

MEP Fall 2025 Collaboration meeting

A=3 Physics Program with CLAS12 Hall B- Jlab

Dien Nguyen

Outline of the program

- ❑ Two components: Polarized ^3He And $A = 3$ (^3He , ^3H)

- ❑ Polarized ^3He :

- ❑ Experiment E12-20-005: DIS and SIDIS
 - ❑ Neutron spin structure
 - ❑ Nuclear correction to SIDIS

- ❑ $A = 3$ (^3He and ^3H)

- ❑ Experiment: E12-20-002: Quasi-elastic
 - ❑ (e,e'p): Few-Body nuclear Structure
 - ❑ (e,e'pN): SRCs
 - ❑ (e,e'): Neutron form factor

- ❑ Experiment: PR12-21-004: SIDIS

- ❑ Nuclear PDF, flavor-dependent EMC effect
- ❑ Nuclear TMD and Fragmentation Function

Polarized ^3He :

Experiment E12-20-005: DIS and SIDIS

Neutron spin structure

Nuclear correction to SIDIS

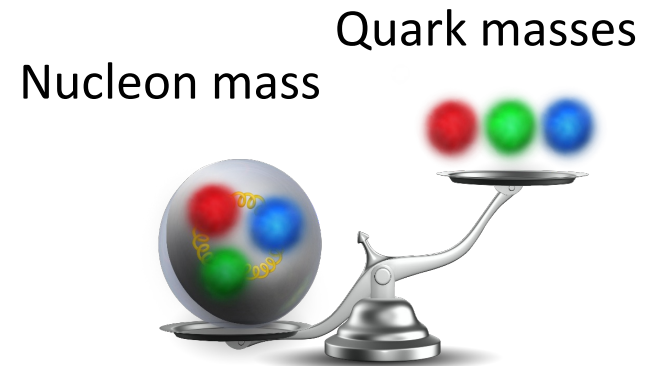
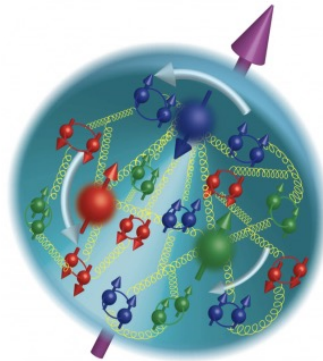
Experiment 12-20-002: Conditional approval, A- physics

Co-spokespeople: H. Avakian, J. Maxwell, R. Milner, D. Nguyen

How do quarks make nucleons?

Nucleon mass:

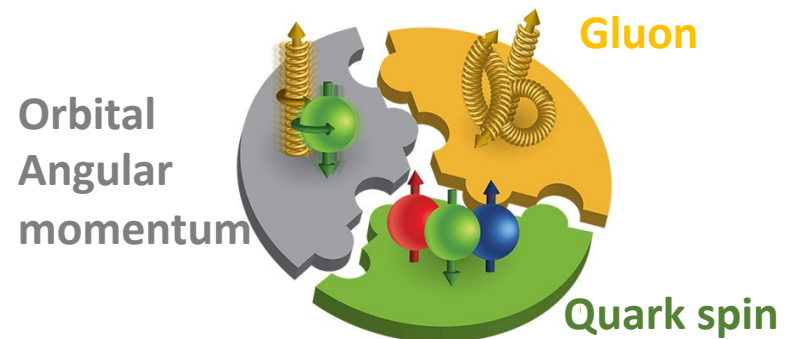
- ❖ Only ~1% due to quark masses
- ❖ Rest due to quark-gluon interactions



$$S_Z^N = S_Z^q + S_Z^g + L_Z^{q,g} = \frac{1}{2}$$

Nucleon spin:

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



Nucleon Spin

□ How do quark and gluon carry nucleon spin?

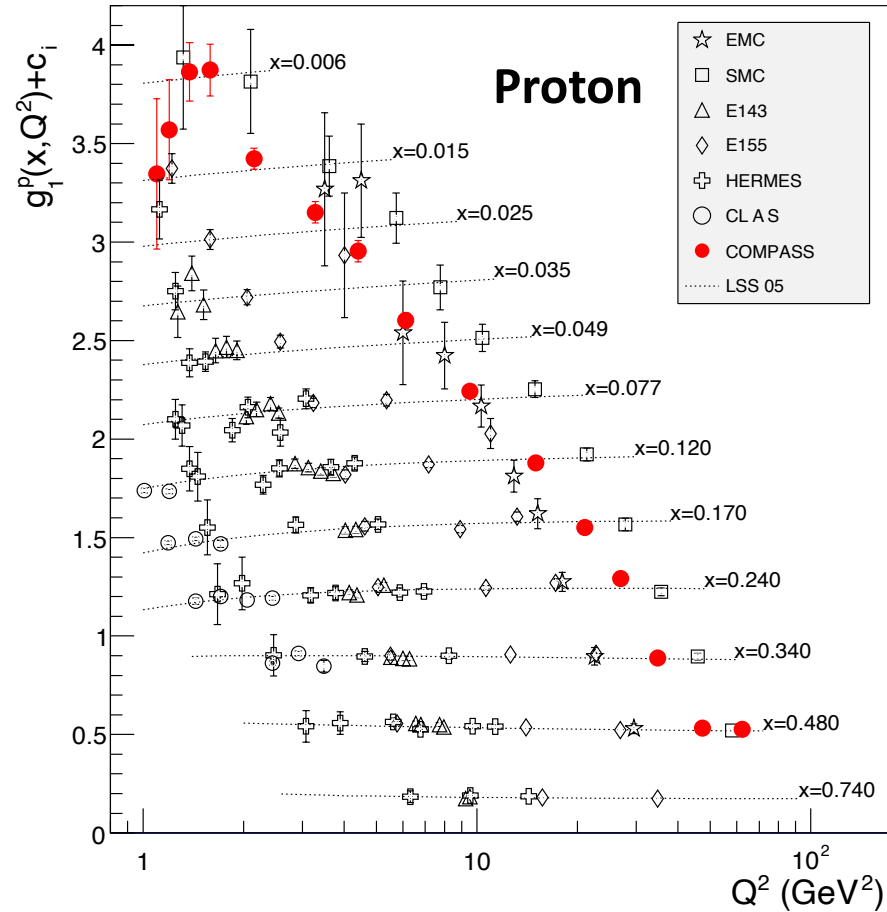
$$S_Z^N = S_Z^q + S_Z^g + L_Z^{q,g} = \frac{1}{2}$$

