Nucleon Momentum Distributions in Asymmetric Nuclei
A Comparison of ^{3}He(*e,e'p*) and ^{3}H(*e,e'p*)
PR12-13-012

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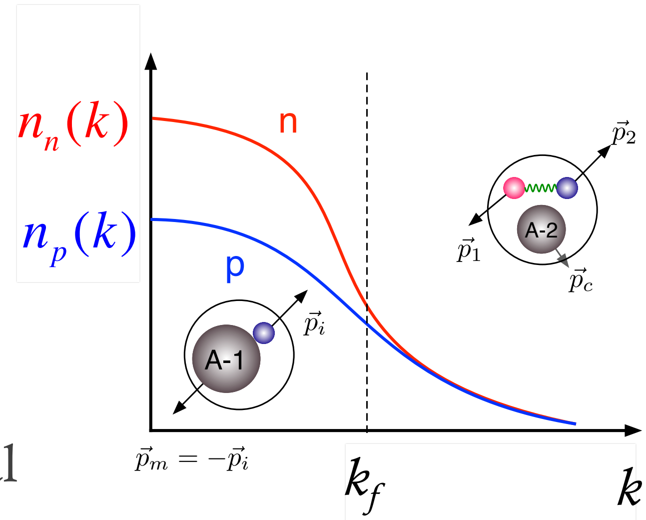
Outline

- Overview
- Short range correlations in nuclei
- Nucleon momentum distributions in asymmetric nuclei
- Calculated ground state momentum distributions in A=3 nuclei
- Avoiding the problems of previous measurements
- The proposed experiment
- The expected results

Overview

- Measure the quasielastic $(e,e'p)$ reaction on ^{3}H, ^{3}He, and d
  - First measurement of $^3\text{H}(e,e'p)$
  - Choose kinematics where FSI are small
  - Measure cross sections sensitive to ground state momentum distributions
  - Measure ratios of cross sections so residual FSI cancel

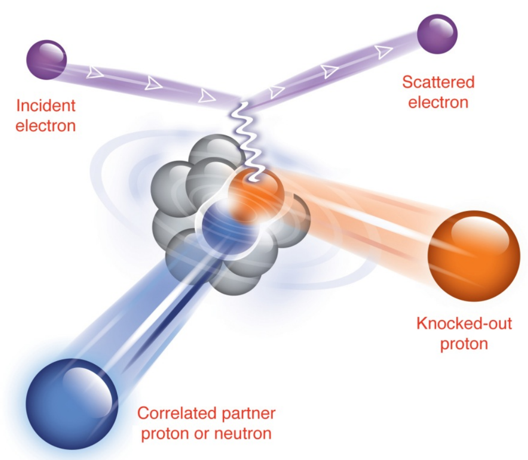


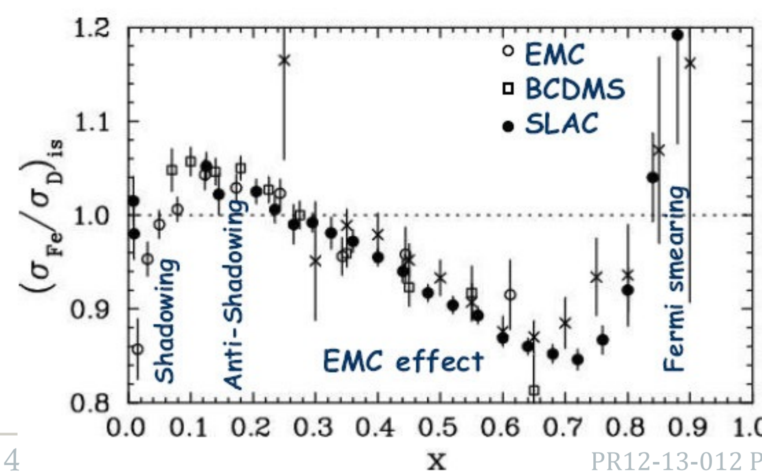
- Simple picture: Map the transition as $\sigma(^3\text{He})/\sigma(^3\text{H})$ changes from 2 at small p_{miss} due to proton counting to 1 at large p_{miss} due to *np* pair counting

- Quantitative picture: compare to calculations with exact ground states and eikonal approximation FSI

Short Range Correlations in Nuclei

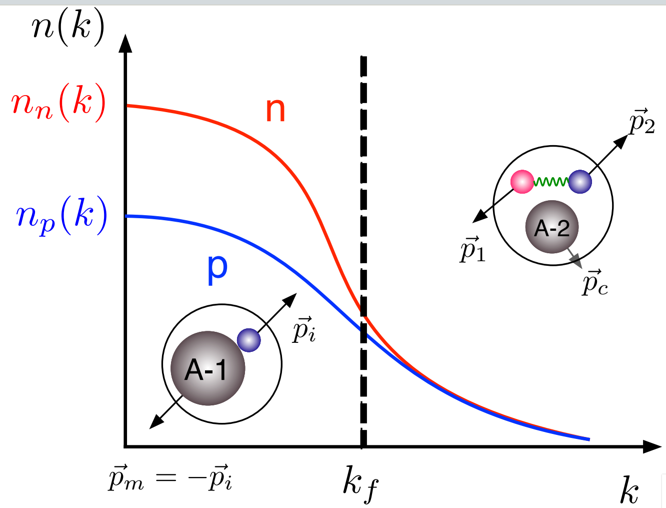
- Almost all nucleons with $p > 275$ MeV/c belong to a short range correlated (SRC) *NN* pair with small cm momentum and large relative momentum.
- 90% of these pairs in ^{12}C are *pn* pairs.
- The proportion of nucleons belonging to SRC *NN* pairs is about 5% in *d* and 10% in ^{3}He.
- The strength of the EMC effect in a nucleus is closely correlated with the number of SRC pairs in that nucleus.





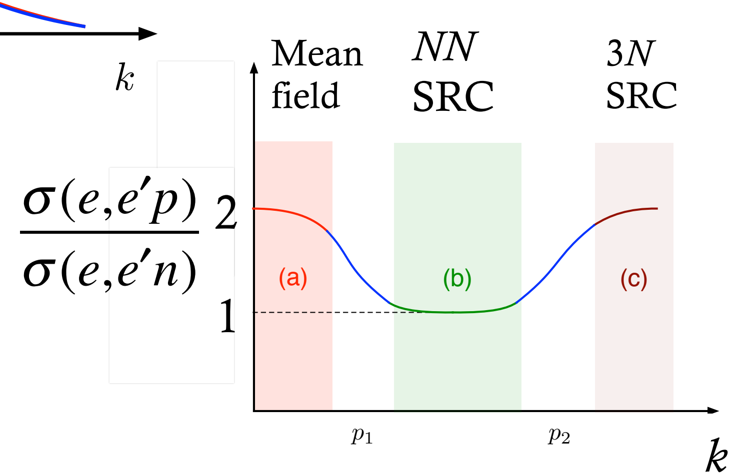
Nucleon momentum distributions in asymmetric nuclei

