Tritium x>1 Analysis Status

Shujie Li
On behalf of the E12-11-112 Collaboration

JLAB Hall A Winter Meeting
Jan 21, 2021

BERKELEY LAB

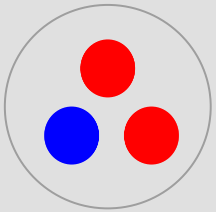
Jefferson Lab E12-11-112 (Hall A) :

Precision Measurement of the Isospin Dependence in the 2N and 3N Short-range Correlation Region

Spokespersons:
Patricia Solvignon (UNH), John Arrington (ANL), Donal Day (UVa), Douglas Higinbotham (Jefferson Lab), Zhihong Ye (ANL)
Students:
Shujie Li (UNH), Nathaly Santiesteban (UNH), Leiqaa Kurbany (UNH)

Measurements:
1H, 2H, 3H, 3He, (C12, Ti48) inclusive cross sections at 0.6<xbj<3

Primary Physics Topics:
Check the 2N SRC isospin dependence at 1<x<2, and also 3N momentum sharing configuration.

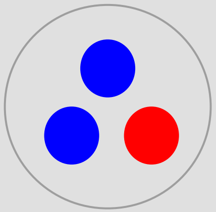


np pair dominates:

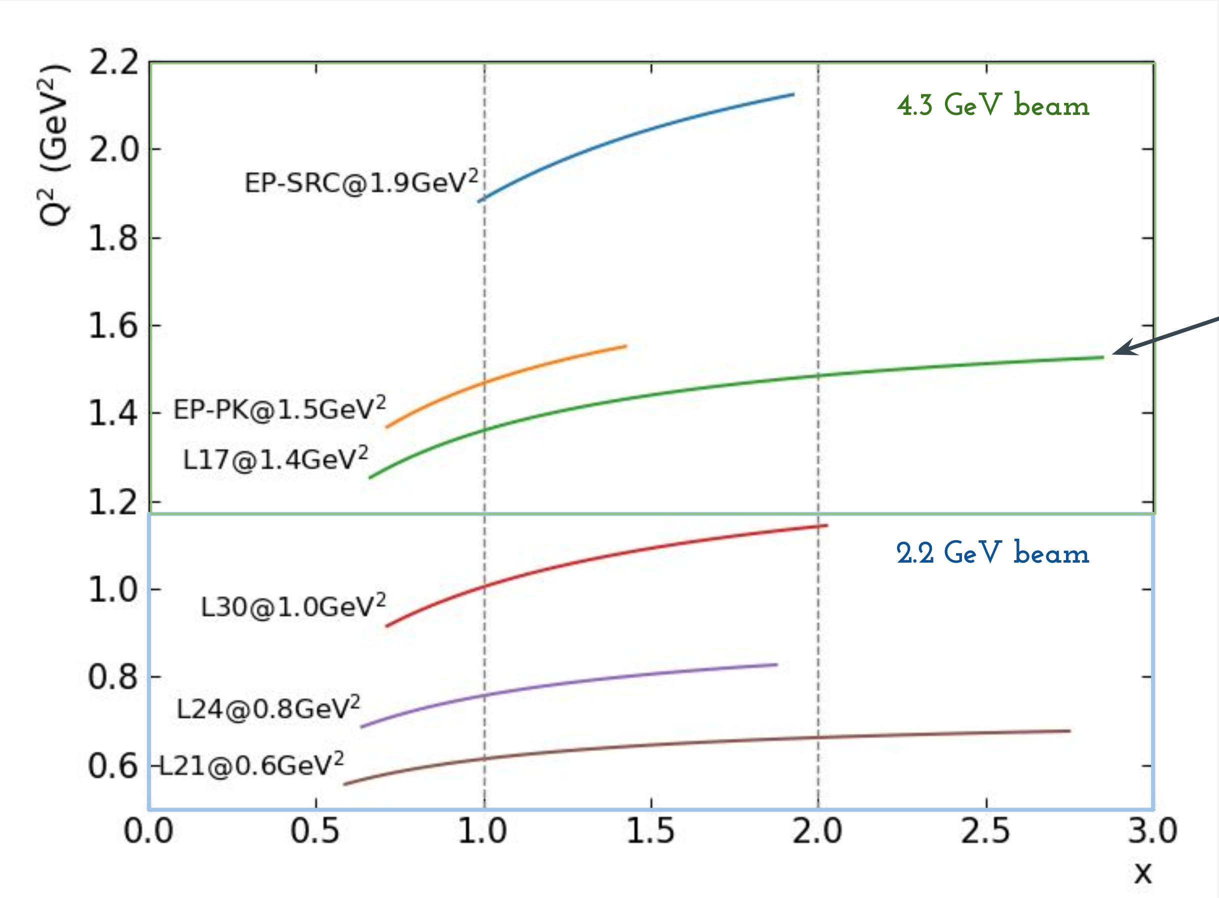
$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{\sigma_{np} + \sigma_n}{\sigma_{np} + \sigma_p} \simeq \frac{\sigma_{np}}{\sigma_{np}} = 1$$

no isospin preference:

$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{2\sigma_{nn} + \sigma_{pp}}{\sigma_{nn} + 2\sigma_{pp}} \xrightarrow{\sigma_p \sim 3\sigma_n} 0.7$$



x>1 Kinematics:

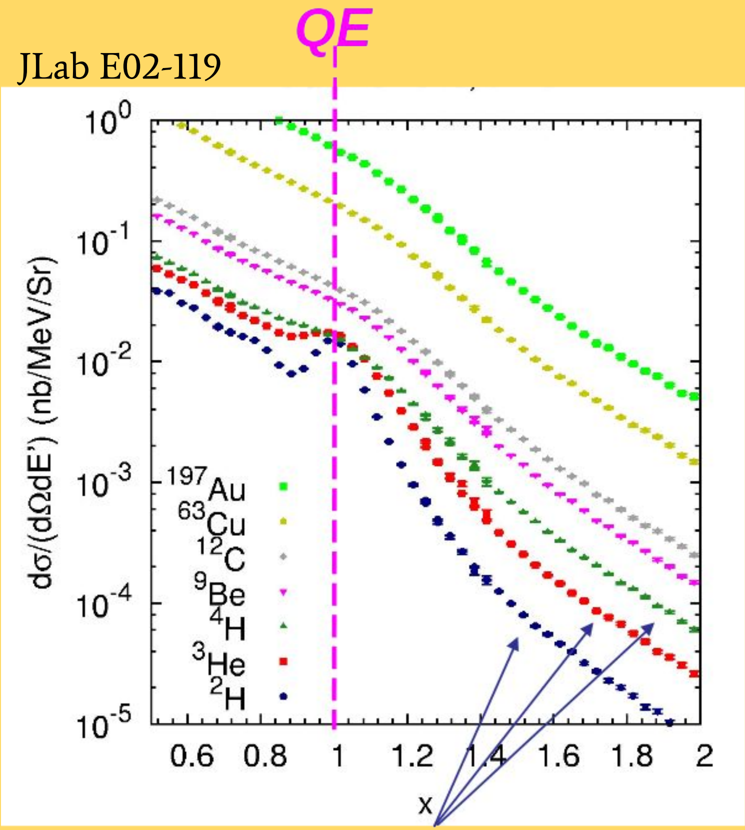


2018 fall data with 2nd tritium cell, affected by the hydrogen contamination

Probing 2N SRC at x>1

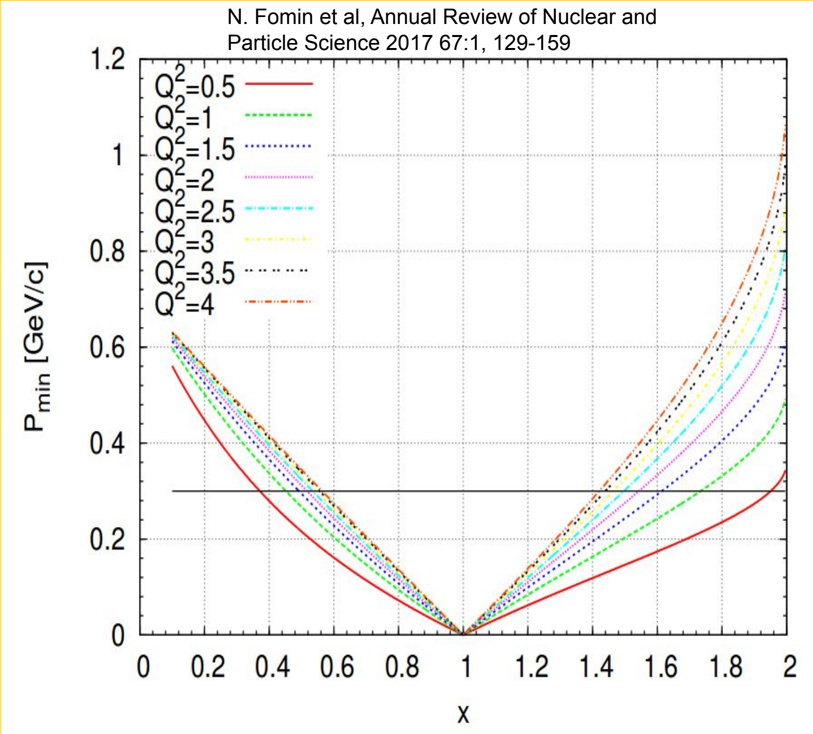
Inclusive electron scattering:
- high statistics
- background suppressed at high Q2

