

# $^3\text{He}$ Nucleon Effective Polarization and Momentum Study

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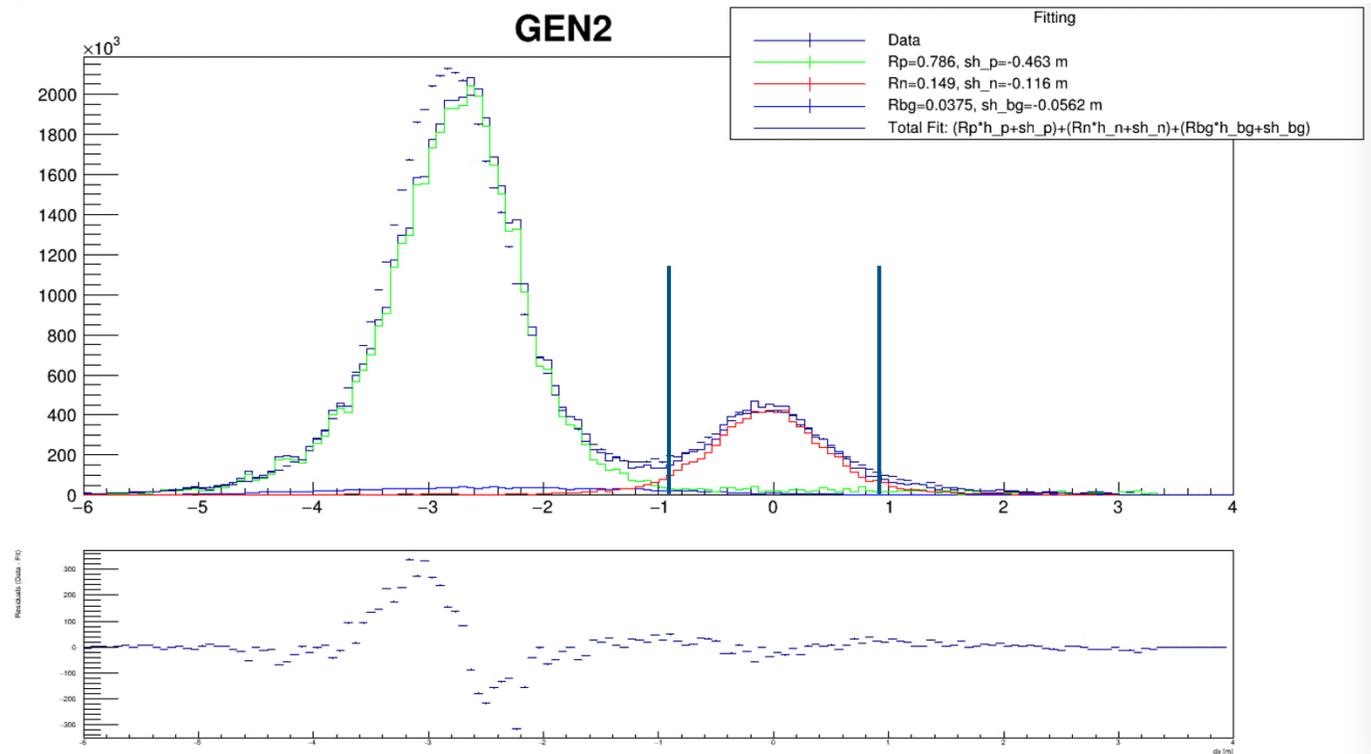
SBS Collaboration Meeting

March 3<sup>rd</sup>, 2026



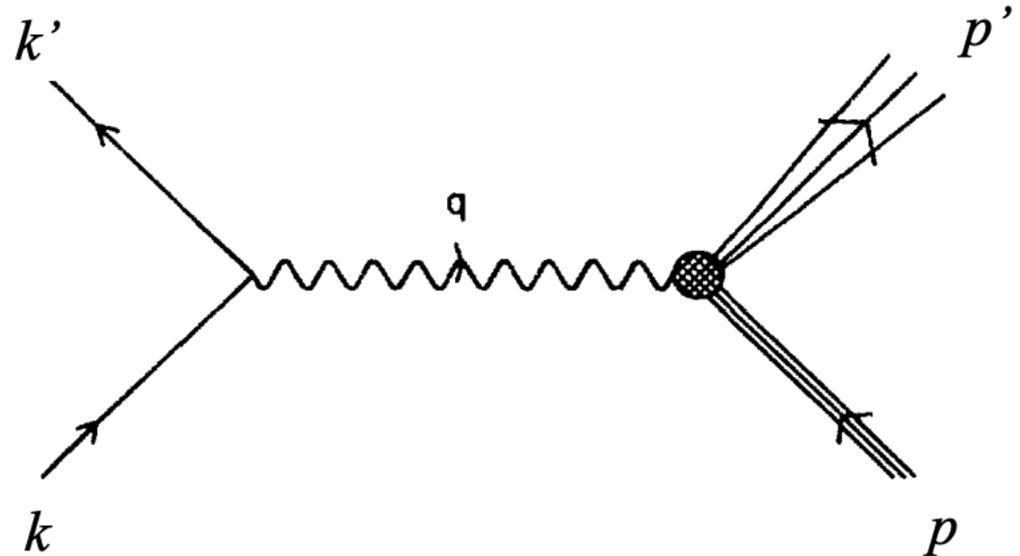
# Purpose

- Understand and parameterize nucleon effective polarization as a function of  $dx$  for each GEN-II kinematic
- Start by confirming average effective polarization for QE scattering within our neutron window
  - Standard values are **-2.8%** for the proton and **96%** for the neutron (see previous GEN theses)



# Variables of Interest

- The initial 3-momentum of the electron is  $k$
- The 3-momentum of the scattered electron is  $k'$
- The initial 3-momentum of the nucleon is  $p_n$  or  $p_p$  (or  $p_{nucl}$  generically)
- The 3-momentum of the scattered nucleon is  $p'_n$  or  $p'_p$  (or  $p'_{nucl}$  generically)



\*Adapted from B. Blankleider, R. M. Woloshyn. Quasi-elastic scattering of polarized electrons on polarized  $^3\text{He}$ . Phys. Rev. C Vol 29-2. February 1984.

