Jefferson Lab

Spin Asymmetry Measurements at EIC

Arun Tadepalli – Jefferson Lab

In collaboration with I. Ivica, J. R. Pybus, A. Jentsch, E. P. Segarra, M. D. Baker, O. Hen, D. Higinbotham, R. Milner, D. Nguyen*, Z. Tu, J. Rittenhouse West

* = special thanks!

Contents

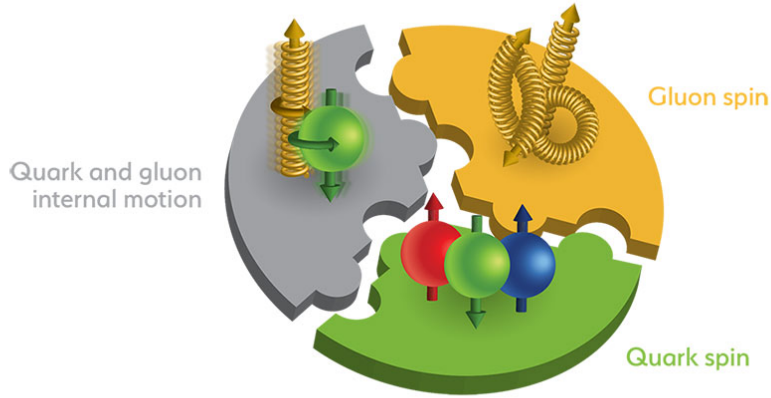
- Introduction
- A1n in the high-x region
- Most recent A1n measurement in Hall C at Jefferson Lab
- Double spectator tagging method at the EIC
- Summary

Introduction

- Understanding the spin structure in the valence region is a central goal
  - Free from sea effects
  - Valence region defines the global properties of the nucleon

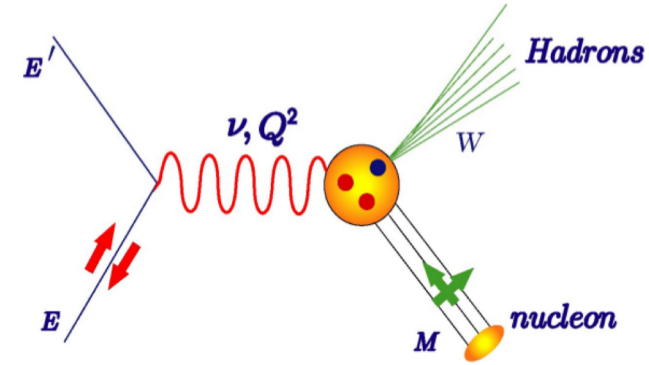
- Pinning down the spin and OAM contribution of various constituents is the current "spin puzzle"

- Virtual photon asymmetries A1n at high-x give an insight into the role of orbital angular momentum of the valence quarks

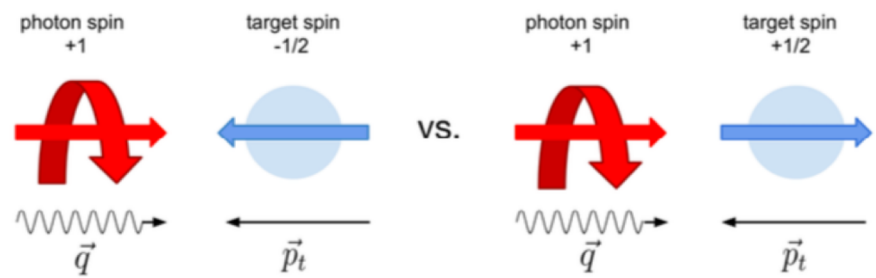


$$S_z^N = S_z^q + L_z^q + J_z^g = \frac{1}{2}$$

Longitudinal Virtual Photon Asymmetry A_1^n



$$A_1 = \frac{g_1 - \frac{(2Mx)^2}{Q^2} g_2}{F_1} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



Anti-parallel spins

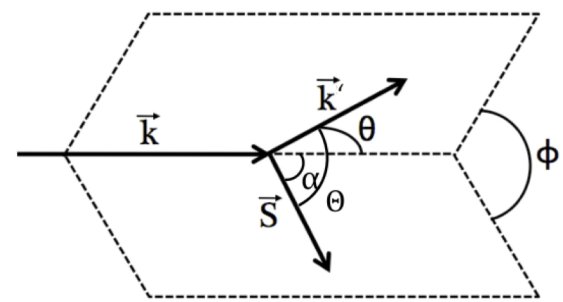
Parallel spins

$$A_1 = \frac{1}{(E + E')D'}\left[(E - E'\cos\theta)A_\parallel - \frac{E'\sin\theta}{\cos\phi}A_\perp\right]$$

$$A_\parallel = \frac{\sigma_{\downarrow\uparrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\downarrow\uparrow} + \sigma_{\uparrow\uparrow}}$$

$$A_\perp = \frac{\sigma_{\downarrow\rightarrow} - \sigma_{\uparrow\rightarrow}}{\sigma_{\downarrow\rightarrow} + \sigma_{\uparrow\rightarrow}}$$

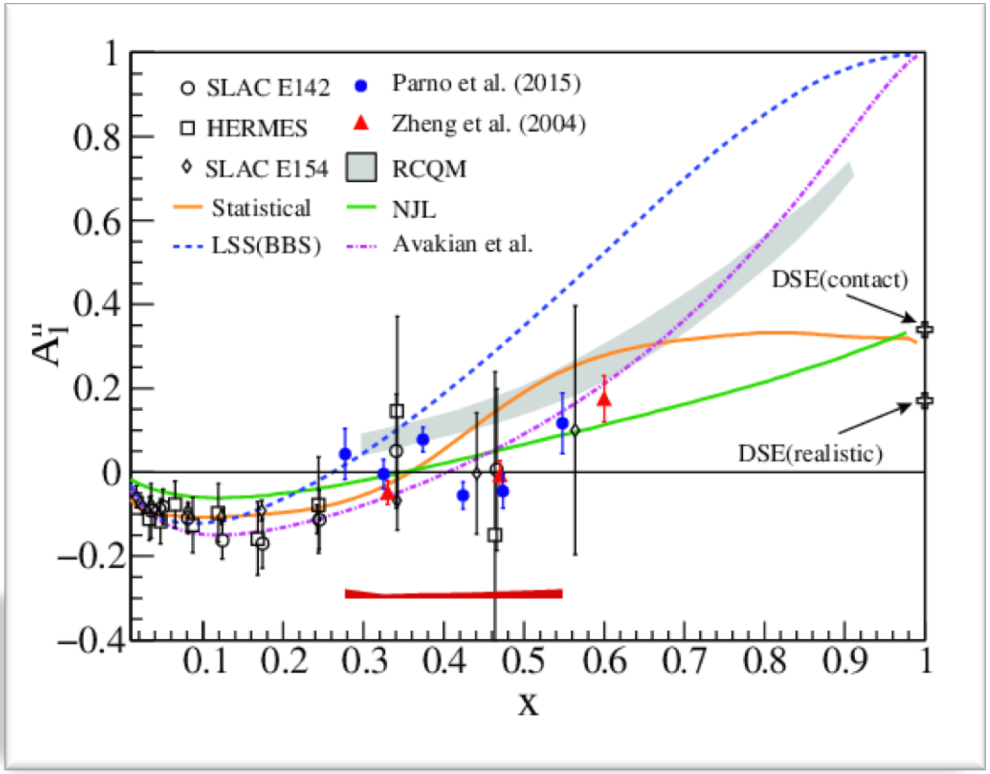
$$D' = \frac{(1-\epsilon)(2-y)}{y[1+\epsilon R]}$$



Angular kinematics for polarized electron scattering

Why A_1^n in high-x region?