□ Spin Structure function

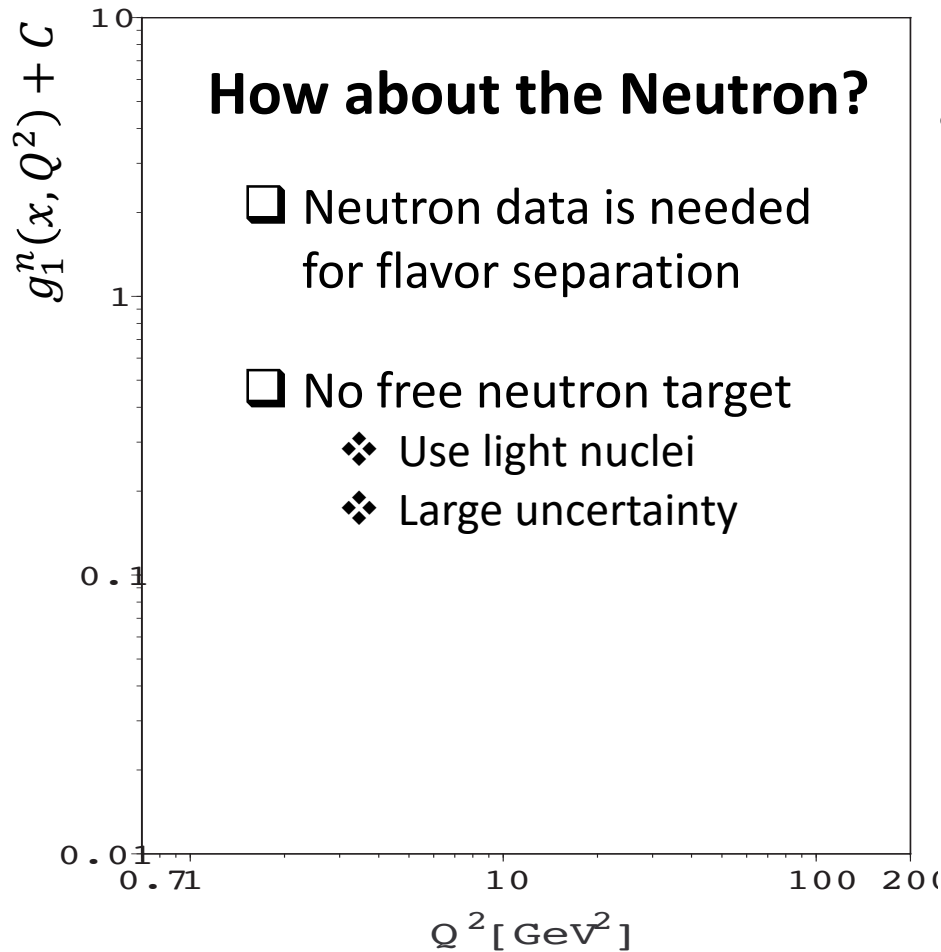
$$g_1(x, Q^2) = \frac{1}{2} \sum_i e_i^2 [q_i^\uparrow(x, Q^2) - q_i^\downarrow(x, Q^2)]$$

$$S^N = \int g_1$$

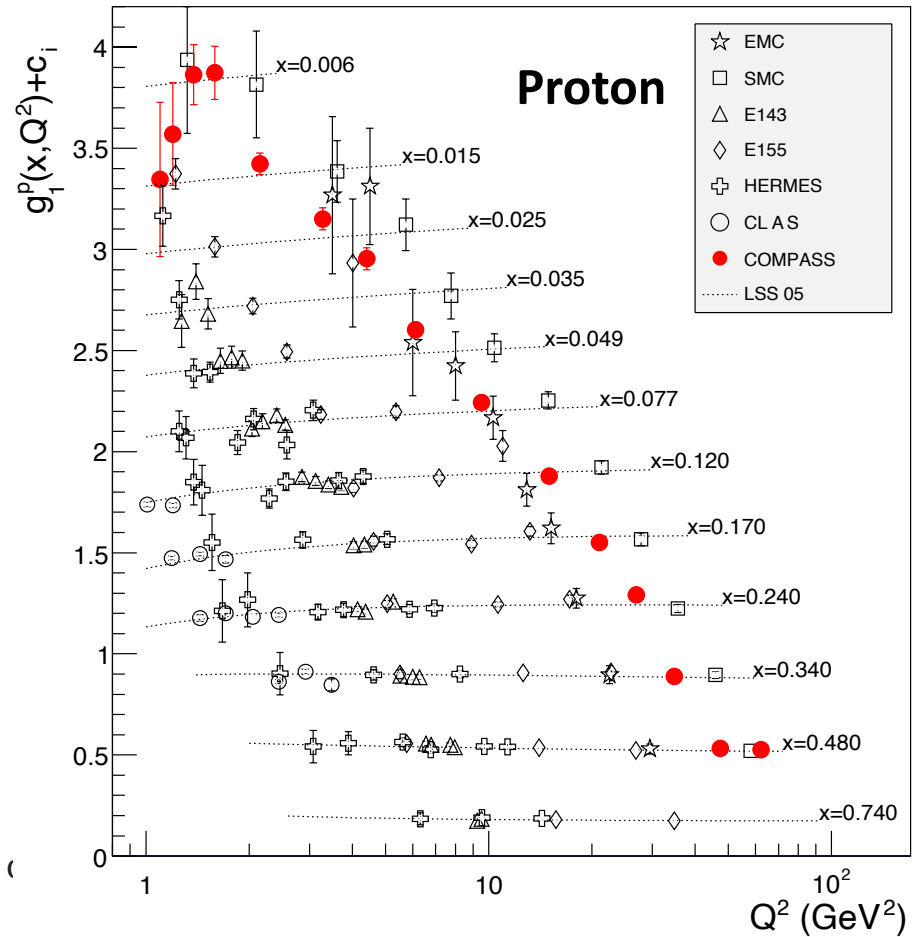
Christine A. Aidala RMP (2013)