# $^3\text{He}$ Nucleon Effective Polarization Basic Summary

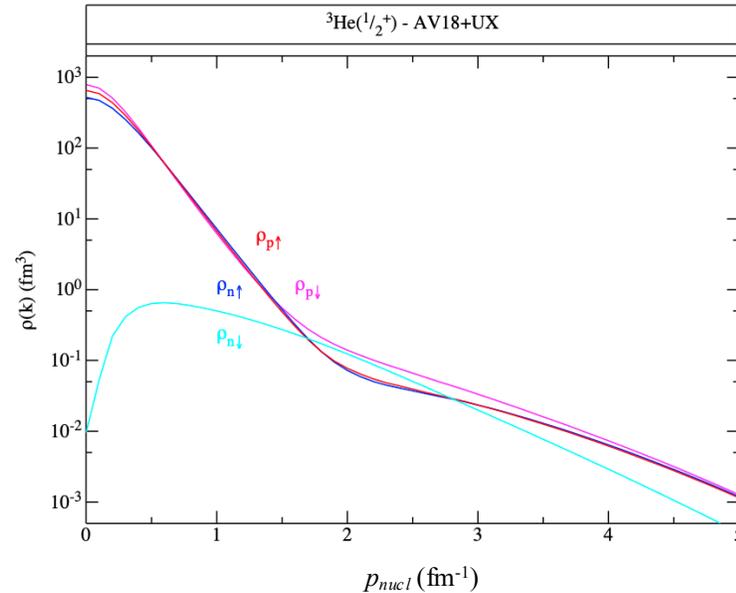
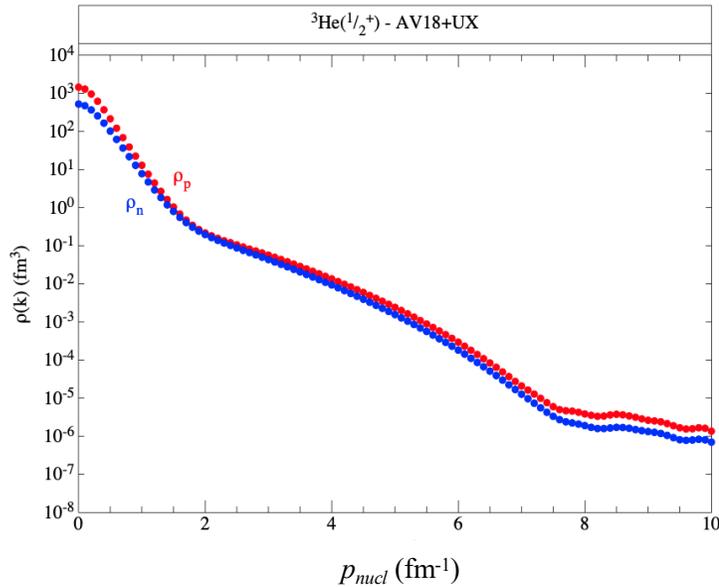
- Variational Monte Carlo (VMC) simulation is used to consider the probability of finding a nucleon with specific momentum and spin-isospin projection in a given nuclear state.
  - I.e., use simulation to estimate **nucleon momentum density**.
  - This probability is normalized such that the integrated densities over momentum phase space is equal to the number of spin-up or spin-down protons or neutrons.

Nucleus	$N_{\uparrow p}$	$N_{\downarrow p}$	$N_{\uparrow n}$	$N_{\downarrow n}$
$^3\text{He}(1/2^+)$	0.974	1.026	0.938	0.062

- Three different considerations are folded into the wave functions used in the simulation:
  - Non-relativistic nucleon kinetic energy
  - Two-nucleon interactions (**AV18**)
  - Three-nucleon interactions (**UX**)

[Wiringa, et al., Phys. Rev. C \*\*89\*\*, 024305 \(2014\).](#)  
[Piarulli, et al., Phys. Rev. C \*\*107\*\*, 014314 \(2023\).](#)

# Momentum Density Results Using AV18+UX for ${}^3\text{He}(1/2^+)$



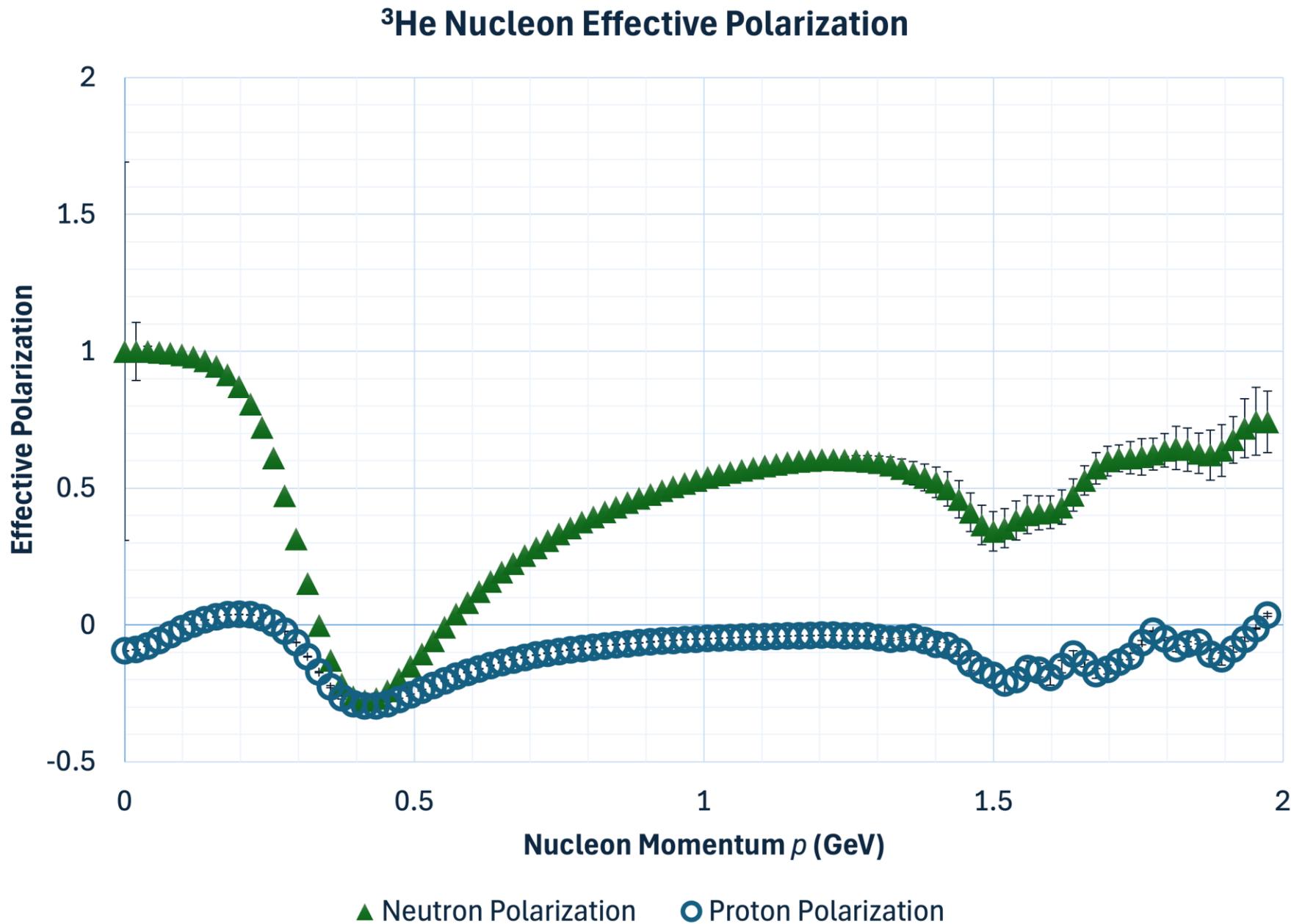
Use the momentum densities to extract effective polarization.