- Virtual photon asymmetry A1 give insight into role of OAM of valence quarks in the high-x region
- Also, Q^2 dependence needs to be mapped out for a wide range of values



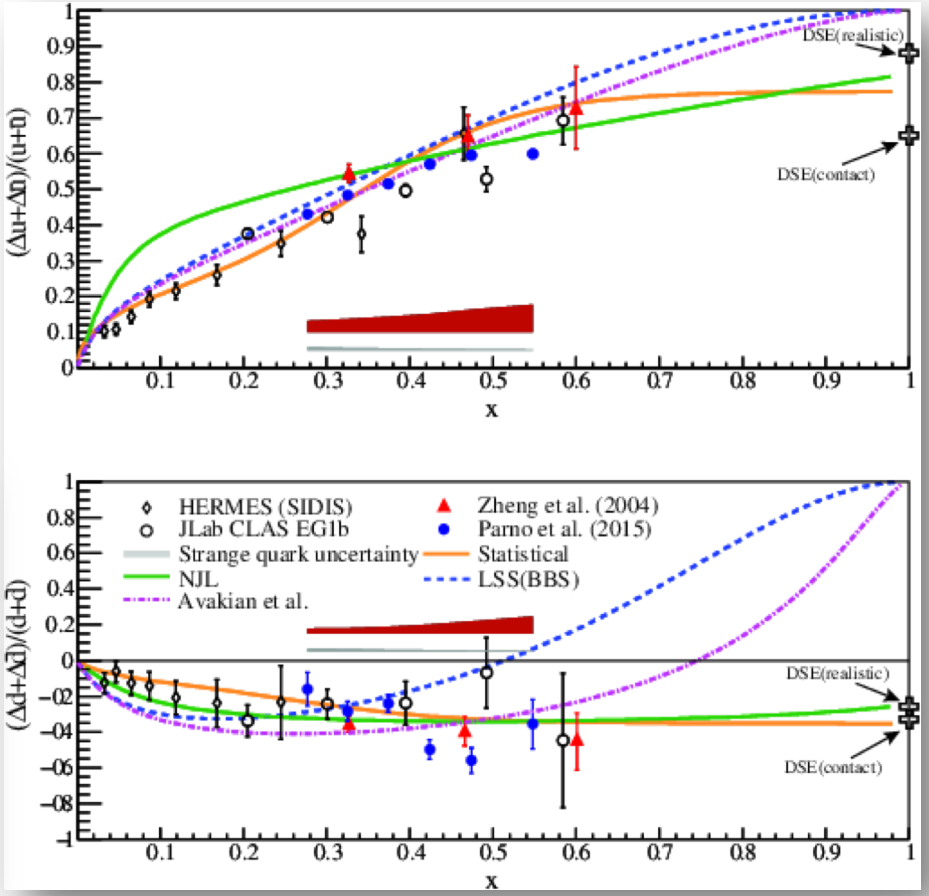
Parno et al., Phy Let B DOI: 10.1016/j.physletb.2015.03.067
X. Zheng et al., PRL 92, 012004 (2004); PRC 70, 065207 (2004)

Flavor Spin Decomposition of Nucleon Structure

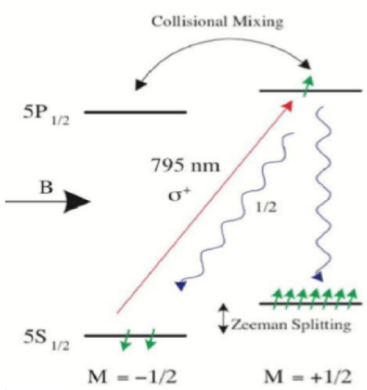
- A1n taken together with A1p could give flavor separated spin distributions in the valence region

	$\frac{F_2^n}{F_2^p}$	$\frac{d}{u}$	$\frac{\Delta d}{\Delta u}$	$\frac{\Delta u}{u}$	$\frac{\Delta d}{d}$	A_1^n	A_1^p
DSE-1	0.49	0.28	−0.11	0.65	−0.26	0.17	0.59
DSE-2	0.41	0.18	−0.07	0.88	−0.33	0.34	0.88
$0^+_{[ud]}$	$\frac{1}{4}$	0	0	1	0	1	1
NJL	0.43	0.20	−0.06	0.80	−0.25	0.35	0.77
SU(6)	$\frac{2}{3}$	$\frac{1}{2}$	$-\frac{1}{4}$	$\frac{2}{3}$	$-\frac{1}{3}$	0	$\frac{5}{9}$
CQM	$\frac{1}{4}$	0	0	1	$-\frac{1}{3}$	1	1
pQCD	$\frac{3}{7}$	$\frac{1}{5}$	$\frac{1}{5}$	1	1	1	1

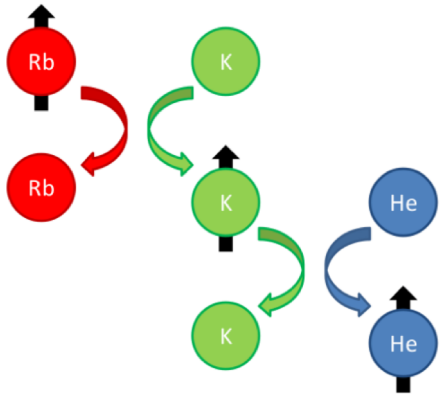
Table 1: Predictions for the x = 1 value of various models. From Craig D. Roberts et al 10.1016/j.physletb.2013.09.038