Nucleon Spin

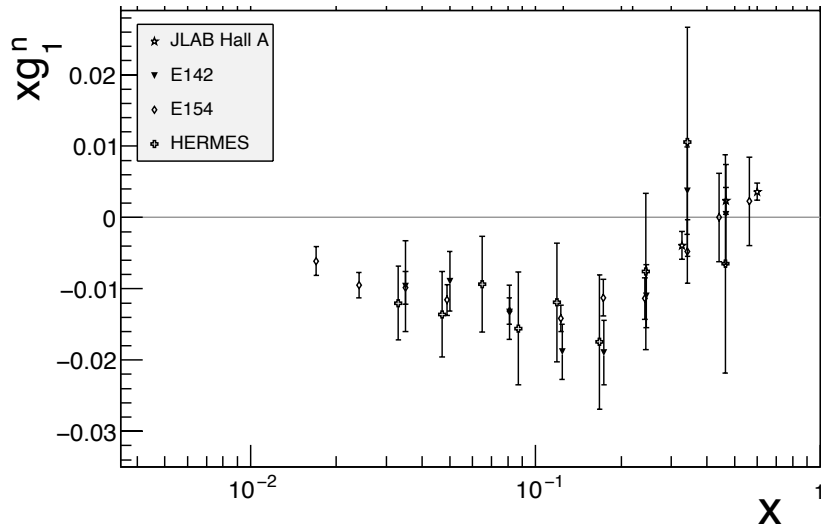


Christine A. Aidala RMP (2013)

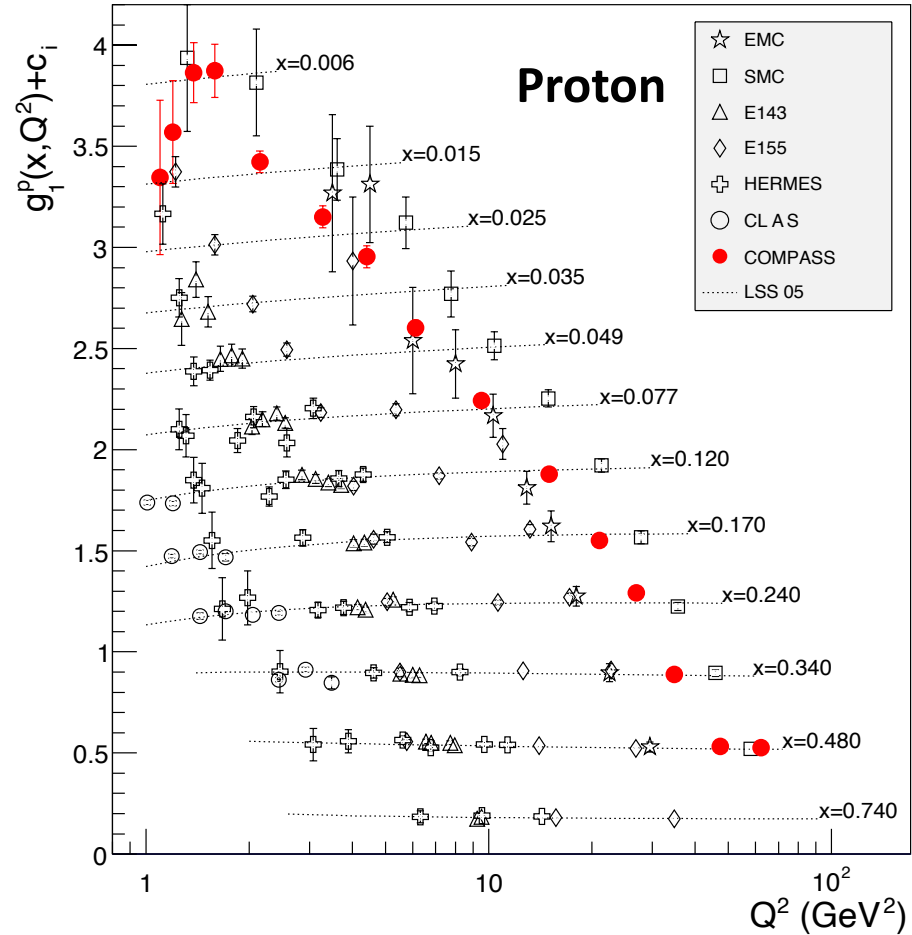


Nucleon Spin

How about the Neutron?



