# Proton and Neutron Momentum Distributions in A=3 Asymmetric Nuclei

# PR12-13-012

Spokespersons: Werner Boeglin (FIU), Or Hen (Tel-Aviv), Lawrence Weinstein (ODU), and Shalev Gilad (MIT).

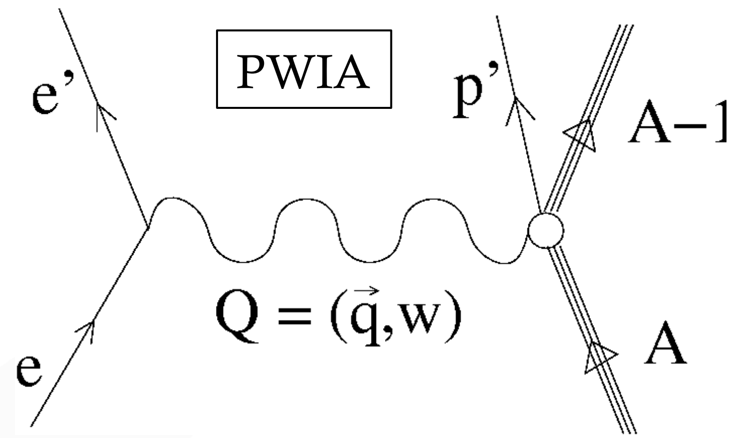
Cheerleader: Douglas Higinbotham (JLab)