\*From <https://www.phy.anl.gov/theory/research/momenta/>

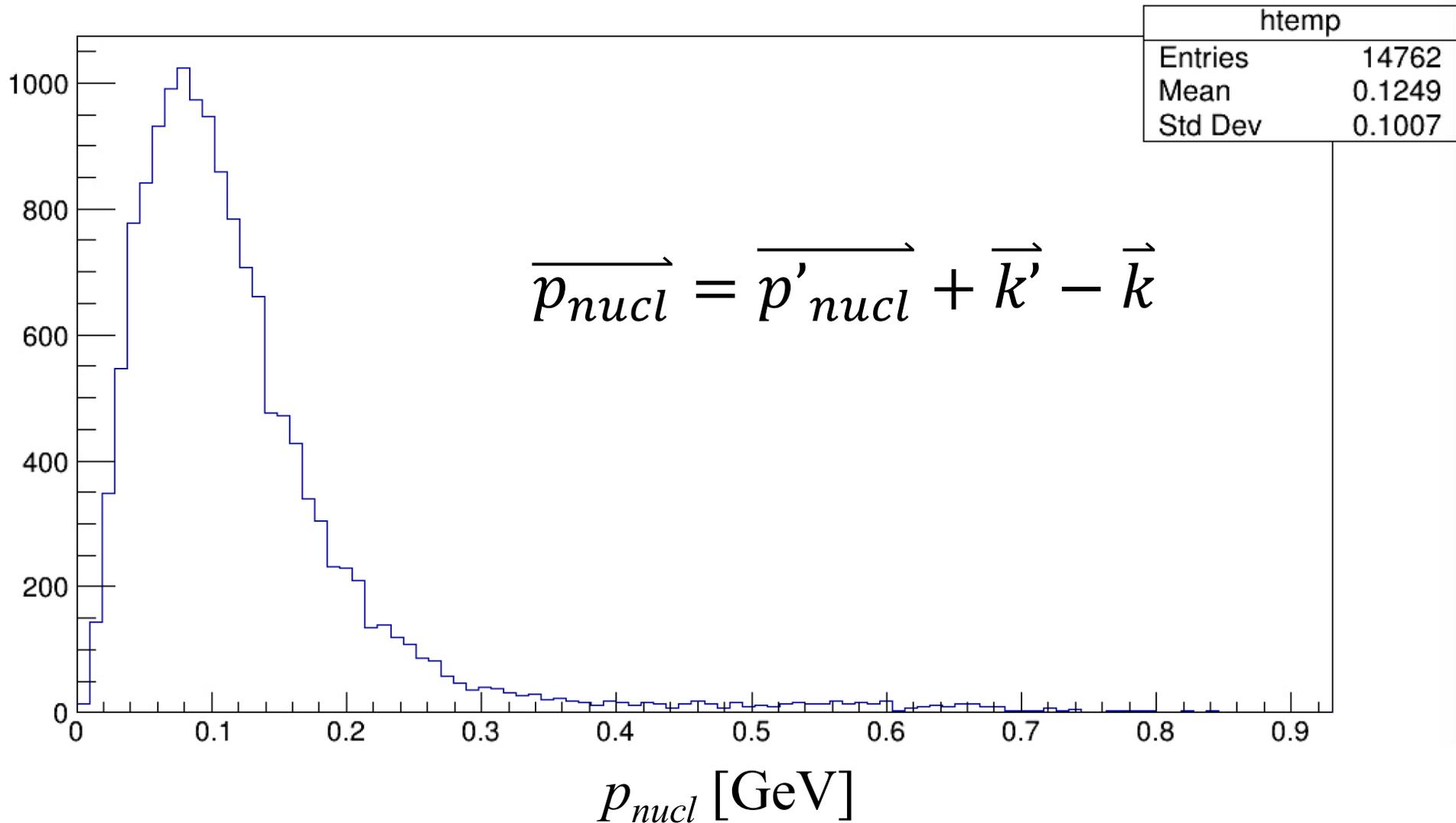
$$\text{Pol}_p = \left( \frac{\rho_{p\uparrow} - \rho_{p\downarrow}}{\rho_{p\uparrow} + \rho_{p\downarrow} + \rho_{n\uparrow} + \rho_{n\downarrow}} \right) / \left( \frac{\rho_p}{\rho_p + \rho_n} \right)$$

$$\text{Pol}_n = \left( \frac{\rho_{n\uparrow} - \rho_{n\downarrow}}{\rho_{p\uparrow} + \rho_{p\downarrow} + \rho_{n\uparrow} + \rho_{n\downarrow}} \right) / \left( \frac{\rho_n}{\rho_p + \rho_n} \right)$$

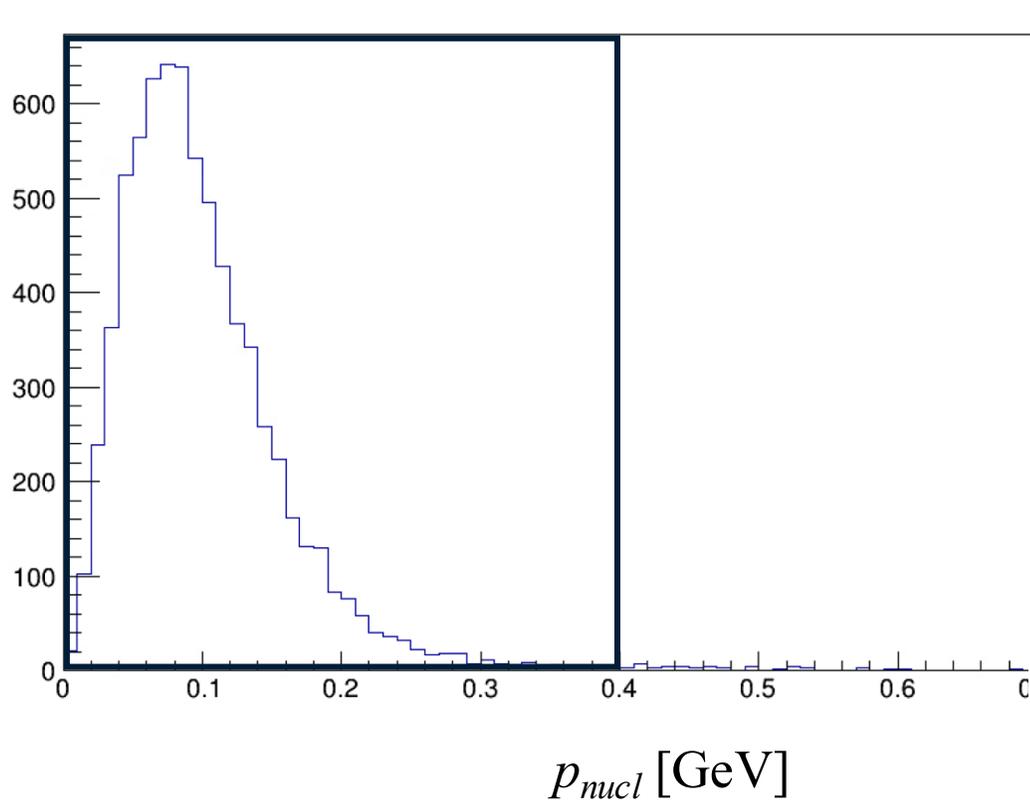
We need to extract the missing nucleon momentum from our simulation in order to use these results.