JLab E02-119



High momentum tails should yield **constant ratio** *if SRC-dominated*

N. Fomin, et al., PRL 108 (2012) 092052

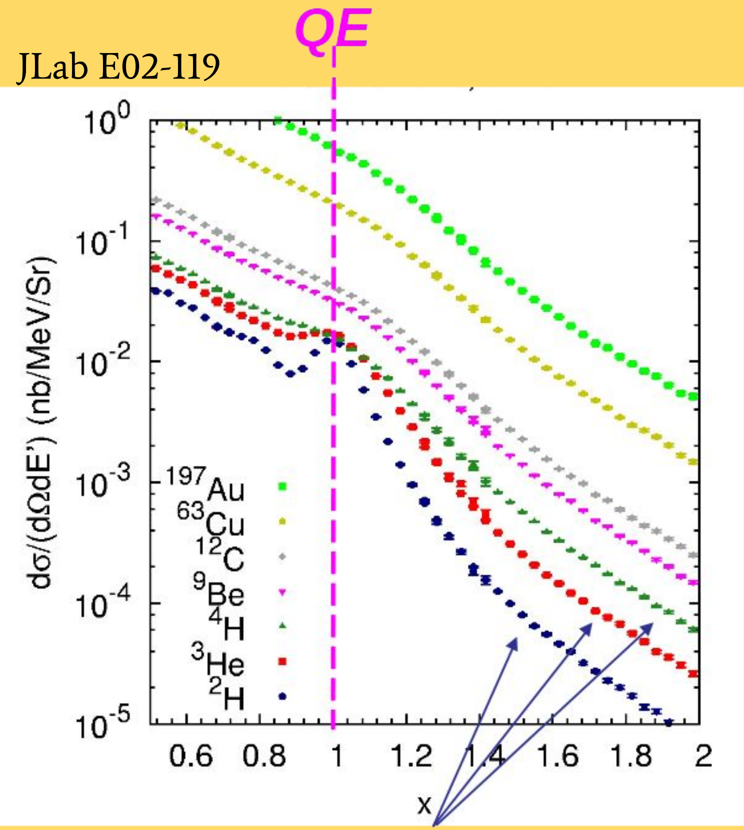


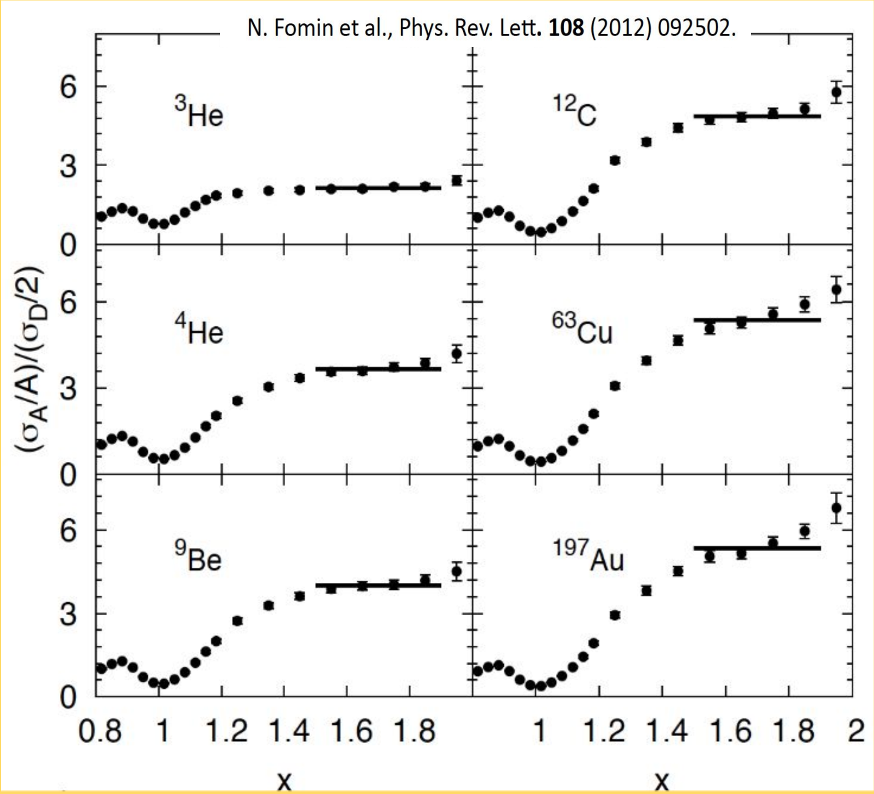
In inclusive (e,e') quasi-elastic scattering, high momentum nucleons dominate the x = Q2/2mν > 1 kinematics

Probing 2N SRC at x>1

Inclusive electron scattering:
- high statistics
- background suppressed at high Q2

JLab E02-119





High momentum tails should yield ***constant ratio*** *if SRC-dominated*

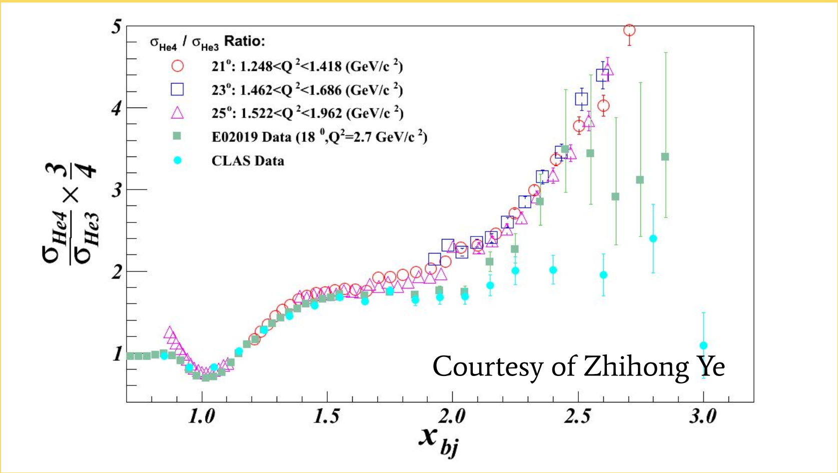
N. Fomin, et al., PRL 108 (2012) 092052

The x>1 plateau of A/D cross section ratios give the percentage of deuteron-like high momentum pairs in each nucleus

Probing 2N SRC at x>1

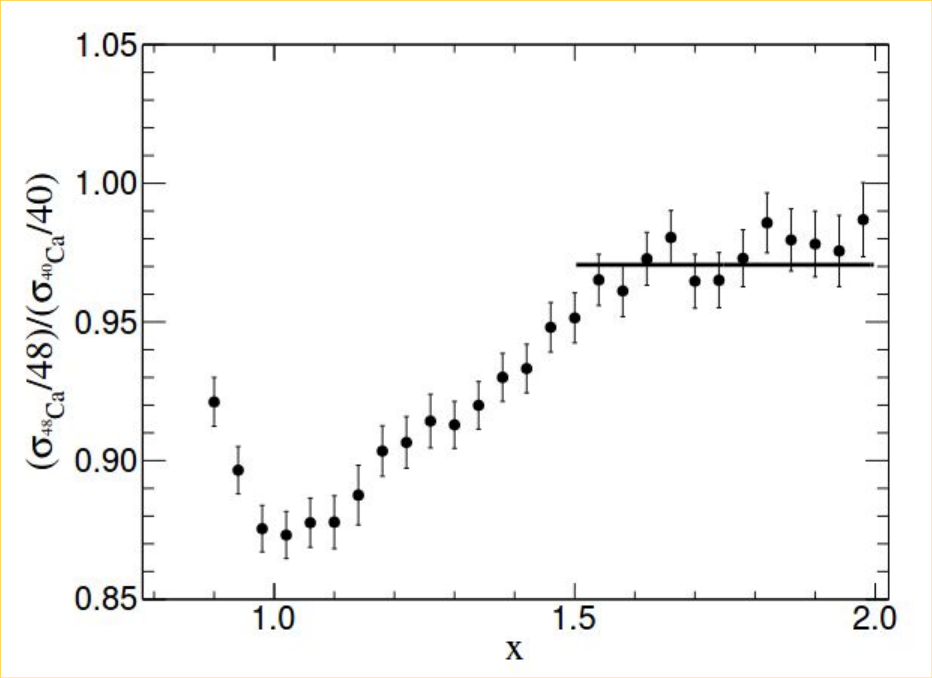
Inclusive electron scattering:
- high statistics
- background suppressed at high Q2

