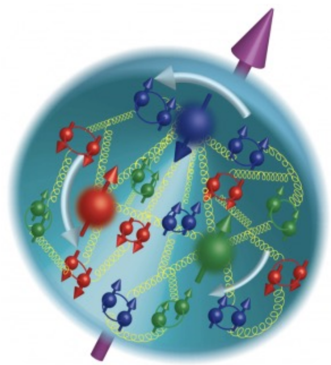
Jefferson Lab
Exploring the Nature of Matter

Neutron Spin study using CLAS12 and Polarized 3He target at Jlab

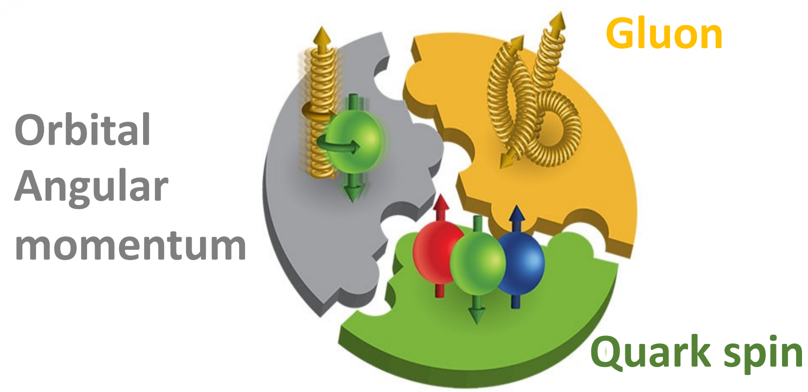
Dien Nguyen
Nathan Isgur Fellow at JLab

25th International Spin Symposium (SPIN 2023)

How do quarks and gluon carry nucleon Spin?



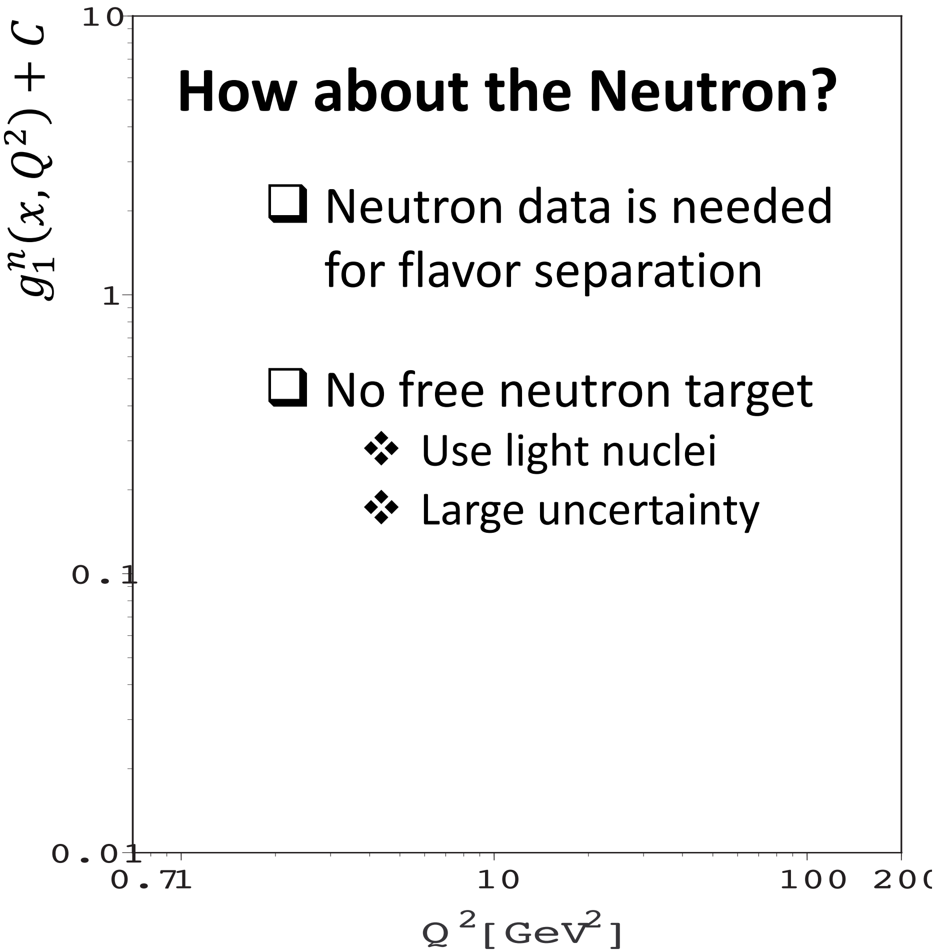
$$S_z^N = S_z^q + S_z^g + L_z^{q,g} = \frac{1}{2}$$



Nucleon spin:

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

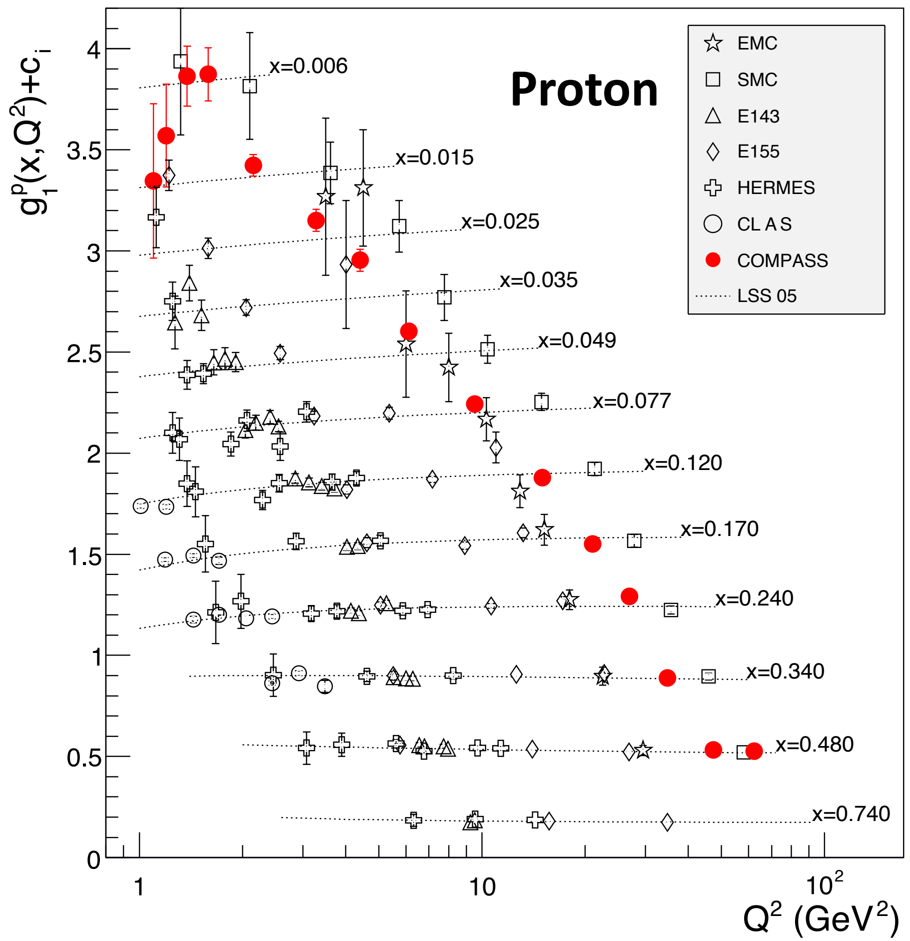
Nucleon Spin measurements



How about the Neutron?

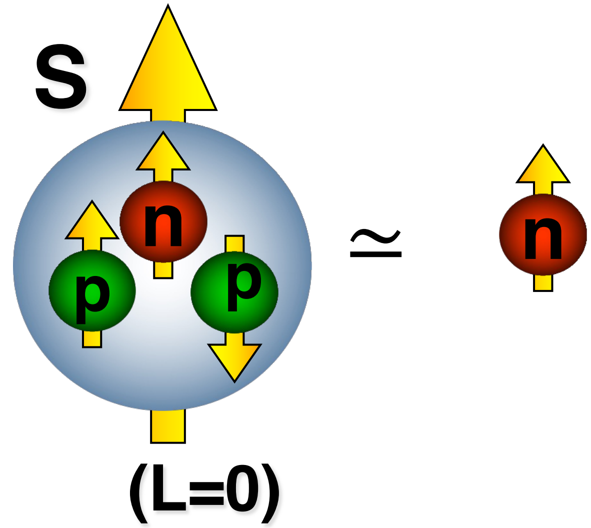
- Neutron data is needed for flavor separation
- No free neutron target
  - Use light nuclei
  - Large uncertainty

Christine A. Aidala RMP (2013)



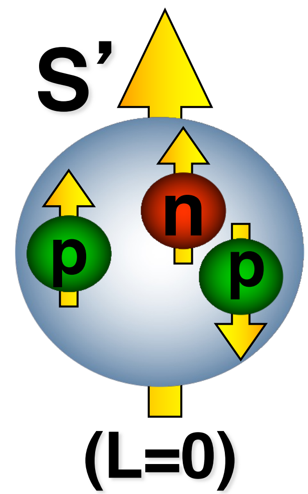
^{3}He ground-state wave-function

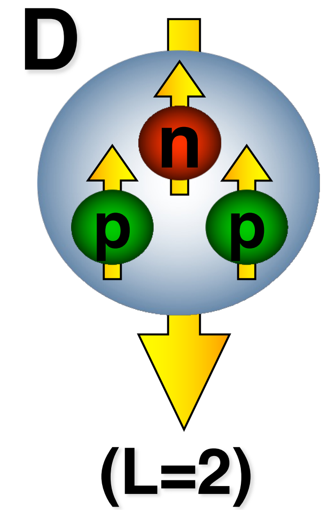
1.) **Spatially symmetric state S (90%):**
Spin is dominated by spin of neutron, thus can be used as an **effective polarized neutron target**:



$$\frac{\mu_{^3\mathrm{He}}}{\mu_\mathrm{n}} = \frac{-2.131}{-1.913} \approx 1$$

2.) **State D (8%):**
Generated by tensor component of NN force.