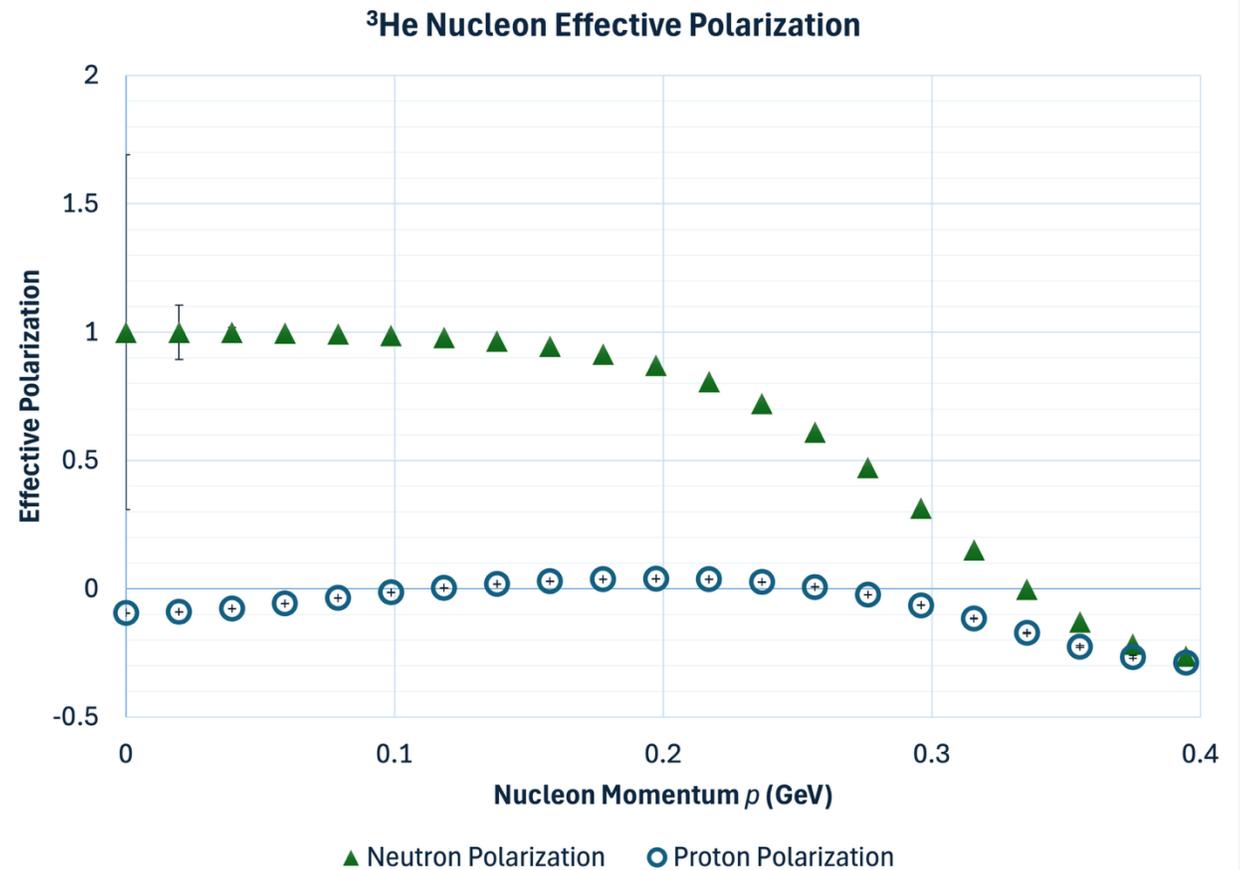
# Missing Momentum - GEN2 He3 Simulation



# Compare Our Nucleon Momentum Distribution to the $^3\text{He}$ Nucleon Effective Polarization



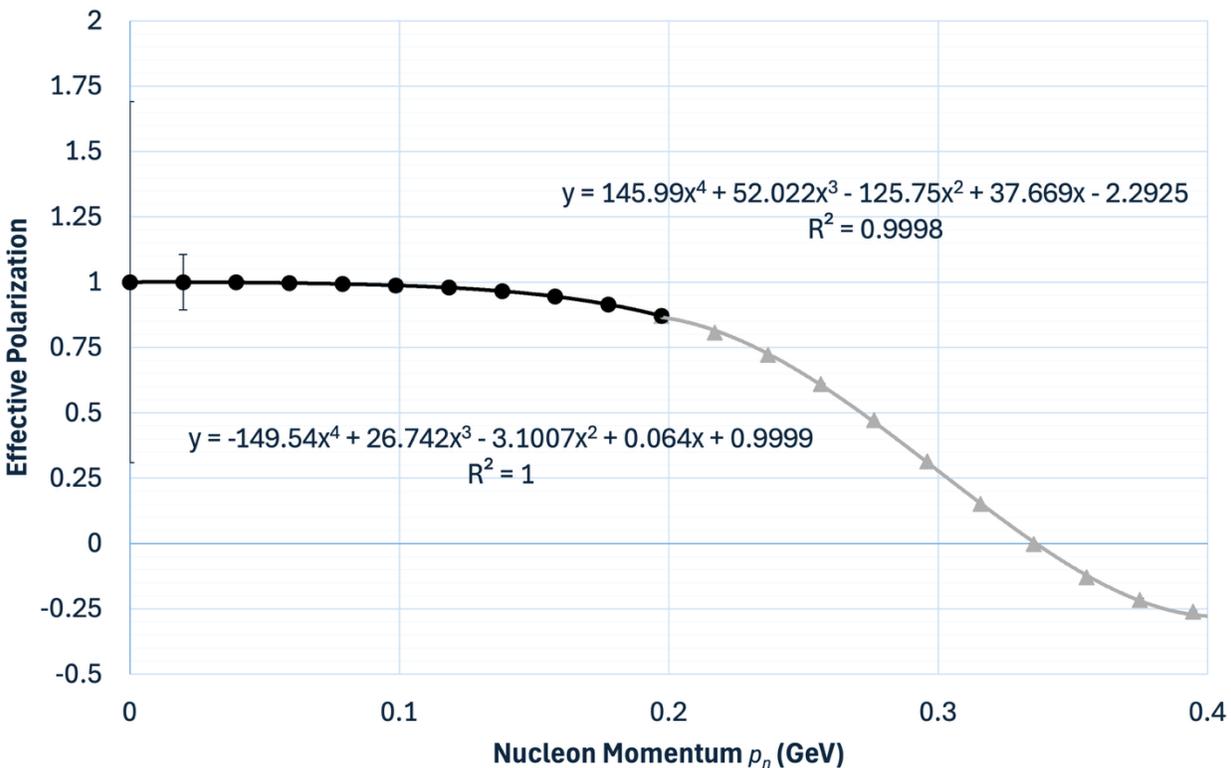
hist	
Entries	7342
Mean	0.103
Std Dev	0.06848