Dominated by independent (mean-field) nucleons



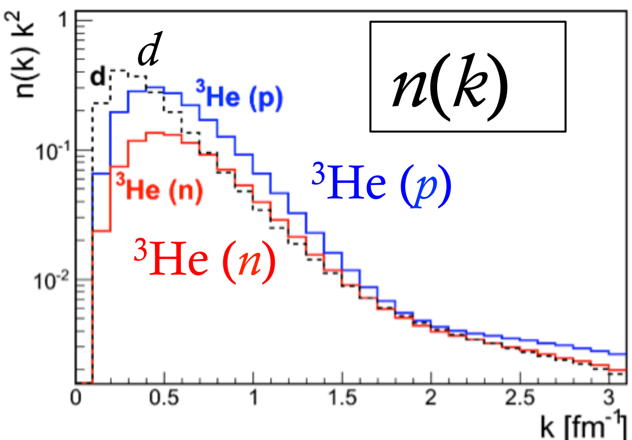
Dominated by nucleons belonging to SRC *pn* pairs

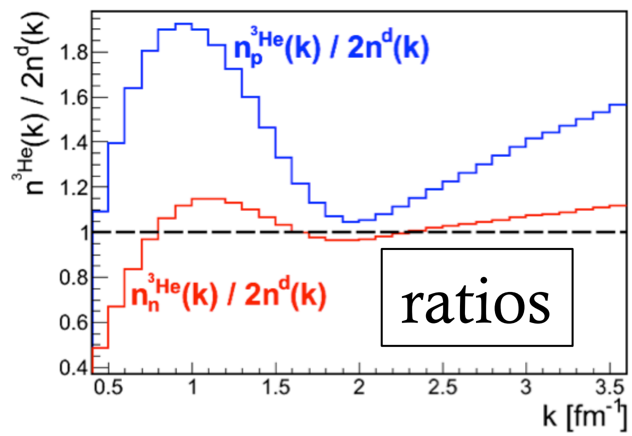
- If there are fewer protons than neutrons then the protons should have higher average momentum and kinetic energy
  - If there are fewer boys than girls at a dance, the average boy will dance more than the average girl (assuming *bg*-pair dominance).



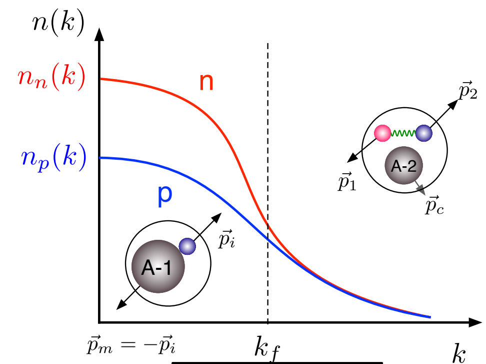
Naively expected ^{3}He ratio

A=3 ground state momentum density calculations

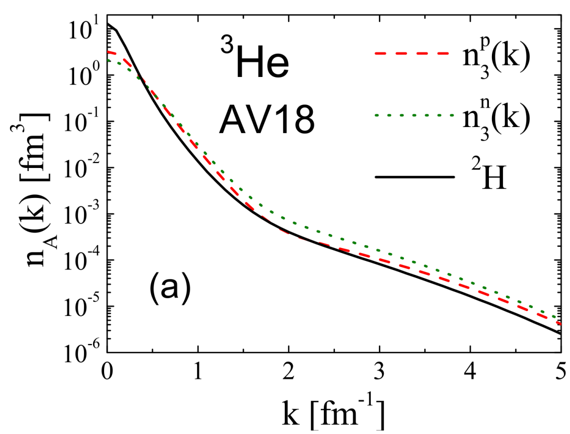


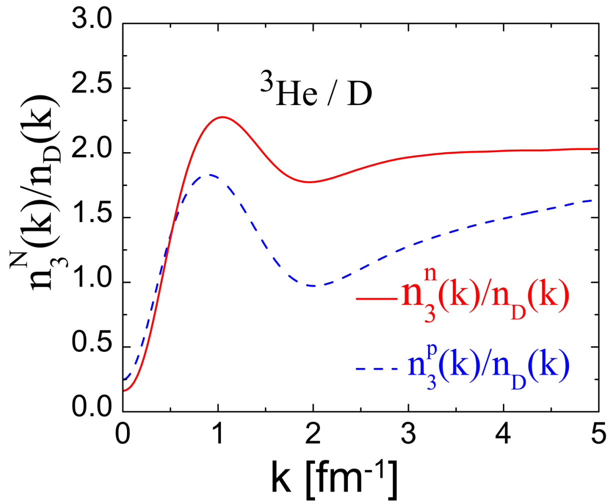


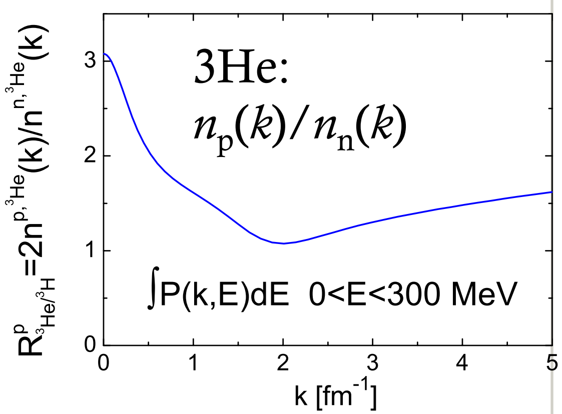
Wiringa, *et al.*



Cartoon

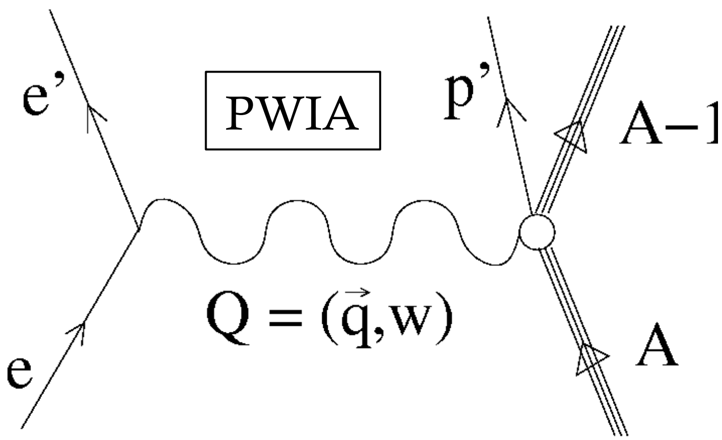






Kaptari, *et al.*

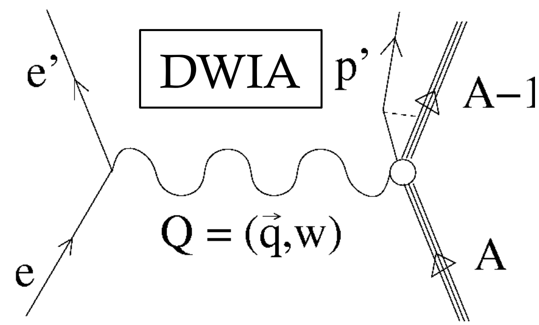
$A(e,e'p)$ kinematics



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

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

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



$$\vec{p}_m \approx \vec{p}_{init}$$

$A(e,e'p)$ Formalism

Spectral function $S(E_m,p_m)$: probability of finding a nucleon in the nucleus with momentum p_m and separation energy E_m