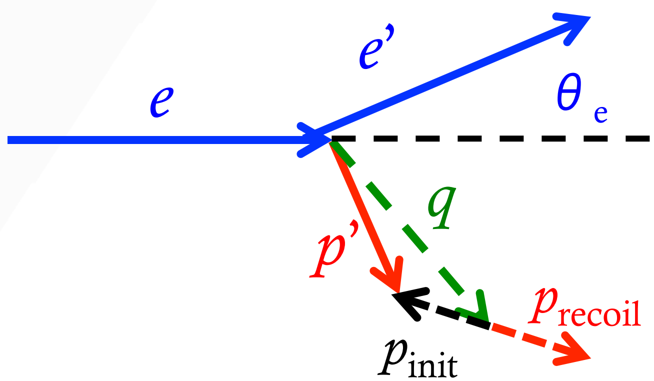
# $A(e,e'p)$ kinematics

$$E_m = \omega - T_p - T_{A-1}$$

$$= \omega - T_p - \frac{p_m^2}{4m_p}$$

$$\vec{p}_m = \vec{q} - \vec{p}' = -\vec{p}_{init}$$



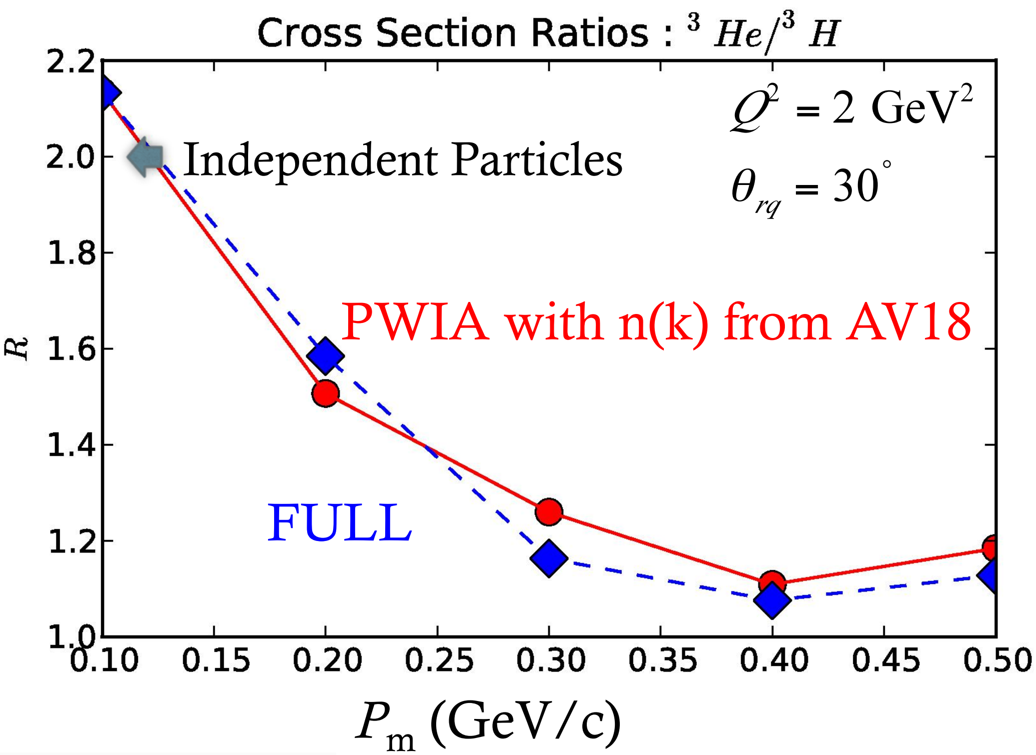



# Guesstimation Problem

- Guesstimate the $^{3}He(e,e'p)$ to $^{3}H(e,e'p)$ ratio at missing momentum near zero.
  - First in an independent particle picture
  - Second using a realistic NN potential
- Bonus Question
  - What are these ratio for momentums much great then the Fermi momentum?

# Theory Calculations

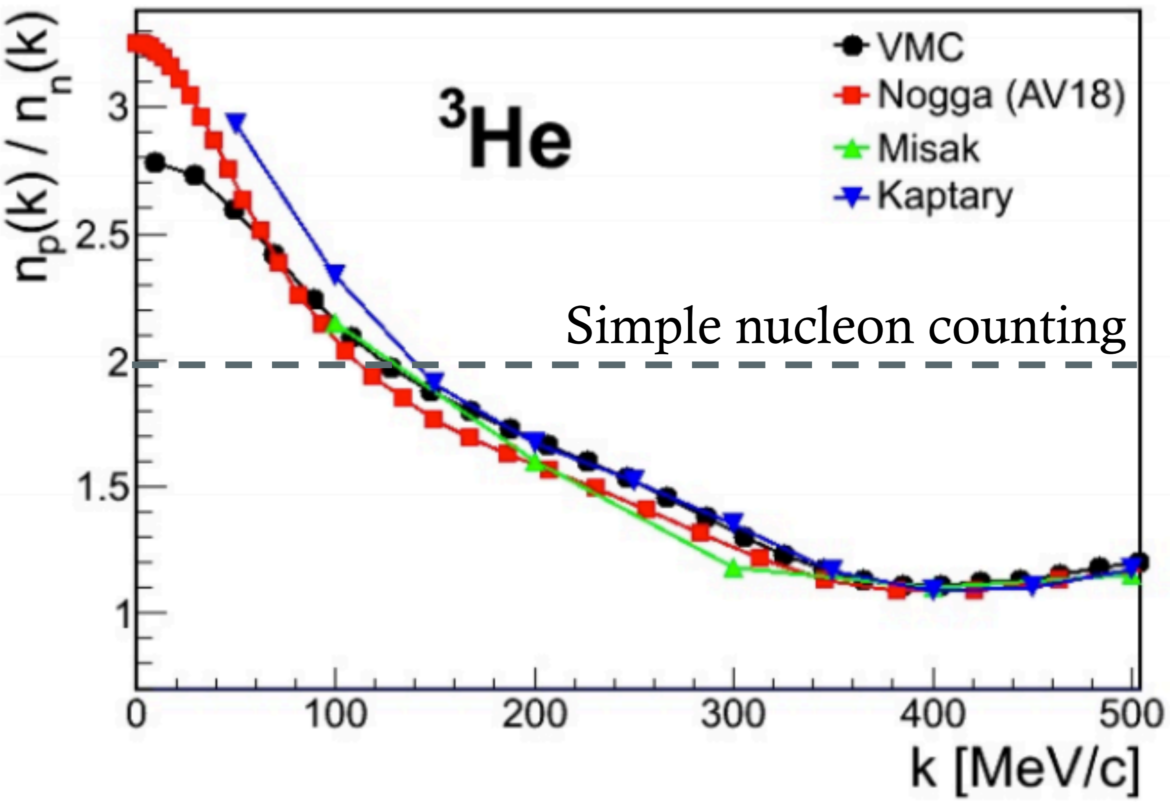
$$\frac{\sigma(^{3}\mathrm{He}(e,e'p))}{\sigma(^{3}\mathrm{H}(e,e'p))}$$