# 4<sup>th</sup> order polynomials fit the effective polarization data nicely.

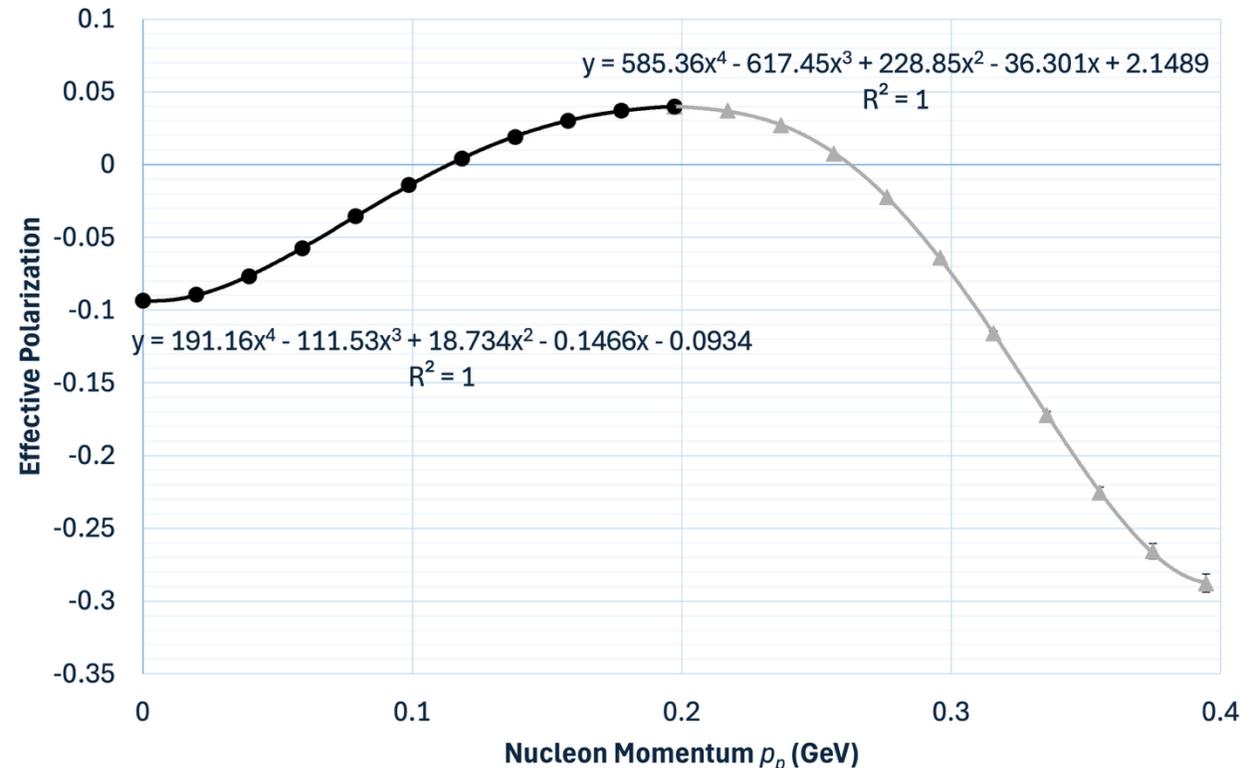
### <sup>3</sup>He Neutron Polarization

▲ ≥0.2GeV ● <0.2GeV — Poly. (≥0.2GeV) — Poly. (<0.2GeV)