$\rho(p_m) = \int S(E_m, p_m)dE_m$ Nuclear momentum distribution

$$\frac{d^6\sigma}{d\omega d\Omega_e dE_m d\Omega_p} = \kappa\sigma_{ep} S(E_m, p_m)$$

κ is a known kinematic factor

σ_{ep} is the half-off-shell electron-proton elementary cross section

We measure: $\sigma_{red}(E_m, p_m) = \left[\frac{d^6\sigma}{d\omega d\Omega_e dE_m d\Omega_p}\right] / [\kappa\sigma_{ep}]$

In the absence of Final State Interactions [FSI] this becomes:

$$S(E_m, p_m) = \sigma_{red}(E_m, p_m)$$

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

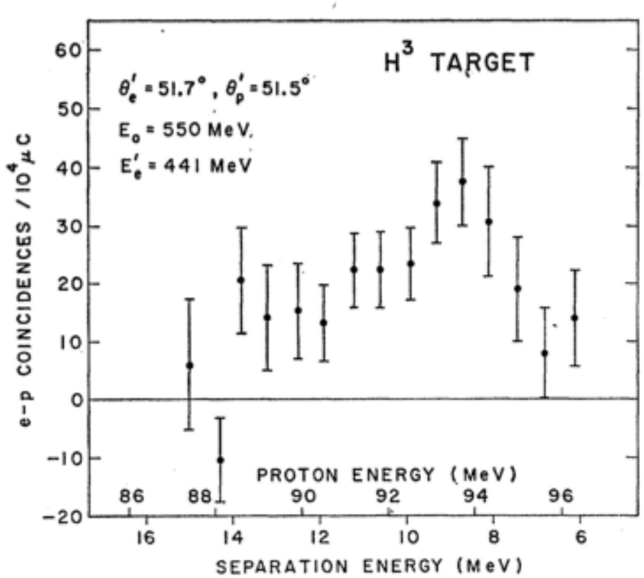


FIG. 2. The energy spectrum of protons at 51.5° in coincidence with 441-MeV electrons at 51.7° from H^3 $(e,e'p)$.

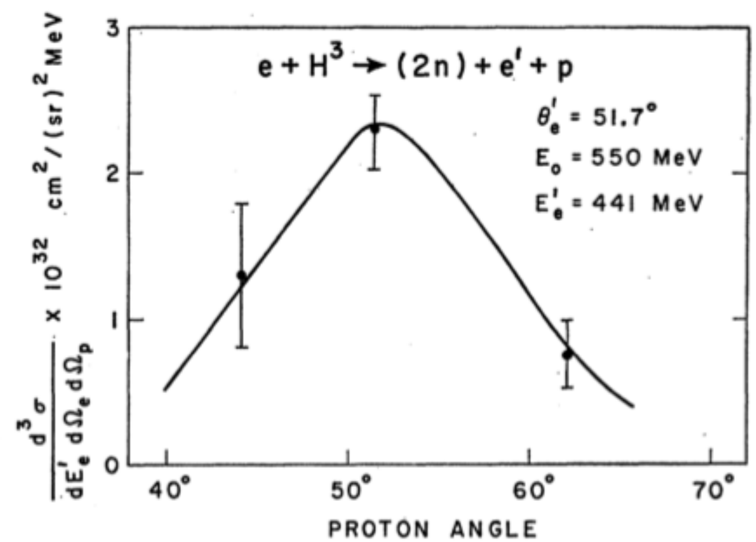
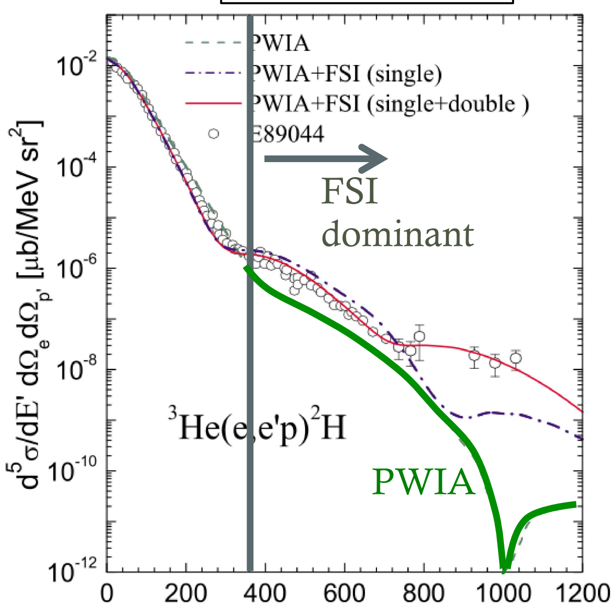


FIG. 4. The coincidence cross section of reaction (C) as a function of proton angle. The curve is explained in Sec. VI of the text.

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

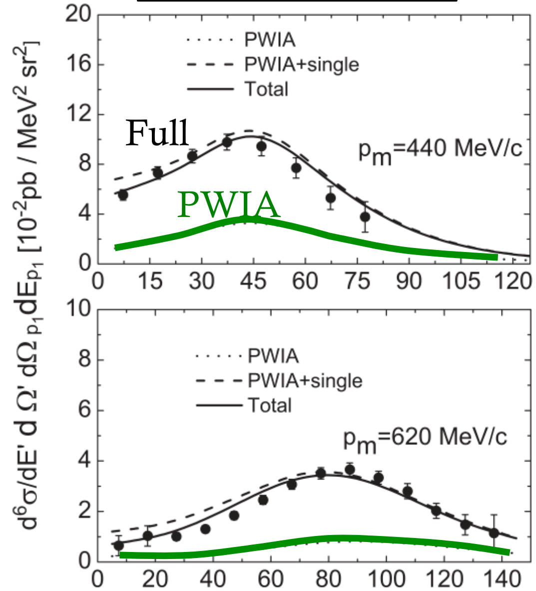
Previous $^3He(e,e'p)$ measurements

$^3He(e,e'p)d$



p_m [MeV/c]

$^3He(e,e'p)np$



E_m [MeV]