JLab E08-014



No x>2 plateau observed

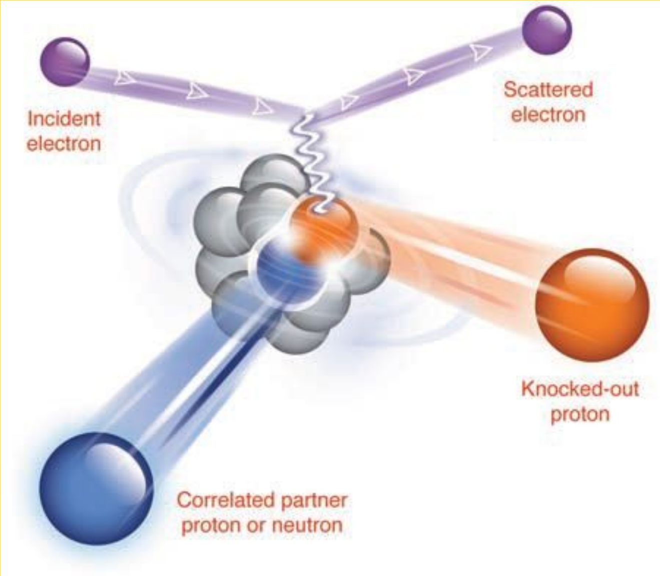
D Nguyen et al., Phys. Rev. C 102, 064004 (2020)

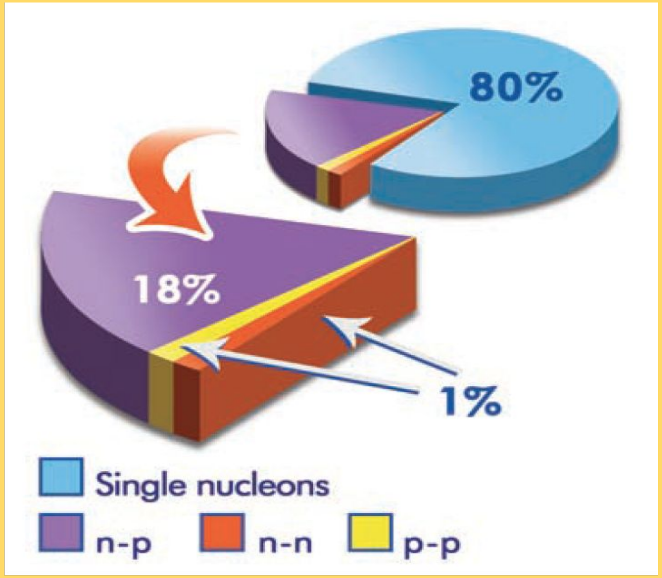


The x>1 plateau of A/D cross section ratios give the percentage of deuteron-like high momentum pairs in each nucleus

np-dominance in Triple-coincidence Experiment

Subedi, R. et al. https://doi.org/10.1126/science.1156675

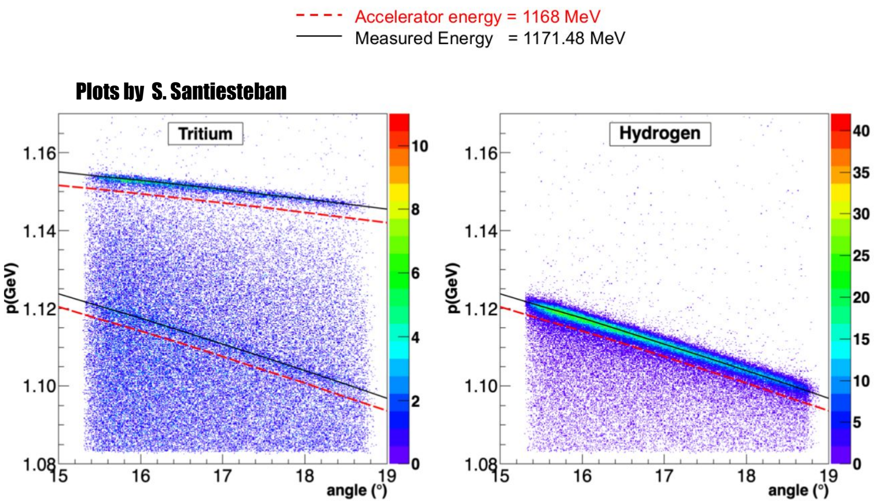




Strong isospin preference from initial state
(NOT final state interaction)

The Gas Target System:

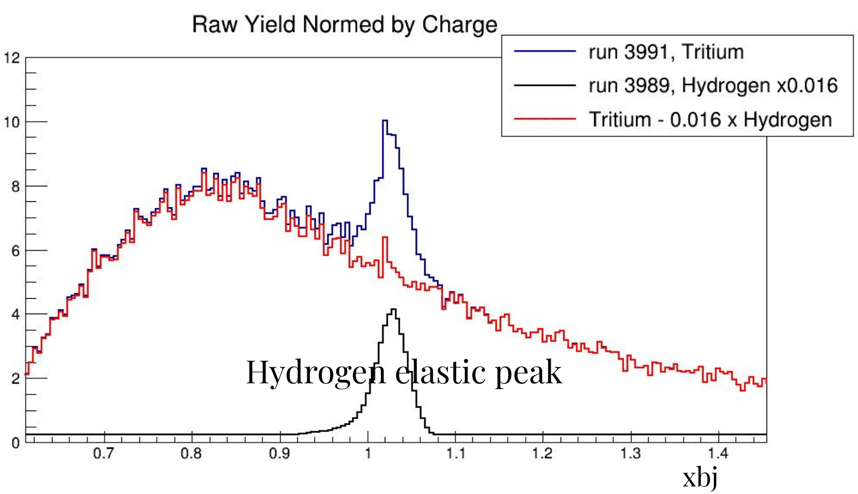
Hydrogen in the 2nd Tritium cell (used in the fall 2018, Q2 = 1.4 GeV2 data)



gas

$$H_2O + T_2 \rightarrow HTO + HT$$

Liquid, stick to the wall at low temperature



Tritium replaced by hydrogen:
1.6% * 0.0708 g/cm2 * 3 (H2O->HTO) / 0.0851g/cm2 = 4.0 %

Remained tritium density:
0. 0851 g/cm2 * (1-4%) ⇒ 0.0817 g/cm2 ??

In this analysis: use 2+- 2 %

Better guess: comparing ratio from 1.4 and 1.9 GeV2

Ideal case: spectroscopy analysis from Savannah River Site

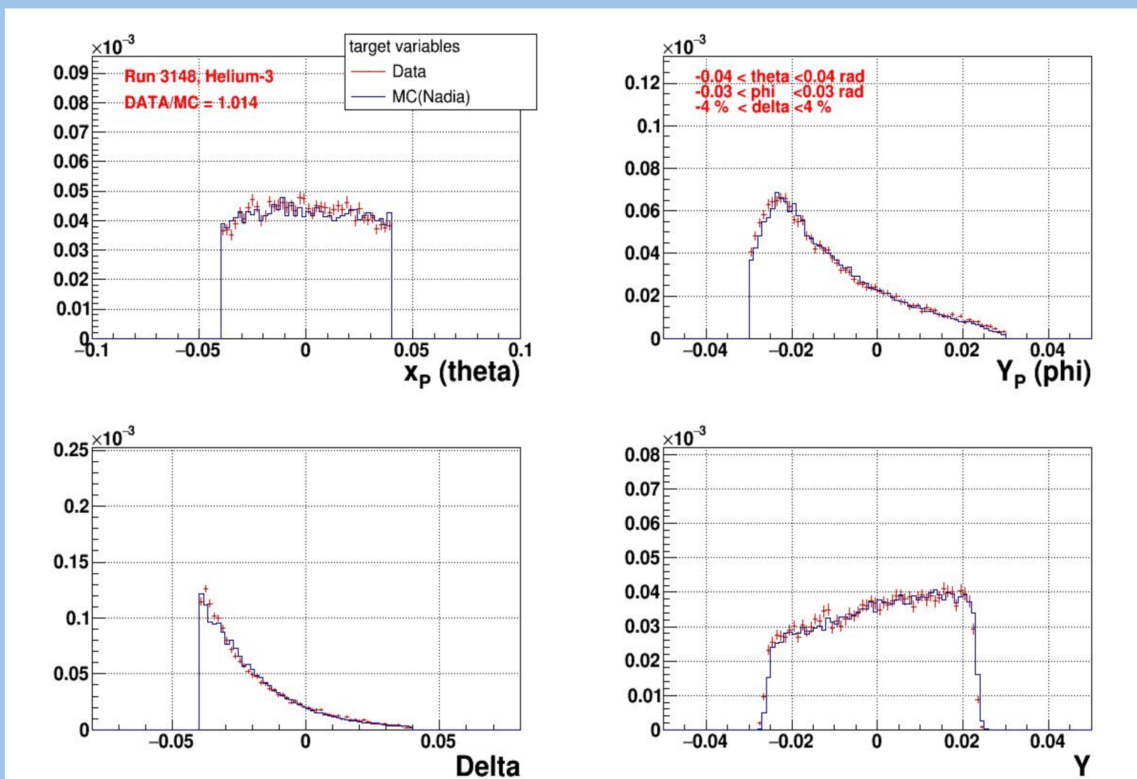
Cross Section Extraction with Simulaiton