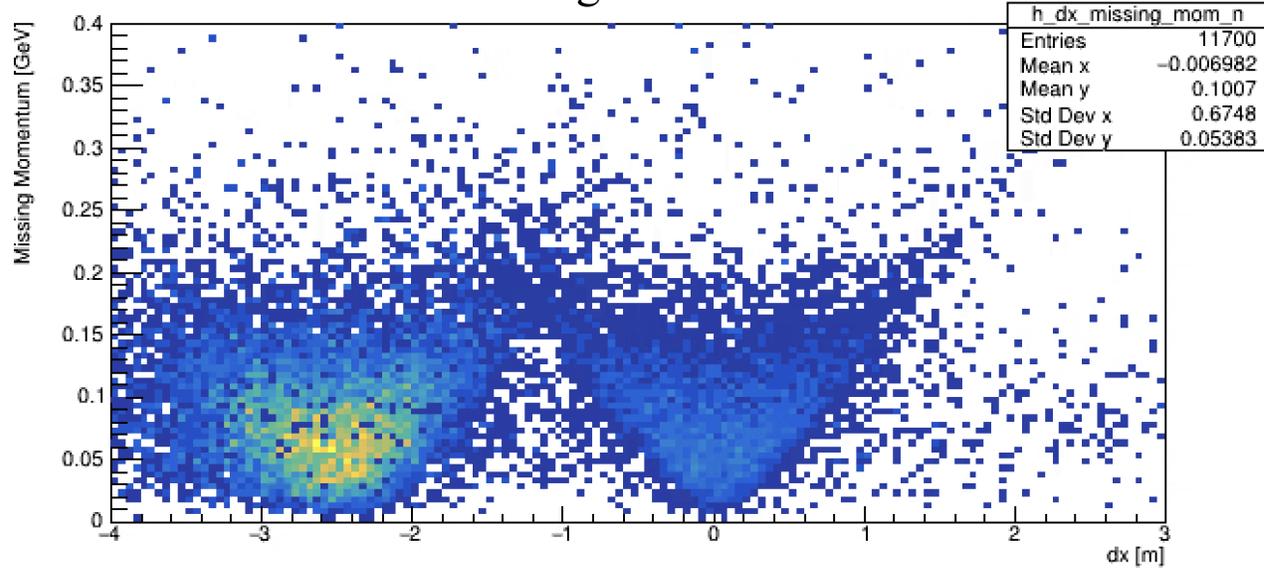


### <sup>3</sup>He Proton Polarization

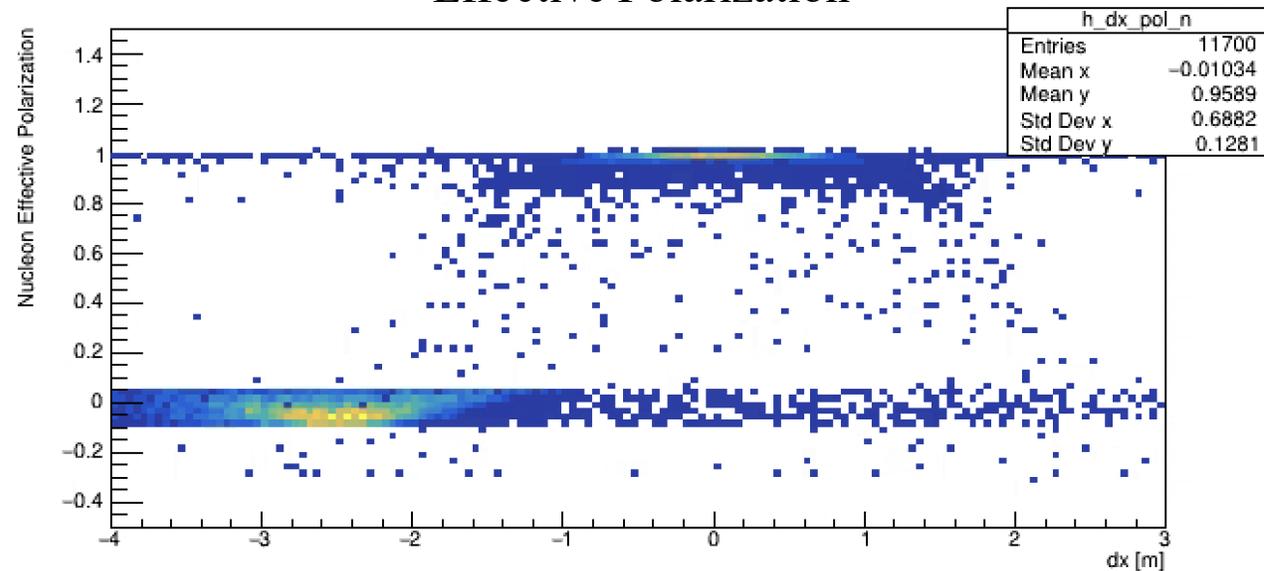
▲ ≥0.2GeV ● <0.2GeV — Poly. (≥0.2GeV) — Poly. (<0.2GeV)



## Missing Momentum



## Effective Polarization



Use the fit to the effective polarization data to transform simulated missing momentum to effective polarization.

← GEN2 QE simulation

Take the average effective polarization within our neutron window.

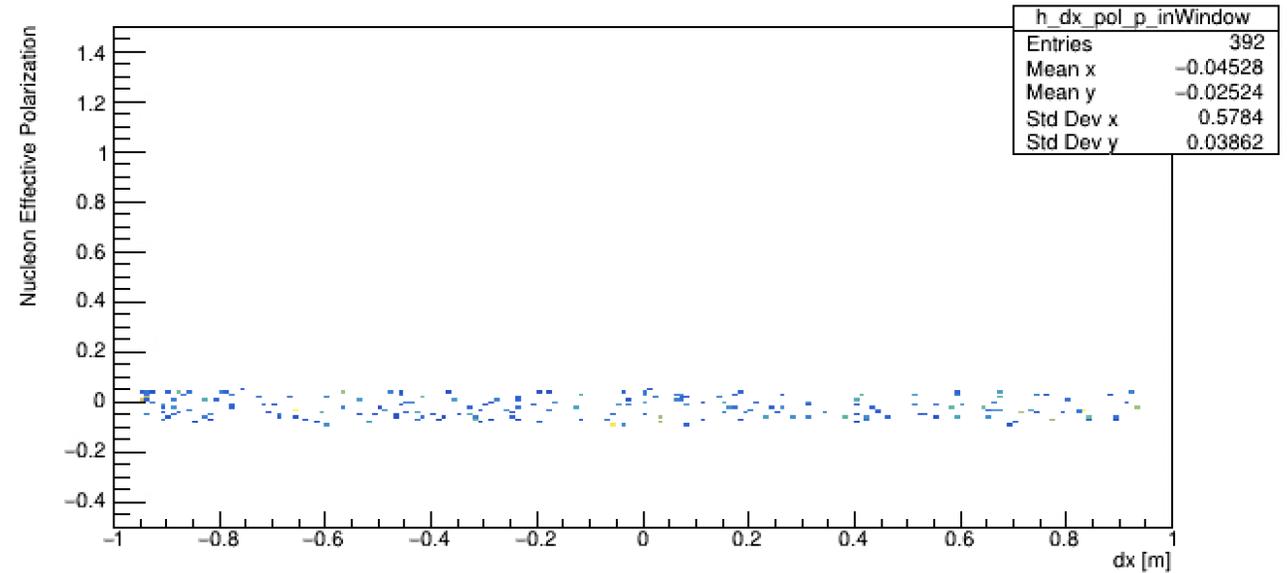
For GEN2, the averages are:

