Zheng et al., PRL 92, 012004 (2004); PRC 70, 065207 (2004)

^{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%

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

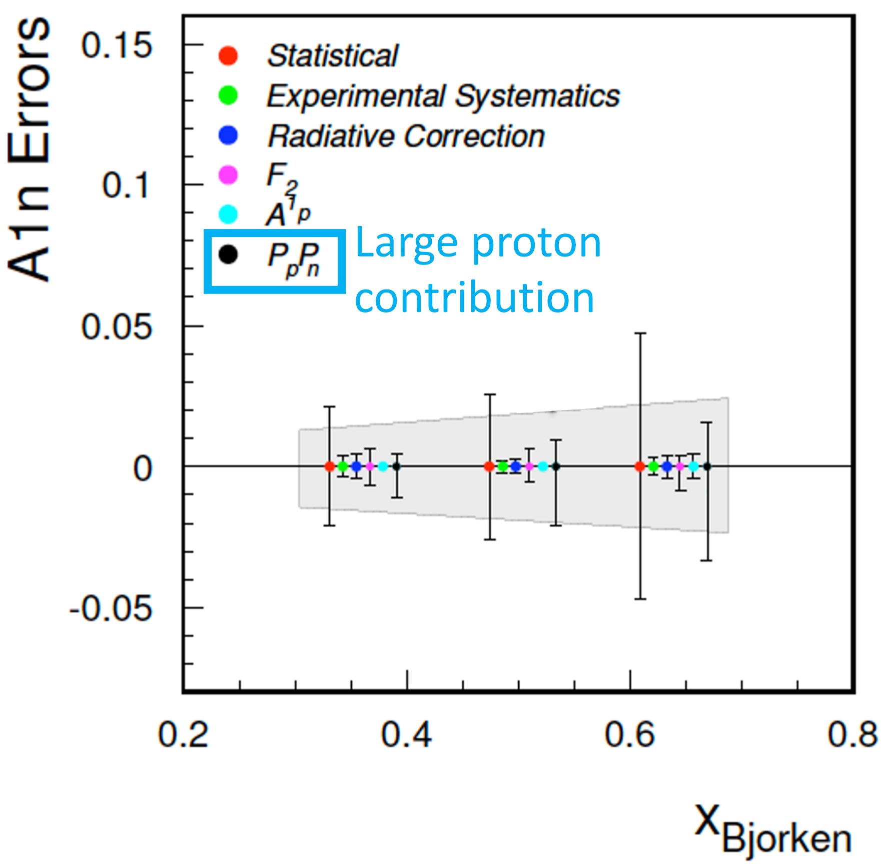
A_1^n is extracted from inclusive DIS e-^{3}He