$$\sigma(x,Q^2) = \sigma_{model}(x,Q^2) \cdot \frac{Y_{data}(x,Q^2)}{Y_{MC}(x,Q^2)}$$

"Yield" extracted from data

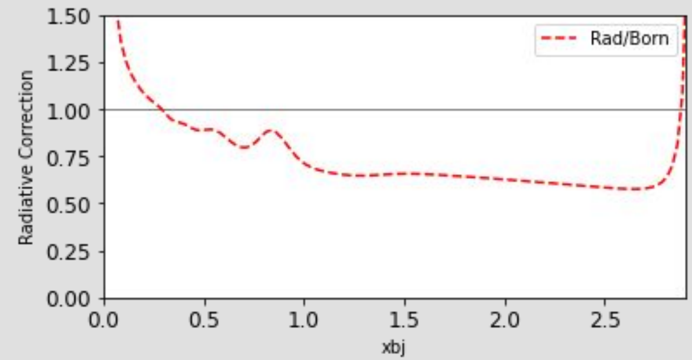
$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\#\text{ of events}}{Q\cdot\rho_l/M_A\cdot\text{efficiencies}}\boxed{\frac{A(\Omega,E')}{\Delta\Omega\Delta E'}}$$

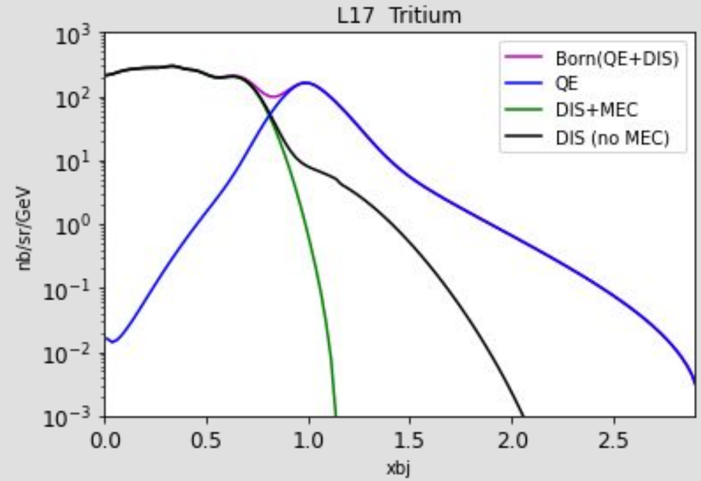
"HRS Acceptance effect" included in Monte-Carlo Simulation



Cross Section Model

- **Inelastic (including MEC):**
  - F1F209
- **QE:**
  - **form factors** :JRA PRL C 69, 022201(R) (2004) for GMP and GEP and JRA/Qattan from PRL C 86, 065210 (2012)
  - **F(y)** scaling with parameters from N. Fomin's thesis (E02-119)
- **Radiative Cross Section:**
  - **Mo Tsai** (Tsai 1971 , SLAC-PUB-848)
  - **Elastic** cross section for the elastic tail (MCEEP)



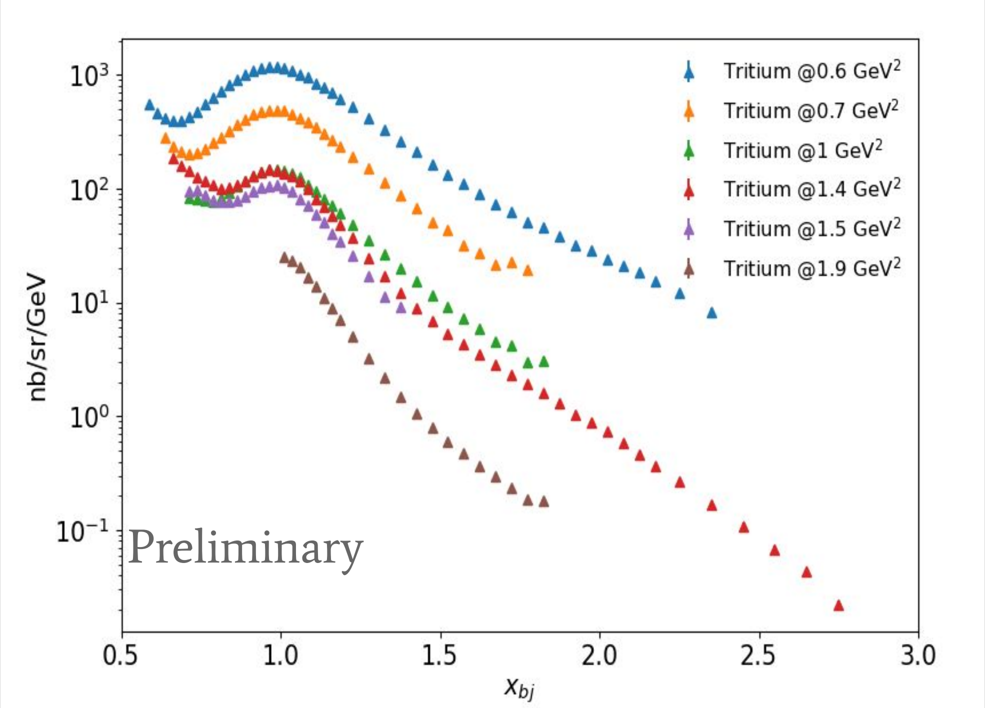


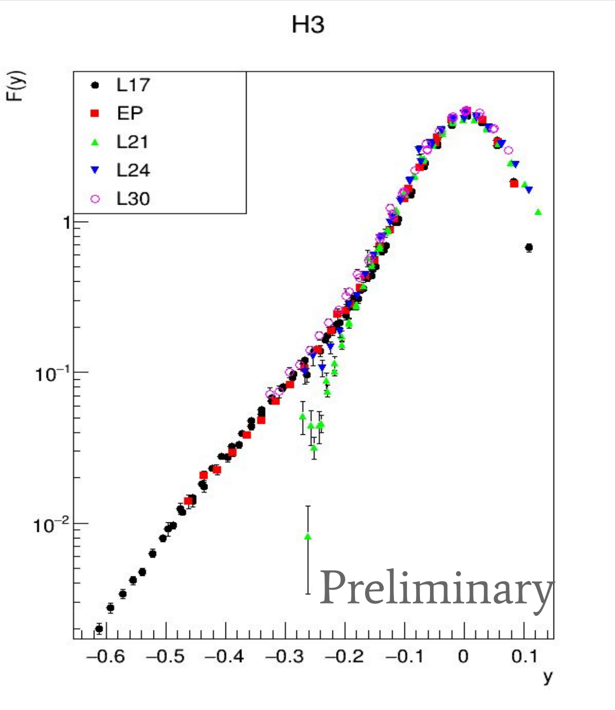
Need better MEC model??