Christine A. Aidala RMP (2013)



JLab CLAS12: Neutron Spin physics program

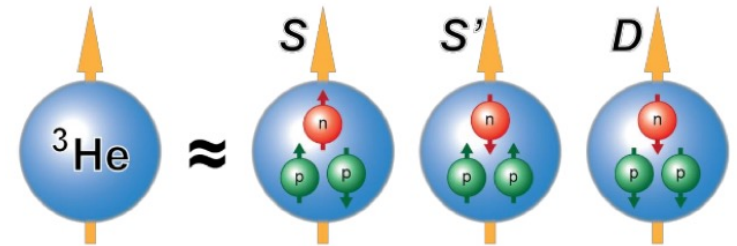
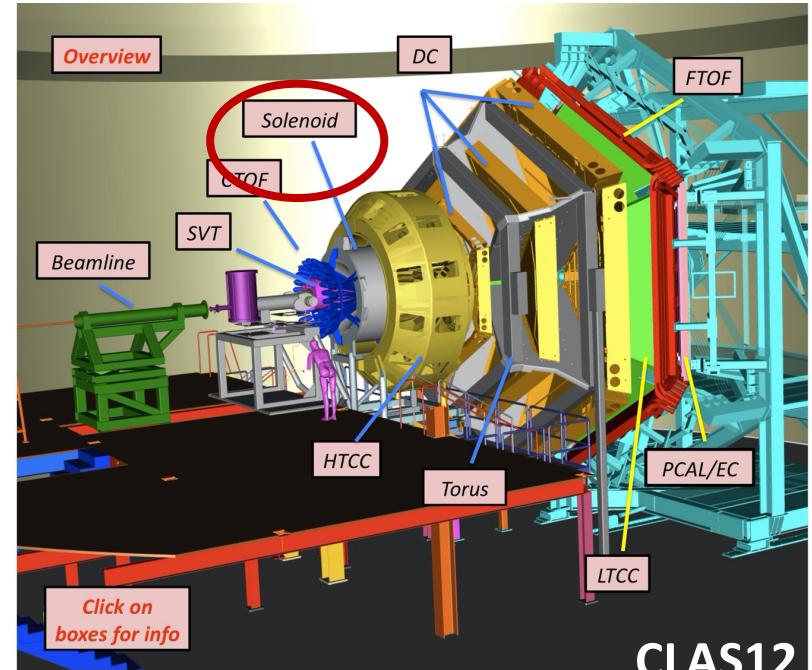
CLAS12

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

Polarized ^3He target

- ❖ Neutron carries 87% of spin in pol ^3He
- ❖ Effective polarized neutron target
- ❖ Calculable light nuclear system
- ❖ Crucial for neutron spin structure
- ❖ Challenge: Polarization in 5T solenoid field

CEBAF Large Acceptance Spectrometer

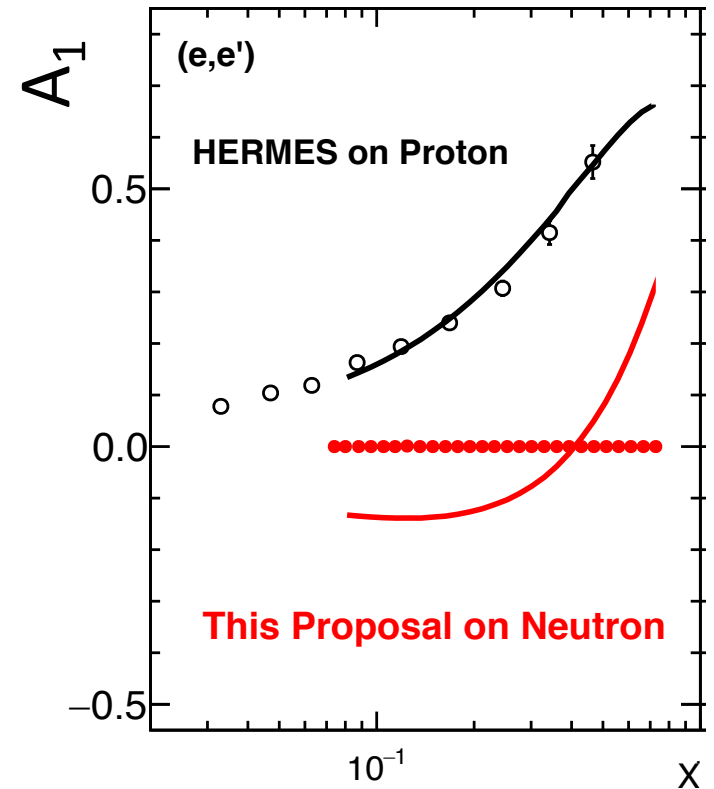
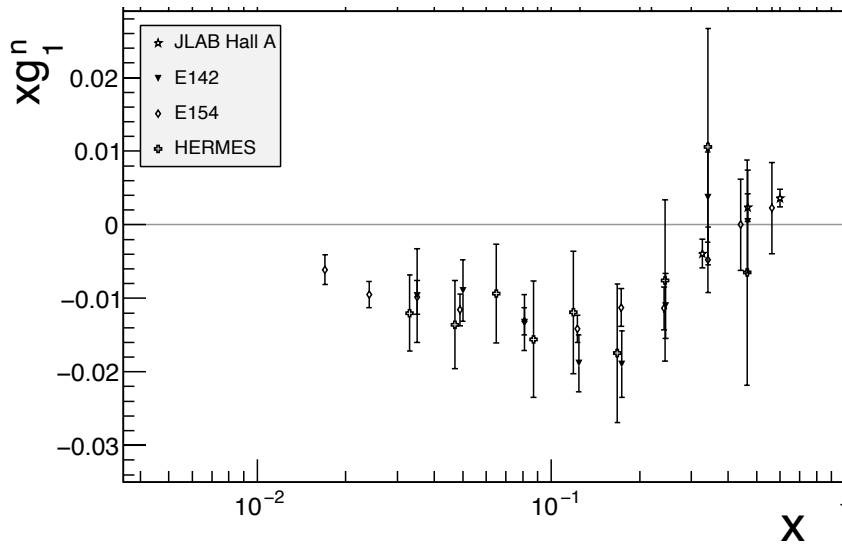