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

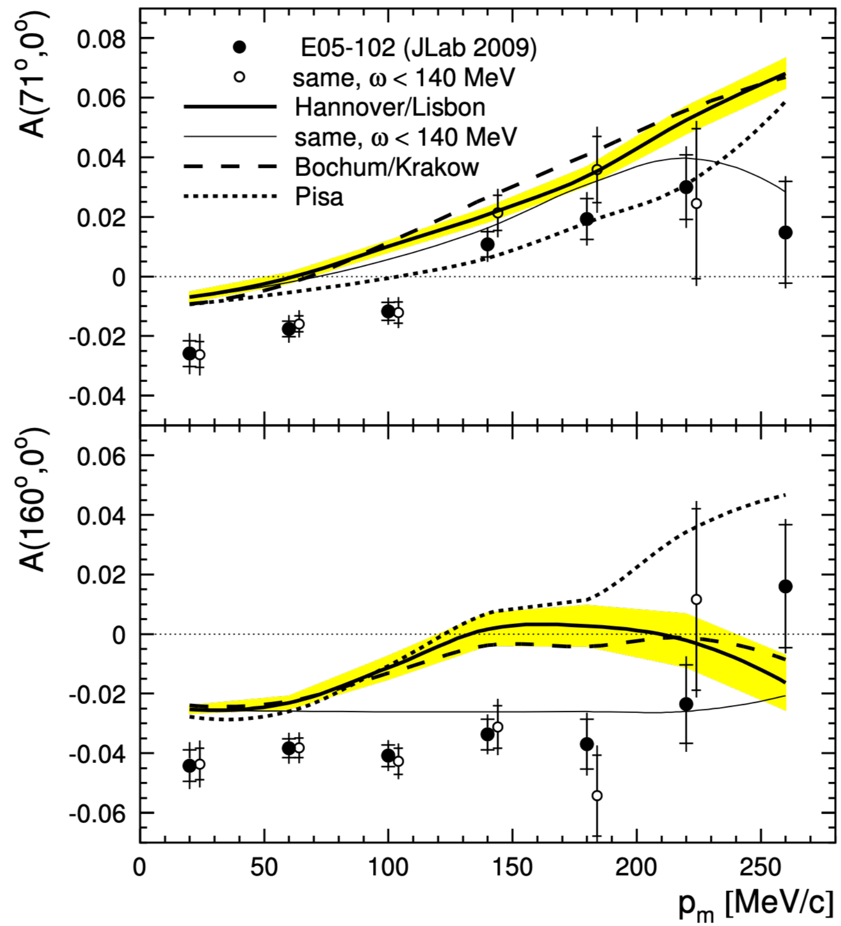
Large model dependence

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

Inclusive extraction has large systematic uncertainties



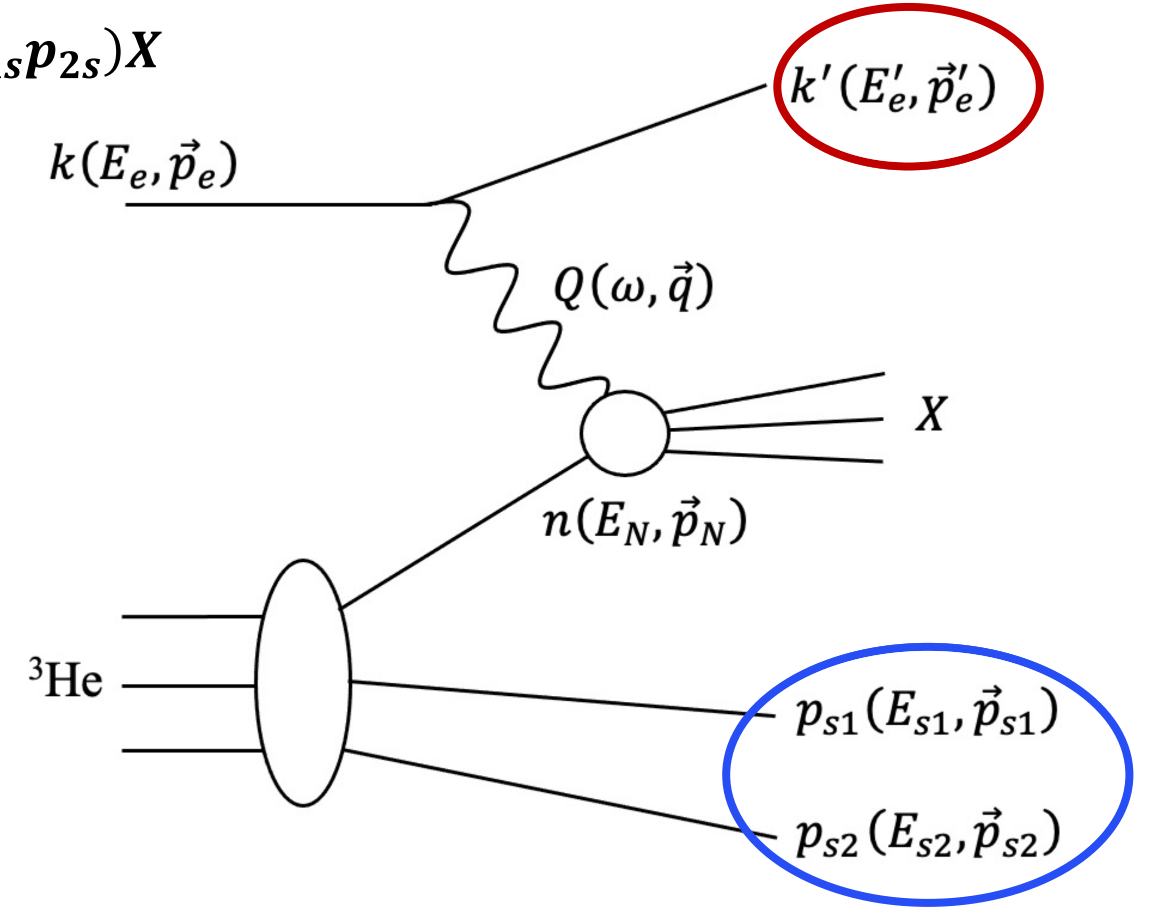
PRL 113, 232505 (2014)



See talk by Douglas Higinbotham

Double spectator tagging suppress model dependence

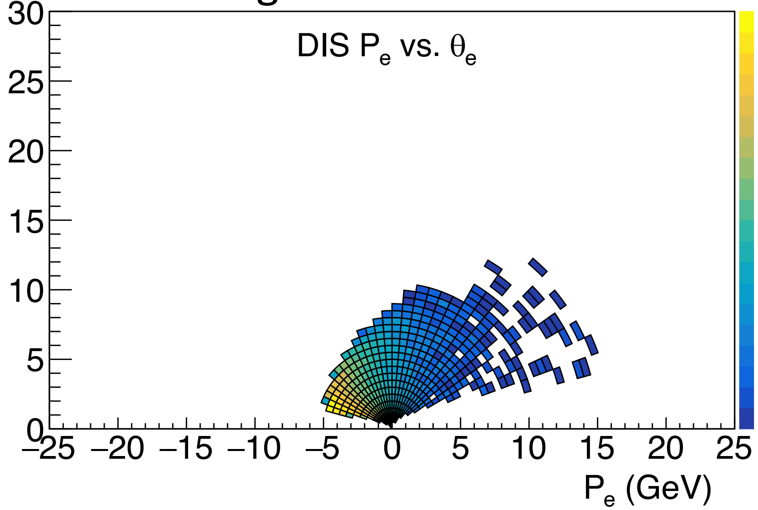
$e^3\text{He}(e'p_{1s}p_{2s})X$



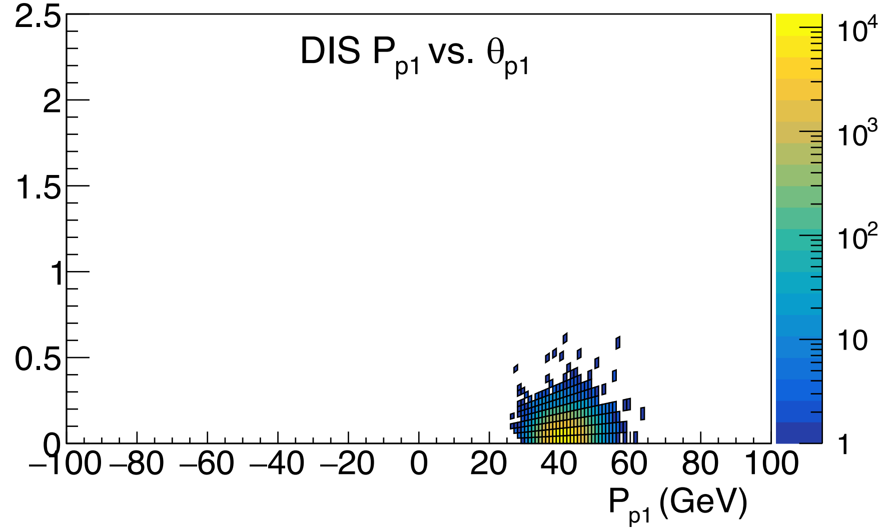
- ❑ Select the active nucleon in the reaction and break up channel
- ❑ Suppress the contribution of non-nucleonic degree of freedom
- ❑ Low total momentum => "Effective" free neutron target