$$W_1^{MEC} = \frac{P_0}{f} e^{-[(\sqrt{W^2} - P_1)^2]/P_2]}$$

Absolute Cross Sections and Momentum Distribution

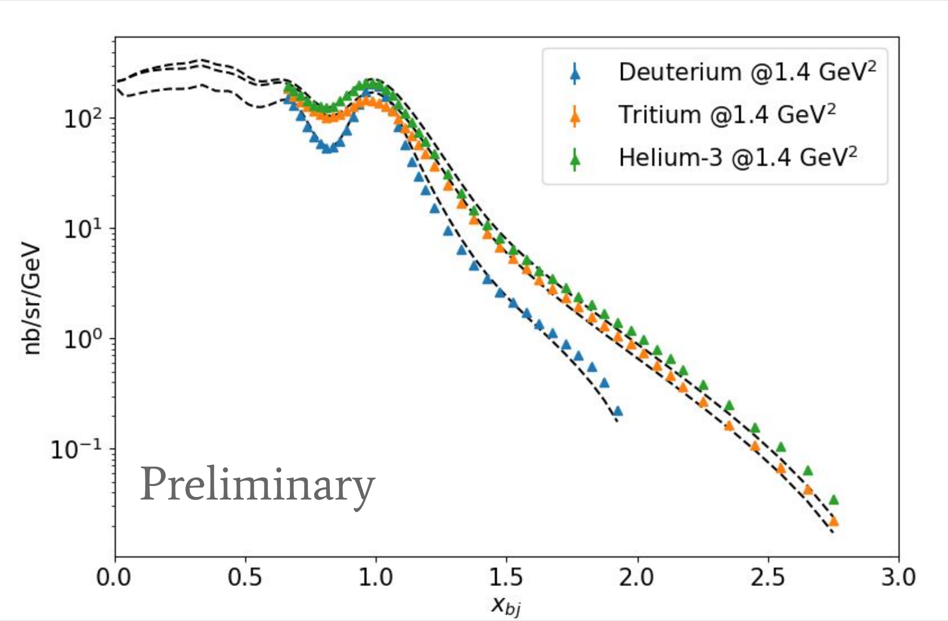
Approximated momentum distribution can be extracted from F(y) to compare with theories

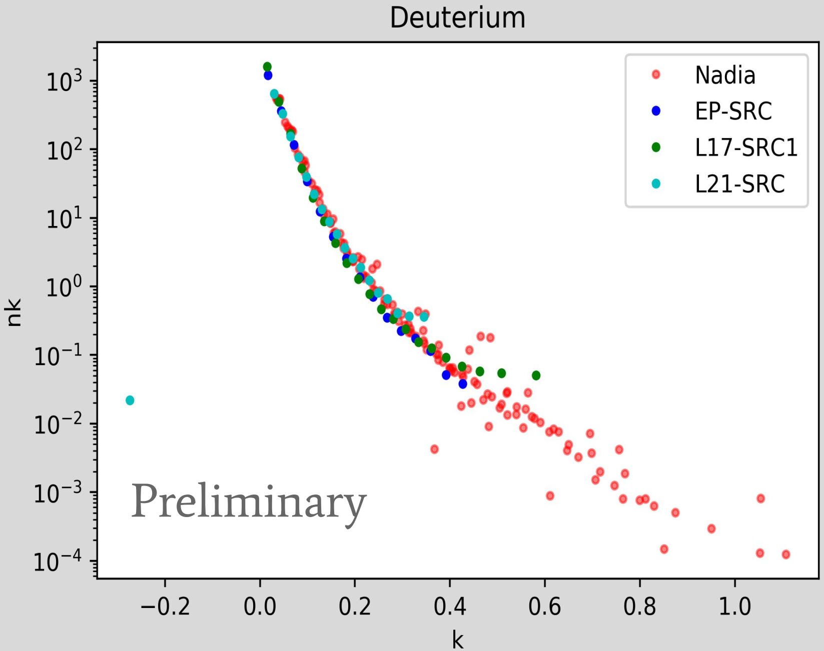




F(y) ~ longitudinal momentum distribution

Absolute Cross Sections and Momentum Distribution





$$\frac{dF(k)}{dk} \approx -2\pi k n(k)$$

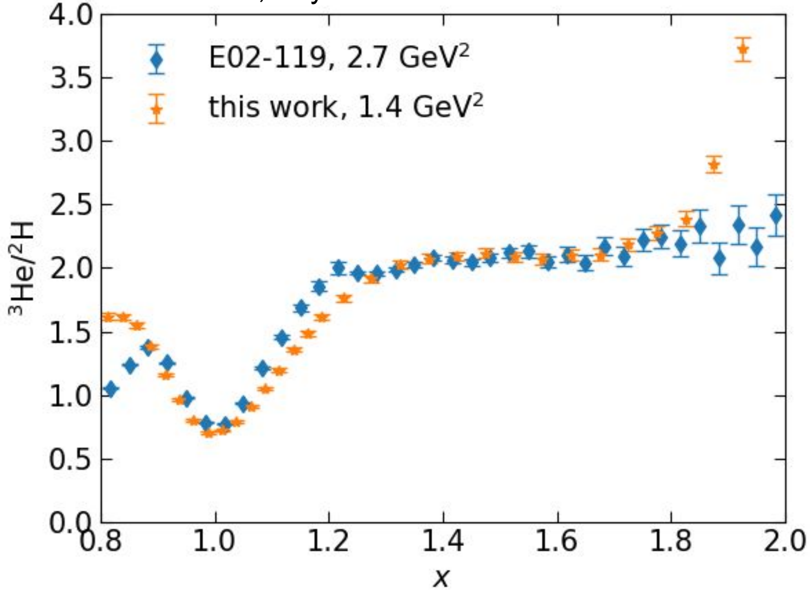
Uncertainties

Sources	Uncertainties	Absolute XSection norm	Absolute XSection ptp	Yield Ratios norm	Yield Ratios ptp
Beam Energy	0.050%	0	0.1-2%		
Scattering Angle	0.3 mrad	1.65-2.65%	0.4-8%		
Momentum	0.02%	1.1-1.8%	0.2-10%		
Tracking Efficiency	0.20%	0.20%	0.10%		
Acceptance		2%	1.50%		0.2-1%
PID		0	0		
Trigger		0	0		
Radiative Correction		1%	1%	0.30%	0.20%
Endcap Contamination		0	0.1-1%		0.1-1.5%
Charge		1.00%	0.30%	0.10%	
Boiling		0.40%	0.30%	0.50%	0.30%
Target Thickness		0.6 - 1.1%	0	1.2-1.4%	
Hydrogen Contamination		2%	0	2.00%	
Total		*3.0-4.5%*	*0.6-13%*	*1.4-2.5%*	*0.4-1.8%*

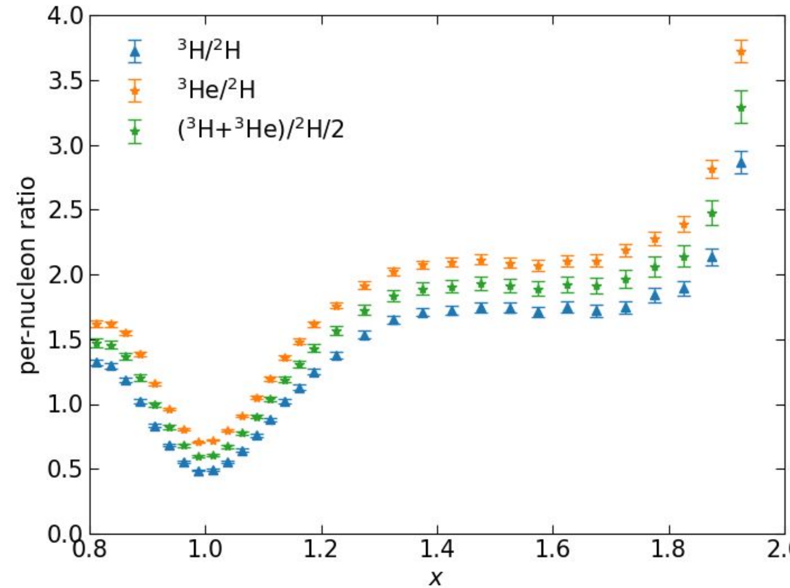
x>1 cross section ratio:

Calibration result: 3He/2H ratio from E02-119

N. Fomin, PhysRevLett.108.092502

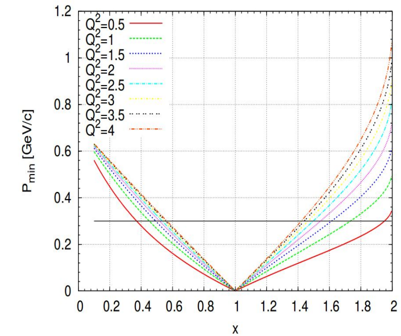


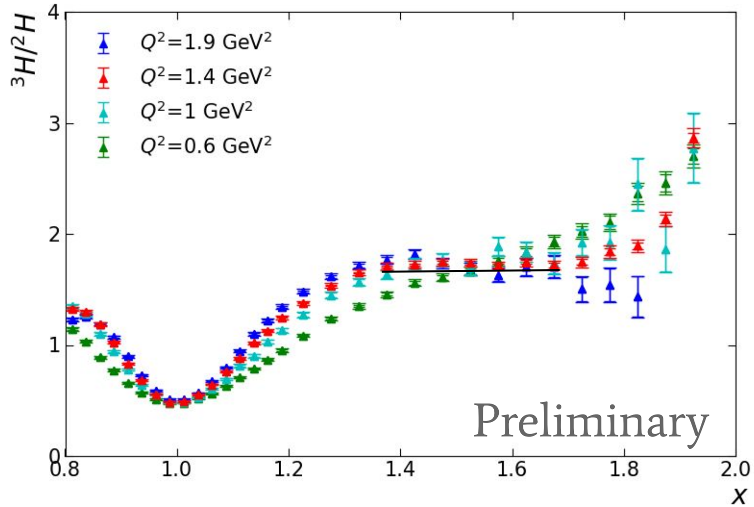
This work: A=3 to D ratios at 1.4 GeV2

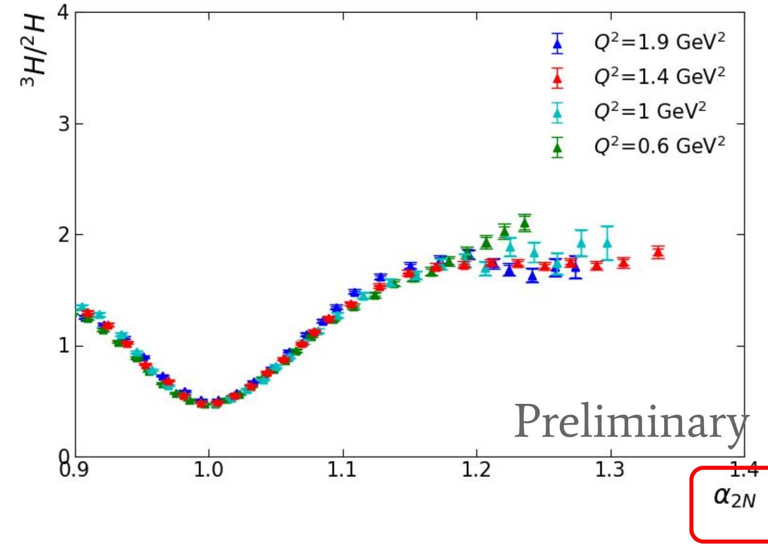


x>1 cross section ratio:

Q2 dependence on 3H/2H ratio







Light cone variable:

$$\alpha_{2N} = 2 - \frac{q_- + 2m}{2m} \frac{\sqrt{W^2 - 4m^2} + W}{W}$$

x>1 cross section ratio:

Combined results of data from 2 experiments:

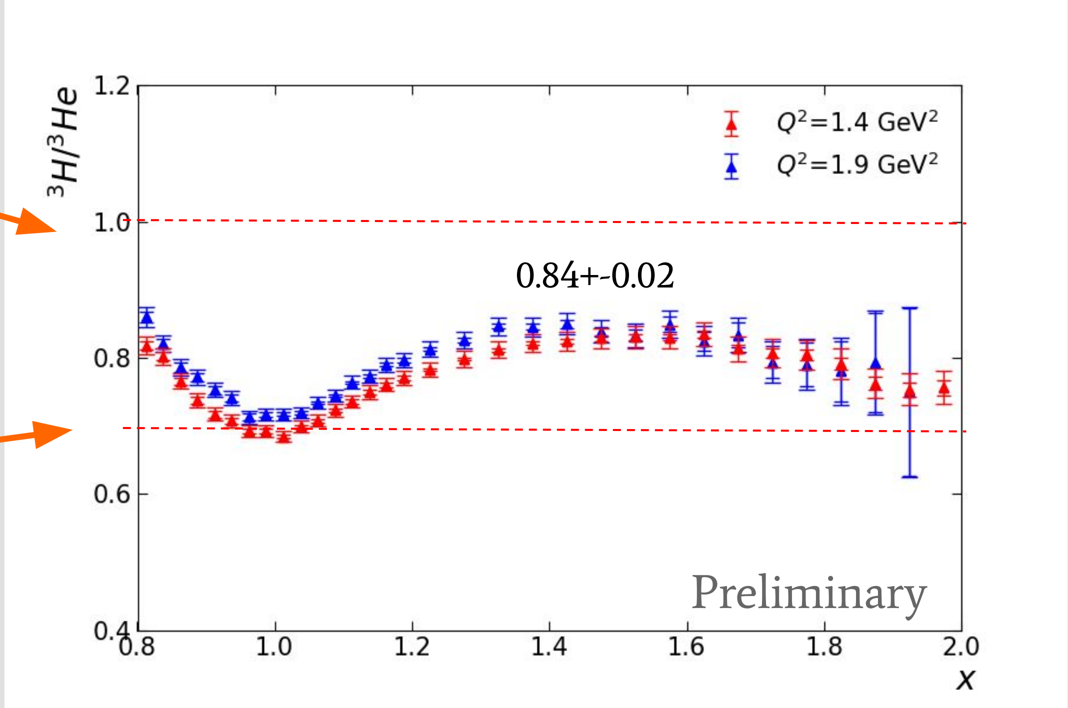
- 1.4 GeV2 data from inclusive SRC: 0.829+-0.03 norm. uncert.
- 1.9GeV2 data from the exclusive SRC 0.840+-0.014

Completely np dominant

$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{\sigma_{np}+\sigma_n}{\sigma_{np}+\sigma_p} \simeq \frac{\sigma_{np}}{\sigma_{np}} = 1$$

No isoscalar dependence

$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{2\sigma_{nn}+\sigma_{pp}}{\sigma_{nn}+2\sigma_{pp}} \xrightarrow{\sigma_p \sim 3\sigma_n} 0.7$$



Isospin Dependence in 2N-SRC

SRC ratios break down:

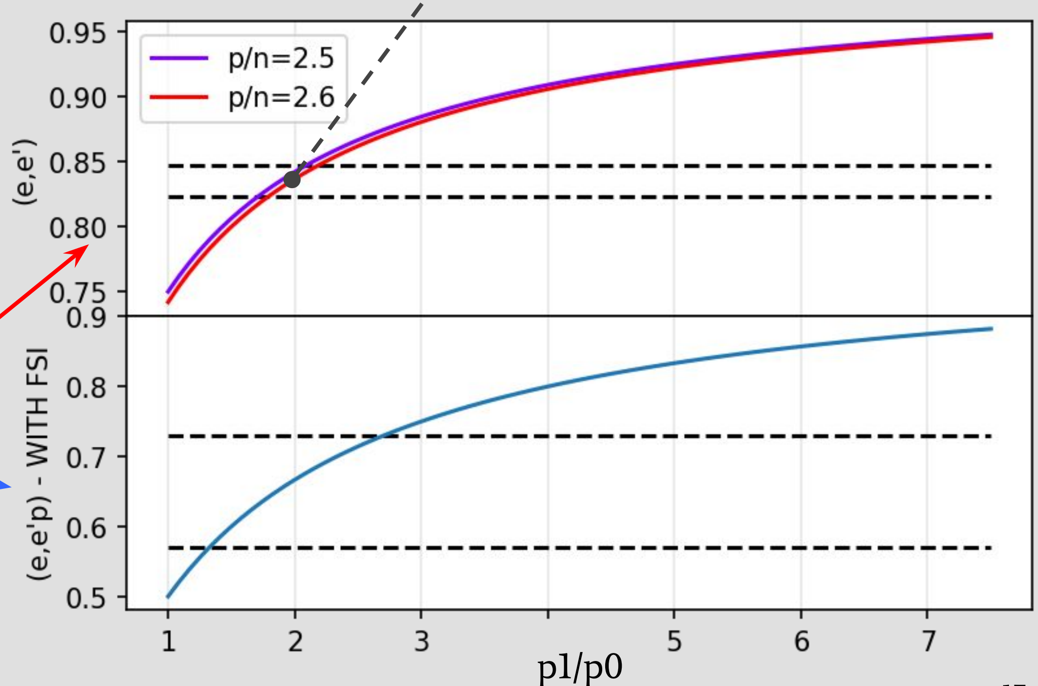
- Probability of np or pp pair up in nuclei from pair counting:
  - 2np and 1 pp(nn) in 3He(3H)
- Probability of np(pp) pair to have high momentum : p1 (p0). Assumed to be the same for 3H and 3He
- The off-shell elastic cross section ratio of proton to neutron at Q2=1.4-1.9 GeV2 is p/n ~ 2.55

$$inclusive\ \frac{\sigma(3H)}{\sigma(3He)} = \frac{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_n \cdot p_0}{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_p \cdot p_0}$$

$$exclusive\ \frac{\#(3H)}{\#(3He)} = \frac{2\cdot p_1}{2\cdot p_1 + 2\cdot p_0}$$