Proton: -2.525%

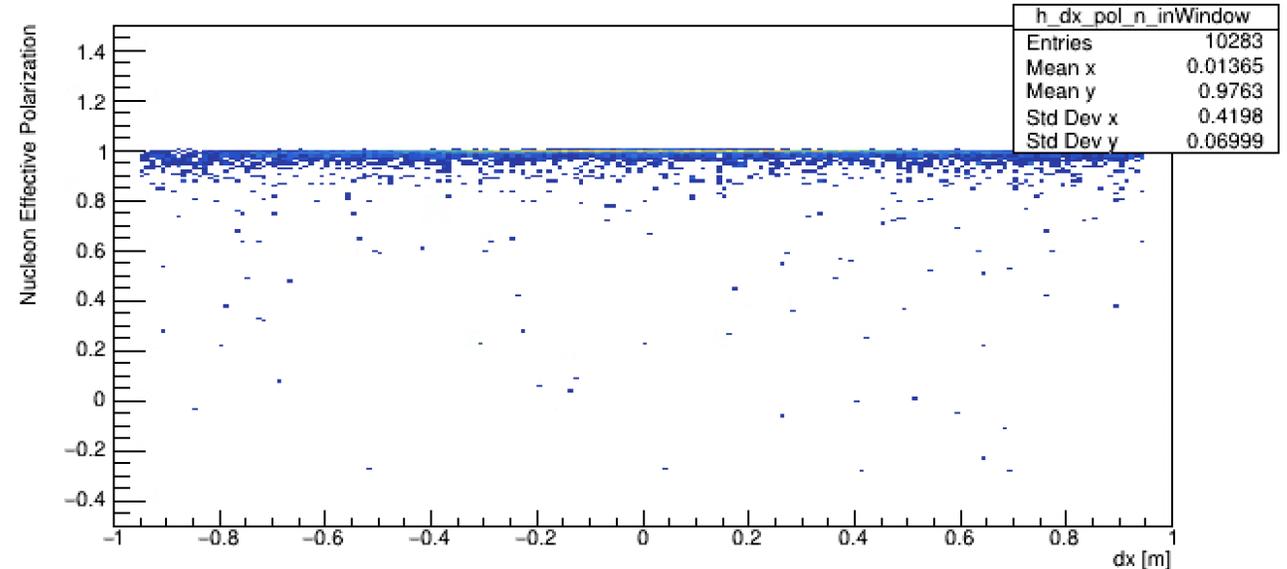
Neutron: 97.634%

\*Dependent on dx cut

Proton Effective Polarization in the Neutron Window



Neutron Effective Polarization in the Neutron Window



# Summary of Results

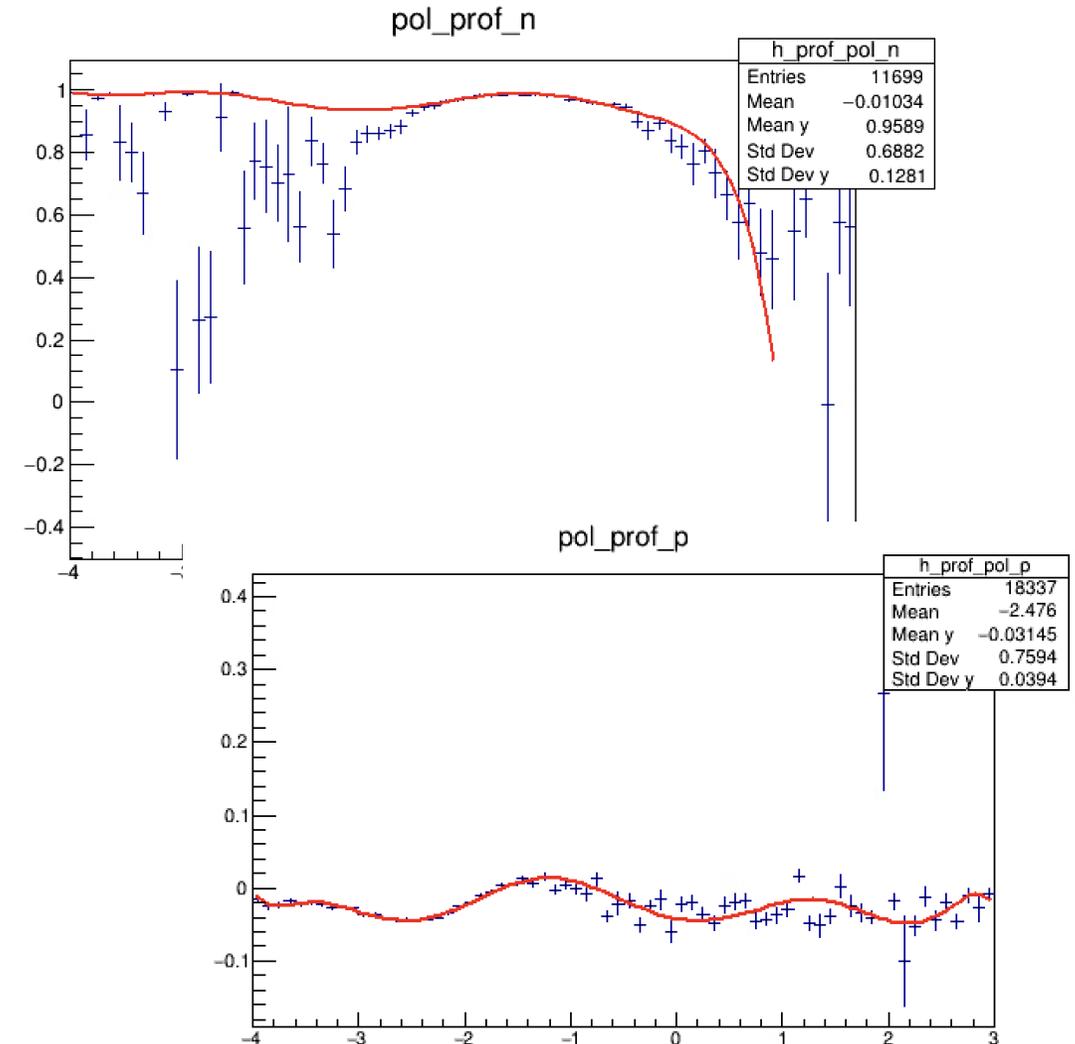
<b>GEN Kinematic</b>	<b>Pol<sub>n</sub></b>	<b>Pol<sub>p</sub></b>
GEN2	97.6%	-2.52%
GEN3	97.92%	-2.81%
GEN4	98.17%	-2.45%

# Future Steps

- Define some functions  $\text{Pol}_p(dx)$  and  $\text{Pol}_n(dx)$  for each kinematic and use these to weight the asymmetries.
- Apply a simultaneous fit to  $dx$  of the form:

$$= [A_p \times \text{Pol}_p(dx) \times P_p(dx)] + [A_n \times \text{Pol}_n(dx) \times P_n(dx)] + [A_{bg} \times P_{bg}(dx)]$$

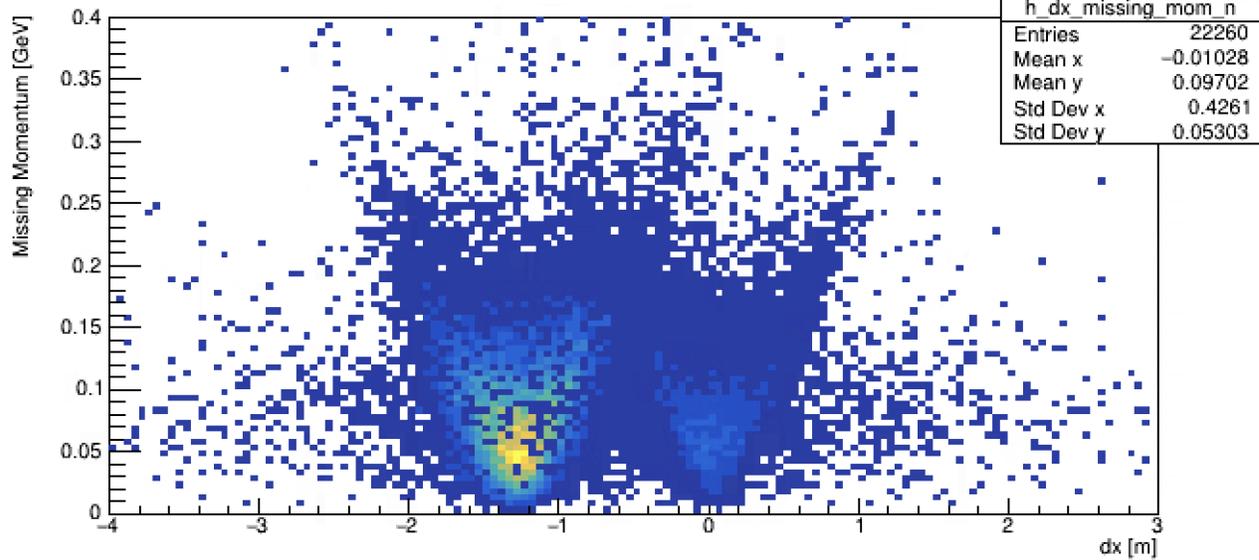
- $A_{\text{raw}}$  is the raw asymmetry as a function of  $dx$
- $A_i$  is the scattering asymmetry for a particle belonging to the  $i^{\text{th}}$  group ( $i = [\text{proton}, \text{neutron}, \text{background}]$ )
- $\text{Pol}_i$  is the effective polarization of a particle belonging to the  $i^{\text{th}}$  group as a function of  $dx$
- $P_i$  is the probability of a particle belonging to the  $i^{\text{th}}$  group as a function of  $dx$