Polarized ^3He target + CLAS12: exciting spin physics program

New Target development to have pol ^3He in CLAS12 detector 8

Neutron Spin expected results

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



- High precision neutron spin structure function data
- Allow quark-flavor separation of nucleon spin

Now detect a hadron: Semi-inclusive DIS

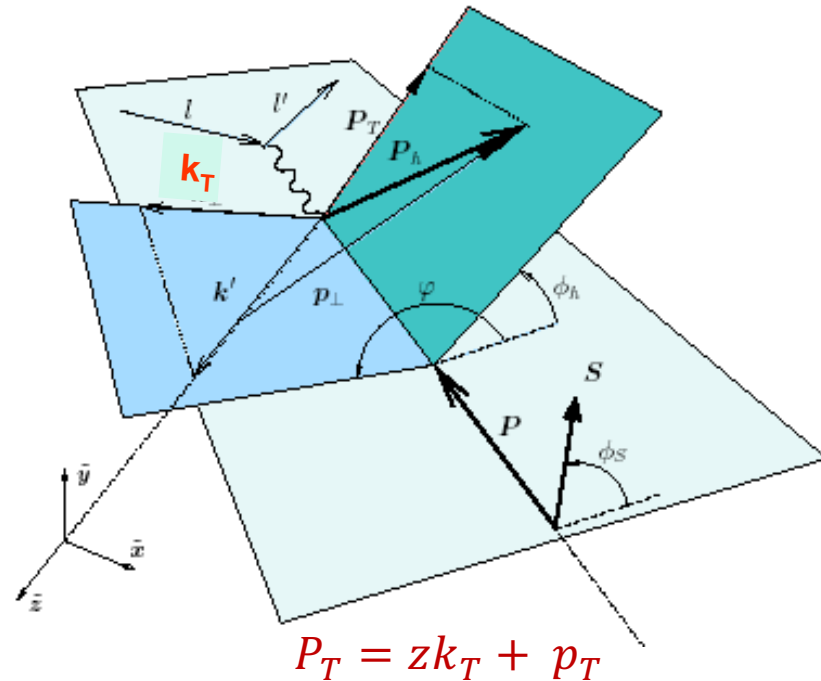
- Measure asymmetries:

$$\sigma = \text{func} (A_{UU}, A_{UL}, A_{LL}, \dots)$$

Quark Polarization

Nucleon Polarization

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



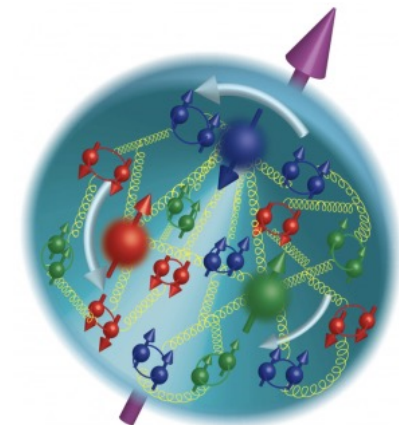
Transverse momenta

- Extract spin structure functions:

- ❖ $f(x, Q^2, \mathbf{k}_T), g_1(x, Q^2, \mathbf{k}_T), h(x, Q^2, \mathbf{k}_T)$

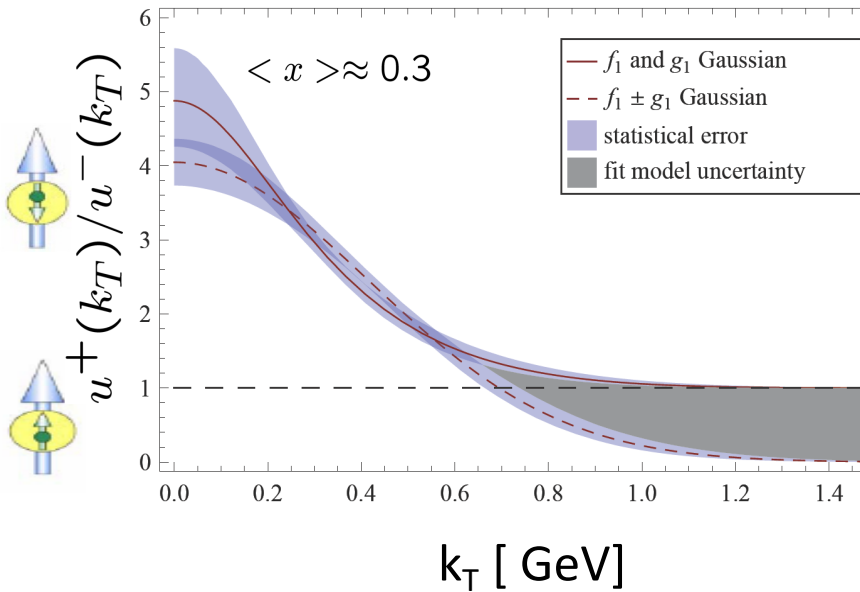
- ❖ Infer \mathbf{k}_T from hadron \mathbf{P}_T