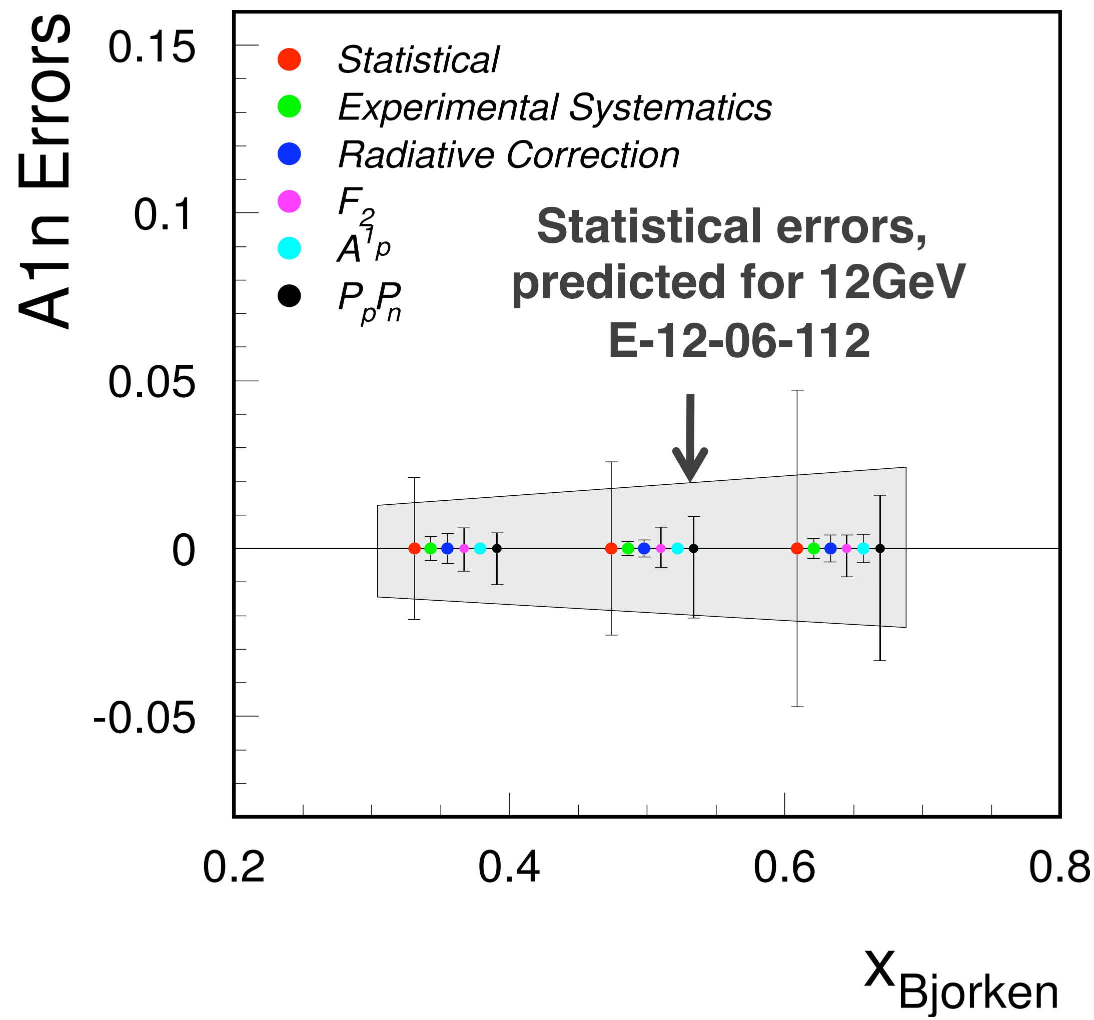
3.) **Mixed symmetry state S' (2%):**
Arises from differences between T=0 and T=1 forces and hence reflects (spin-isospin)-space correlations.

^{3}He Used As Effective Neutron Target

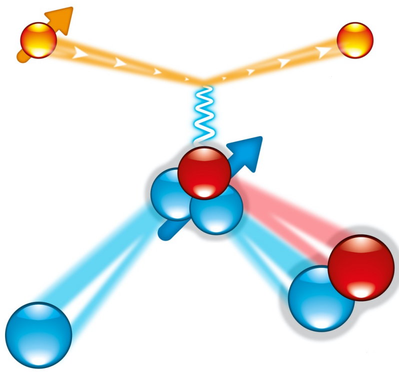
For Example: Measurements of DIS neutron spin asymmetry A_1^n

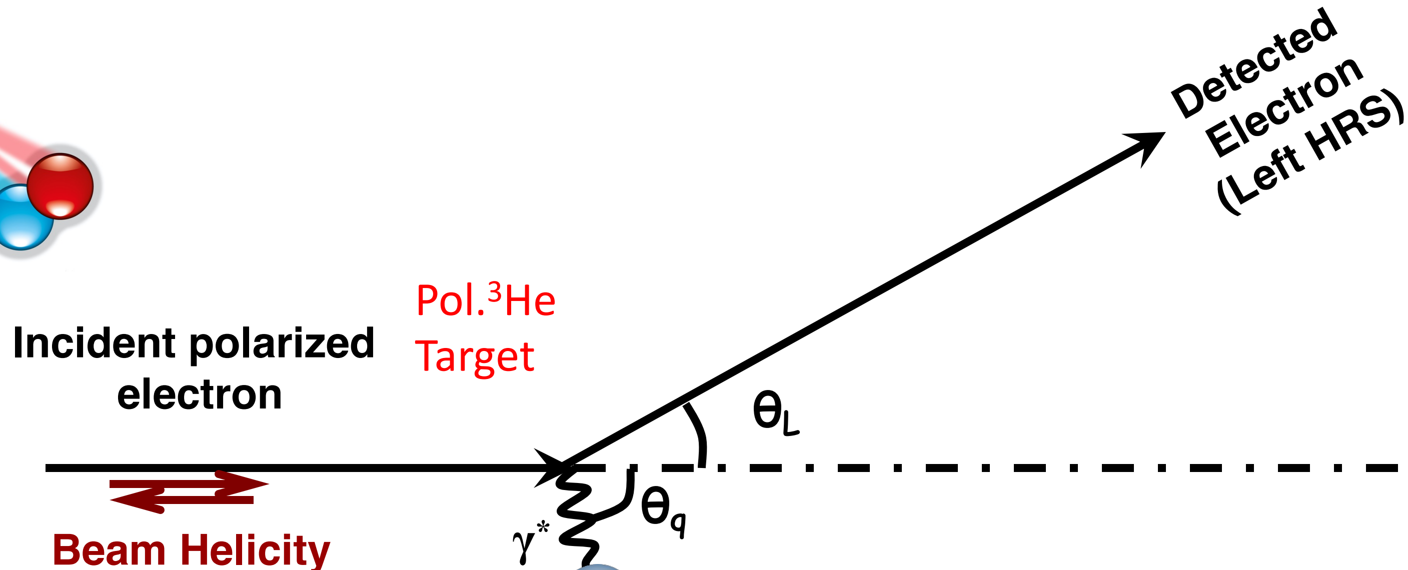
X. Zheng *et al.*, Phys .Rev. Lett. **92** (2004) 012004 and Phys. Rev. C70 (2004) 065207