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

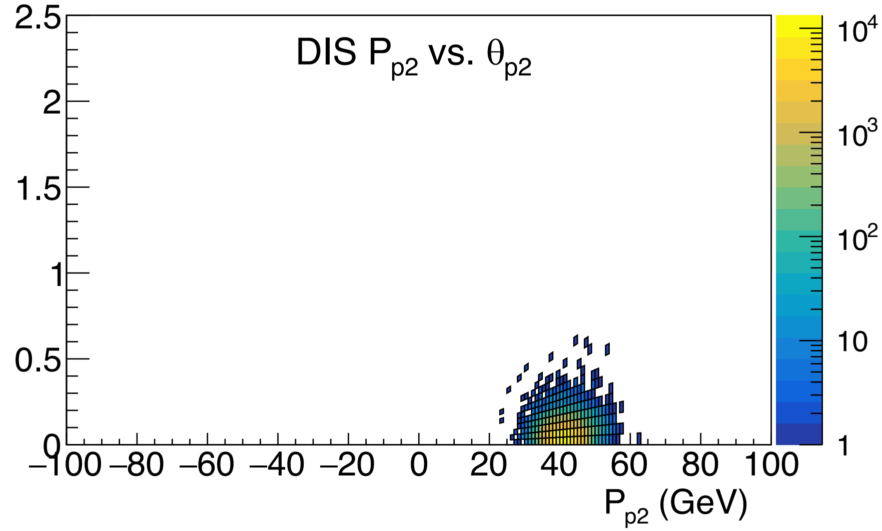
Scattering electron



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)