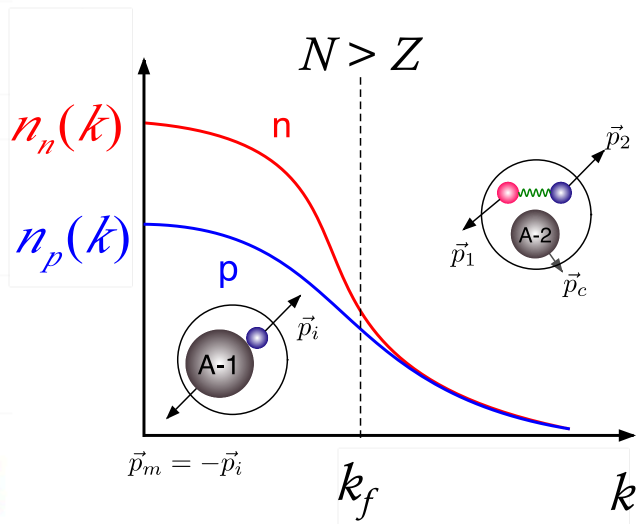



These are the kinematics of this proposal

Calculations by Misak Sargsian

# Full Range of Momentum




Nucleon counting fails at both high and low Pmiss due to *tensor correlations.*

# Asymmetric nuclei momentum distributions: the broader picture

## Light nuclei $A$<11

Ab initio Variational Monte Carlo calculations by Wiringa

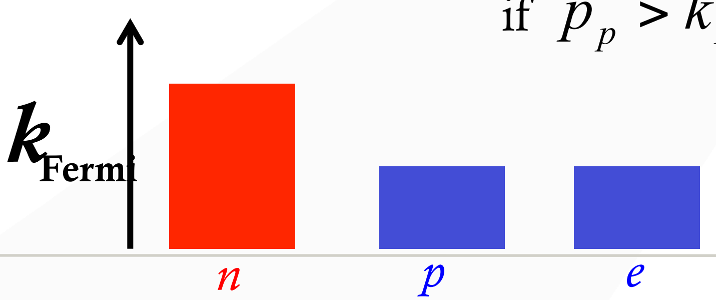
| | $\frac{\lvert N-Z \rvert}{A}$ | $\langle KE \rangle_p$ | $\langle KE \rangle_n$ | $\langle KE \rangle_{p-n}$ |
|---|---|---|---|---|
| $^{8}$He | 0.50 | 30.13 | 18.60 | 11.53 |
| $^{6}$He | 0.33 | 27.66 | 19.06 | 8.60 |
| $^{9}$Li | 0.33 | 31.39 | 24.91 | 6.48 |
| $^{3}$He | 0.33 | 14.71 | 19.35 | -4.64 |
| $^{3}$H | 0.33 | 19.61 | 14.96 | 4.65 |
| $^{8}$Li | 0.25 | 28.95 | 23.98 | 4.97 |
| $^{10}$Be | 0.2 | 30.20 | 25.95 | 4.25 |
| $^{7}$Li | 0.14 | 26.88 | 24.54 | 2.34 |
| $^{9}$Be | 0.11 | 29.82 | 27.09 | 2.73 |
| $^{11}$B | 0.09 | 33.40 | 31.75 | 1.65 |

