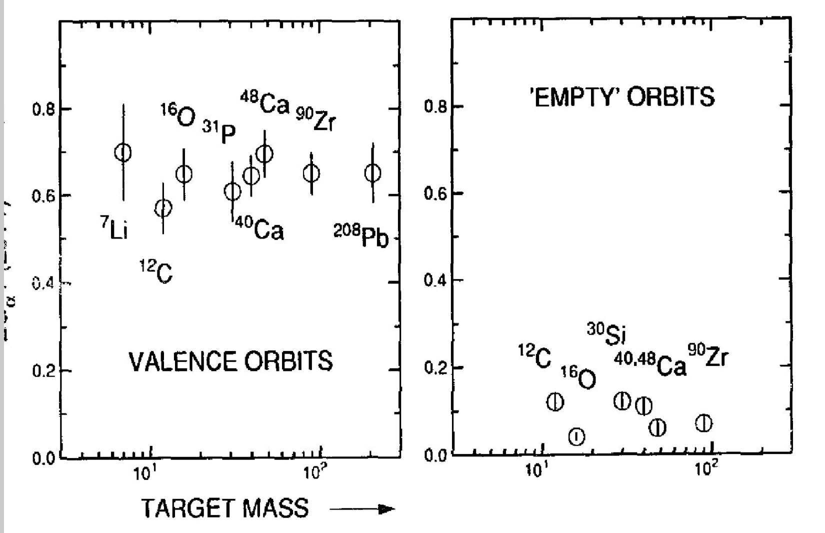
Determine the Isospin-dependence of Short-range Correlations in A=3 Nuclei

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

APS-GHP Workshop
April, 2021

BERKELEY LAB
Jefferson Lab
University of New Hampshire

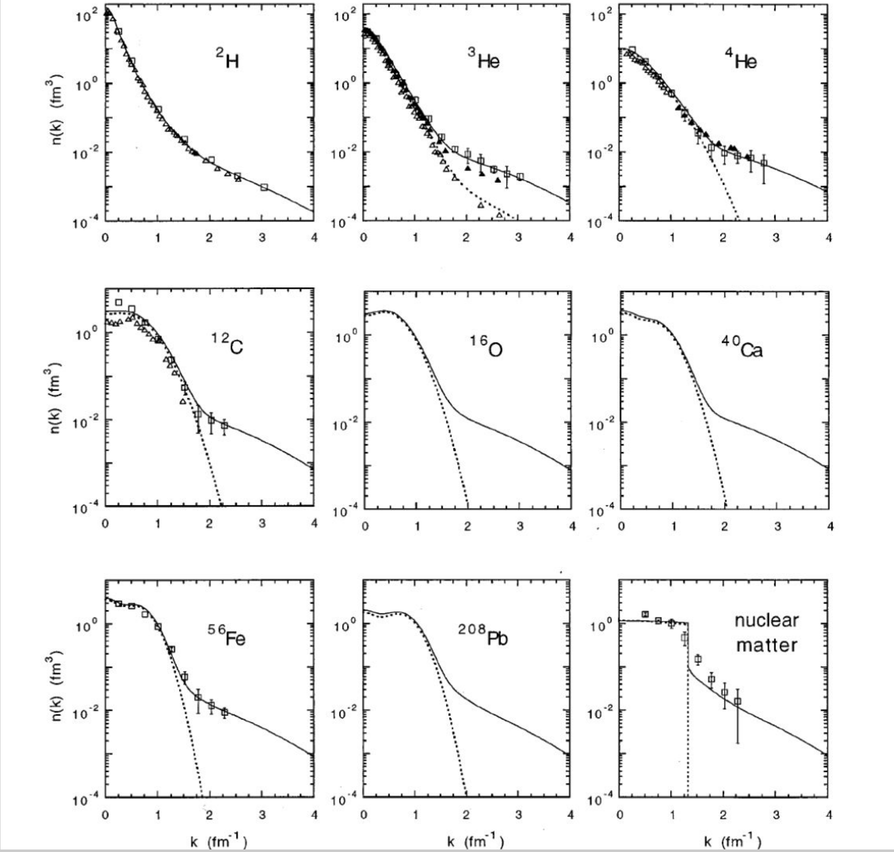
Nucleons in Nuclei:
Beyond Shell Model



- The closed orbits are NOT fully occupied.