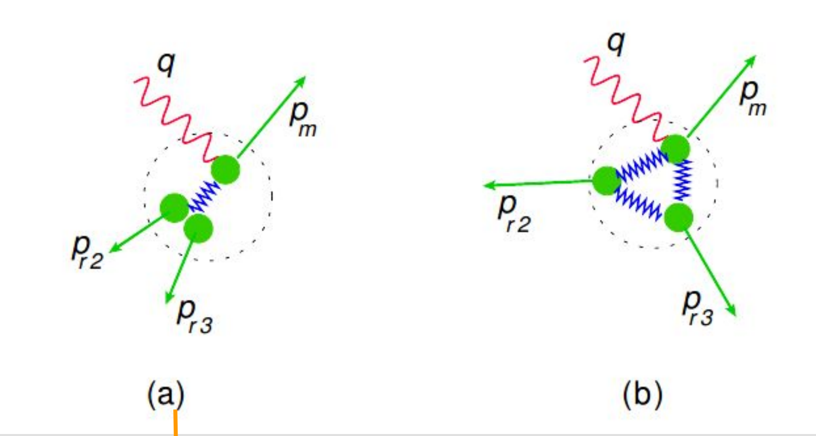
*Ratio of np/pp SRC pairs in A=3 nuclei = 2*p1/p0 = 3.94*

σ(3H/3He)



Towards 3N-SRC

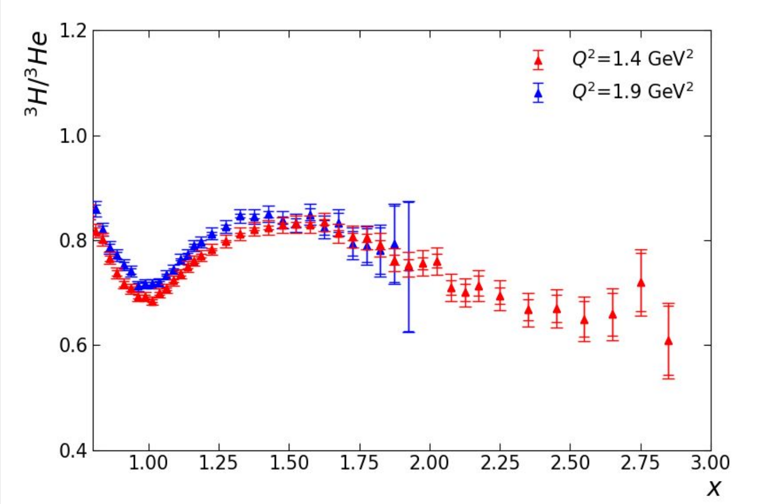
Thanks M. Sargsian for useful discussions

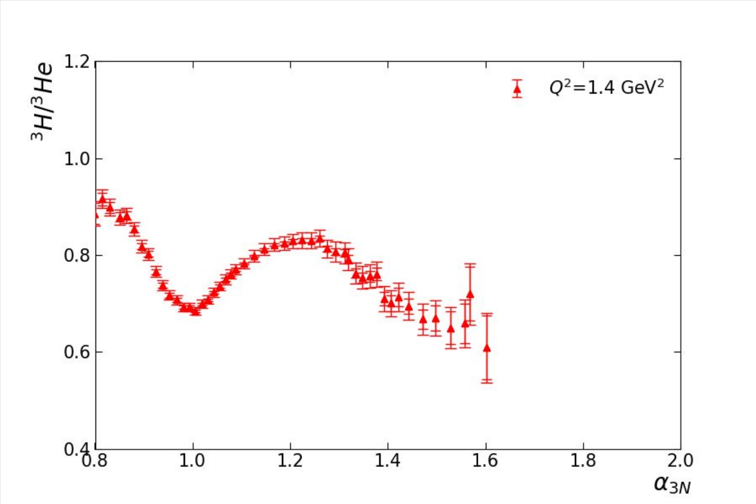


Dominant channel:

$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{2\sigma_{nn} + \sigma_{pp}}{\sigma_{nn} + 2\sigma_{pp}} \xrightarrow{\sigma_p \sim 3\sigma_n} 0.7$$

3N-SRC contribution is predicted to dominate at somewhere alpha_3N > 1.6. Ratio will drop from 2N-SRC plateau

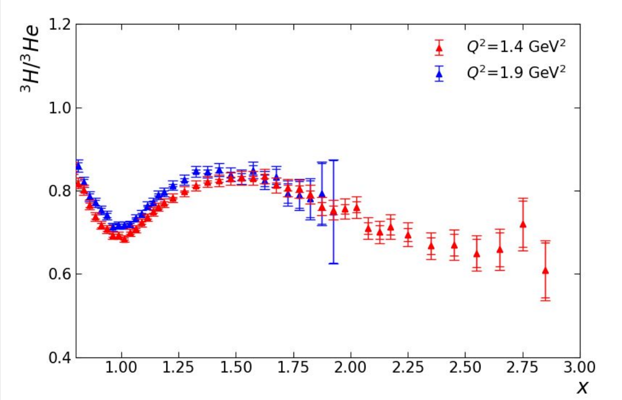


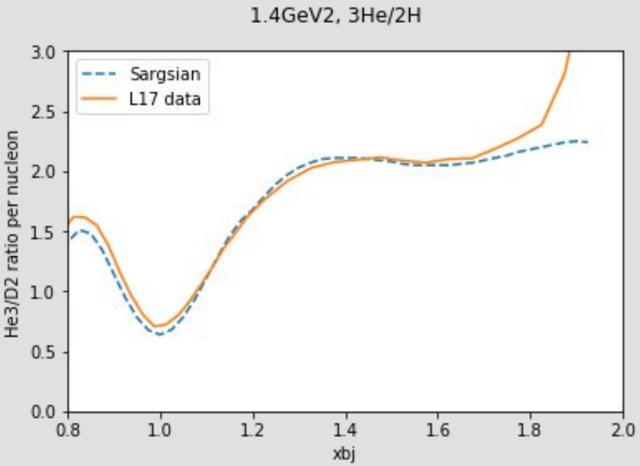


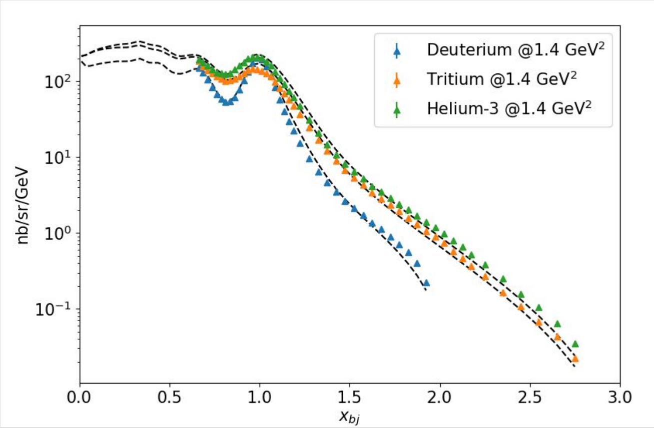
Summary

- Isospin Dependence in 2N-SRC
  - Analysis finished, preparing paper draft

- Absolute cross section of 2H, 3H, and 3He:
  - Updated radiative cross section and energy loss
  - Cross section are compared to theory and used to extract momentum distribution





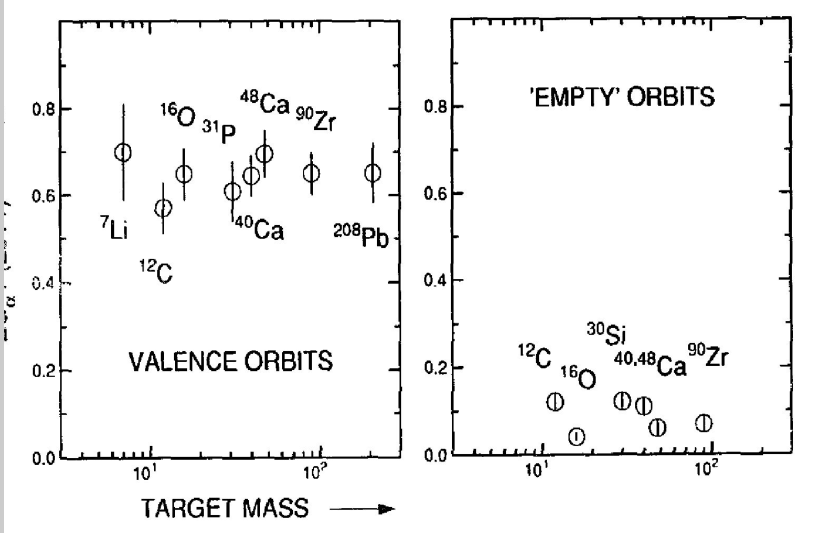


Acknowledgement

- Tritium experiments students and postdocs
- Dave Meekins and the target group
- Hall A engineers
- GMp and DVCS collaboration
- E12-14-011 (e'p SRC) collaboration

Thank you !