CLASDIS Event Generator

⬇

Fermi motion correction

J. Pybus
MIT & JLab-EIC

arXiv: 2103.05419

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

CLASDIS Event Generator

↓

Fermi motion correction

J. Pybus
MIT & JLab-EIC

↓

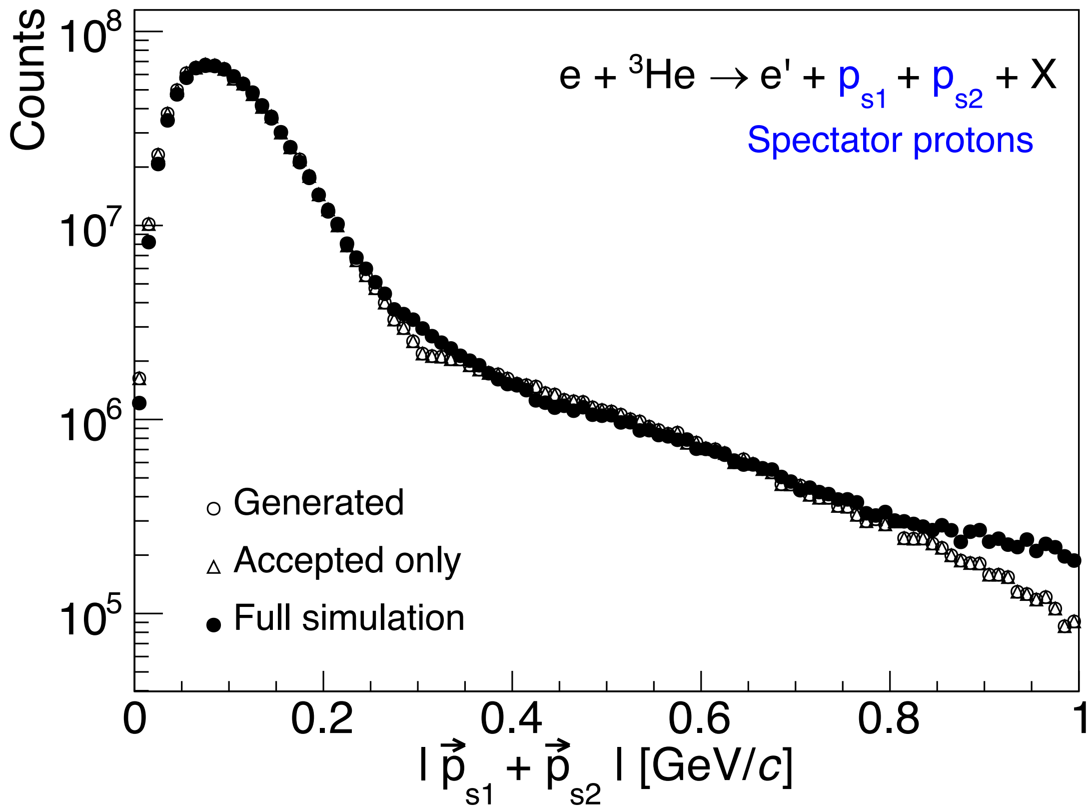
EIC simulation

arXiv: 2103.05419

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

Spectator momentum at the Ion Rest Frame

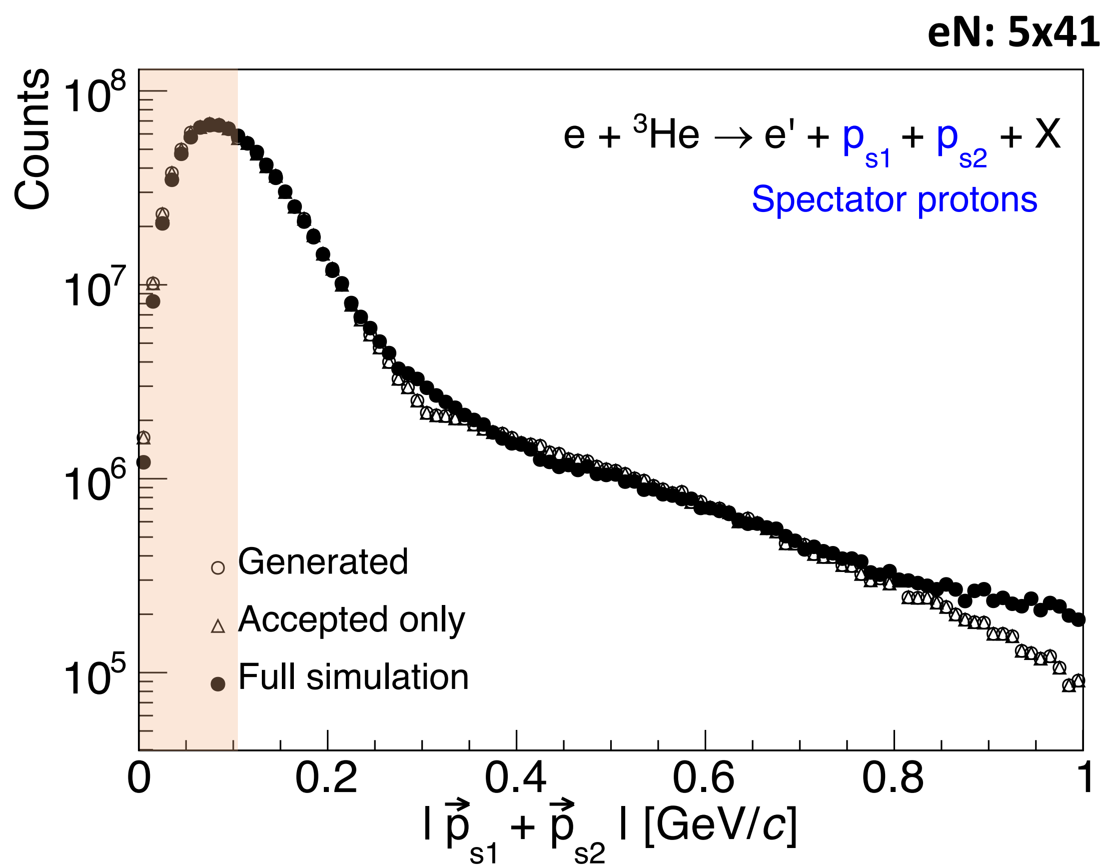
eN: 5x41



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



Friscic, 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)