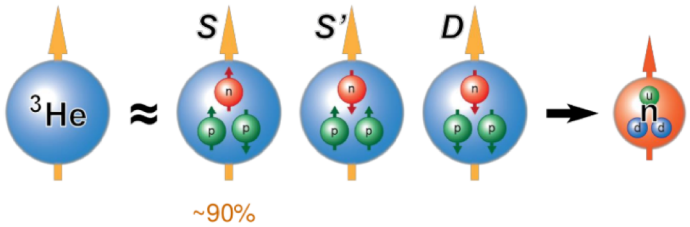
Polarized ^{3}He target in Hall C



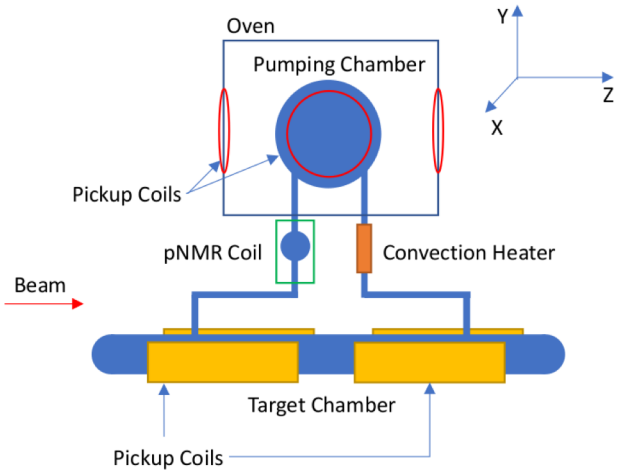
Collisional mixing

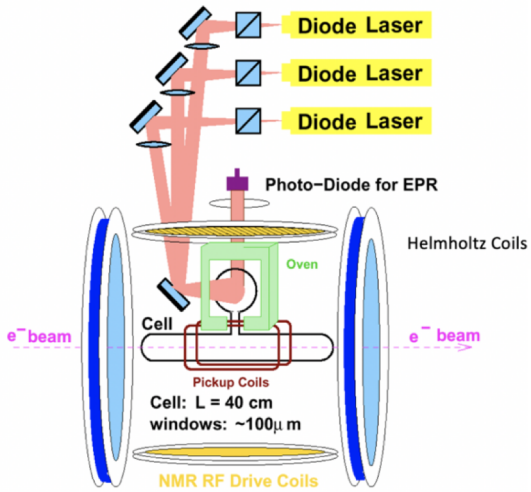


Spin exchange optical pumping

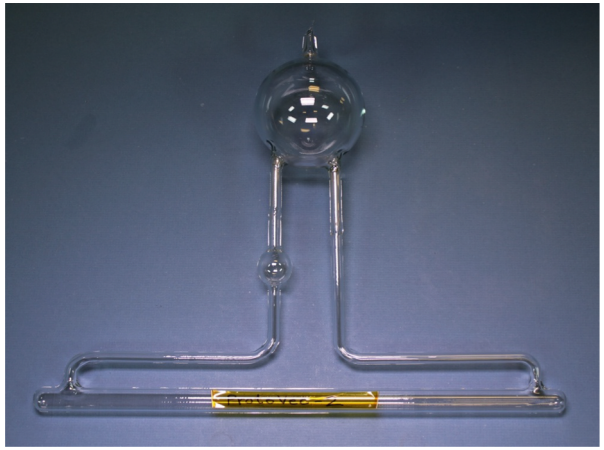


Effective neutron target

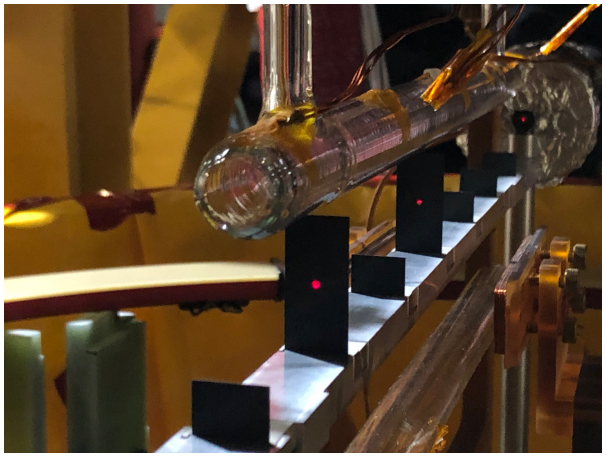




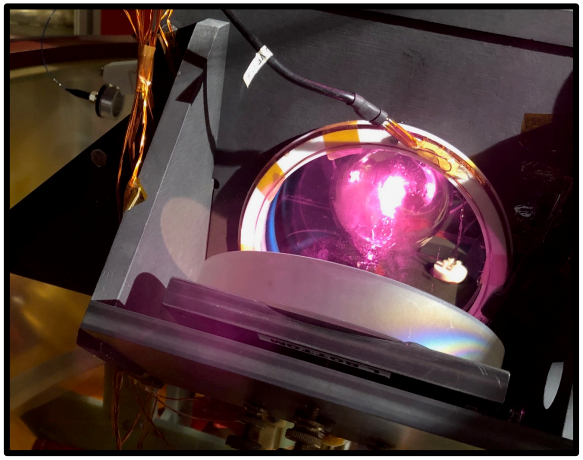
Polarized Target in Hall C



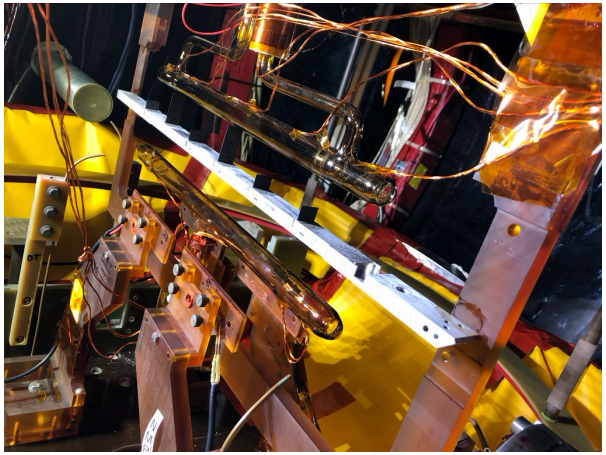
Polarized He3 cell



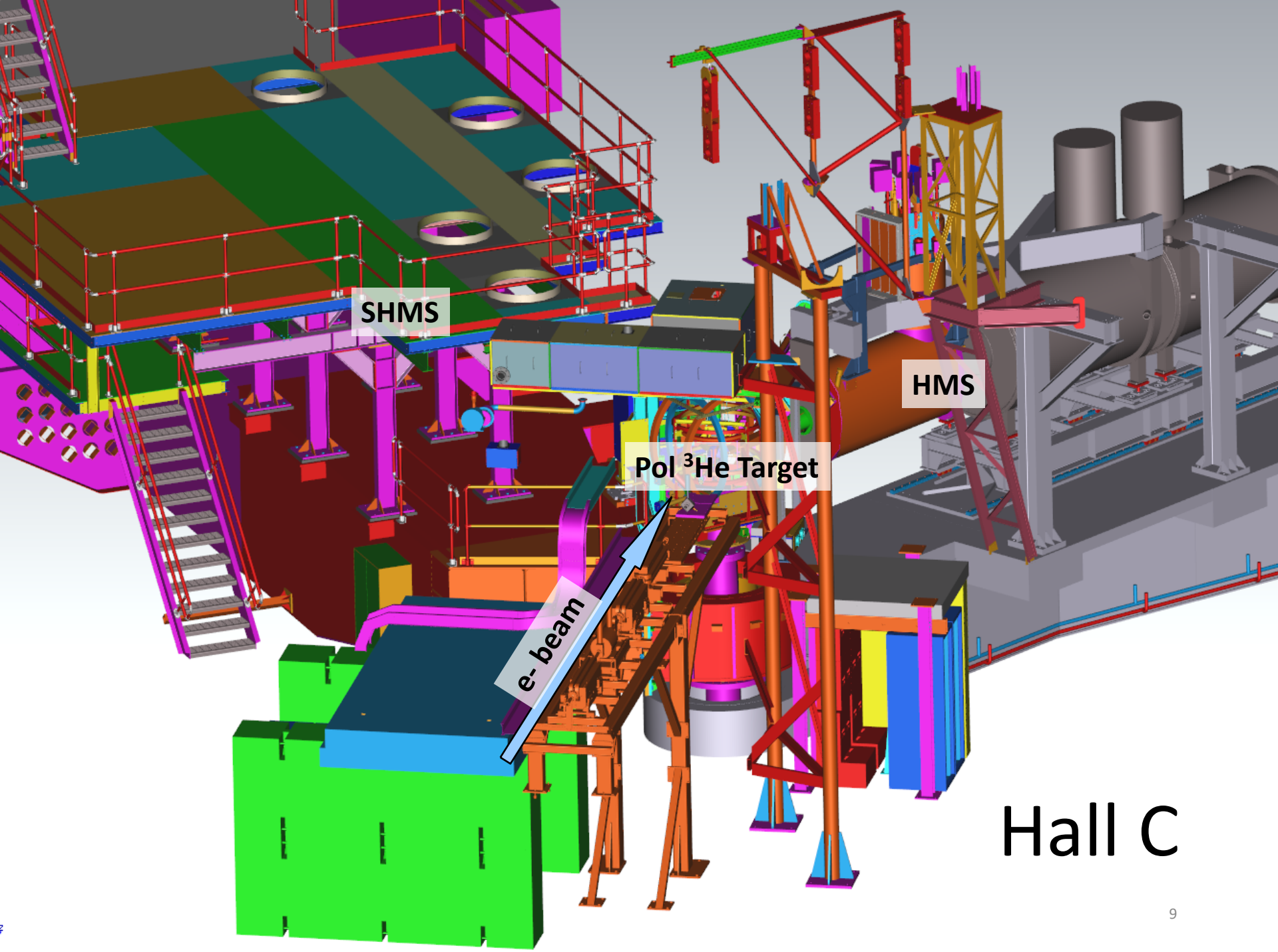
Target ladder



Infrared hue captured by iPhone



Cell installation in Hall C



Hall C

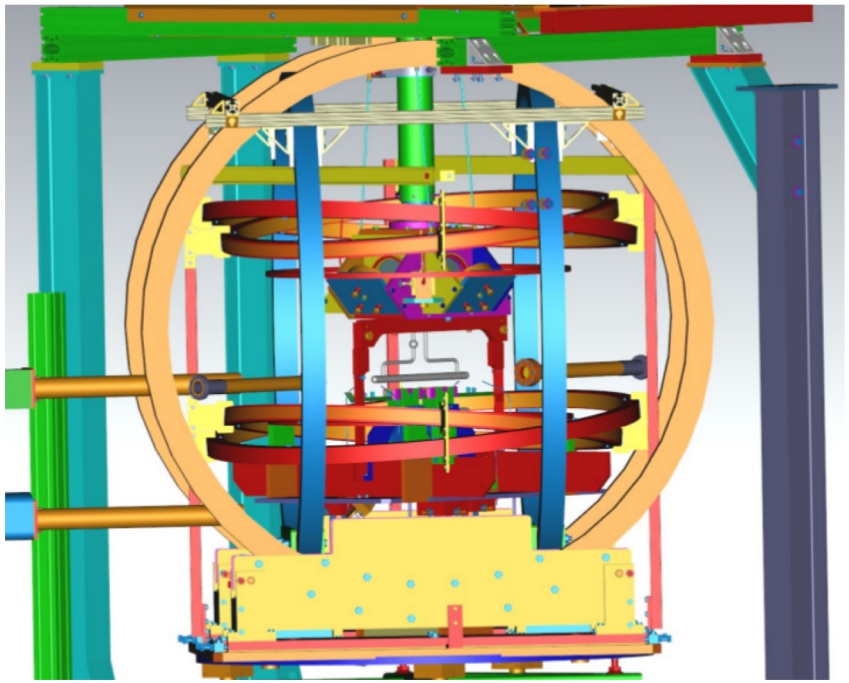
A1n experiment in Hall C at Jefferson Lab