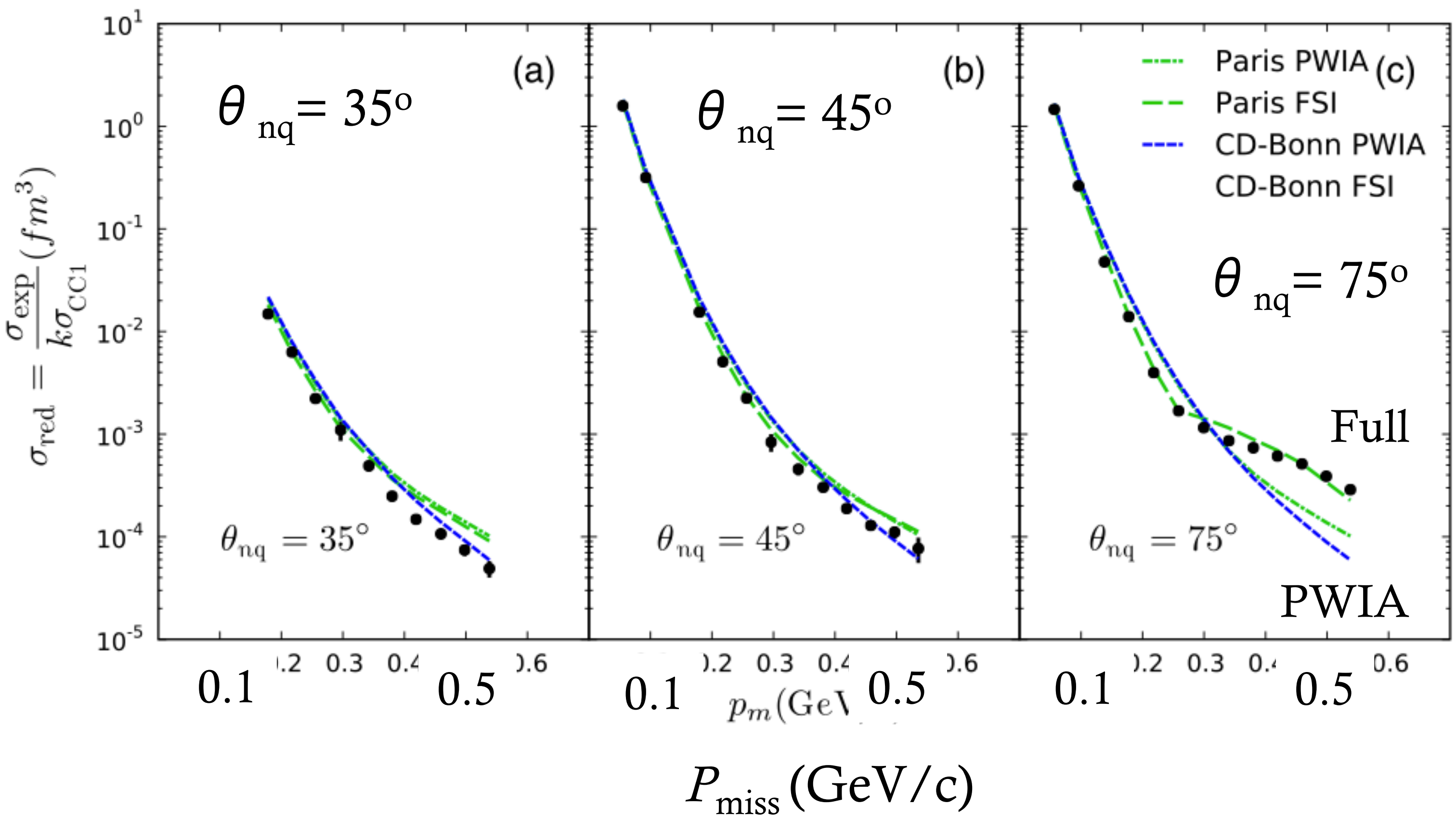
p_m = 440 MeV/c

p_m = 620 MeV/c

Data:
Rvachev *et al.*, PRL94 192302
Benmokhtar *et al.*, PRL94 082305
Calculations:
Ciofi degli Atti and Kaptari, PRL95 052502
Alvioli *et al.*, PRC81 021001
Laget, PLB609 49 (not shown)

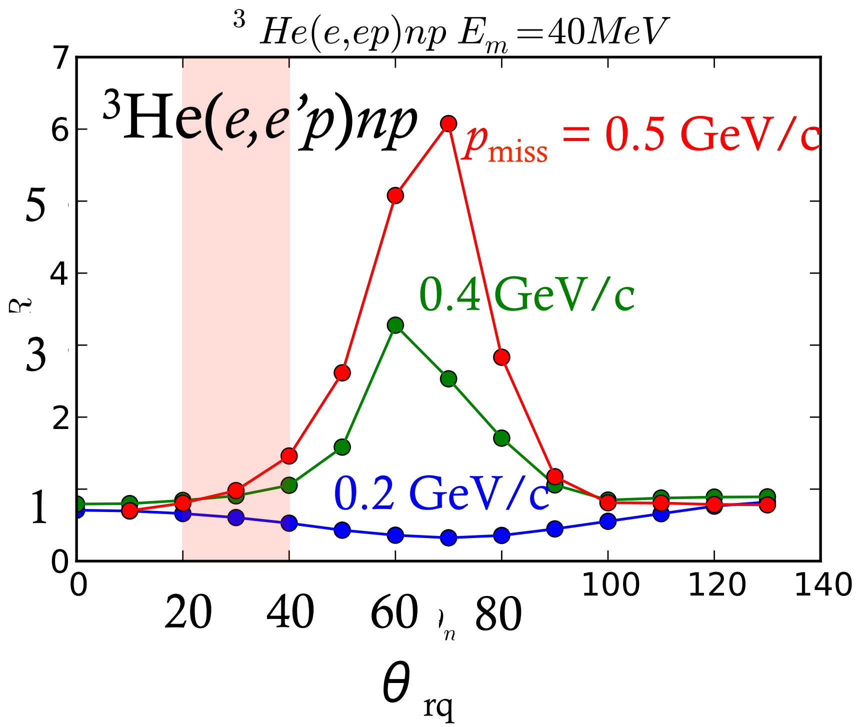
Dominated by FSI at large missing momentum
Well described by calculation