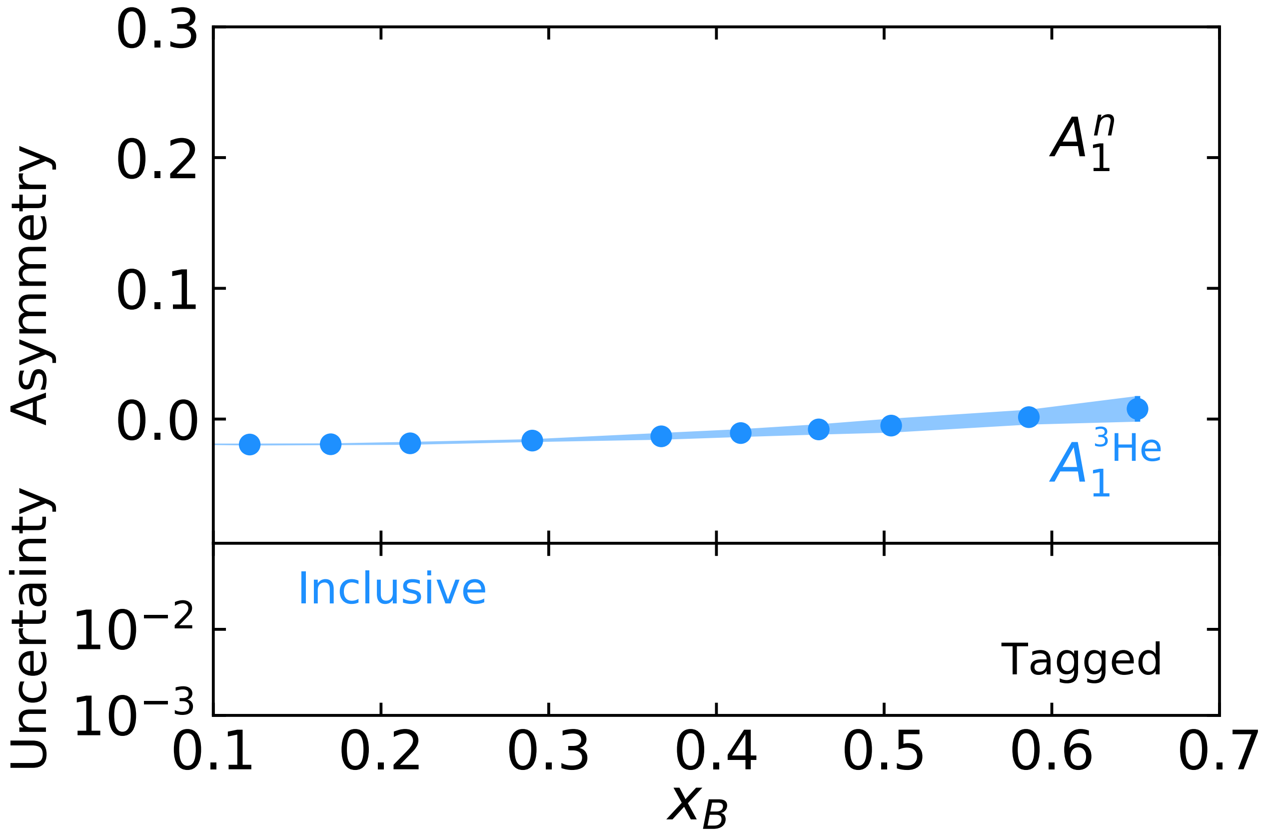
$A_1^{^3\mathrm{He}}$ prediction

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

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

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

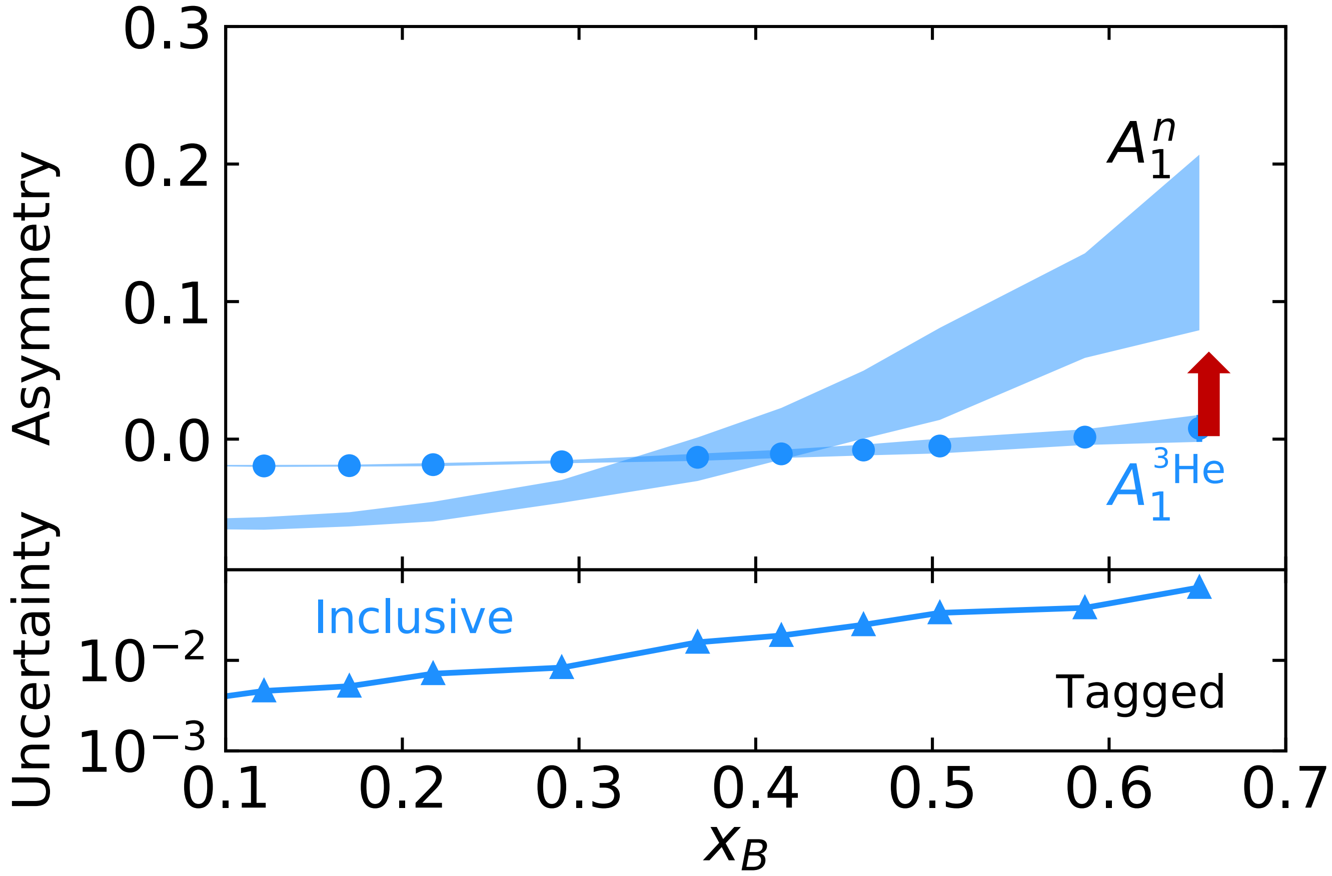
$A_1^{^3\mathrm{He}}$ from 3He(e, e′)



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

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

A_1^n from 3He(e, e′)