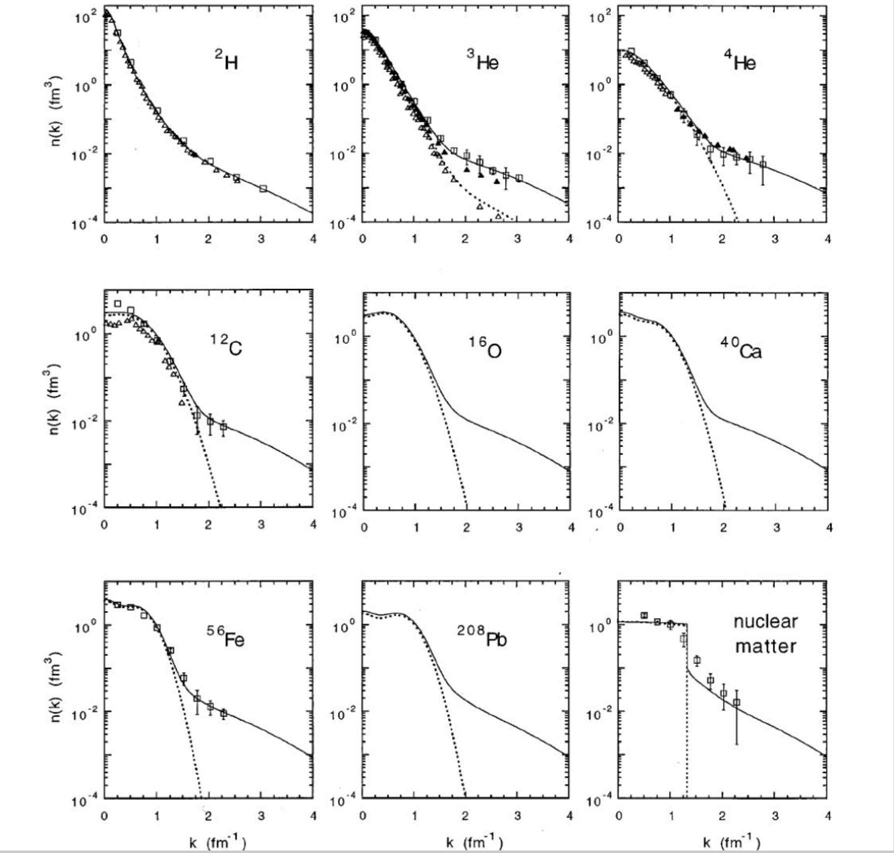
Nucleons in Nuclei:
Beyond Shell Model



- The closed orbits are NOT fully occupied.

"The main effects of NN correlations is to generate high momentum and high removal energy components"

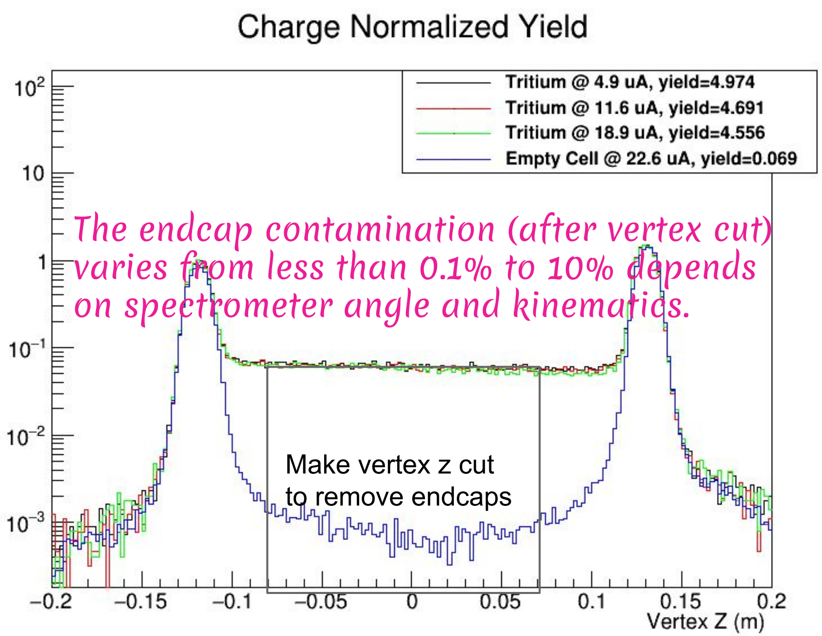
C. Atti and S. Simula, PRC 53. 1689 (1996)



- High momentum nucleons in different nuclei

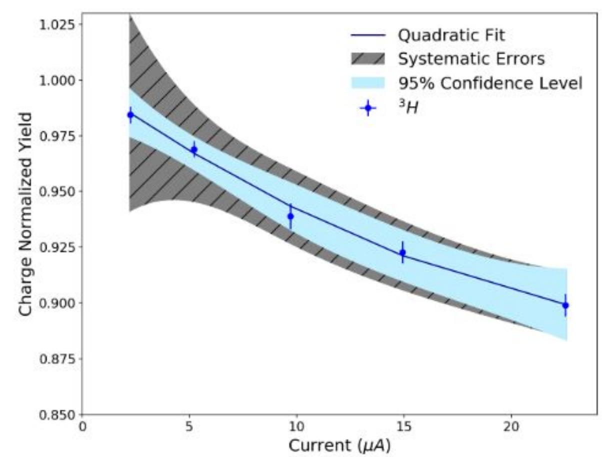
The Gas Target System: special handling

- Maximum current = 22.5 uA on gas cells to minimize the risk of gas leak.
- Endcap(75mg/cm2 Aluminum) being mis-reconstructed into thin gas body (77mg/cm2 Tritium)
- “Boiling”: gas density change along beam path



The Tritium density reduced by ~ 10 percent at 22.5 uA

S. Santiesteban et al. , https://doi.org/10.1016/J.NIMA.2019.06.025



Radiative tail from Elastic Scattering

Soft photon

internal

Peak approx.

$$\frac{d\sigma_{j,\exp}(E_s)}{d\Omega\, dE_p} = (v_s v_p)^{b\left(\frac{T}{2}+t_r\right)}\left[\frac{d\sigma^{\text{eff}}_{j,r}(E_s,E_p)}{d\Omega\, dE_p}\right.$$

$$+\frac{M+(E_s-\omega_s)(1-\cos\theta)}{M-E_p(1-\cos\theta)}\,\frac{d\sigma^{\text{eff}}_{j}(E_s-\omega_s)}{d\Omega}\left\{\frac{bT}{2}\,\frac{1}{\omega_s}\,\phi(v_s)+\frac{\xi}{2\omega_s^2}\right\}$$

$$\left.+\frac{d\sigma^{\text{eff}}_{j}(E_s)}{d\Omega}\left\{\frac{bT}{2}\,\frac{1}{\omega_p}\,\phi(v_p)+\frac{\xi}{2\omega_p^2}\right\}\right] \qquad (3.1)$$

straggling

$$\frac{d\sigma^{\text{eff}}_{0,r}}{d\Omega\, dE_p} = bt_r\left[\frac{M+(E_s-\omega_s)(1-\cos\theta)}{M-E_p(1-\cos\theta)}\,\frac{d\sigma^{\text{eff}}_{0}(E_s-\omega_s)}{d\Omega}\,\frac{1}{\omega_s}\,f(v_s)\right.$$

$$\left.+\frac{d\sigma^{\text{eff}}_{0}(E_s)}{d\Omega}\,\frac{1}{\omega_p}\,f(v_p)\right] \qquad (3.2)$$

Effective Cross Section:
(most probable ionization energy loss applied)

$$\boxed{\sigma_{\text{eff}}(E_s,E_p) = F(q'^2,T)\,\sigma(E_s-\Delta_s,E_1+\Delta_p)}$$

Nucleon-Nucleon Short Range Correlation (SRC)

Free nucleon-nucleon potential = **Repulsive core** **+** **attractive tensor force**
T = 1, S = 0 :np, pp, nn pairs. The tensor operator $S_{1,2}$= 0 , no attractive tensor force
T = 0, S = 1: Deuteron-like np pair.