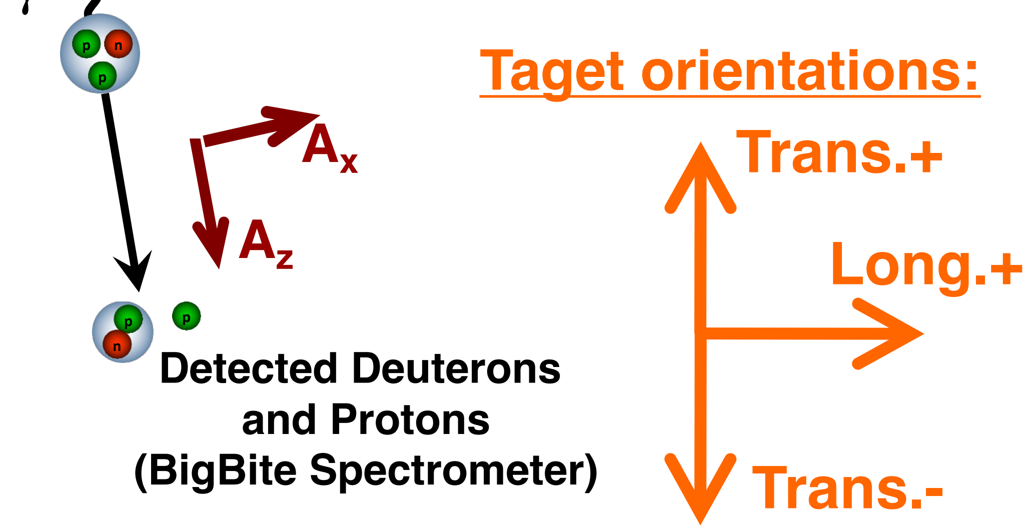
- Main source of the systematic error is uncertainty of the proton and neutron polarization.
- For 12 GeV data, a better understanding of ^{3}He needed.
- Also impacts form factor and structure function experiments that use polarized ^{3}He.



Experiment E05-102 @ Hall-A







Kinematic Settings:

E_{beam} = 2.425 GeV

θ_L = 12.5, 14.5 deg

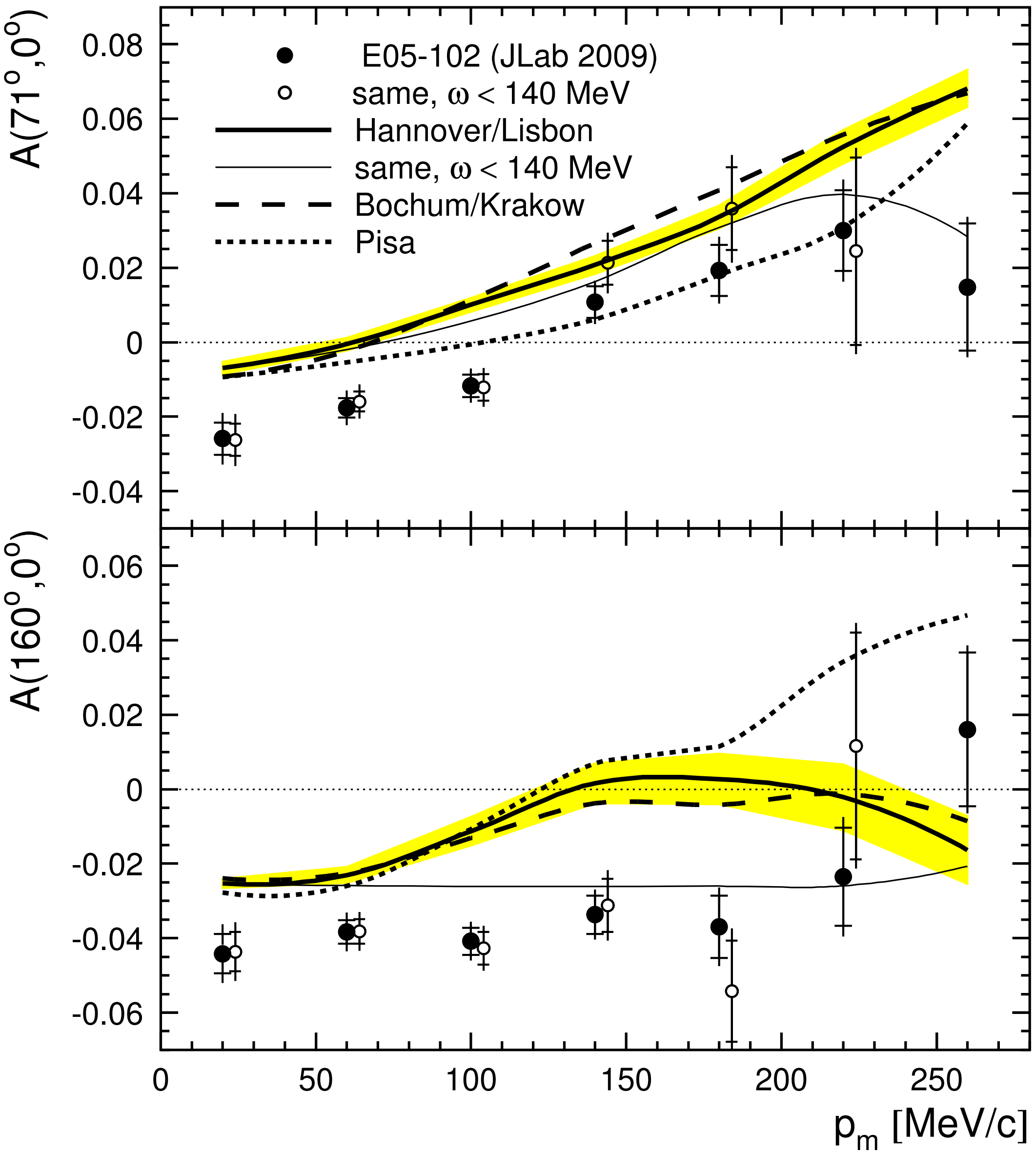
θ_{BB} = -75.0, -82.0 deg

Q^2 = 0.25 and 0.35 $(GeV/c)^2$

Results for $^3\vec{He}(\vec{e},e'd)p$

M. Mihovilvic *et al.,* Phys. Rev. Lett. **113** (2014) 232505

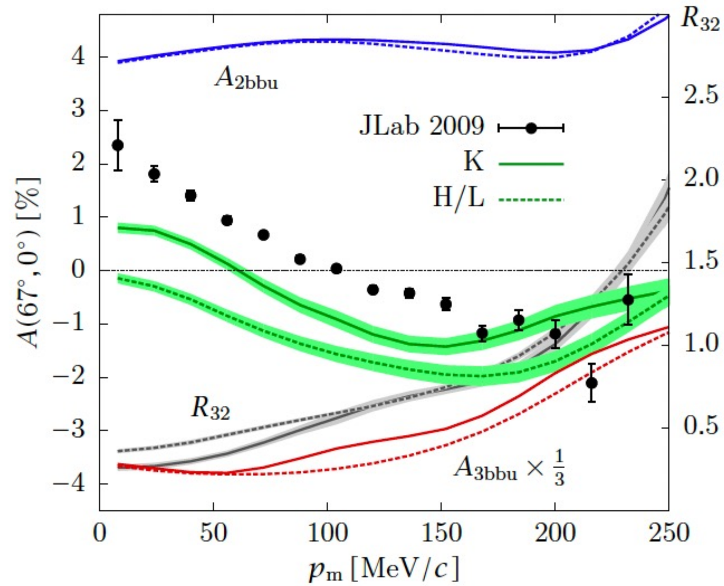
- Measured asymmetries are of order of 1%.
- Theories reasonably well describe behavior of the data. Hannover (Bonn), Bochum (AV18), Pisa (AV18 + Urbana IX)
- Calculations underestimate the measured asymmetries.
- **Hard to determine what is causing the discrepancy: FSI, SRC, 3NF and/or ?? but clearly state-of-the-art calculations don't agree with the data.**