Electron Beam:

- E_{beam}=2.17 GeV (1-pass commission)
- E_{beam}=10.38 GeV (5-pass DIS production)
- Beam polarization: 85%
  - <3% uncertainty by Moller Polarimeter
- Circular beam raster with 2.0 - 2.5mm radius
- < 50 ppm charge asymmetry

Polarized ^{3}He target:

- ^{3}He production cell (40cm)
- 55–60% polarization without beam
- Reached over 50% polarization with 30 uA beam current
- About 3% uncertainty for polarimetry
- Offline analysis in progress



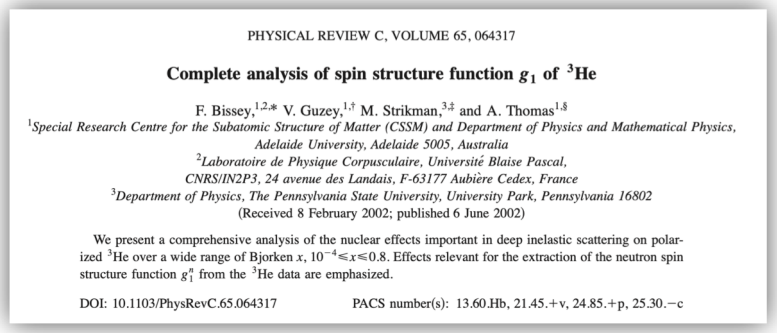
Kine	Spec	E_b GeV	E_p GeV	θ (∘)	beam time (hours)
$\Delta(1232)$	SHMS	2.17	-1.79736	8.5	4.0
Elastic	SHMS	2.17	-2.12860	8.5	8.0

Kine	Spec	E_b GeV	E_p GeV	θ (∘)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
DIS							
3	HMS	10.38	2.90	30.0	88.0	0.0	88.0
4	HMS	10.38	3.50	30.0	511.0	0.0	511.0
B	SHMS	10.38	3.40	30.0	511.0	4.0	515.0
C	SHMS	10.38	2.60	30.0	88.0	4.0	92.0

Limitations of a Fixed Target

- Measured is $^{He3}A_1$ from which A_1^n is extracted
- Systematic errors separated into different components
- Although F_2, A_1^p, P_p and P_n contribute, the model dependent proton polarization P_p dominates the systematic uncertainty

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



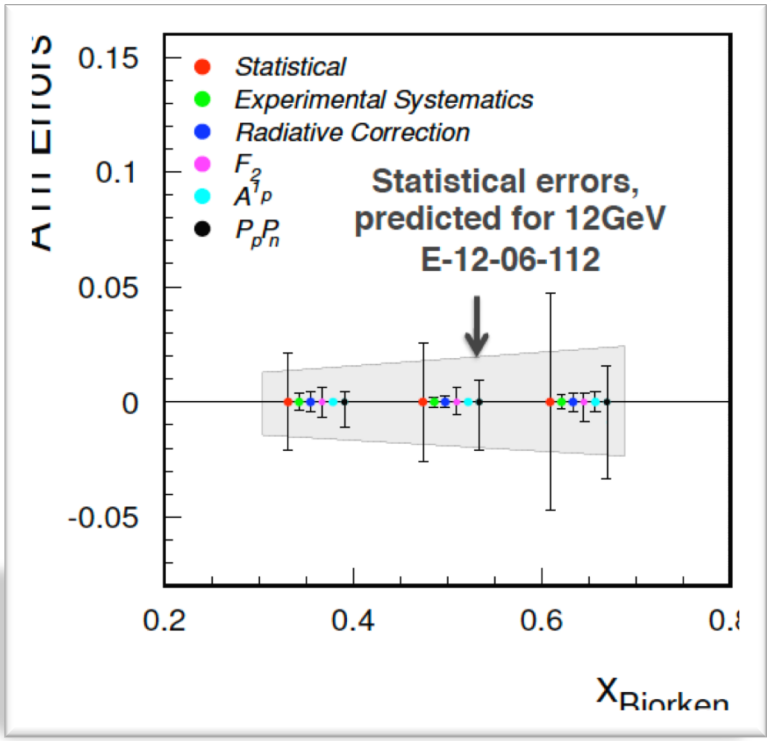
PHYSICAL REVIEW C, VOLUME 65, 064317

Complete analysis of spin structure function g_1 of ^{3}He

F. Bissey,[1,2,*] V. Guzey,[1,†] M. Strikman,[3,‡] and A. Thomas[1,§]
[1]*Special Research Centre for the Subatomic Structure of Matter (CSSM) and Department of Physics and Mathematical Physics, Adelaide University, Adelaide 5005, Australia*
[2]*Laboratoire de Physique Corpusculaire, Université Blaise Pascal, CNRS/IN2P3, 24 avenue des Landais, F-63177 Aubière Cedex, France*
[3]*Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802*
(Received 8 February 2002; published 6 June 2002)

We present a comprehensive analysis of the nuclear effects important in deep inelastic scattering on polarized ^{3}He over a wide range of Bjorken x, $10^{-4} \leq x \leq 0.8$. Effects relevant for the extraction of the neutron spin structure function g_1^n from the ^{3}He data are emphasized.

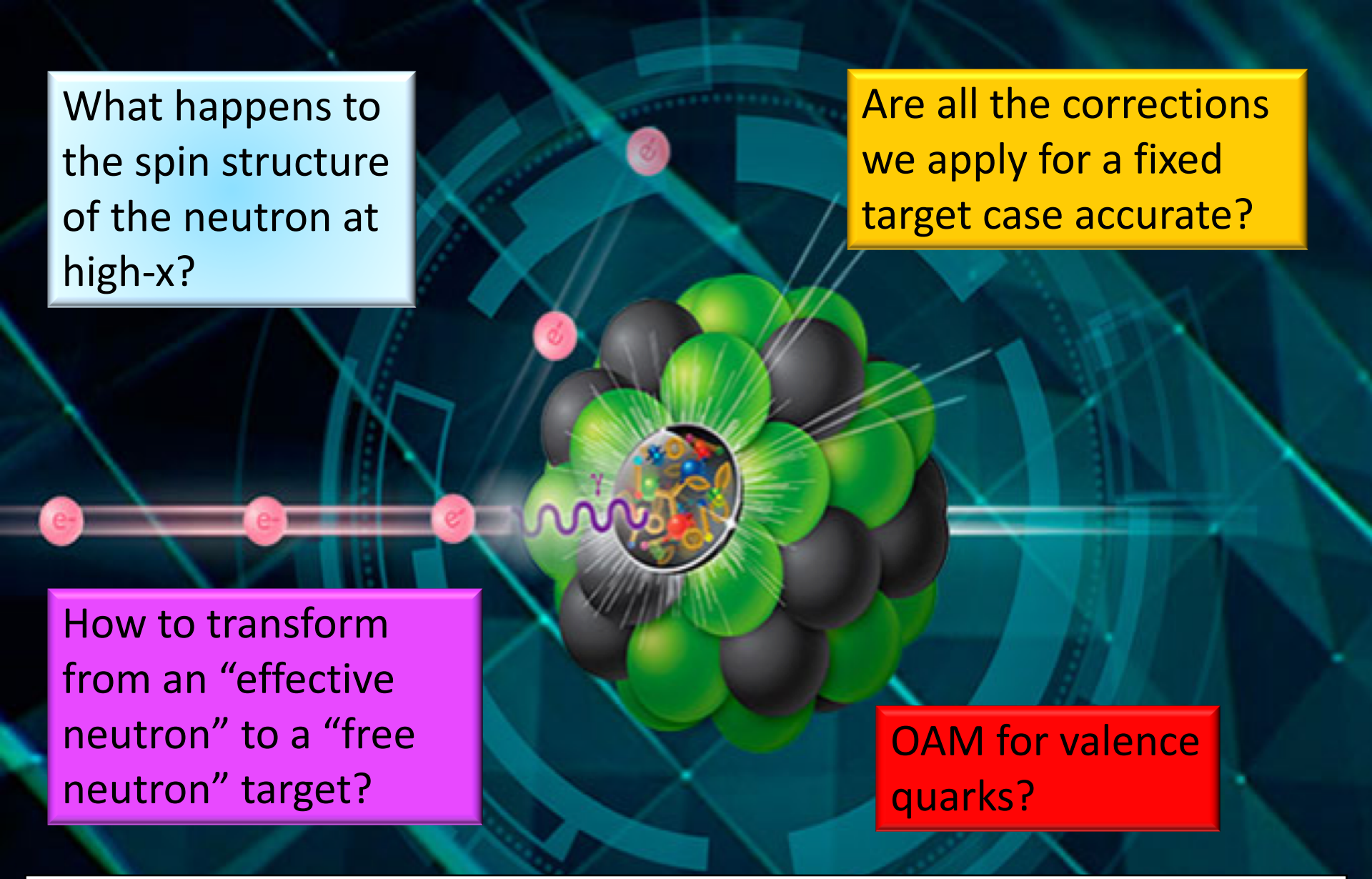
DOI: 10.1103/PhysRevC.65.064317 PACS number(s): 13.60.Hb, 21.45.+v, 24.85.+p, 25.30.−c