## Qualitative connections:

### Heavy nuclei

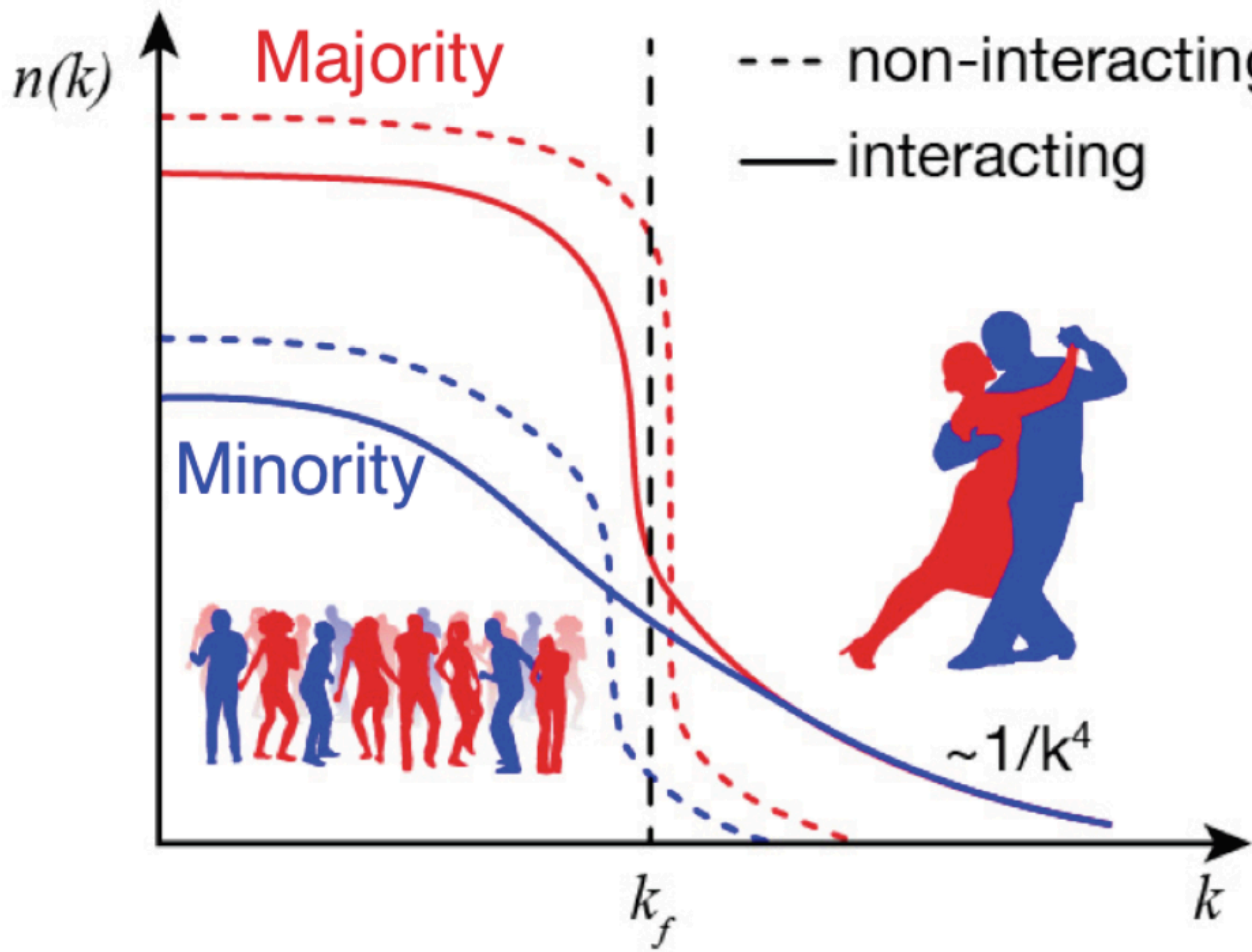
Possible explanation to the NuTeV anomaly (if $u$ quarks move faster than $d$ quarks)

### Neutron stars




if $p_p > k^p_{Fermi}$

- Changes the cooling rate via the direct URCA process
- Changed momentum distribution changes the spatial distribution


n(k)
Majority
Minority
non-interacting
interacting
~1/k4
kf
k

# Previous $^3$H(*e,e'p*) measurements

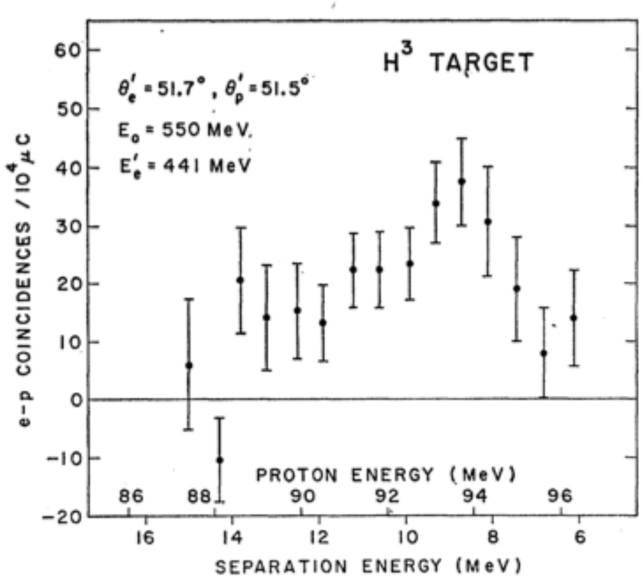



FIG. 2. The energy spectrum of protons at 51.5° in coincidence with 441-MeV electrons at 51.7° from H³ (*e,e'p*).