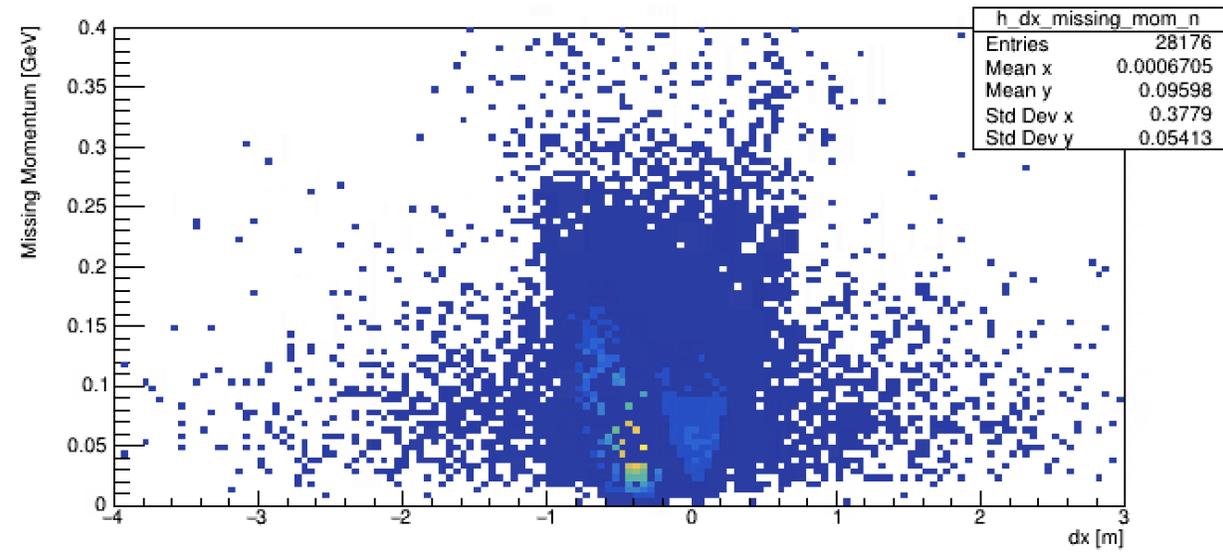
# Questions?

# Backup

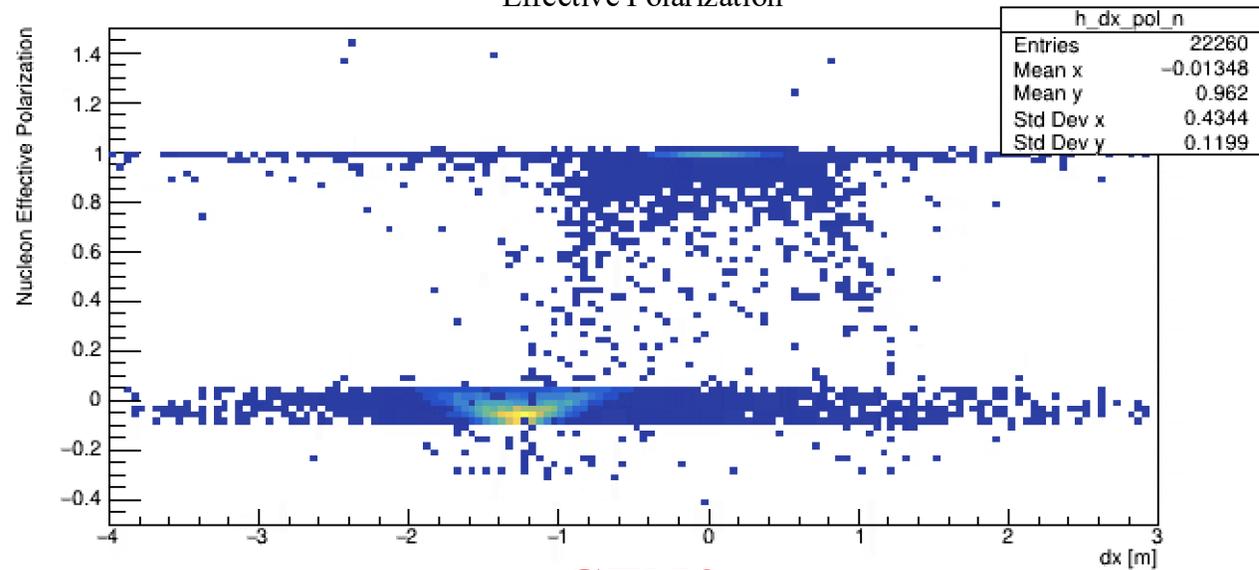
Missing Momentum



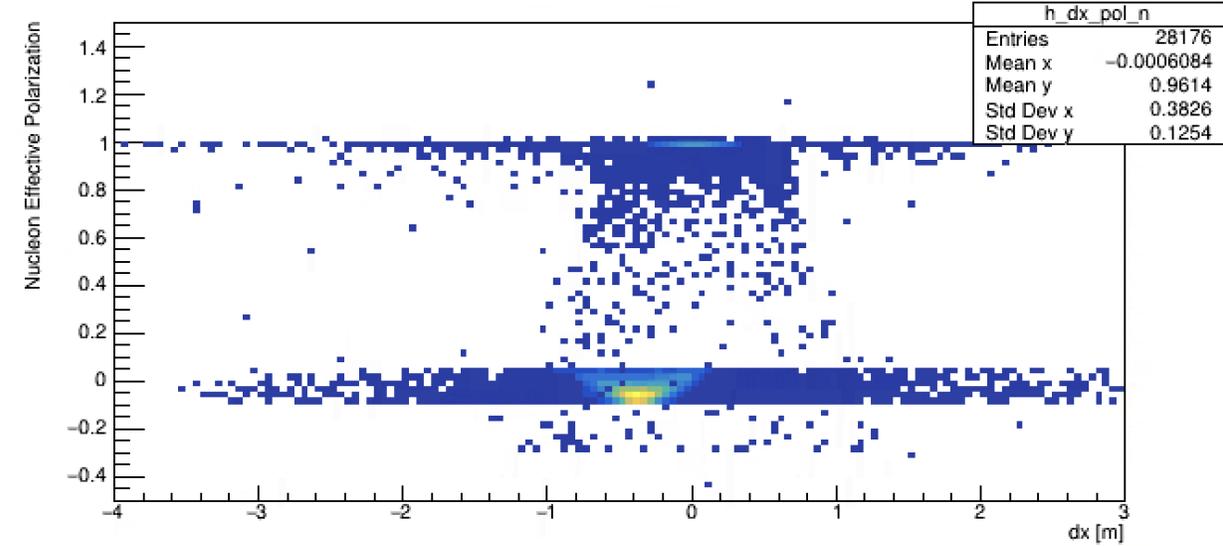
Missing Momentum



Effective Polarization



Effective Polarization



GEN3

GEN4

# More Important Articles for Theory Work

- Piarulli, et al., Phys. Rev. C 107, 014314 (2023).
- Carlson, et al., Rev. Mod. Phys. 87, 1067 (2015).
- Lonardonì, et al., Phys. Rev. C 96, 024326 (2017).
- Bissey, et al., Phys. Rev. C 64, 024004 (2001).

<https://www.phy.anl.gov/theory/research/momenta/>