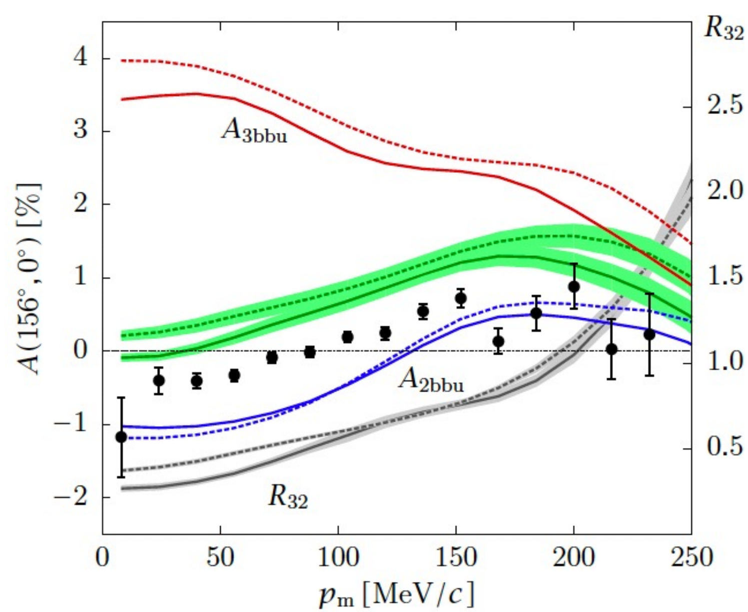


Results for $^3He(e,e'p)X$

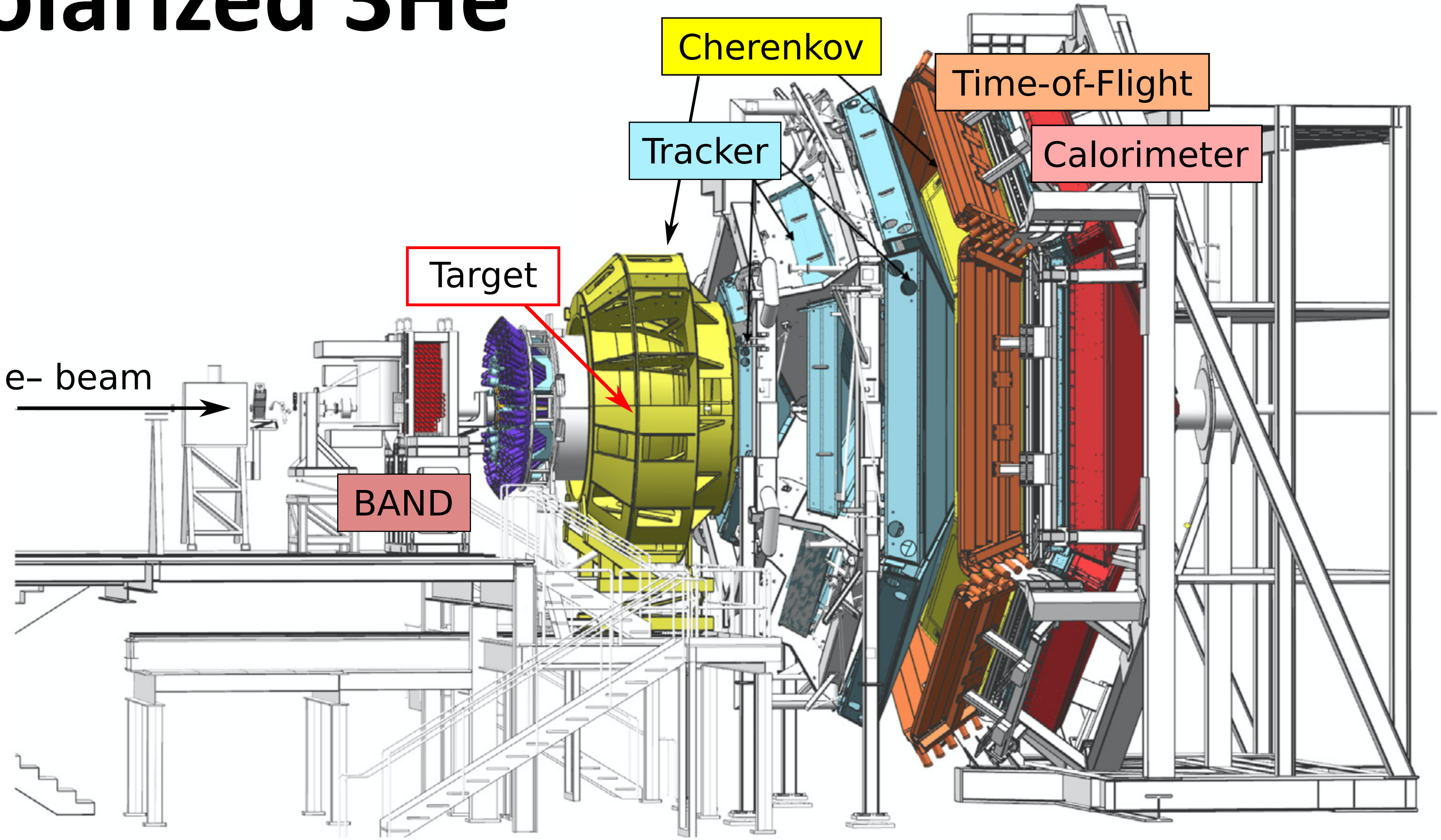
M. Mihovilovic *et al.*, Phys. Lett. B **788** (2019) 117.

- Theories from Krakow-Bochum (AV18) and Hanover-Lisbon (Bonn).
- Theory qualitatively describes behavior of the data.
- A_{2BBU} and A_{3BBU} with opposite signs,
- 2BBU and 3BBu cancelation but 3BBU is dominant
- We still don't know 3He ground-state well enough.





Next Generation Experiment with CLAS12 and Polarized 3He



❑ CLAS12

- ❖ Large acceptance, high luminosity, Excellent particle ID
- ❖ Multi-particle final-state response

❑ Polarized 3He target

- ❖ Challenge: Polarization in 5T solenoid field

See James Maxwell's Talk

Next Generation experiments with CLAS12

Letter of intend

- Asymmetry in Quasi-elastic
  - Better understanding of ground-state of pol 3He

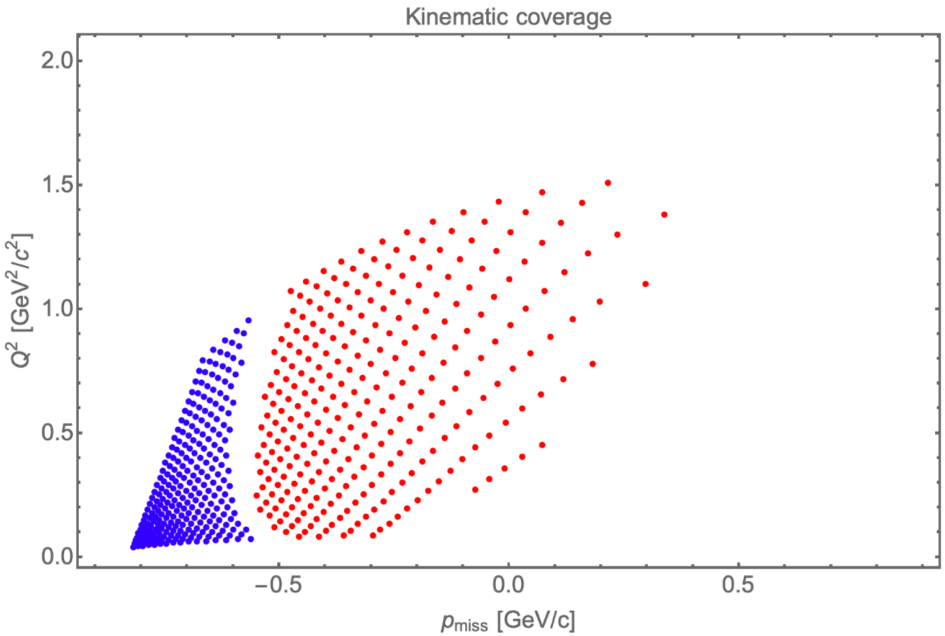
Spoke-person: D. Nguyen, M. Mihovilovič, S. Širca, O. Hen and D. Higinbotham