Pol He3 ion beam at a collider
Pol He3 fixed target
Accessing the same neutron… right?

What happens to the spin structure of the neutron at high-x?

Are all the corrections we apply for a fixed target case accurate?



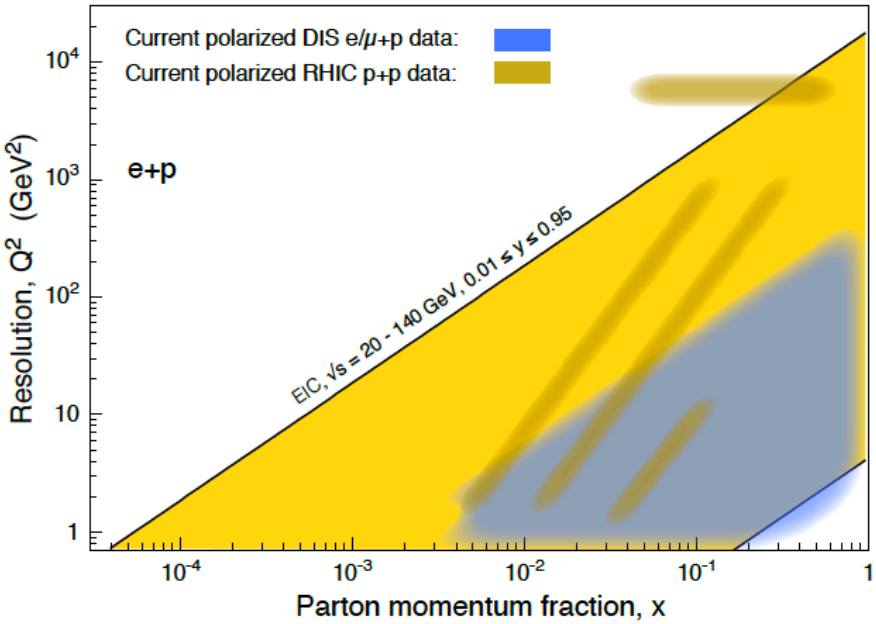
How to transform from an “effective neutron” to a “free neutron” target?

OAM for valence quarks?

Polarized 3He beam allows us to ask interesting physics questions!

EIC (Electron Ion Collider)

EIC x:Q2 coverage

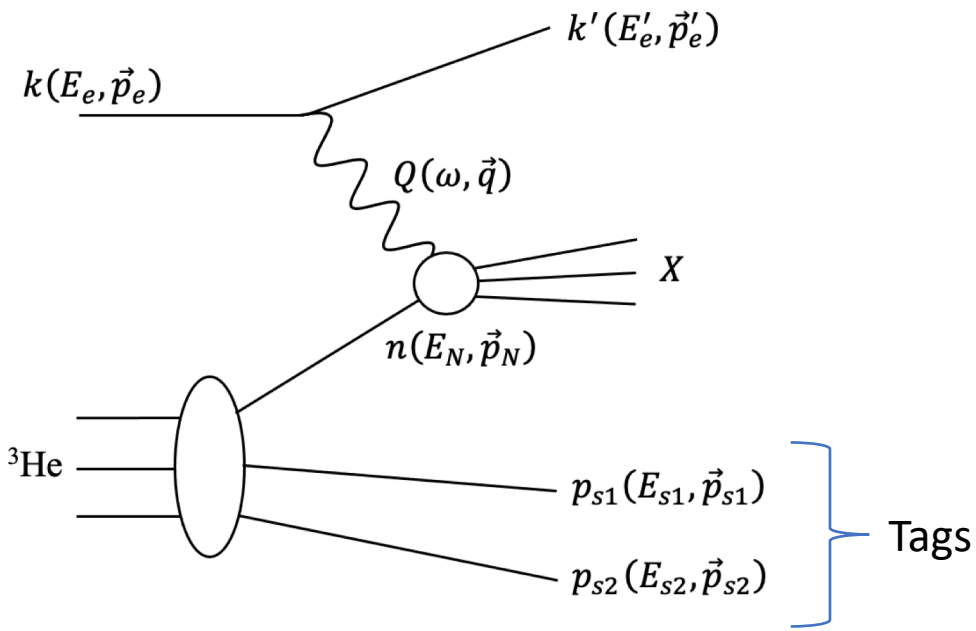


- Unique opportunity for tagging measurements
- Large coverage in x and Q2 (which is what we need for A1n)