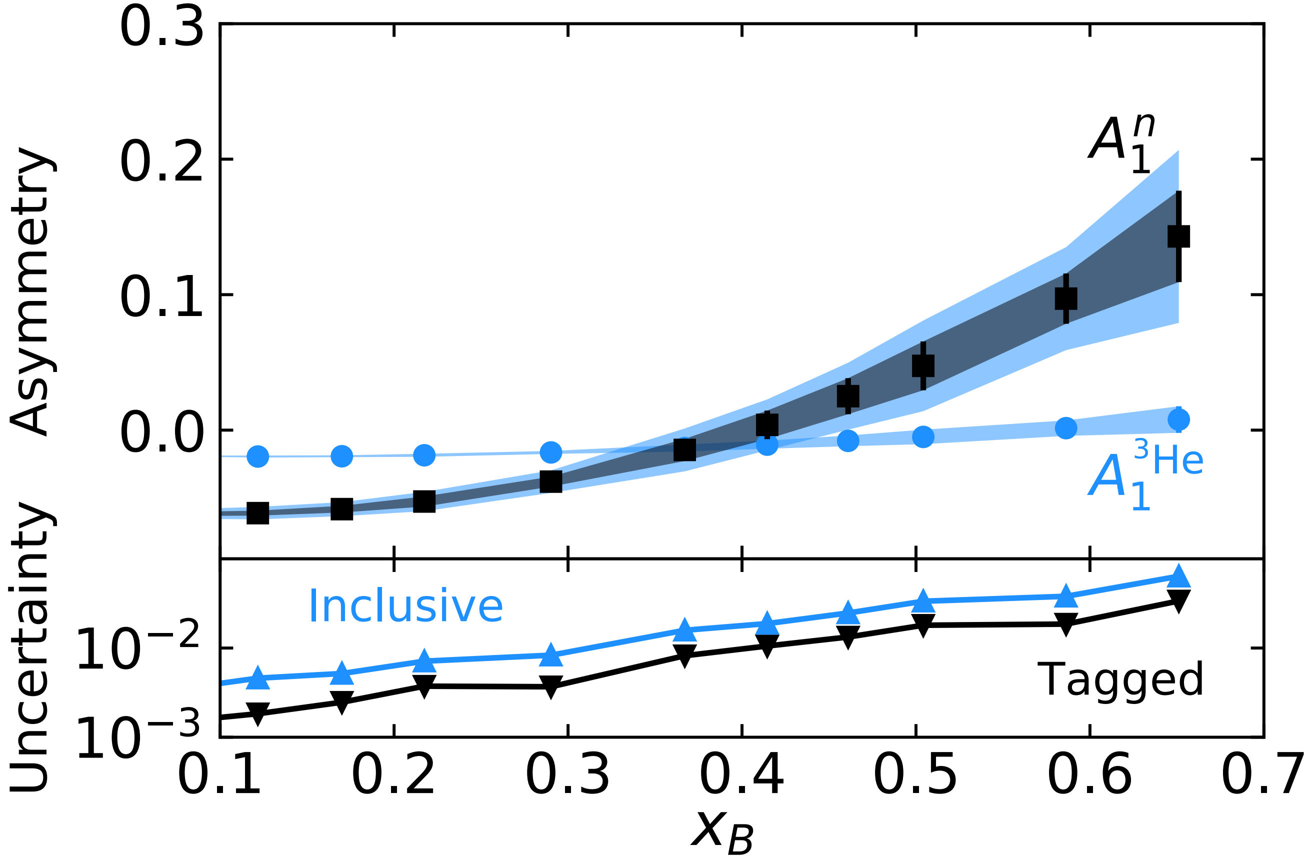


- Extraction introduce a large systematic uncertainty

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

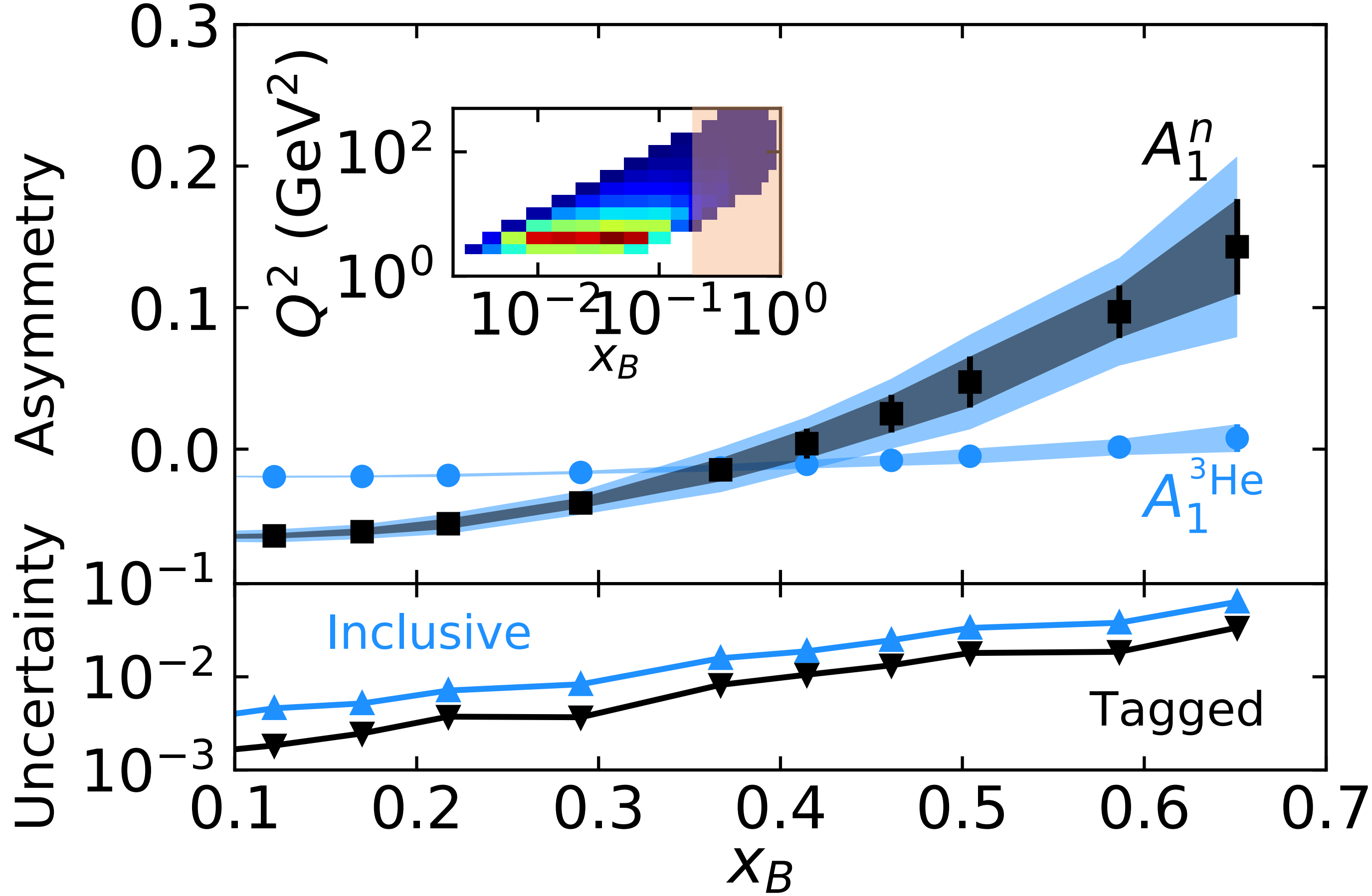
Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