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

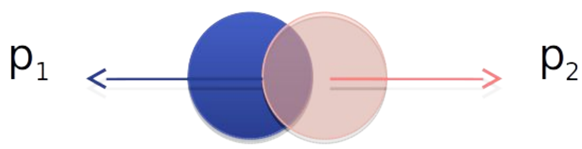
C. Atti and S. Simula, PRC 53. 1689 (1996)



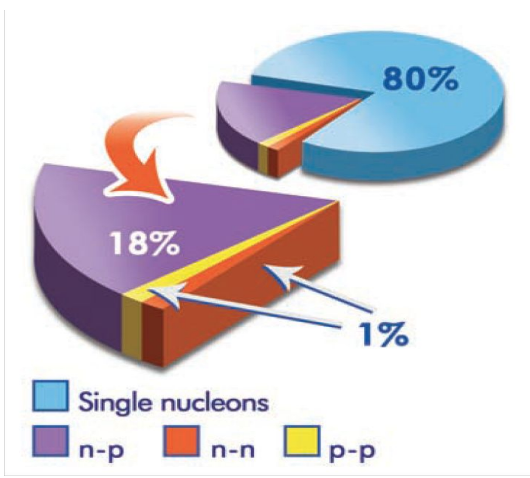
- High momentum nucleons in different nuclei

Nucleon-Nucleon Short Range Correlation (SRC)

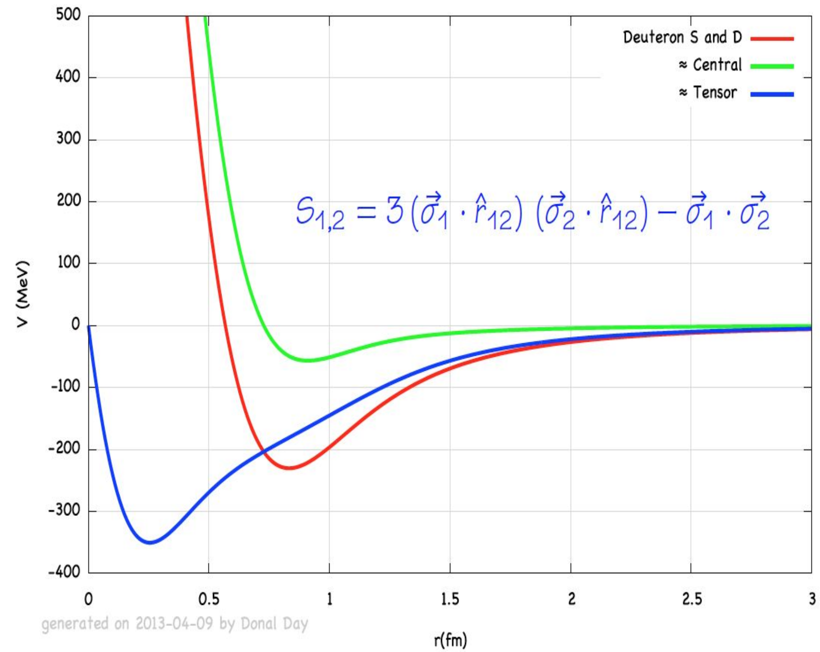
Free nucleon-nucleon potential = **Repulsive core** + **attractive tensor force**
T = 1, S = 0 :np, pp, nn pairs. The tensor operator $S_{1,2}$= 0 , no attractive tensor force
T = 0, S = 1: Deuteron-like np pair.