EIC Yellow report

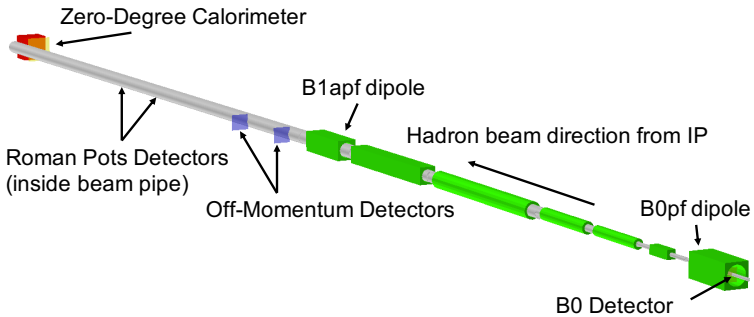
Arxiv: 2103.05419v2

Double spectators tagging from ^{3}He at EIC

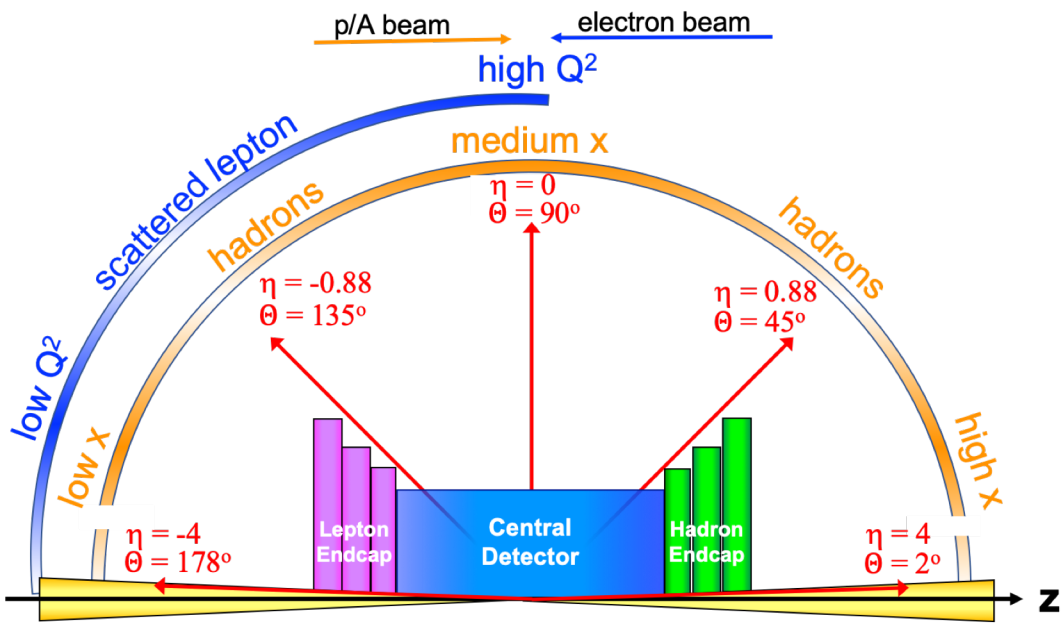


- Select the active nucleon in the reaction and break up channel by spectator tagging
- Suppress the contribution of non-nucleonic degree of freedom
- Access to an “effective” free neutron target

Double spectators tagging from ^{3}He at EIC



$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$



- Particles outside the main detector: θ < 35 mrad
- Protons and light nuclei: B0 tracker, Off-momentum detectors and Roman Pots
- Neutrons: Zero-Degree-Calorimeter (ZDC)

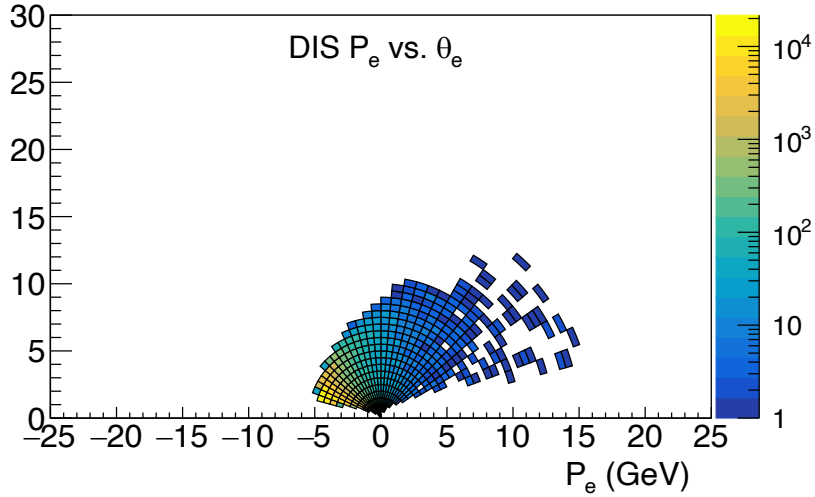
DIS ^{3}He(e, e'pp)X: Electron kinematics