Minimizing *d*(*e*,*e'p*) FSI: choosing kinematics



Minimizing ^{3}He(*e,e'p*) FSI choosing kinematics

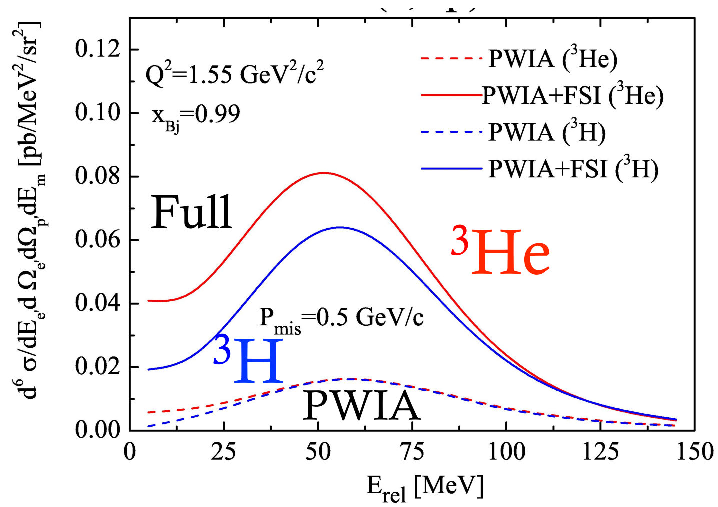
Ratio of FSI to PWIA calculations

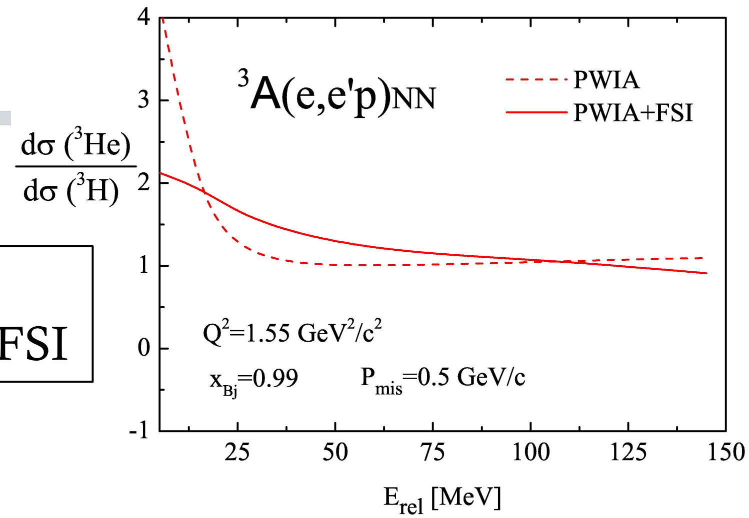


The angle between the recoil momentum and *q*

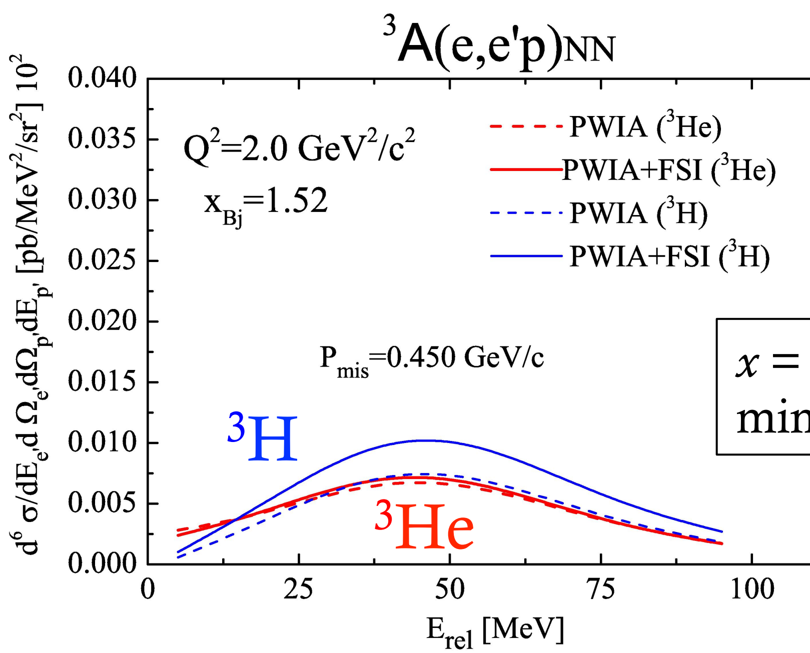
Conclusions: (from both *d* and ^{3}He(*e,e'p*): Measure at $\theta_{rq} \approx 30^o$

Minimizing FSI: taking ratios at p_m = 0.5 GeV/c

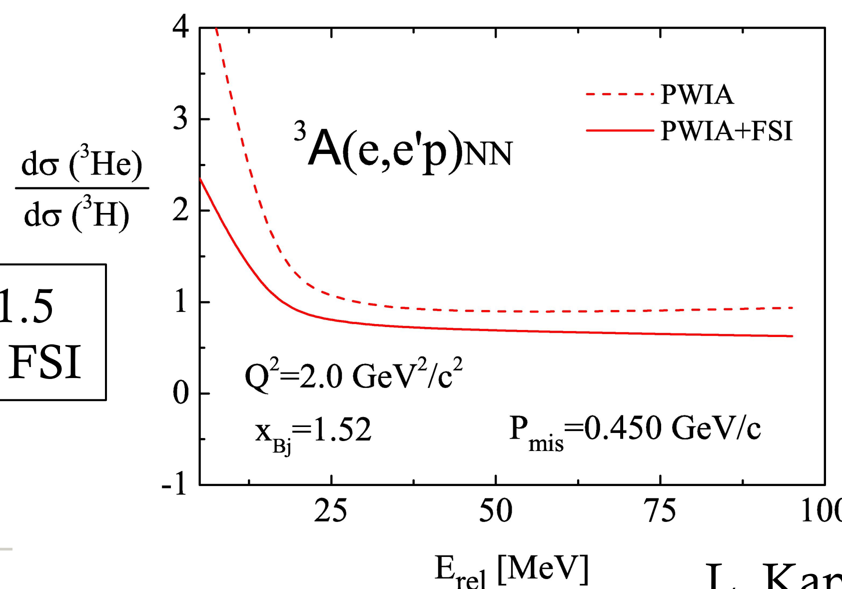




$x = 1$
max FSI



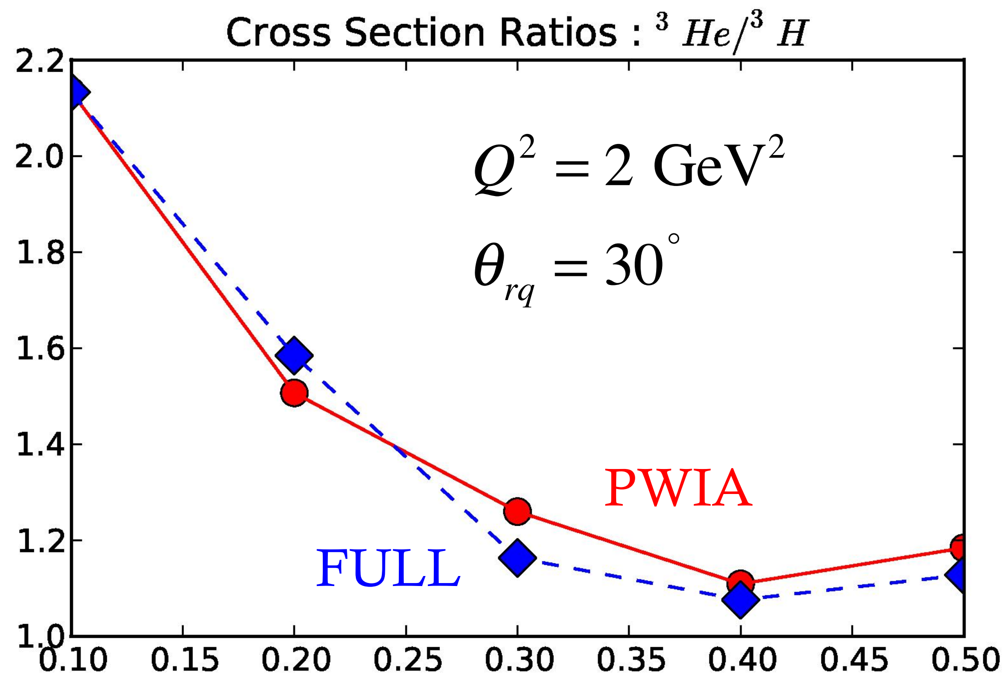
$x = 1.5$
min FSI



L. Kaptari

Minimizing FSI: taking ratios

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



P_m (GeV/c)

These are the kinematics of this proposal

Sargsian

- Minimize FSI by choosing $\theta_{\mathrm{rq}} = 30^\mathrm{o}$
- Cancel the residual effects of FSI by calculating ratios

$$\Rightarrow \frac{\sigma(^3\mathrm{He}(e,e'p))}{\sigma(^3\mathrm{H}(e,e'p))} \approx \frac{S_{3\mathrm{He}}(E_m, p_m)}{S_{3\mathrm{H}}(E_m, p_m)}$$