- Transverse** Momentum Distribution: provides access to quark orbital motion

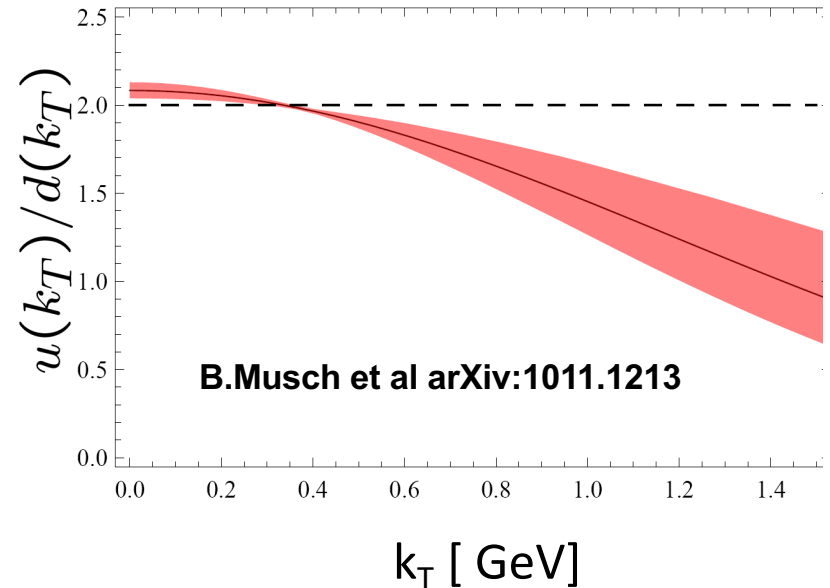


Spin and flavor dependence of k_T distribution

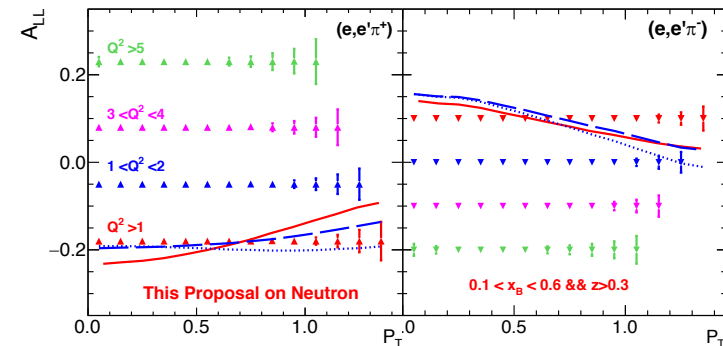
Quark spin parallel, anti-parallel ratio



Quark Up, down ratio



Expected results



- Quark's spin alignment depends on k_T
- Different quarks have different k_T

□ A = 3 (^3He and ^3H)

□ Experiment: E12-20-002: Quasi-elastic

□ (e,e'p): Few-Body nuclear Structure

□ (e,e'pN): SRCs

□ (e,e'): Neutron form factor

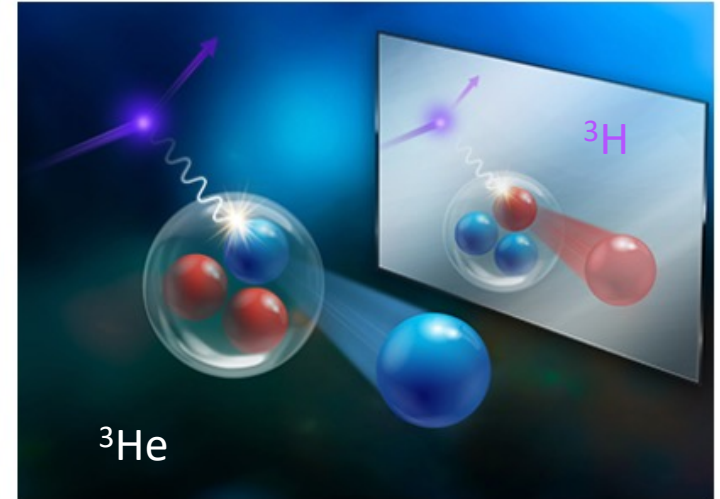
□ Experiment: PR12-21-004: SIDIS

□ Nuclear PDF, flavor-dependent EMC effect

□ Nuclear TMD and Fragmentation Function

Why A=3 nuclei?

- ❑ Exactly calculable
- ❑ Mirror nuclei
 - ❖ Proton in ${}^3\text{He}$ = Neutron in ${}^3\text{H}$
 - ❖ Constraints reaction mechanism



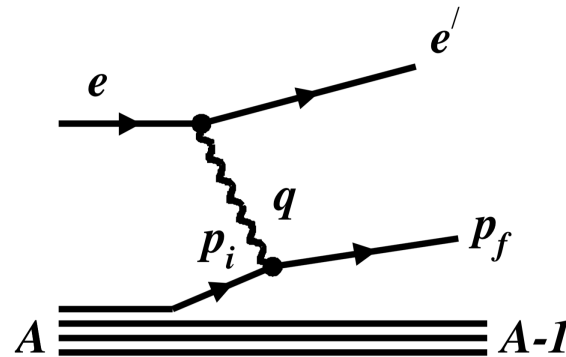
- Better to study proton in ${}^3\text{H}$ than neutron in ${}^3\text{He}$

Plane wave impulsive approximation (PWIA):