$p_1 + p_2 \rightarrow 0$
Large back-to-back momentum



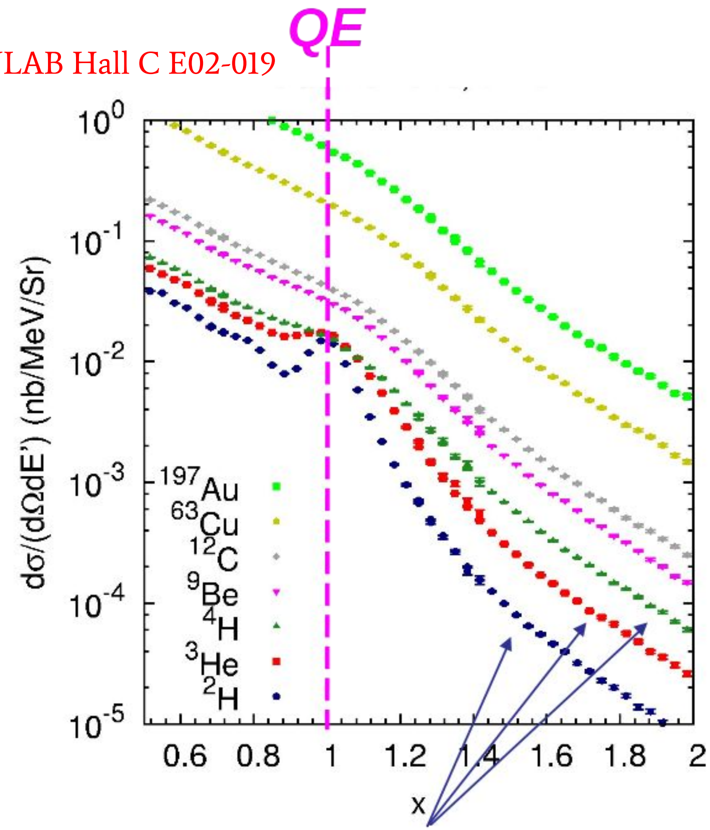
Subedi et al, Science 320, 1476 (2008)