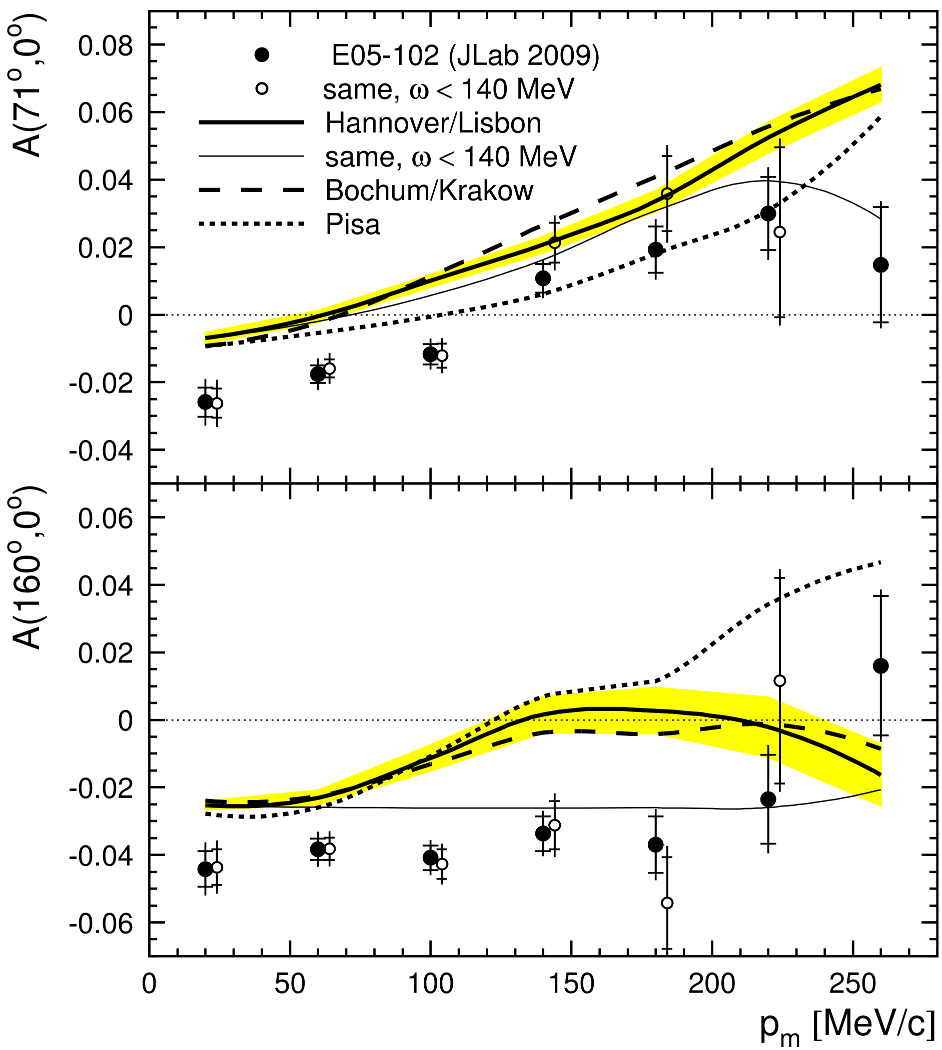
Conditional approval with A- rating

- Longitudinally Spin-dependent DIS and SIDIS
  - P_T-dependence of the neutron spin structure
  - Nuclear correction to SIDIS

Spoke-person: H. Avakian, J. Maxwell, R. Milner, D. Nguyen

CLAS12 ^{3}He(e,e'd/p) Kinematic Coverage





- Extensive kinematics coverage allows us to disentangle reaction mechanisms from initial-state effects to understand what ingredient(s) need to be improved.
- This is important for all experiments that wish to use polarized 3He as an effective neutron target.
- LOI was submitted to JLab PAC, The Full proposal is under development

DIS & SIDIS measurements ($\pi^{+/-}, K^{+/-}$)

High precision 5-D (x, z, P_T, Q^2, ϕ_h) on Neutron

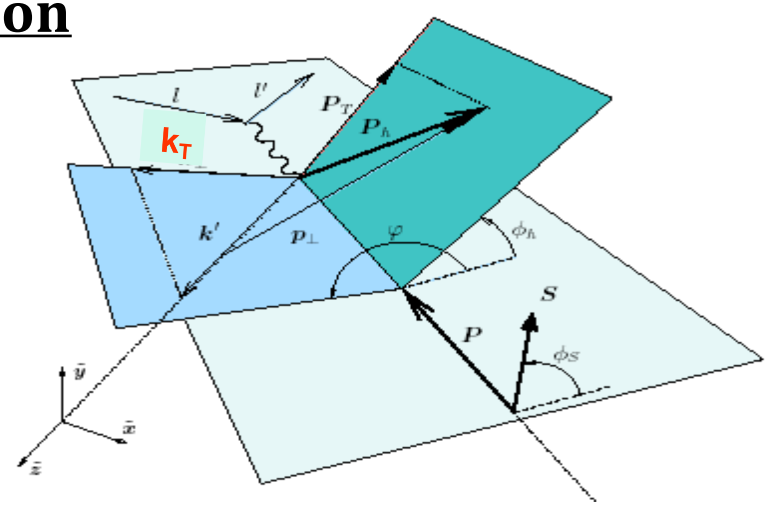
$Q^2 = (k - k')^2 \qquad z = (qP_h)/(qP)$

$x = Q^2/(2qP)$

P_T: Hadron Transvered momentum

ϕ_h: Angle between lepton and hadron planes

k_T: Quark Transvere momentum



Kinematic coverage of this proposal:

$0.05 < x < 0.7 \quad 1 < Q^2 < 9$ (GeV/c)^2

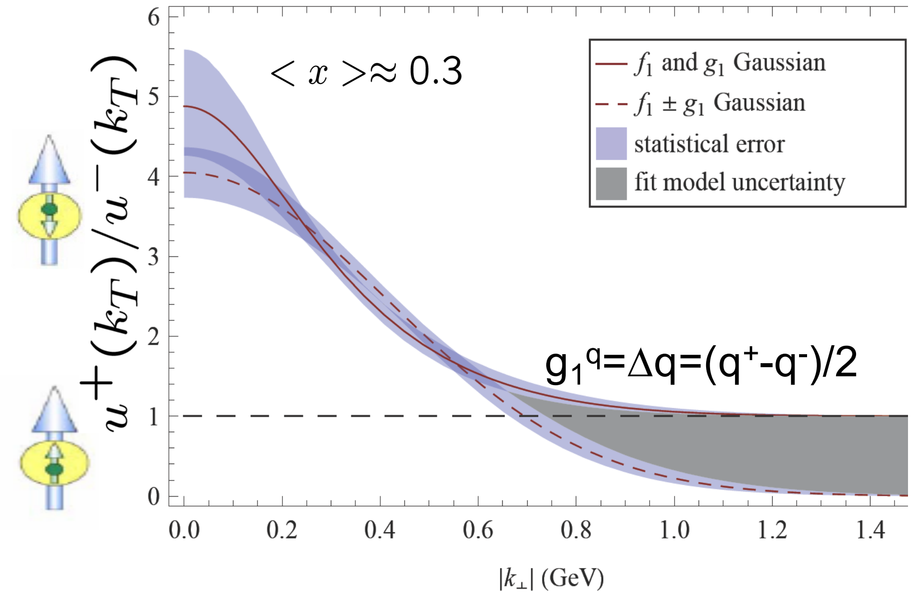
$0.2 < z < 0.9 \quad 0 < P_T < 1.3$ (GeV/c)

$\sigma = F_{UU} + P_t F_{UL}^{\sin\phi} \sin 2\phi + P_b F_{LU}^{\sin\phi} \sin\phi \ldots$

N \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1 \; h_{1T}^\perp$

Transverse momentum of hadrons in SIDIS provides access to orbital motion of quarks

Spin and flavor dependence of k_T distribution



M.Anselmino et al **hep-ph/0608048**

$$f_1^q(x, k_T) = f_1(x) \frac{1}{\pi \mu_0^2} \exp\left(-\frac{k_T^2}{\mu_0^2}\right)$$

$$g_1^q(x, k_T) = g_1(x) \frac{1}{\pi \mu_2^2} \exp\left(-\frac{k_T^2}{\mu_2^2}\right)$$

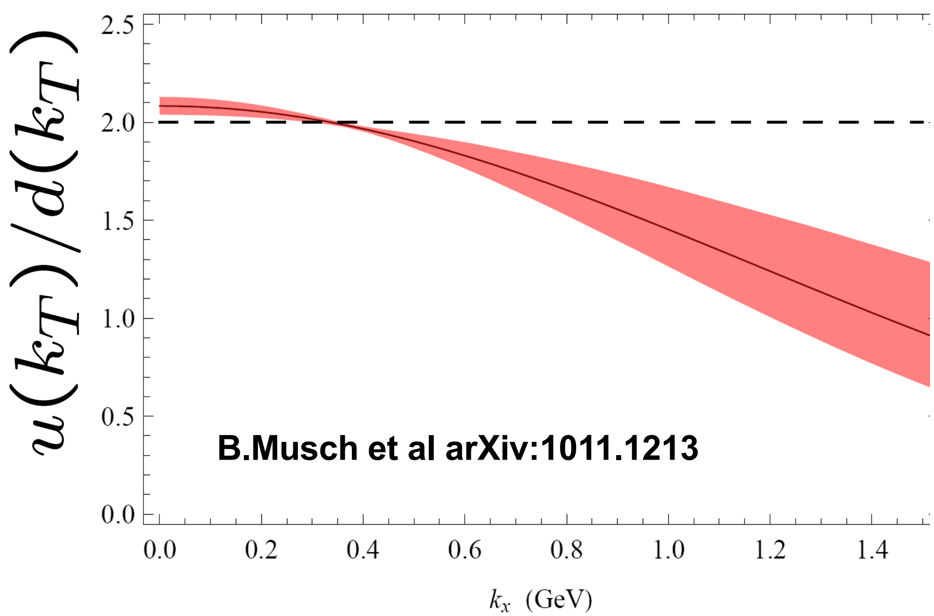
$$D_1^q(z, p_T) = D_1(z) \frac{1}{\pi \mu_D^2} \exp\left(-\frac{p_T^2}{\mu_D^2}\right)$$