$$\mathbf{p}_i \sim \mathbf{p}_{miss} = \mathbf{p}_f - \mathbf{q}$$

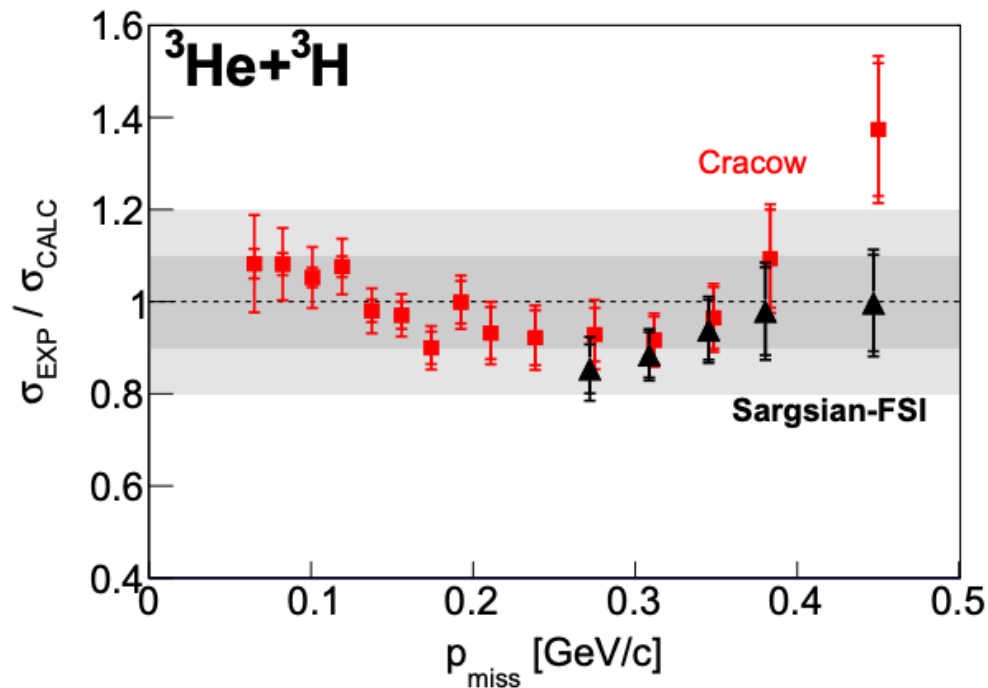
High Q² factorization

$$\sigma = K \sigma_{ep} S(|\vec{P}_i|, E_i)$$



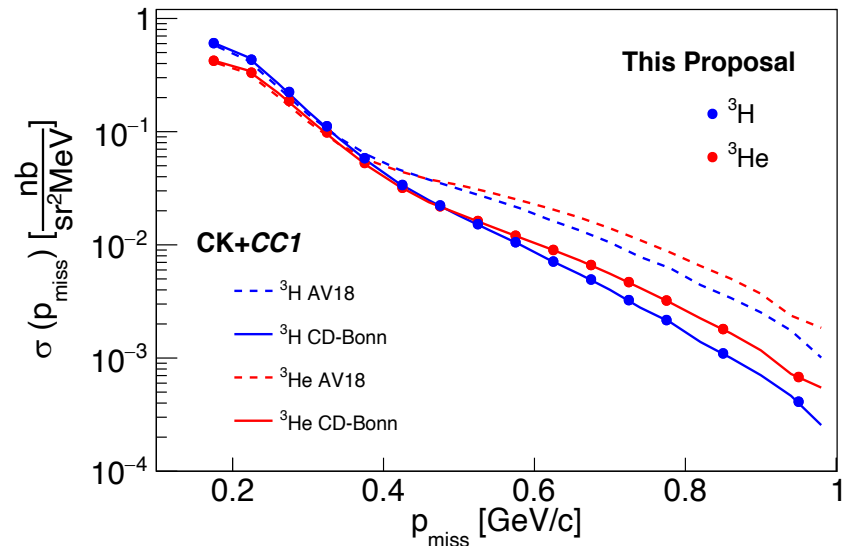
What we have learned in A= 3:

- ❑ ${}^3\text{H}$ has better agreement to calculation than ${}^3\text{He}$
- ❑ Data/PWIA $\sim 20\%$ at high P_{miss}
- ❑ Theory describes ${}^3\text{H}+{}^3\text{He}$ data within 10% up to $P_{\text{miss}} = 500 \text{ MeV}/c$

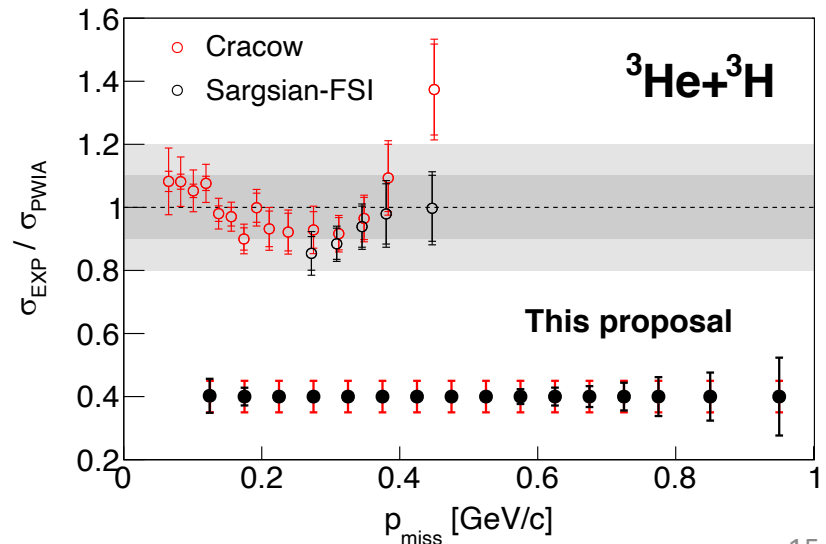


(e,e'p): Few-body nuclear structure

- Unique test of few-body nuclear structure.
- Hall A showed importance of using Helium & Triton BUT \w limited statistics
- CLAS12:
 x0.1 luminosity
 x100 acceptance
 => x10 statistics + larger kinematical coverage!