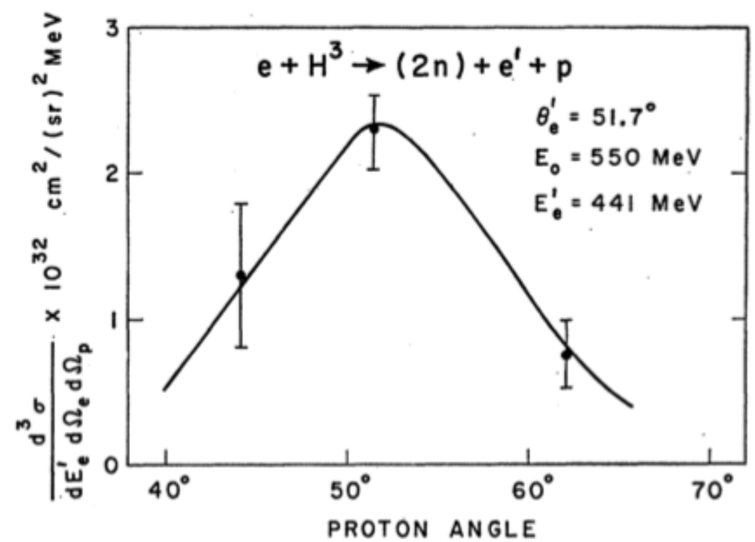


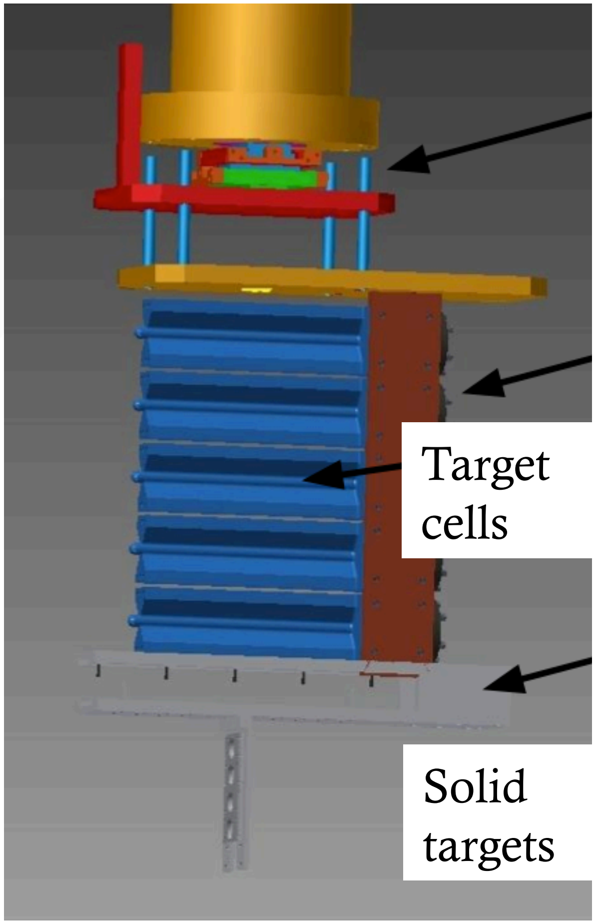

FIG. 4. The coincidence cross section of reaction (C) as a function of proton angle. The curve is explained in Sec. VI of the text.

A. Johansson by himself, PR136 (1964) 1030B.

# Special Triton Target Setup

- Identical 25-cm sealed-cell gas target cells for $H_2$, $D_2$, $T_2$, $^3He$
- $I_{beam} \leq 25\ \mu A$

| Cell | Thickness (mg/cm$^2$) | Pressure (psi) | Number density |
|---|---|---|---|
| $H_2$ | 55 | 400 | 2 |
| $D_2$ | 111 | 400 | 2 |
| $T_2$ | 82 | 200 | 1 |
| $^3He$ | 82 | 400 | 1 |



# New Triton (e,e'p) Experiment

- $Q^2 \approx 2\ \mathrm{GeV}^2$
  - Reduces non-nucleonic currents (MEC, IC)
  - Proton energies high enough for eikonal FSI calculations
- $x = Q^2/2m\omega > 1$ to minimize non-nucleonic currents
- $\theta_{rq} < 40^o$ to minimize FSI
- $E_{\mathrm{beam}} = 4.4$ GeV
  - Maximum beam energy for HRSe
  - Maximizes the cross section
- $0 < p_{\mathrm{miss}} < 450$ MeV/c
  - Covers the region from mean field to SRC
- HRS with standard electron and proton detection packages

# Kinematics

- $E_{beam}$ = 4.4 GeV
- $Q^2$ = 2.0 GeV$^2$
- $I_{beam}$ = 25 $\mu$A
- $\mathcal{L}(^3H) = 8\times10^{36}$ nucleons cm$^{-2}$ s$^{-1}$