The experiment

- $Q^2 \approx 2$ 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
- $E_{beam} = 4.4$ GeV
  - Maximum beam energy for HRSe
  - Maximizes the cross section
- $0 < p_{miss} < 500$ MeV/c
  - Covers the region where the $^3He/^3H$ ratio decreases from 2 to 1
- HRS^2 with standard electron and proton detection packages

Kinematics

- E_{beam} = 4.4 GeV
- Q^2 = 2.0 GeV^2
- I_{beam} = 25 μ A
- $\mathcal{L}(^3H) = 2.5\times10^{36}$ cm^{-2} s^{-1}

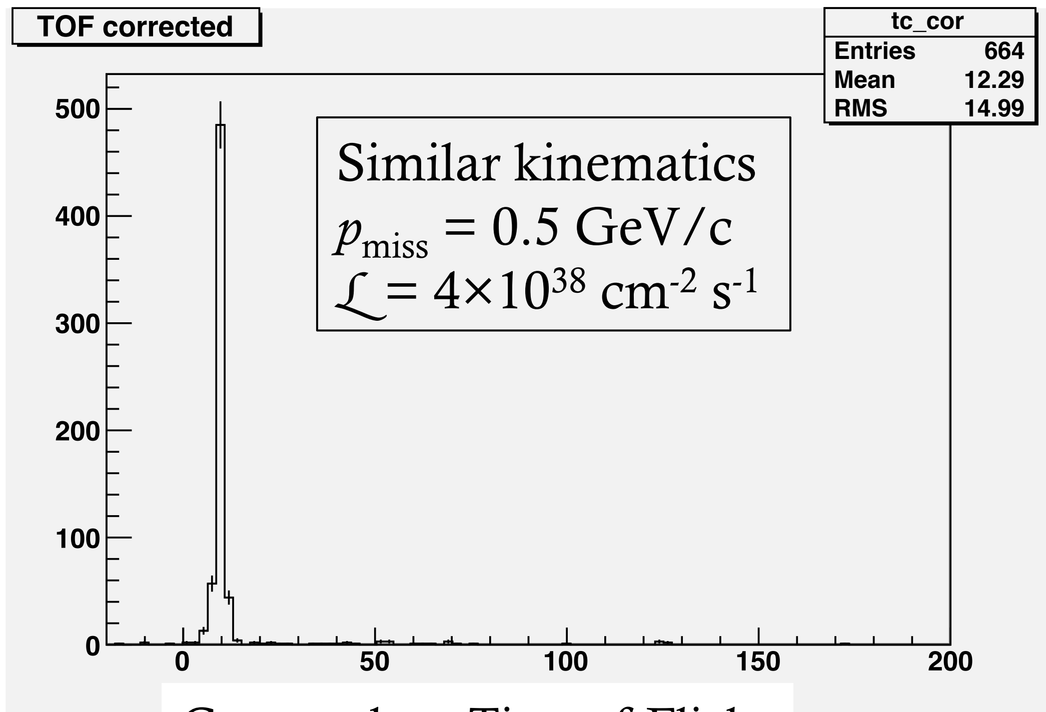
$\langle p_m \rangle$ (MeV/c)	x	E_e (GeV)	θ_e	p_p	θ_p	Time (days)
100	1.15	3.47	20.9°	1.607	48.7°	0.3/0.3/0.3
300	1.41	3.64	20.4°	1.352	58.6°	5/3/3
450	1.52	3.70	20.2°	1.229	64.9°	0/10/10

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

d(*e,e'p*) Backgrounds and Rates



Corrected e-p Time of Flight

From the 6 GeV *d*(*e,e'p*) measurement
W. Boeglin

E_{in} = 4.7 GeV,
θ_{nq} = 40^o,
p_{miss} = 0.5 GeV/c
Q^2 = 2.1 (GeV/c)^2,

Beam current = 94uA
Target = 15cm liquid D

θ_e = 19.3^o
θ_p = 66.3^o

p_e = 3.97 GeV/c
p_p = 1.23 GeV/c

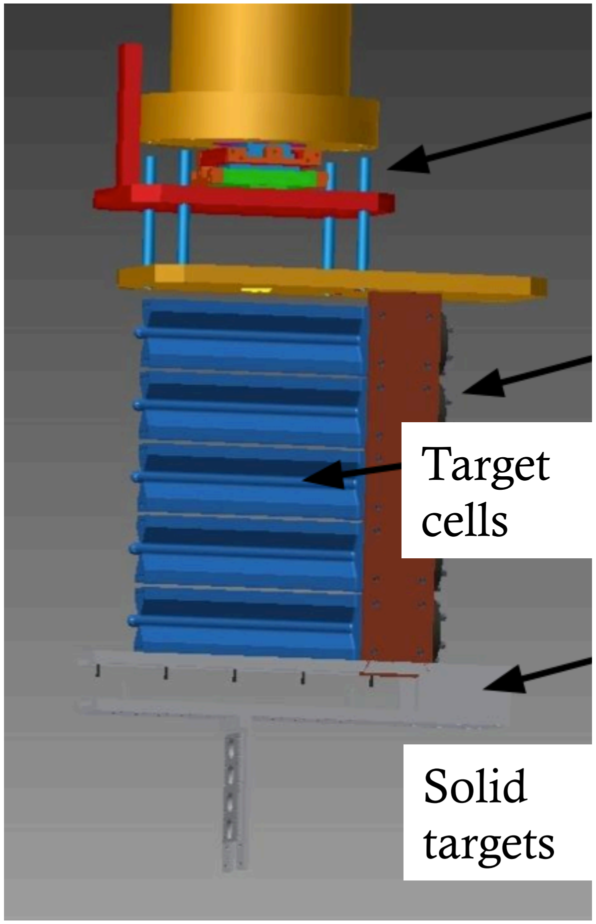
Proton rates (T1): 1.6 kHz
Electron rates (T3): 4.6 kHz
Coincidence rate (T5): 4.3 Hz