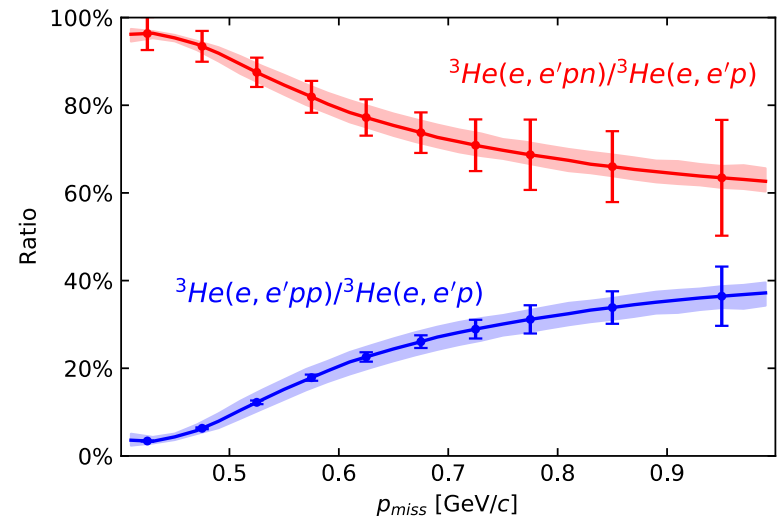
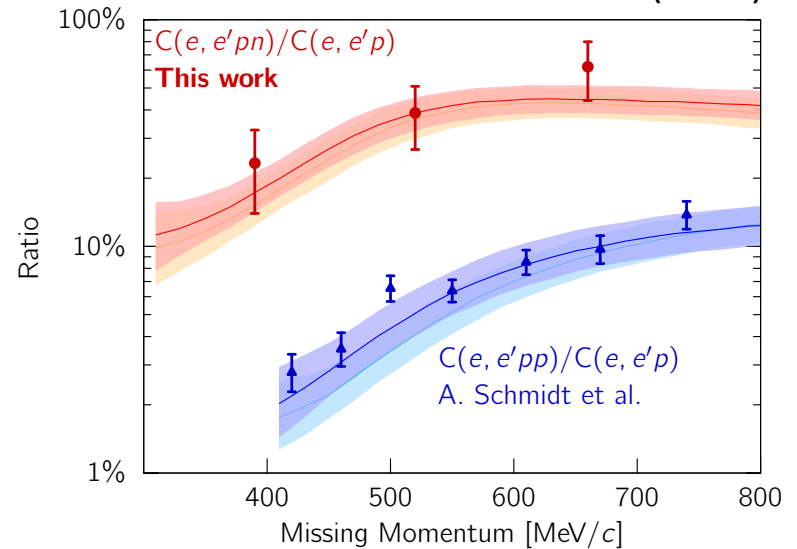
R. Cruz, D. Nguyen et al. PRL (2020)



(e,e'pN): SRCs

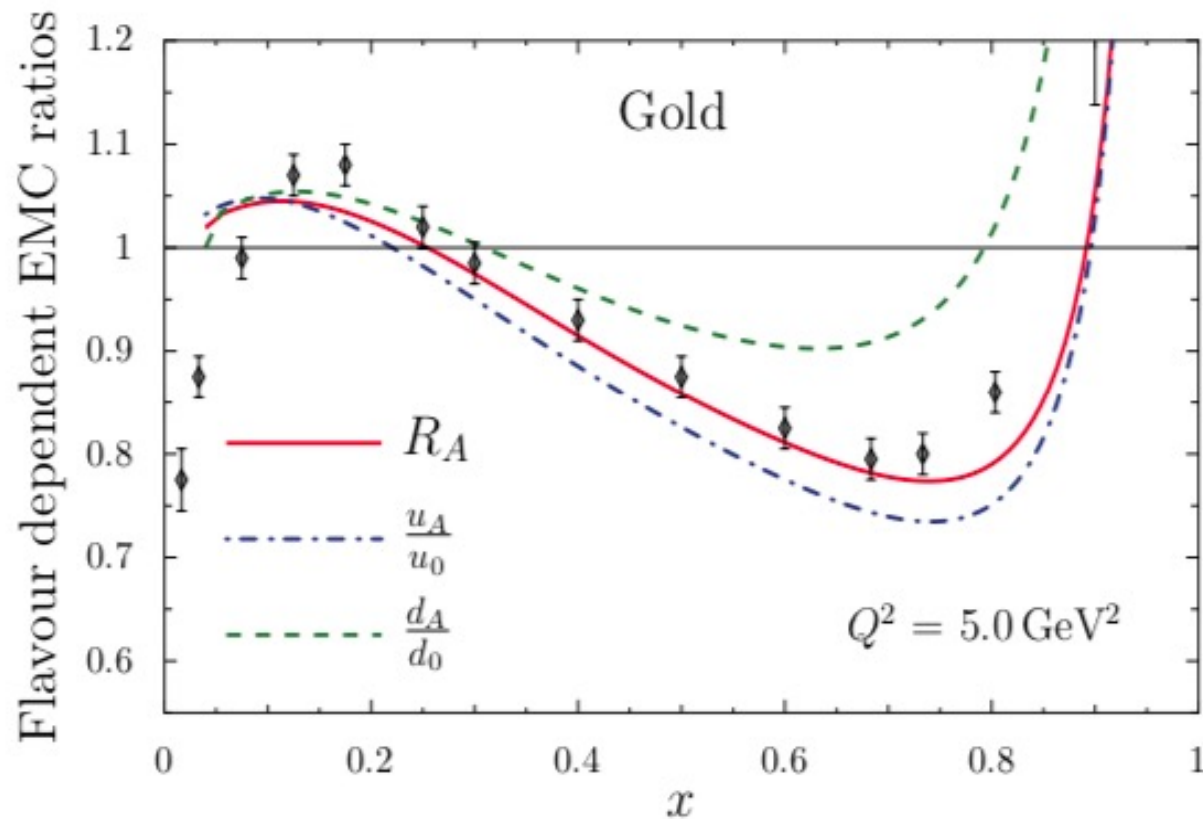
- Recent CLAS6 Nature paper relate SRCs to NN interaction @ short-distance.
- Data analyzed using the GCF factorized cross-section approximation.
- A=3 systems exactly calculatable => Precision tests of 2N interactions!

A. Schmidt et al. Nature (2020)



□ Experiment SIDIS

- Nuclear PDF, flavor-dependent EMC effect
- Nuclear TMD and Fragmentation Function



- Different flavors cause different modifications