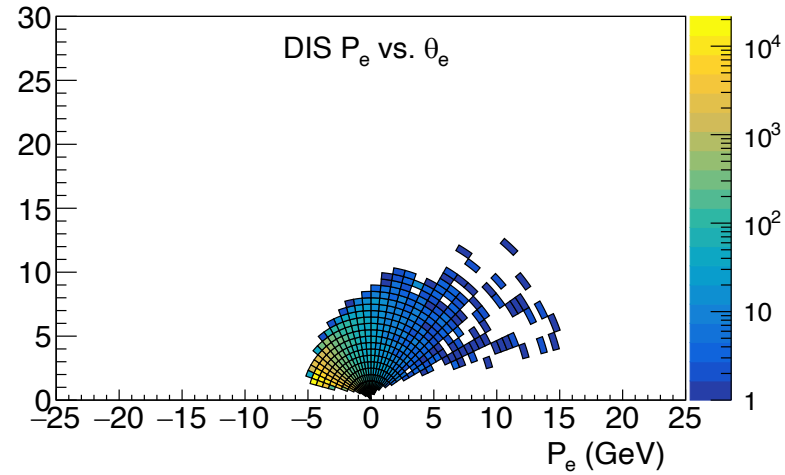
3BBU

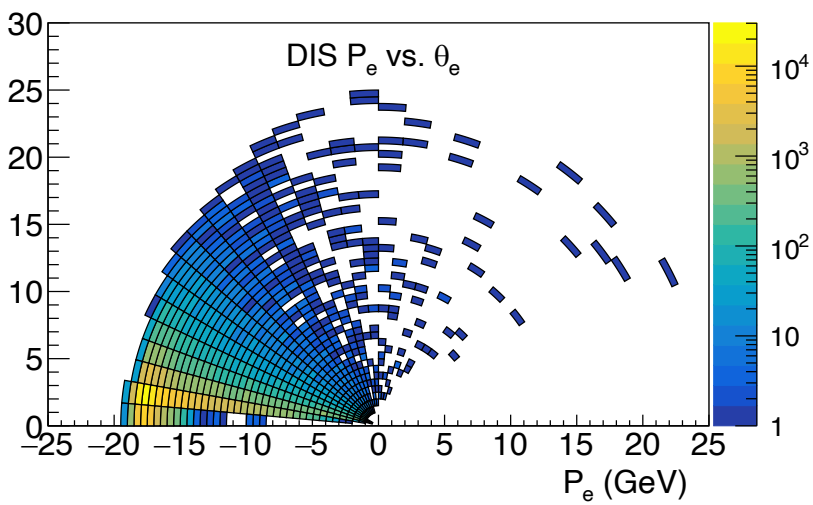
SRC

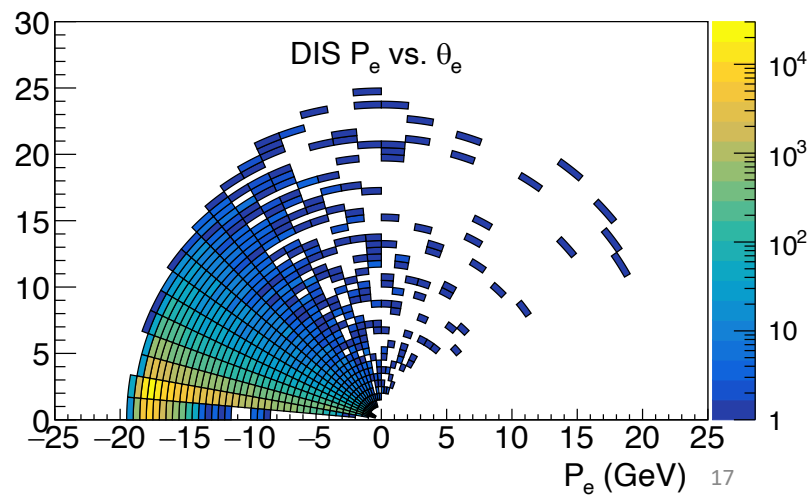
41x5

110x18





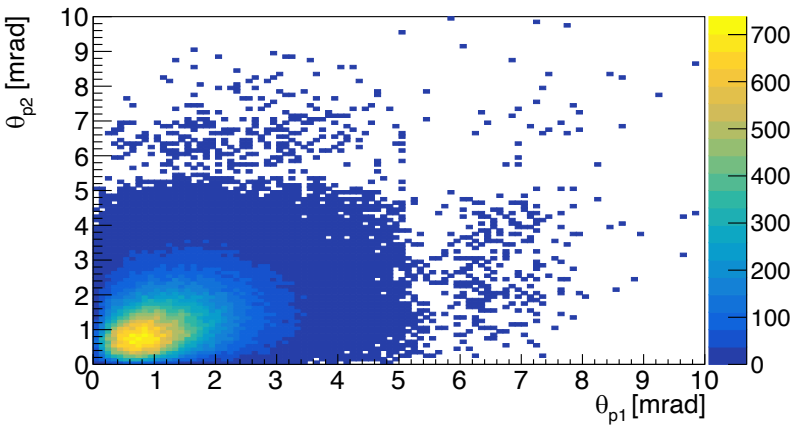


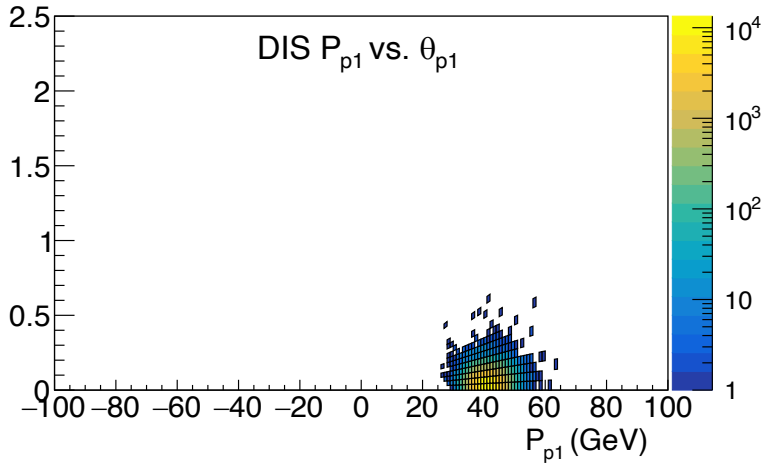


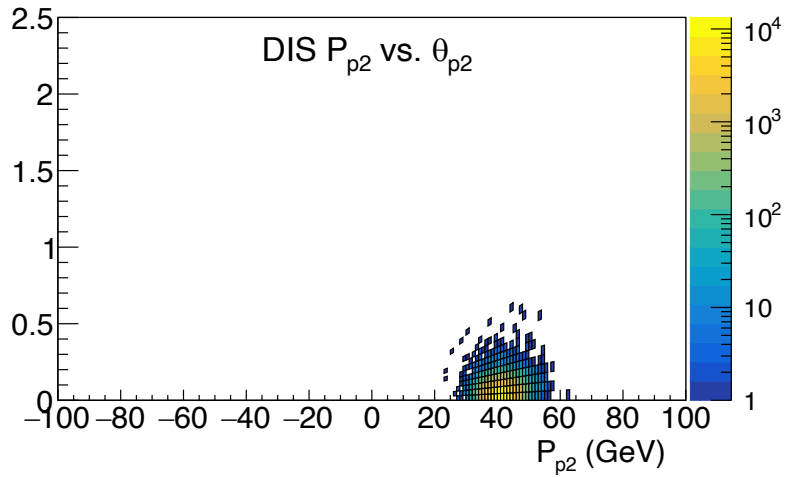
DIS ^{3}He(e, e'pp)X: Spectator protons

eN: 5 x 41

3BBU

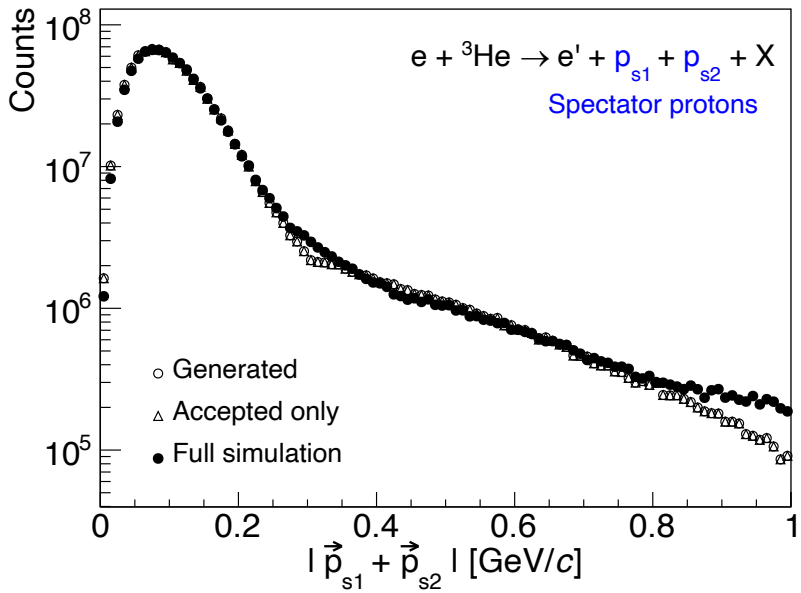




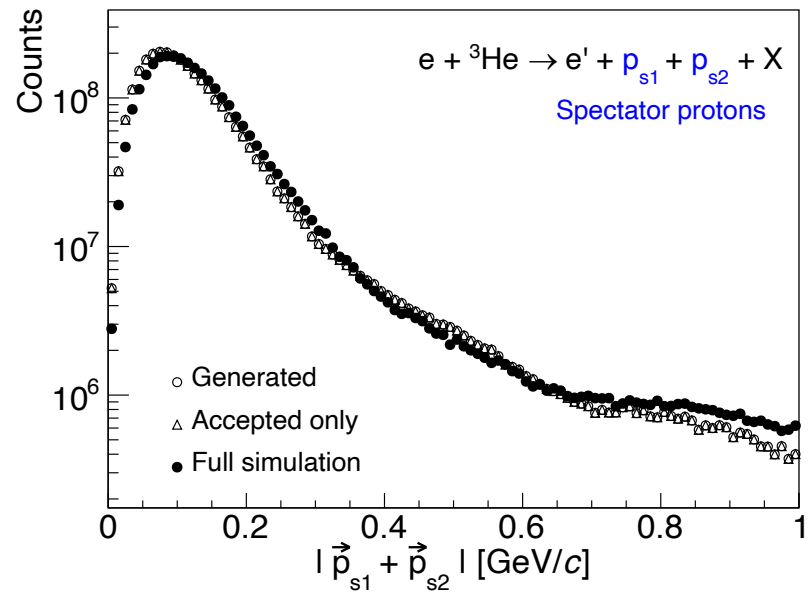


Effective "Free Neutron" target

IRF eN: 5x41



IRF eN:18x110

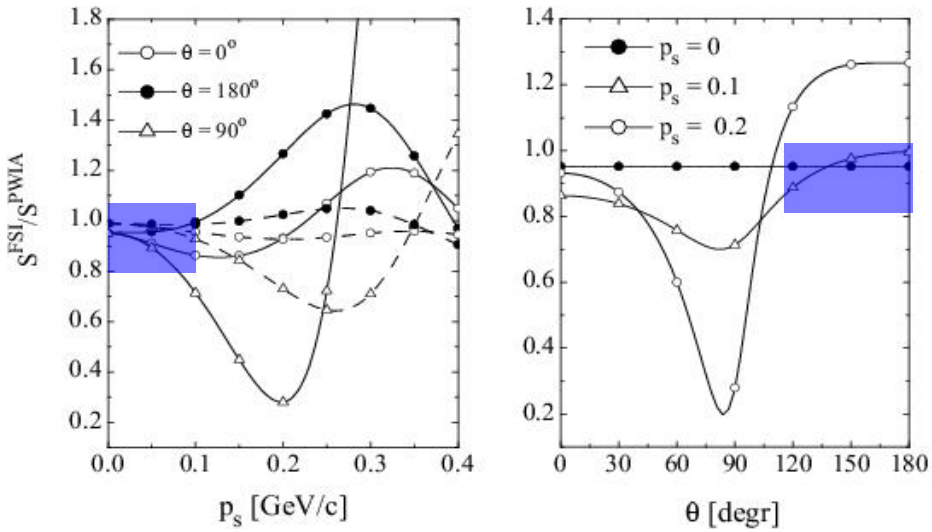


<u>Advantage of the double tagging measurements:</u>

- In Ion Rest Frame (IRF): Constraint the total momentum of two spectator nucleons to low momentum provides almost "Free neutron" target.
- Minimize the nuclear correction model effects.