The Marathon Target

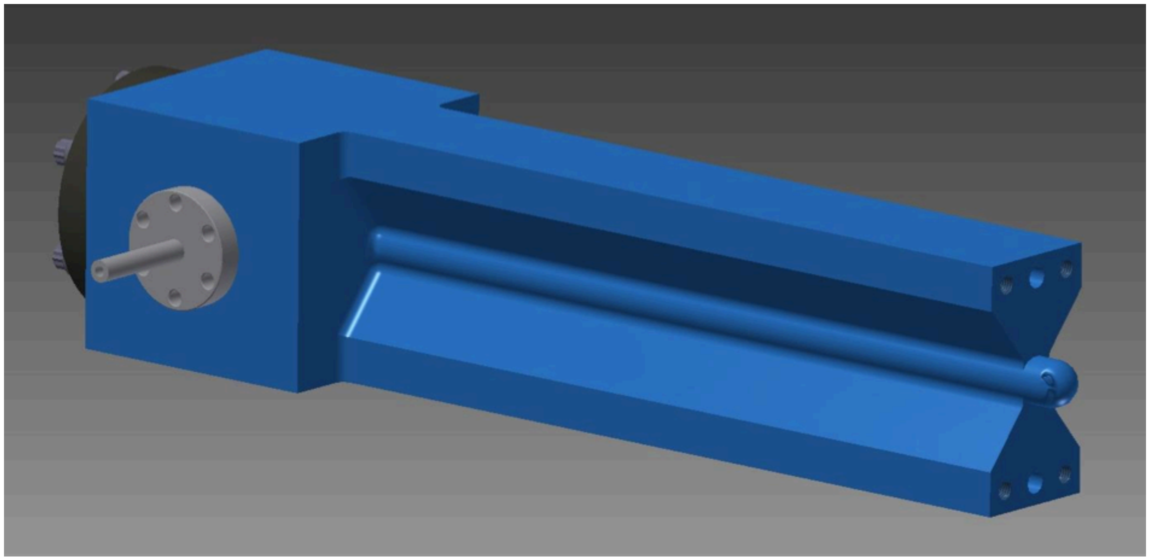
- Identical 25-cm sealed-cell gas target cells for H_2, D_2, T_2, ^3He
- $I_{beam} \leq 25\ \mu A$

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

NB: Pressure is at room temperature. Cells will be cooled during target operation.



The Marathon Target

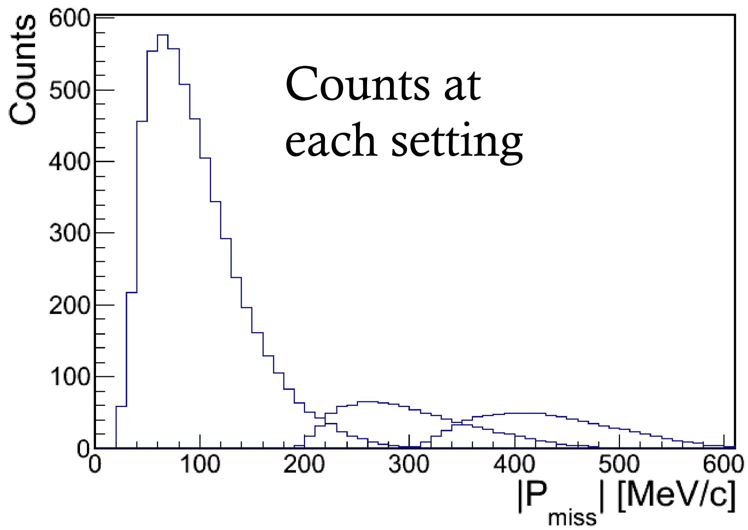


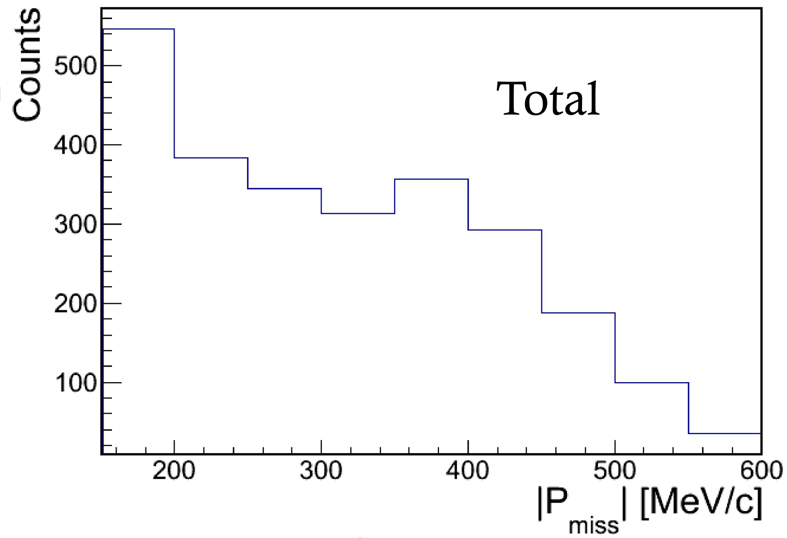
- Open cell design allows a wide range of scattering angles
- Wall thickness 0.018" Al (120 mg/cm^2)
- Entrance and exit windows: 0.010" Al (65 mg/cm^2)
- The proton HRS will not see the cell windows

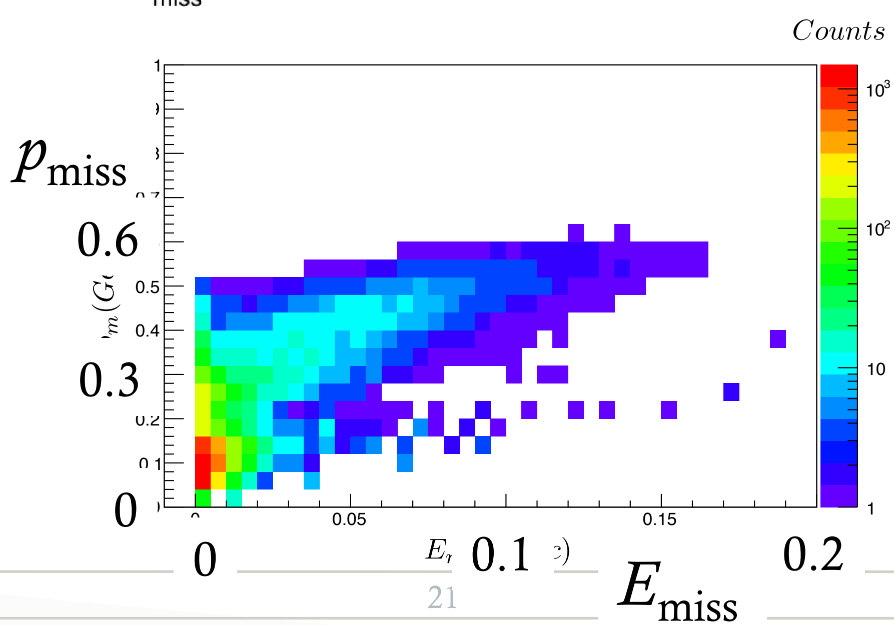
Count Rate Estimates

- MCEEP
  - Automatically includes all spectrometer acceptances
  - *R*-function cuts
- Deuteron PWIA cross section including electron radiation
  - $I_{beam} = 25\ \mu A$
  - t = 75 mg/cm^2 deuterium (actually 111 mg/cm^2)
- Used deuterium count rates for D_2, T_2 and ^3He
  - Ratio of number densities D_2:T_2:^3He = 2:1:1
  - Ratio of high p_{miss} cross sections: 1:2:2
- Factor of 111 / 75 = 1.5 to account for
  - More restrictive acceptance cuts
  - Spectrometer efficiencies (about 15% each)