$F_{LL} \sim g_1 * D_1$ *and* $F_{UU} = f_1 * D_1$

$F_{UL} \sim h_{1L} * H_1 * \sin(2\phi)$

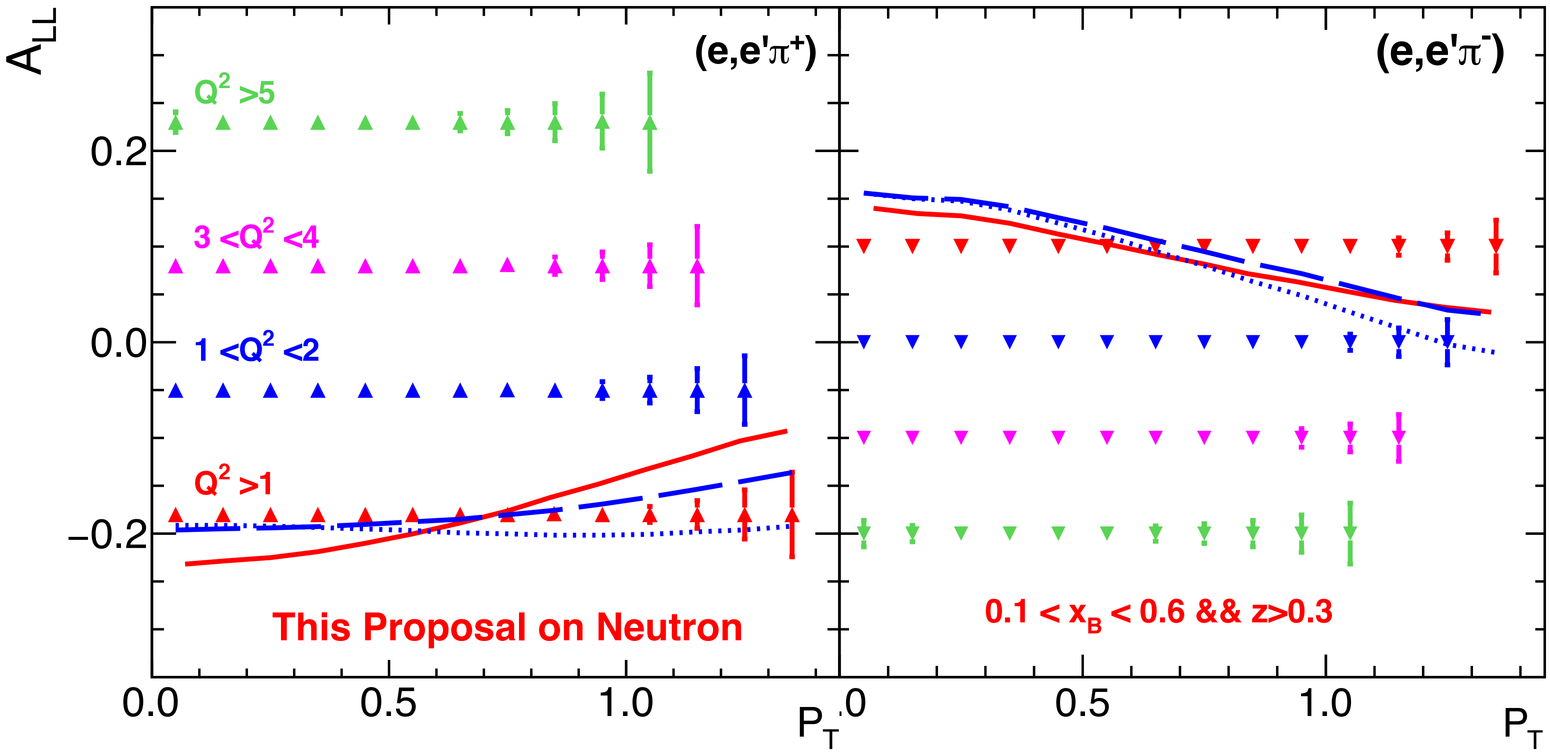
$$A_{LL} \sim \frac{F_{LL}}{F_{UU}} \text{ and } A_{UL} \sim \frac{F_{UL}}{F_{UU}}$$

P_T dependence of the double spin asymmetry provides access to k_T dependence of polarized quarks



Charged Pion P_T projections

P_T dependent projection for different bin in Q^2

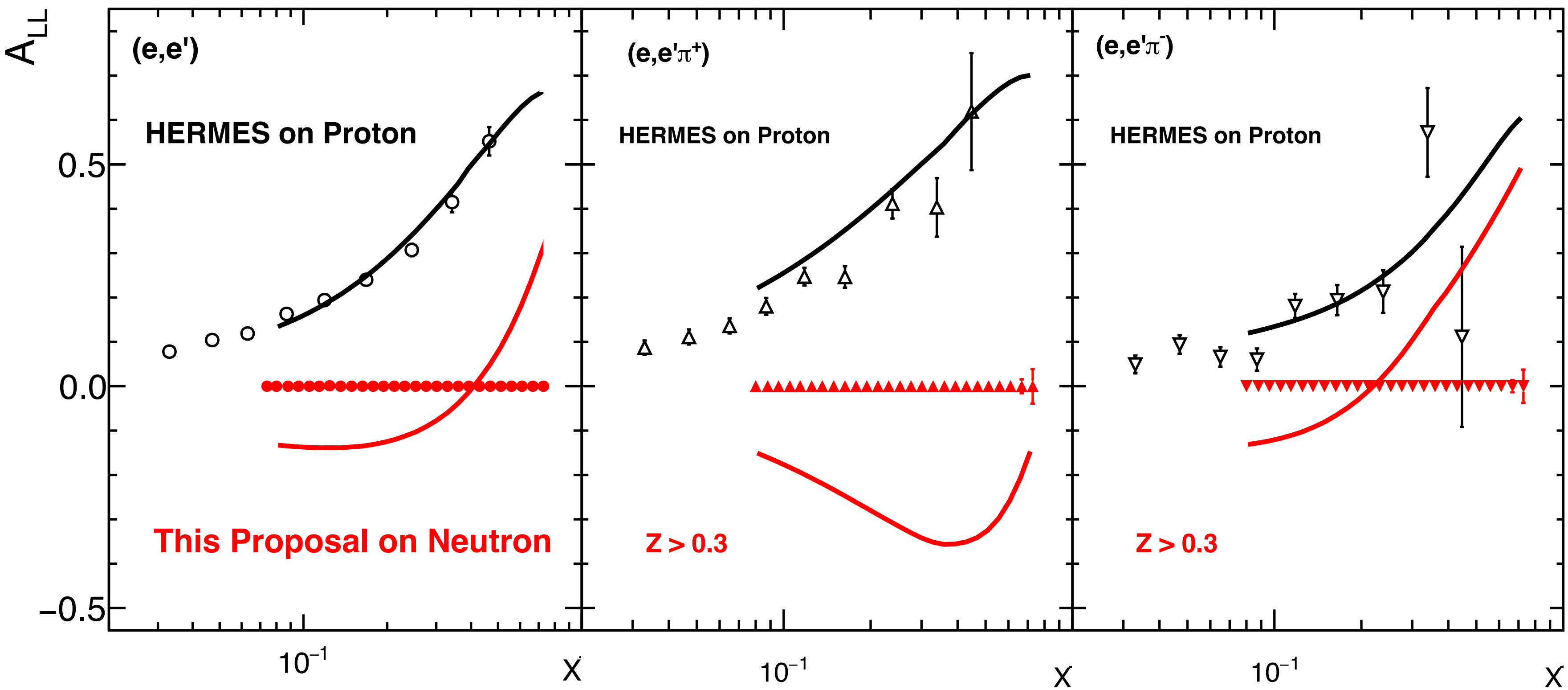


- ❑ Measure P_T dependence: providing access to spin and flavor dependence of k_T distribution of valence quarks

- ❑ Measure in different Q^2 bins: test the validity of underline theory (P_T << Q)