Double Tagging Reduce A_1^n Uncertianty



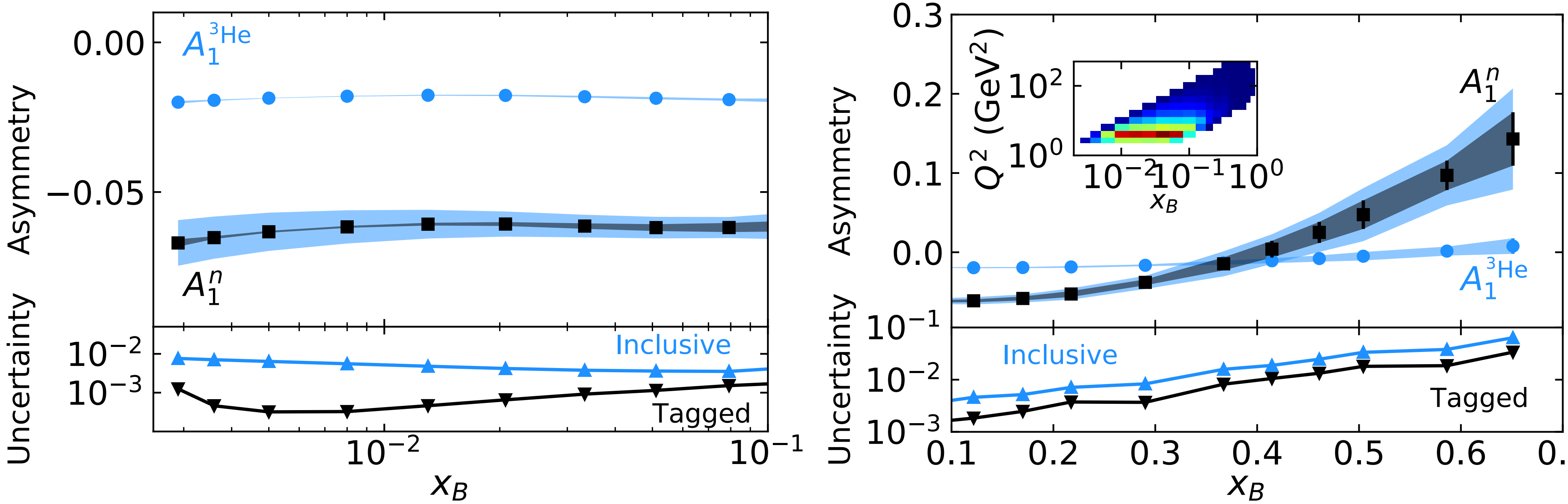
Friscic, Nguyen, Pybus, et al., Phys. Lett. B 823 (2021)13672

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



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

A_1^n: Also cover low-x

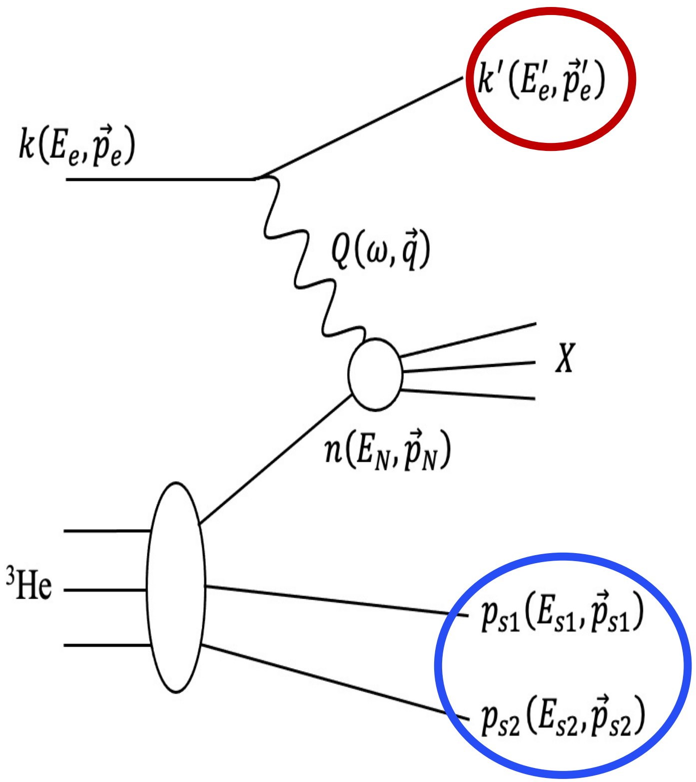


- ❑ Double tagging @ EIC cover $0.003 < x < 0.651$
- ❑ Significantly reduced model dependent uncertainty compare \w (e,e'):
  x10 @ x < 0.1 ; x2 @ x > 0.1