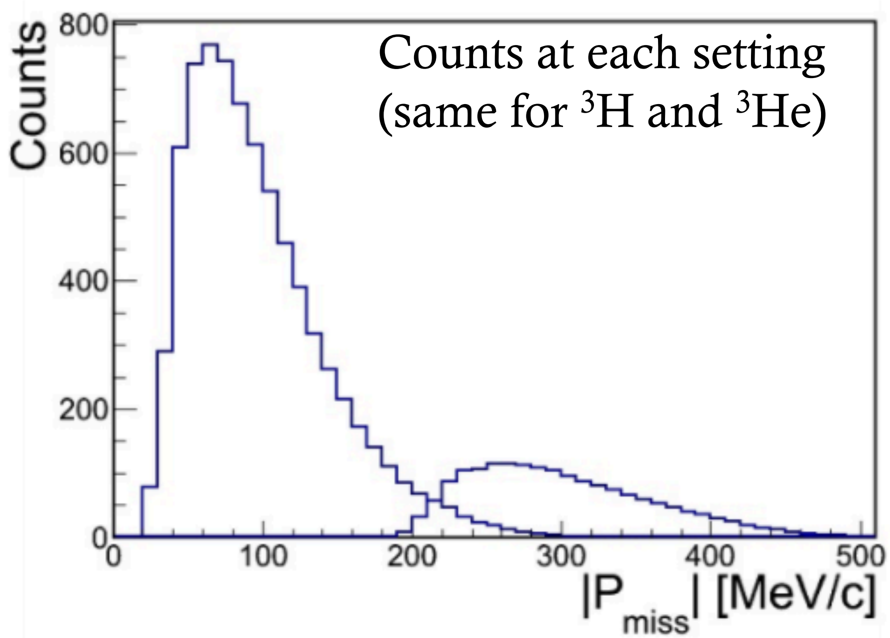
| $<p_m>$ (MeV/c) | $x$ | $E_e$ (GeV) | $\theta_e$ | $p_p$ | $\theta_p$ | Time $^3$H+$^3$He (days) |
|---|---|---|---|---|---|---|
| 100 | 1.15 | 3.47 | 20.9$^o$ | 1.61 | 48.7$^o$ | 1 |
| 300 | 1.41 | 3.64 | 20.4$^o$ | 1.35 | 58.6$^o$ | 8 |

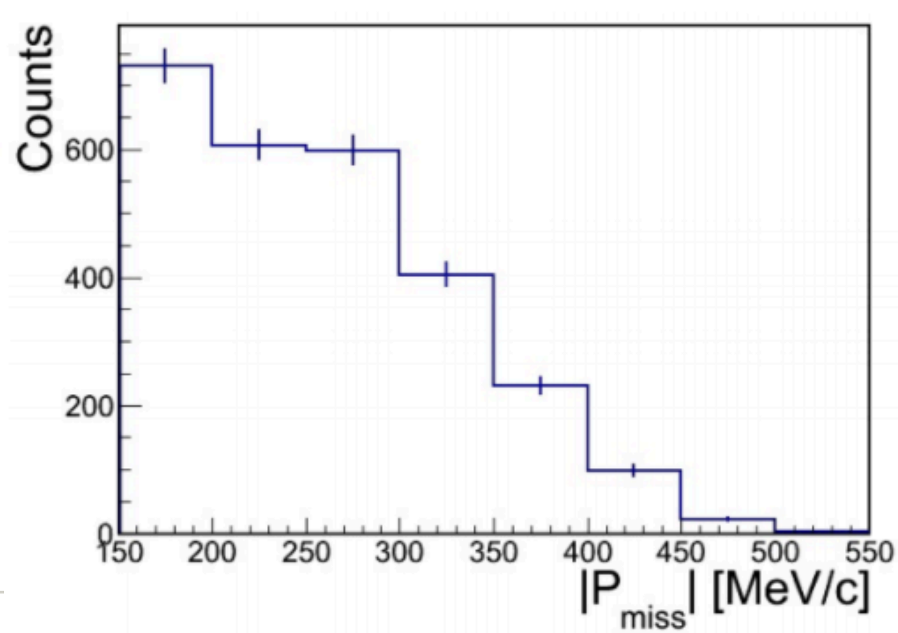
Hall A has done many (*e,e'p*) measurements at similar kinematics and much higher luminosities