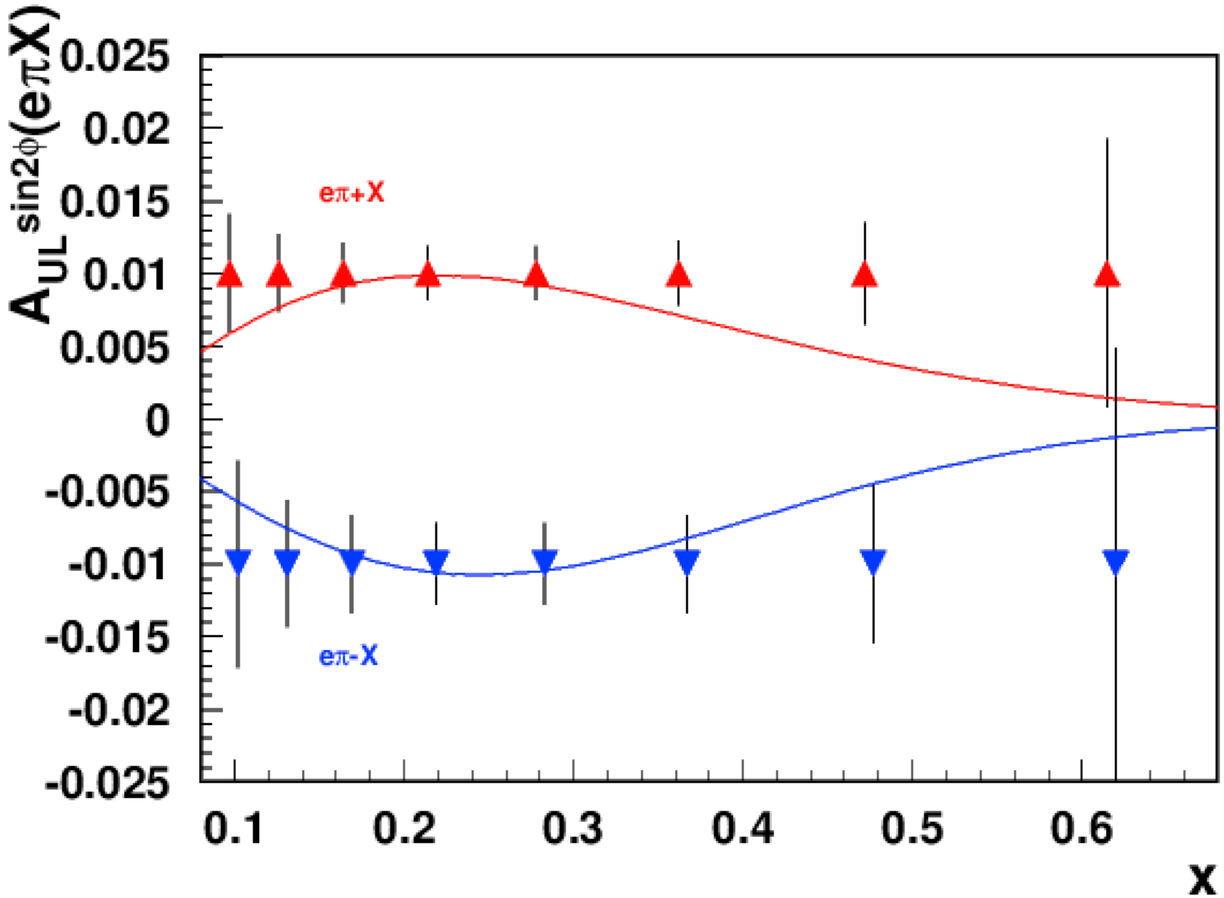
Proposal projection measurements

x dependent projection

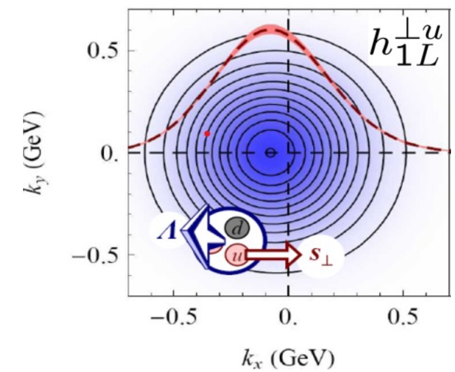


- ❑To study x dependence of $g_1(x, k_T)$ integration over full P_T and phi range
- ❑Data on A_{LL} provides important input in global analysis of polarized PDF
- ❑Statistics is significant to determine different dependence