Probing 2N SRC at x>1

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

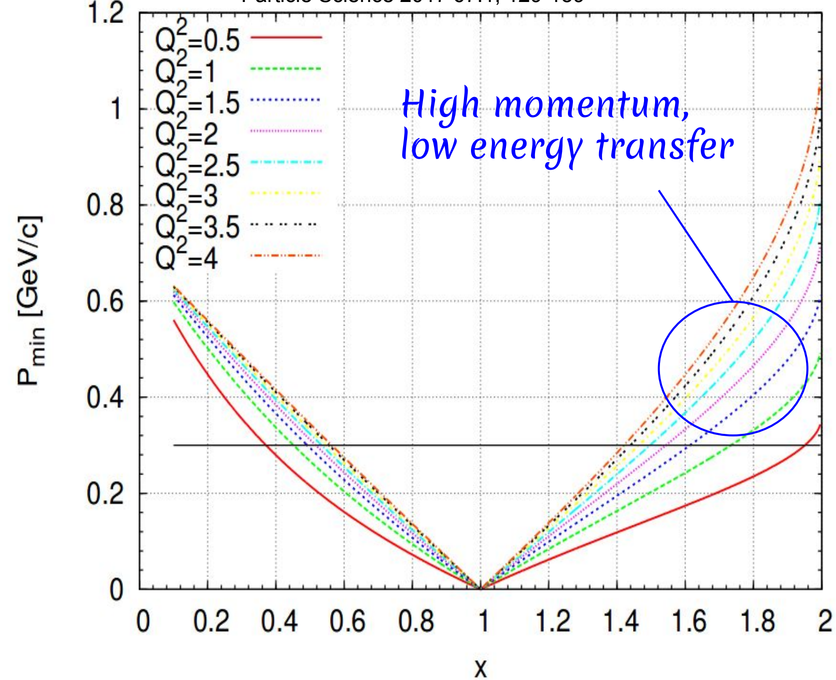
JLAB Hall C E02-019



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

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

N. Fomin et al, Annual Review of Nuclear and Particle Science 2017 67:1, 129-159



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

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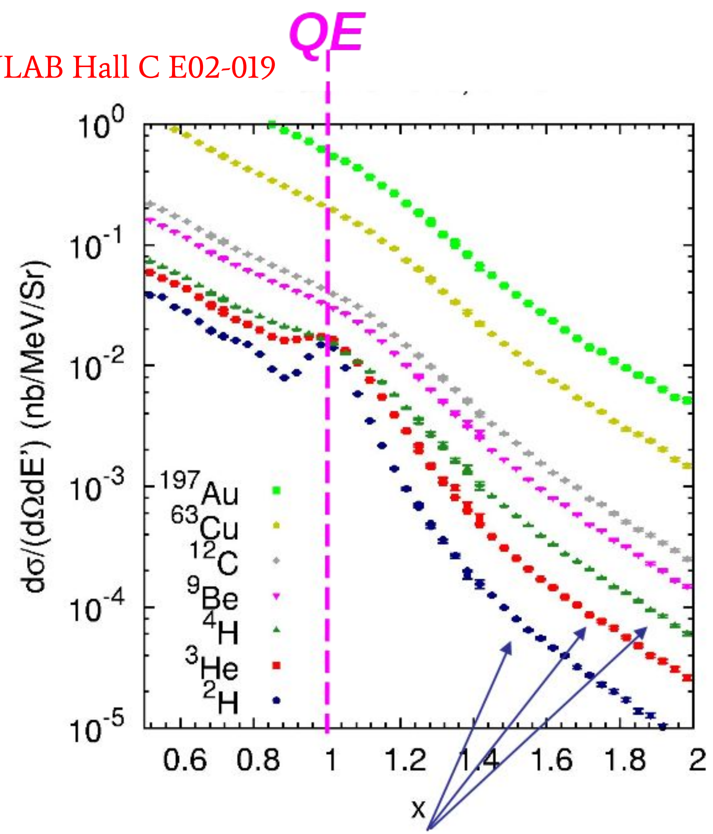


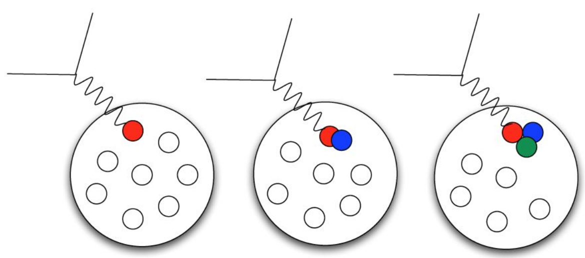
High momentum tails should yield constant ratio if SRC-dominated