This is a very low luminosity for an (*e,e'p*) experiment

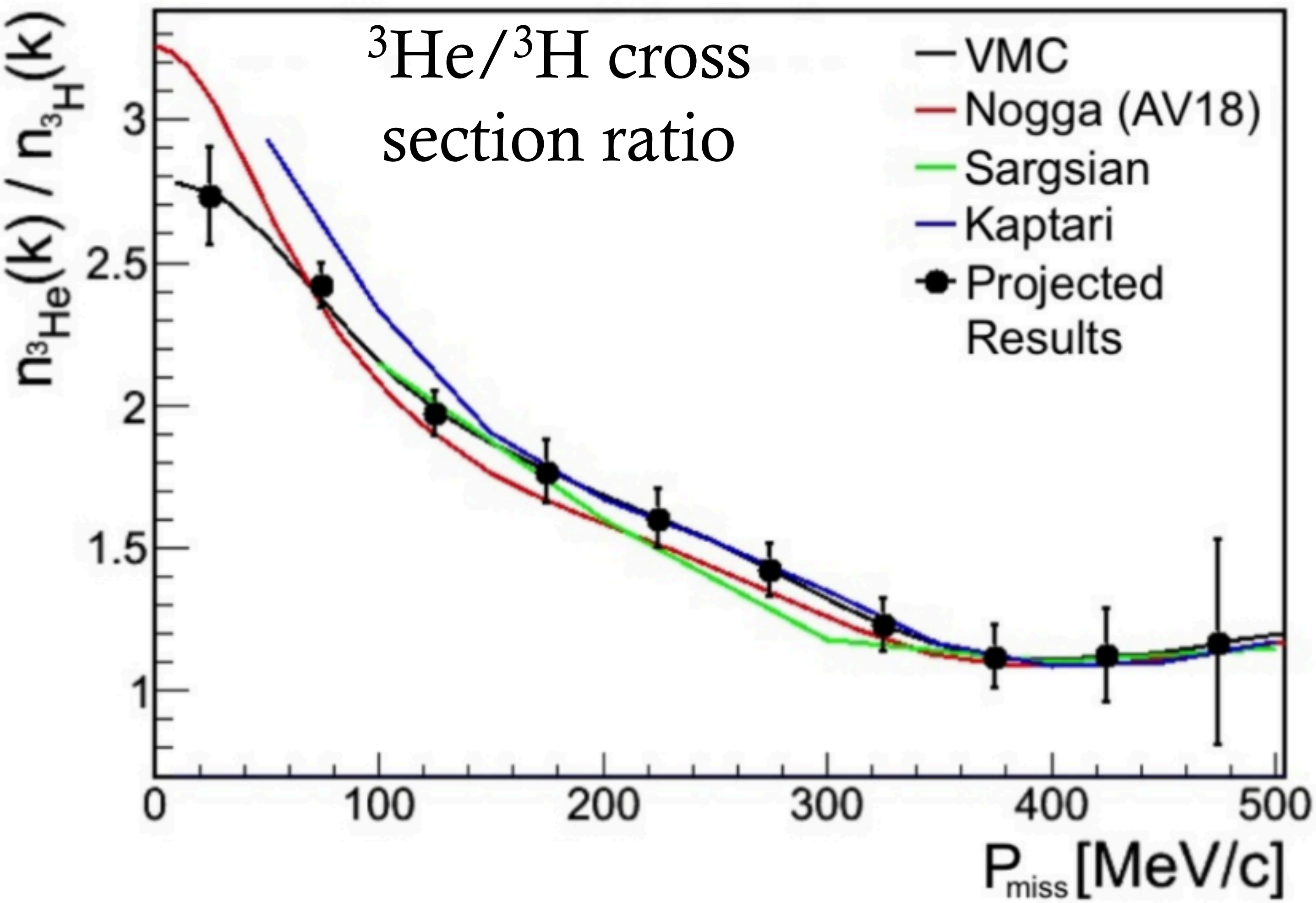
- Low rates
- Very little coincidence background