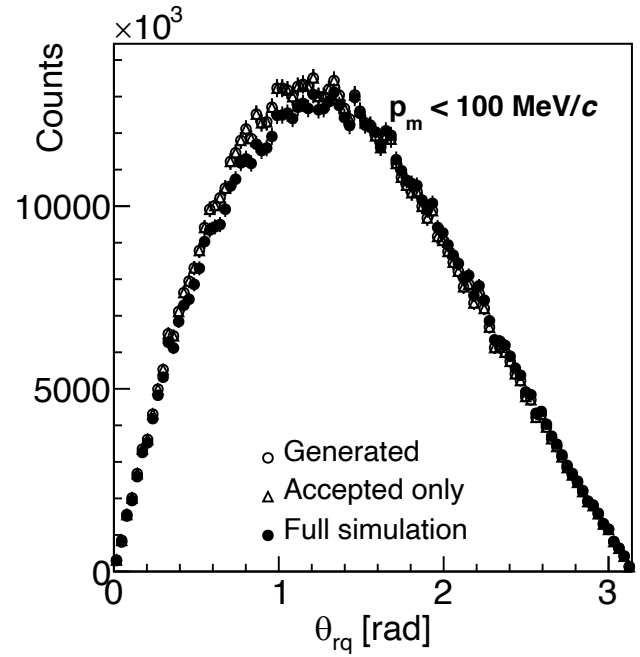
Angle distribution: θ_{rq}: FSI

Ciofi degli Atti and Kopeliovich, Eur. Phys. J. A17(2003)133

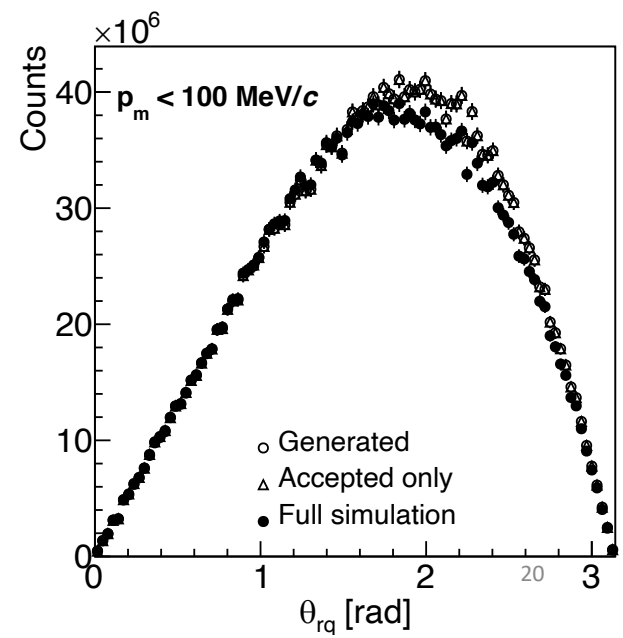


- Minimal FSI for low spectator momenta and large θ (blue bands)

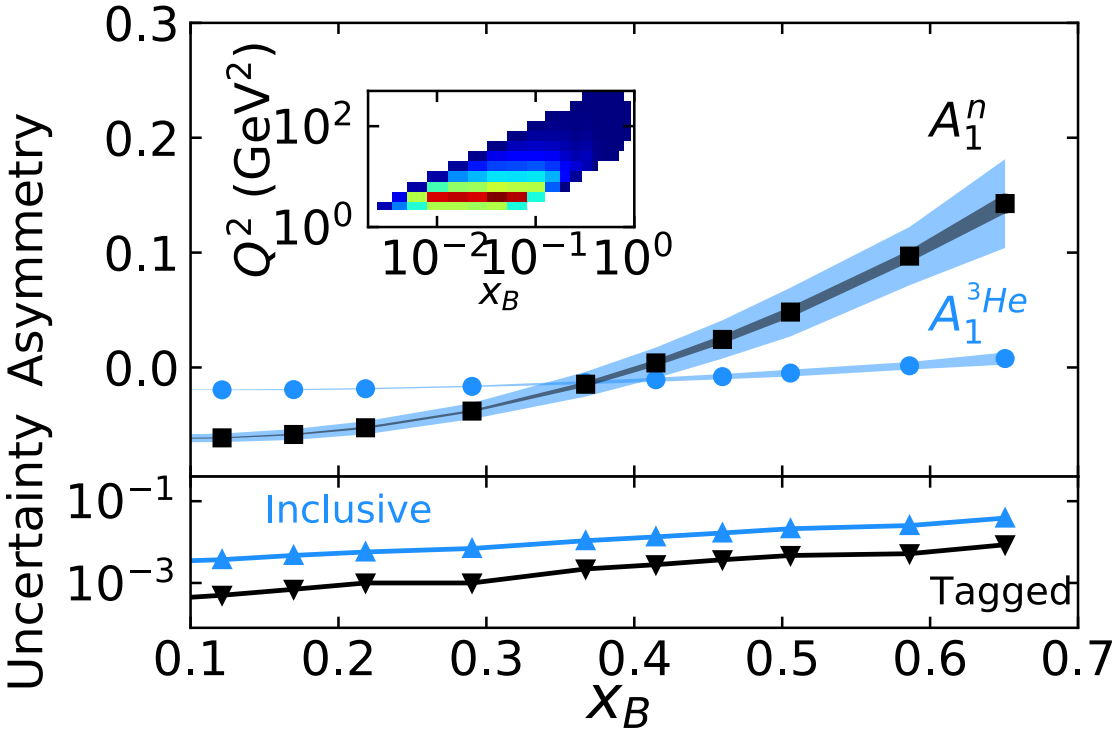
eN: 5x41



eN: 18x110



A1n projections



- Comparison of tagged (black) and inclusive (blue) measurement A1n extractions

Plot credit: Dien Nguyen

Summary

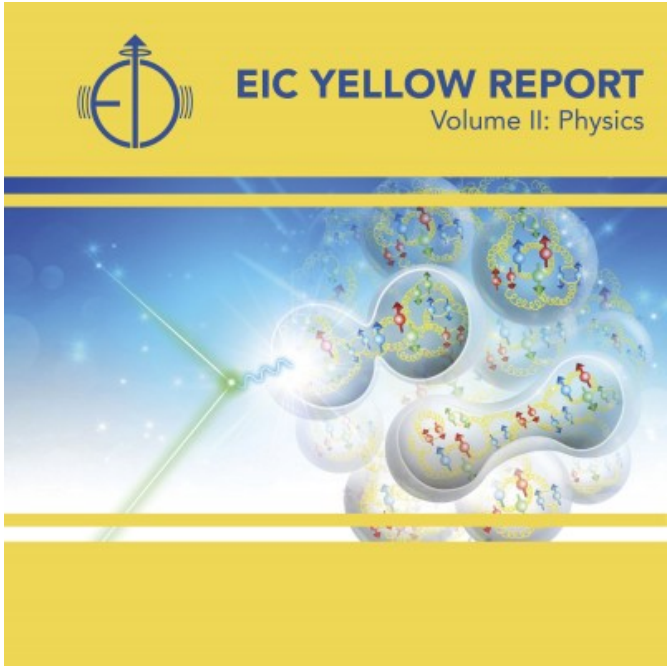
- A1n provides an excellent probe of the nucleon structure in the valence region elucidating on the role of valence quark OAM
- Recent measurements of A1n successfully completed in Hall C of Jefferson lab and offline analysis in progress.
- With the advent of EIC, A1n can be investigated by taking advantage of the far-forward detection capabilities
- Double spectator tagging method greatly reduces the systematic uncertainties by allowing us to select electron scattering DIS events on “free” neutron targets thereby reducing model dependence

In collaboration with I. Ivica, J. R. Pybus, A. Jentsch, E. P. Segarra, M. D. Baker, O. Hen, D. Higinbotham, R. Milner, D. Nguyen*, Z. Tu, J. Rittenhouse West

BACK UP

Event generator and processing

Section: 7.3.8



Generator:

- CLASDIS for inclusive and SIDIS based on PEPSI
- Unpolarized and polarized PDFs
- Generate event at fixed target frame
- No nuclear effect

➡ Boosted to collide frame

Fermi-correction:

- Using the light-cone spectral function
- Adding the motion of active nucleon
- Determine kinematic of spectators
- 2BBU, 3BBU, SRCs

EIC simulation: EIC smear and EIC root

- Acceptance and resolution

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