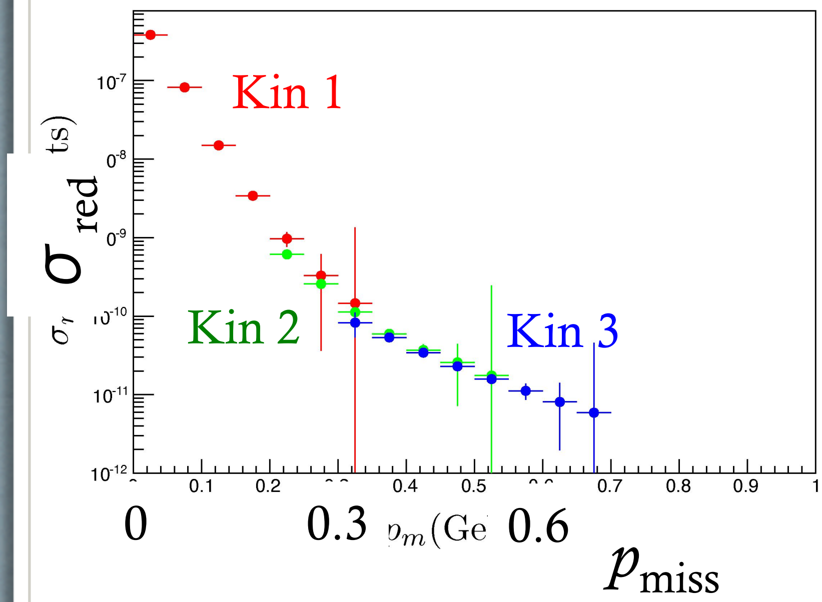
Count Rate Estimates

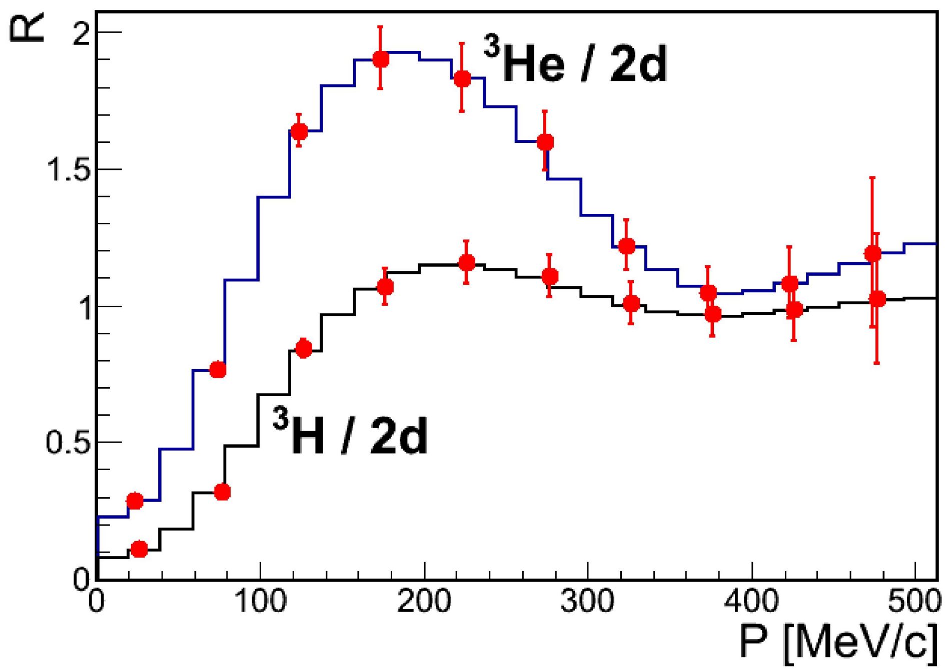






Results





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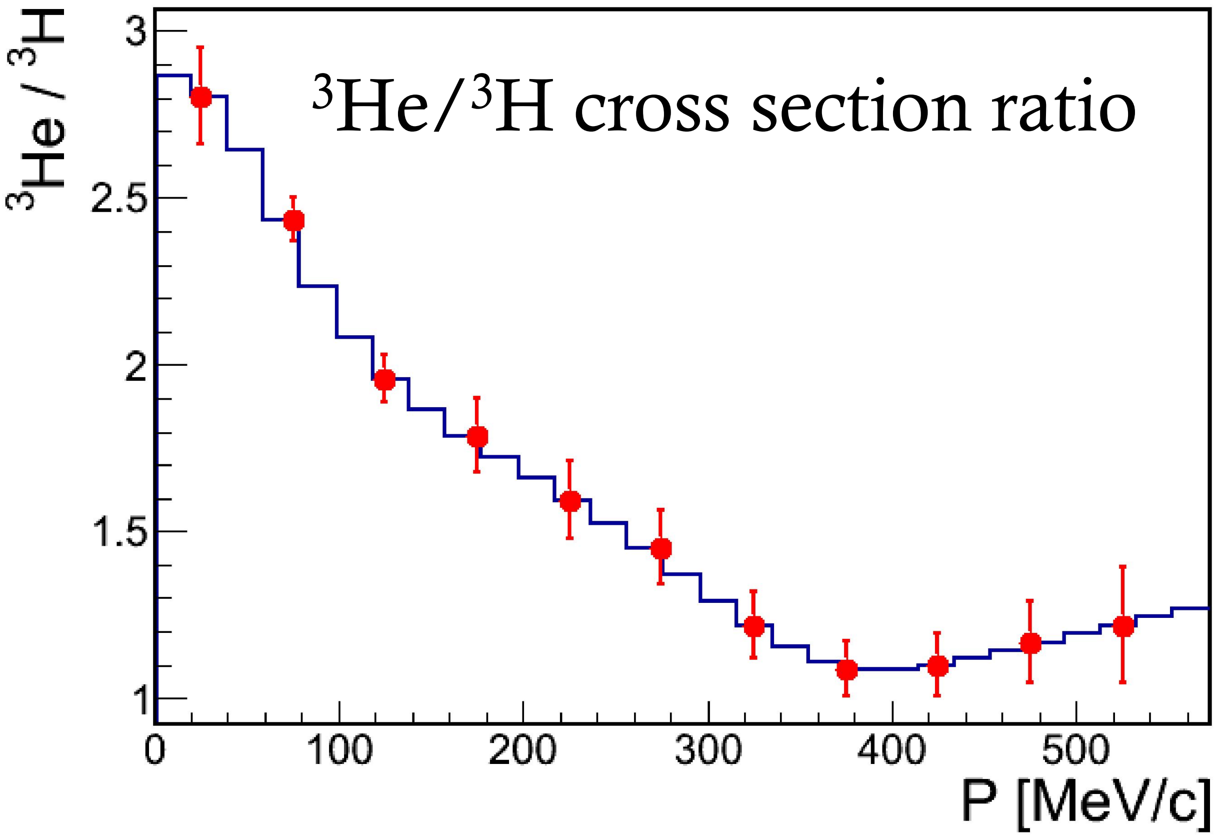

^{3}He/^{3}H cross section ratio
^{3}He / ^{3}H
3
2.5
2
1.5
1
0
100
200
300
400
500
P [MeV/c]

Summary

- Goal: understand nucleon momentum distributions in asymmetric nuclei
- Measure *d*, ^{3}H, and ^{3}He(*e,e'p*)
  - $Q^2 = 2$ GeV^2 and $x > 1$ to minimize MEC and IC
  - $\theta_{rq} = 30^o$ to minimize FSI
  - Calculate ^{3}He/^{3}H ratio to cancel 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*)