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

e^3He at EIC: Other Physics measurements

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

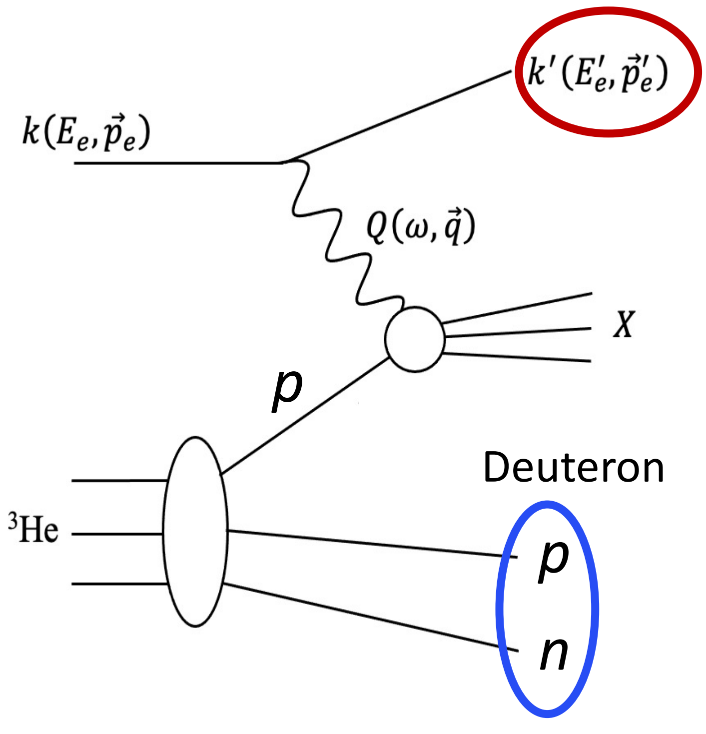


- Spin dependent EMC effect

- Extracting the g_1^n as a function of virtuality

e^3He at EIC: Other Physics measurements

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



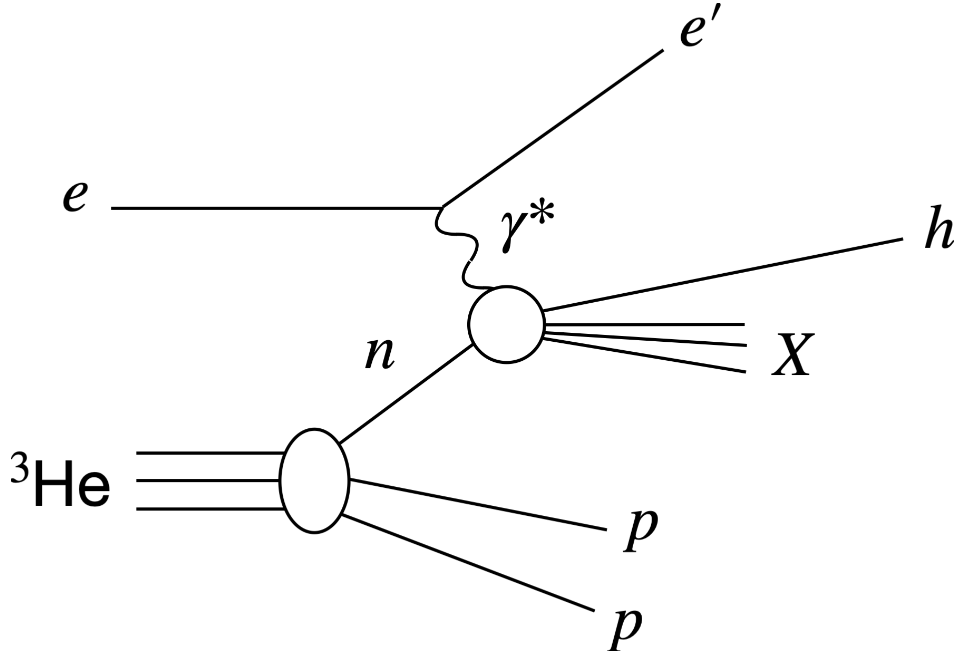
- Spin dependent EMC effects
  - Tagging deuteron: $A_1^p \rightarrow \ g_1^p$
  - Comparing g_1^p from free to bound proton
  - Study feasibility for this measurement at EIC is on going
  - Possibility to do this measurement at CLAS12?

See talk by Sergio Scopetta

R. Milner arXiv:1809.05626

e^3He at EIC: Other Physics measurements

Tagging SIDIS: Neutron spin study



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

Neutron Spin Structure from e-^{3}He Scattering with Double Spectator Tagging at the Electron-Ion Collider

I. Friščić[a,b,1], D. Nguyen[a,b,1], J.R. Pybus[a,b], A. Jentsch[c], E.P. Segarra[a], M.D. Baker[d], O. Hen[a], D.W. Higinbotham[b], R. Milner[a], A.S. Tadepalli[b], Z. Tu[c], J. Rittenhouse West[b,e]

- EIC capable of double spectator tagging
- Minimize the model dependence for neutron spin structure
- Large coverage range of $0.003 < x < 0.651$
- High-x reach limited by resolution
- Open many other potential physics measurement at EIC

Tagging measurement:

Providing – novel probes – rich physics to explore

Many thanks to:

- JLab EIC Center & N. Isgur Fellowship
- EIC YR Diffraction & Tagging working group
- Xiaochao Zheng, Harut Avakian, Barak Schmookler for valuable discussions and suggestions