Collins fragmentation: Longitudinal pol. target



Kotzinian-Mulders Asym



$$h_{1L}^{\perp} H_1^{\perp} \sin 2\phi$$

$$A_{UL}$$

- ❑ Provide access to transverse pol. quark in longitudinal pol. Neutron

- ❑ Provide access to Collins fragmentation function

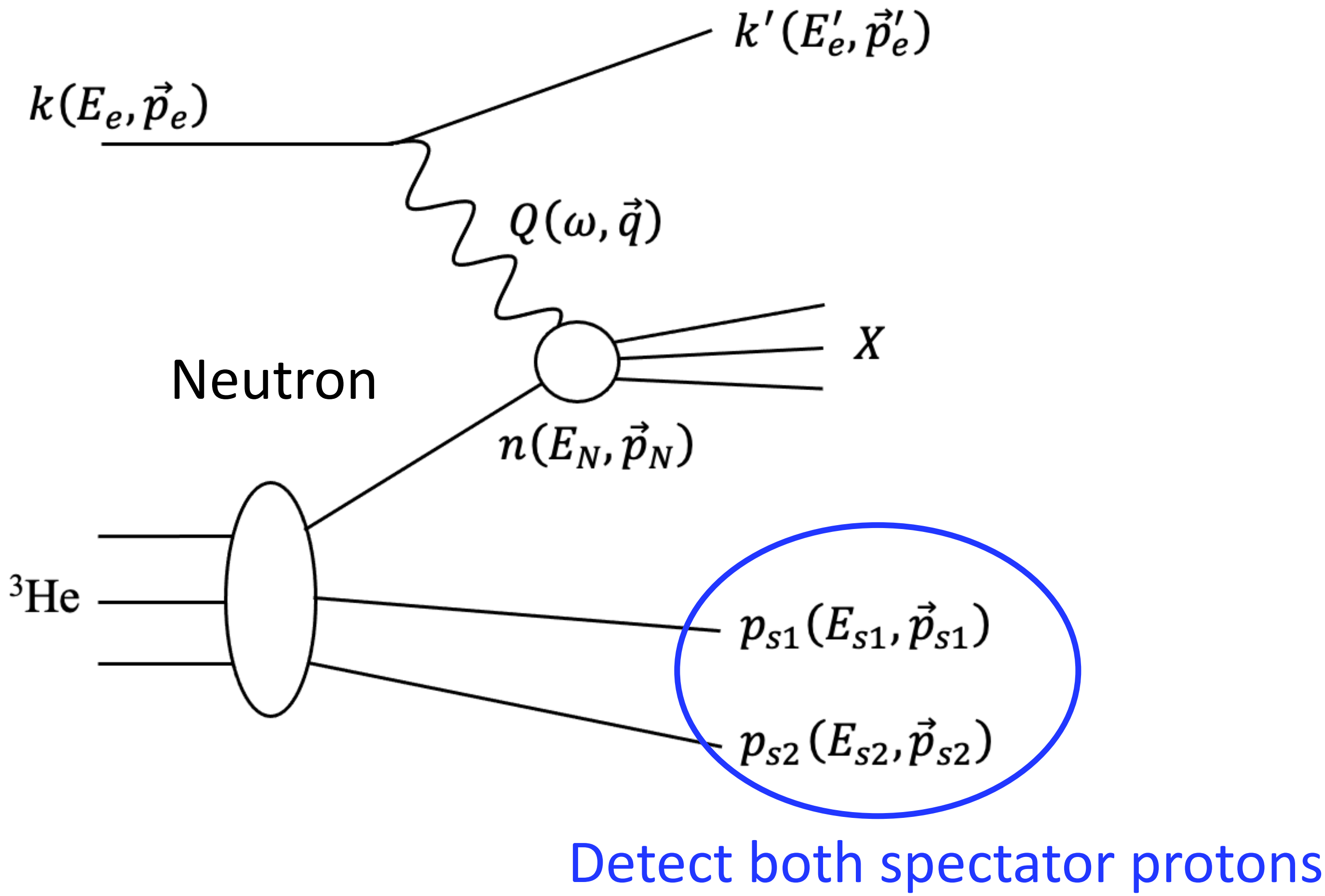
Moving forward to EIC

Polarized ^{3}He at EIC: Double spectator tagging

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

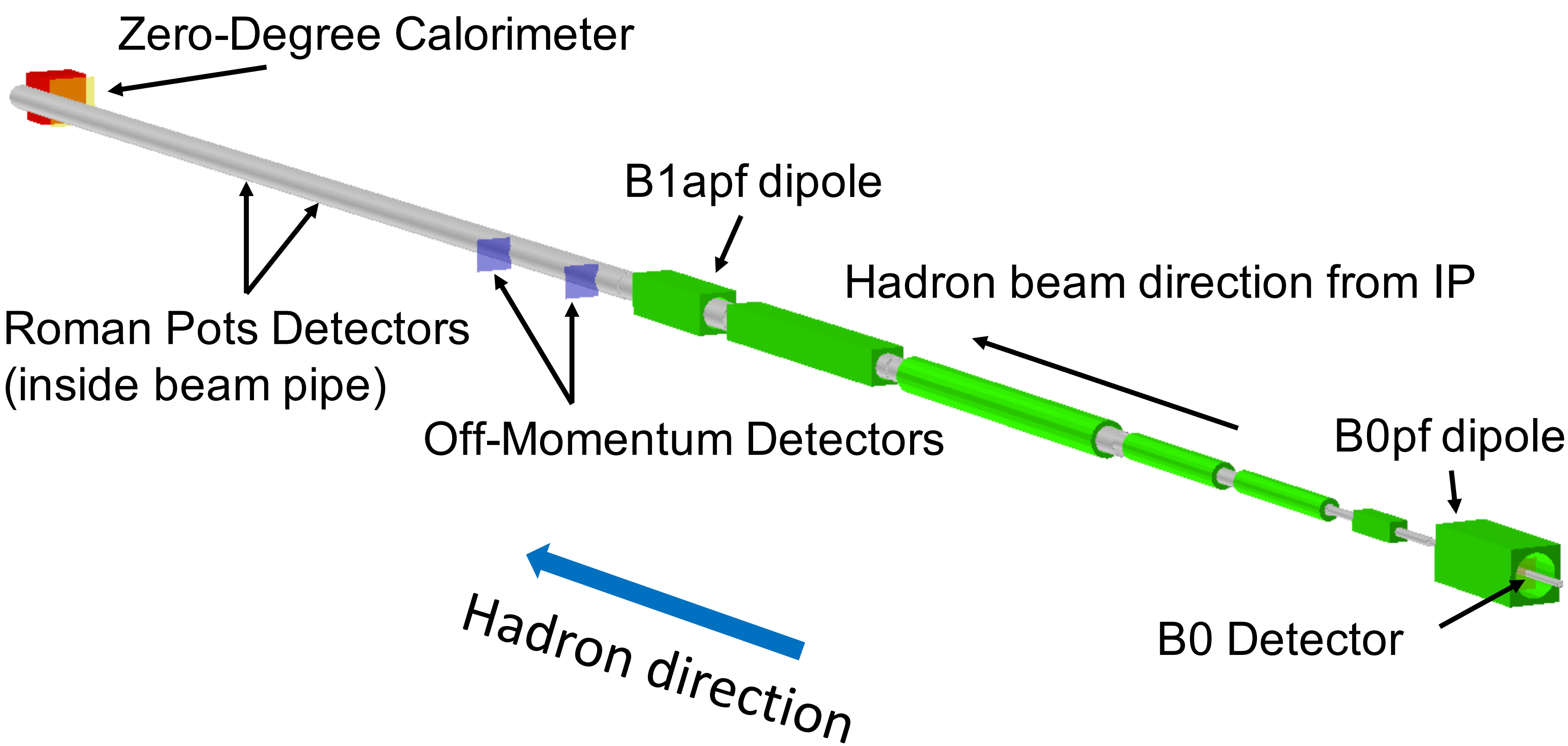
I. Friščić[a,b,1], D. Nguyen[a,b,1], J.R. Pybus[a,b], A. Jentsch[c], E.P. Segarra[a], M.D. Baker[d], O. Hen[a], D.W. Higinbotham[b], R. Milner[a], A.S. Tadepalli[b], Z. Tu[c], J. Rittenhouse West[b,e]

3He Spectator Tagging DIS at EIC



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

Forward Tagging possible @ EIC Far forward region

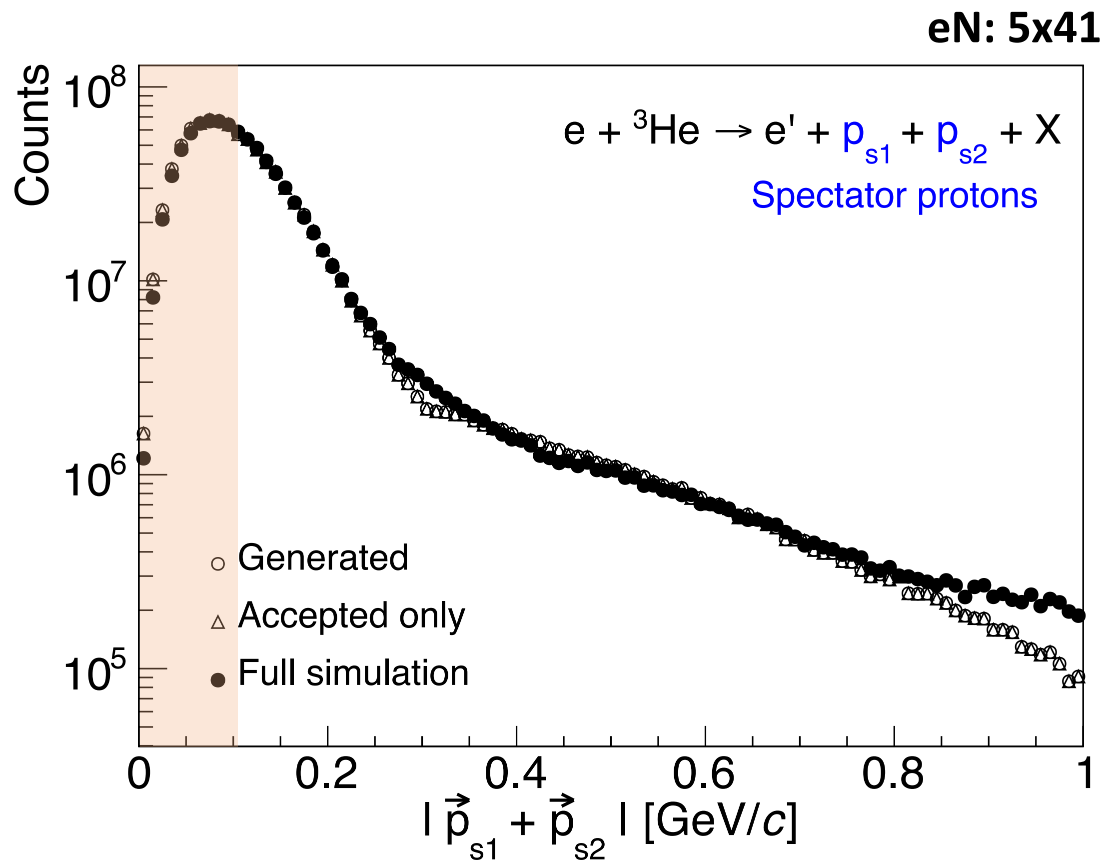


- ❑ Protons: B0, Off-momentum detectors and Roman Pots
- ❑ Neutron: Zero-Degree calorimeter

arXiv: 2103.05419

Spectator momentum at the Ion Rest Frame

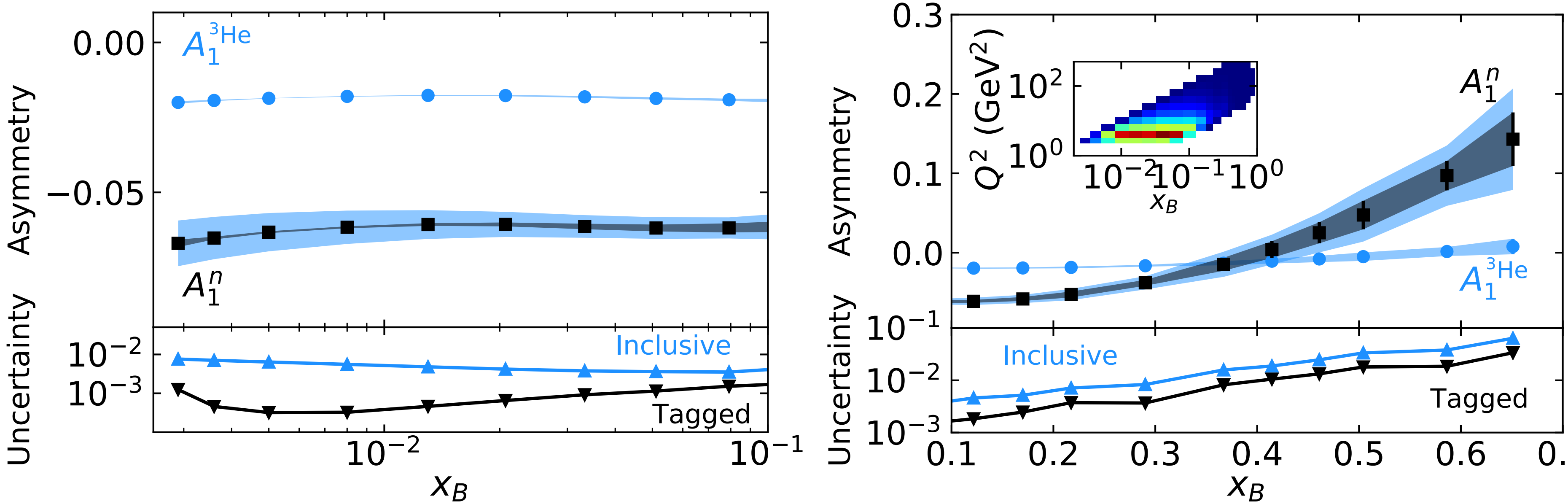
- Spectator protons
  = DIS off neutron
- low total spectator momentum
  = Effective "free neutron" target
- Minimal nuclear effects



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

Extracted A_1^n vs Double tagging A_1^n

See Xiachao's talk



❑ 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

❑ Different potential physics: SIDIS for TMD, 3D PDFs

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

Summary:

- Experimental Results clearly show a deficiency in our current understanding of the ground state of 3He.
- A better understanding of the ground state of 3He is important for neutron extraction
- The new pol. ^{3}He target and large acceptance of CLAS12 provide access to study ground-states
- SIDIS provides information on P_T dependence
- Many other potential physics: DVCS, Tag DIS and more
- EIC opens new opportunity with Tagging measurements