# MCEEP Count Rate Estimates

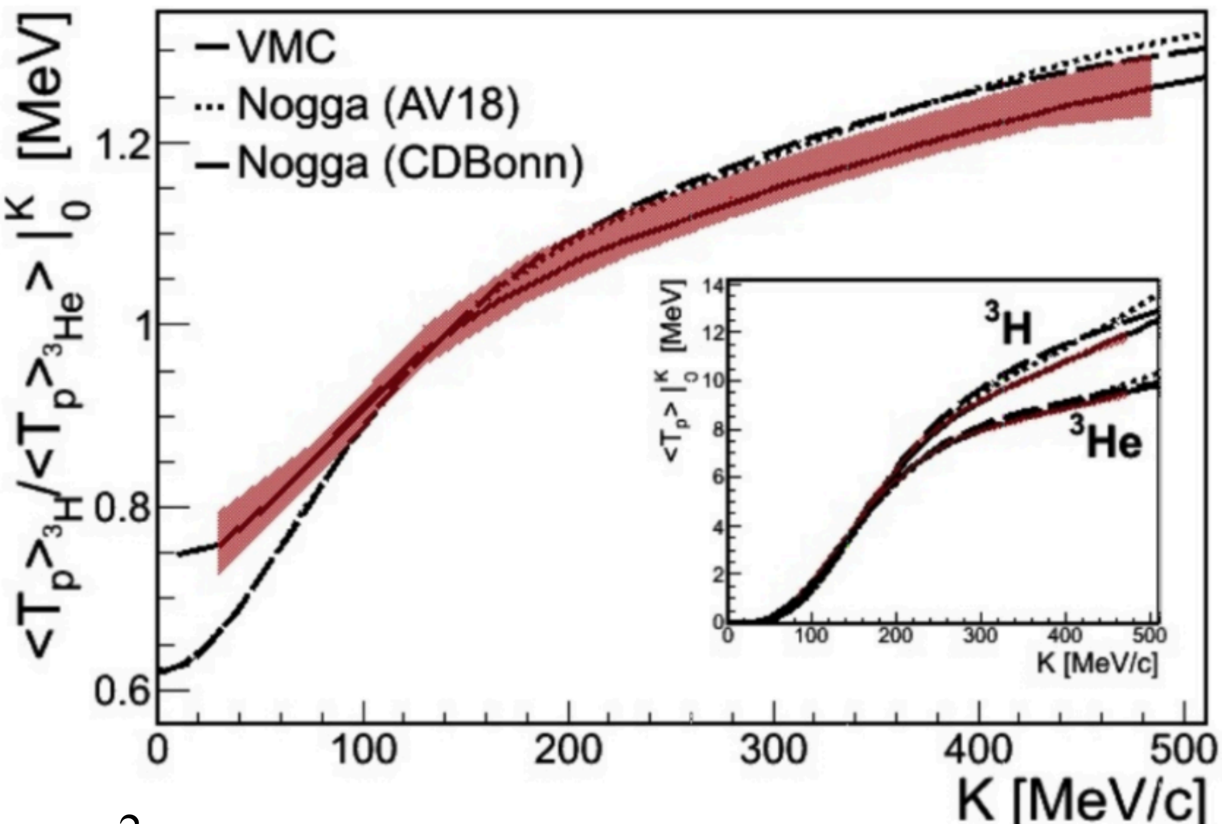


# Expected Results



# Extracted Average KE




$$\left\langle T_p \right\rangle_A \Big|_0^K = \int_0^K \frac{k'^2}{2m} \cdot n_{A,p}\left(k'\right) \cdot d^3 k'$$

# Changes Since PAC40

- Reduced beam time from 33 to 10 days:
  - Remove highest Pmiss kinematical setting
  - Remove deuterium measurements
- More focused physics case:
  - Study the individual proton and neutron momentum distributions in A=3 nuclei – the only highly asymmetric system where one can perform such measurements.
  - Study the effect of np-SRC in both high and low $p_{miss}$ region
    - Compare to detailed calculations.
  - Study the momentum sharing in asymmetric systems.
    - Map the inversion of the momentum sharing in the system.

# Summary

- Measure $^3$H and $^3$He $(e,e'p)$
  - 10 days of beam time at 4.4 GeV
  - $Q^2 = 2$ GeV$^2$ and $x > 1$ to minimize MEC, IC
  - $\theta_{rq} < 40^o$ to maximize sensitivity to nucleon momentum distributions
  - $^3$He/$^3$H ratio cancels residual FSI
- Measure the mean-field to SRC transition in the $^3$He/$^3$H ratio from >2 at low $p_{miss}$ to 1 at high $p_{miss}$
- Measure absolute cross sections and ratios to deuterium to constrain detailed calculations
- Unique opportunity to measure $^3$H$(e,e'p)$ to better understand nucleon momentum distributions in asymmetric nuclei.