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

Probability to find 2N SRC in nucleus A

$$\sigma_A = \sigma_{QE} + a_2(A)\sigma_2 + a_3(A)\sigma_3 + \ldots$$

Cross section from 2N SRC



Probing 2N SRC at x>1

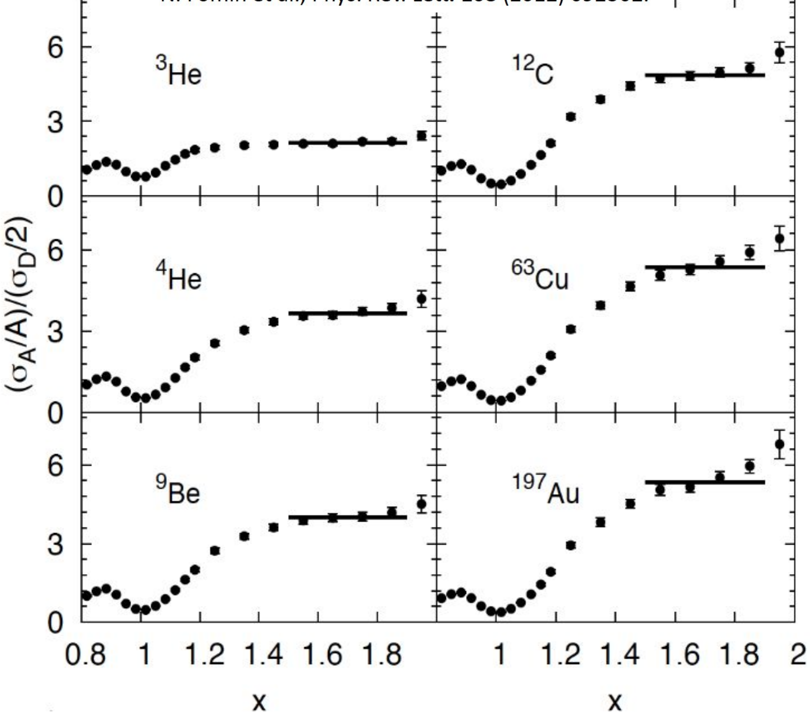
Inclusive electron scattering:

- high statistics
- background suppressed at high Q2

Plateaus in Cross section ratio b/w 1.3< xbj <2:

JLAB Hall C E02-019

N. Fomin et al., Phys. Rev. Lett. **108** (2012) 092502.



$$\sigma_A = \sigma_{QE} + a_2(A)\sigma_2 + a_3(A)\sigma_3 + \ldots$$

$$\frac{\sigma_A}{\sigma_{^2H}} \approx \frac{a_2(A)}{a_2(^2H)} = const$$

$$a_2(^{12}C) \approx 0.04 \times 5 = 0.2$$

The x>1 plateau of A/D ***cross section ratios*** *give the percentage of* ***deuteron-like*** *high momentum pairs in each nucleus up to corrections of center-of-mass motions et al.*

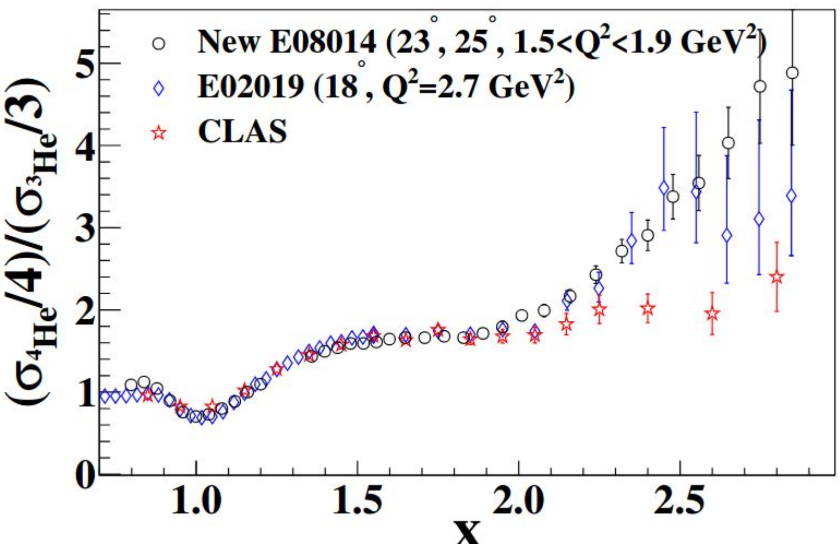
Probing 2N SRC at x>1

JLab E08-014

Inclusive electron scattering:

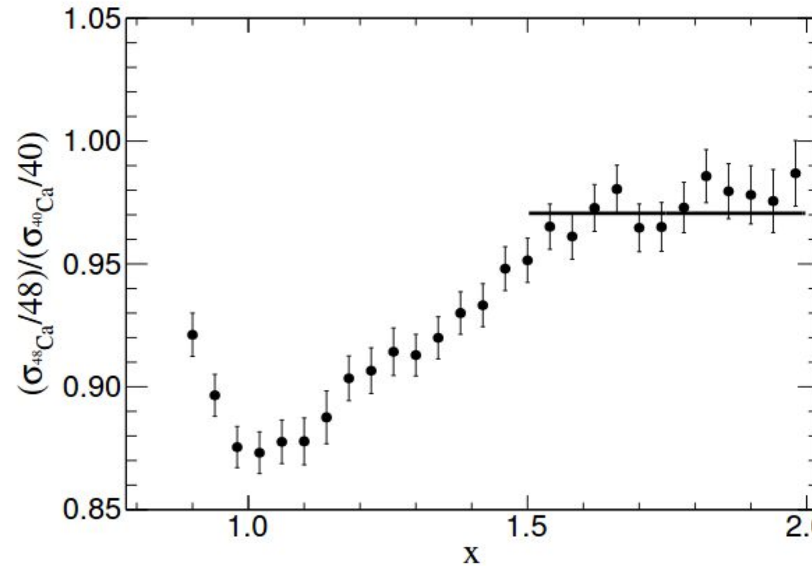
- high statistics
- background suppressed at high Q2

Z.H. Ye et al., Phys. Rev. C 97, 065204 (2018)



*No **x>2 plateau** observed*

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



*Measure **isospin-dependence** of SRC with Calcium isotopes*

3H/3He ratio from (e,e'):

Tritium v.s. Helium-3:

- Large isospin (neutron-proton) asymmetry
- Similar separation energy: 6.26 MeV v.s. 5.49 MeV
- Small Coulomb effect: V_eff = 0.66 MeV v.s. 0

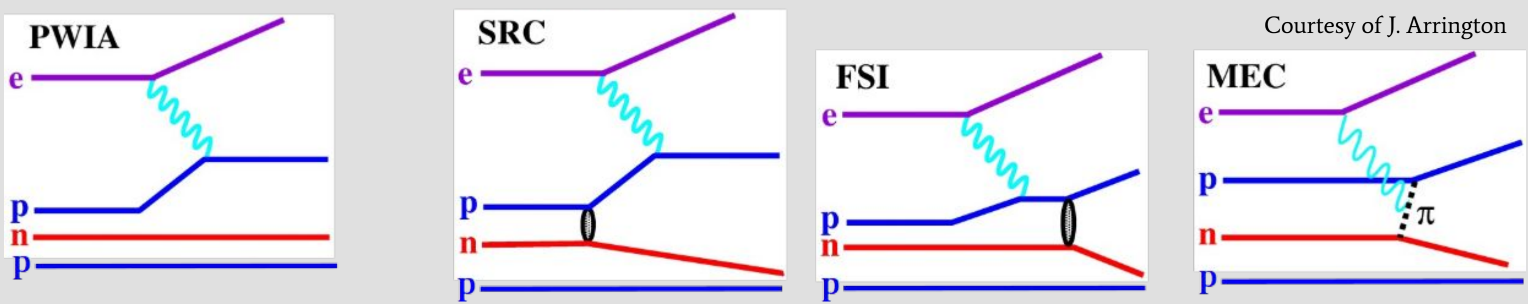
Inclusive cross section ratio at x>1, Q2> 1.4 GeV 2:

- High statistics
- Systematic uncertainties canceled
- Meson-exchange current suppressed
- Final State Interaction within the SRC pairs ⇒ canceled in ratio

"slow" nucleons

"fast" nucleons

Courtesy of J. Arrington



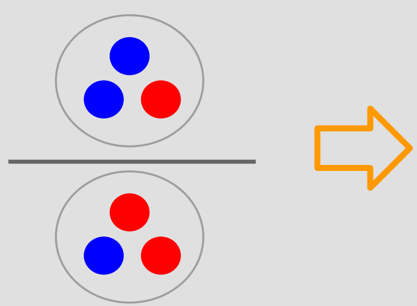
Jefferson Lab E12-11-112 (Hall A) :

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

Spokespersons:
Patricia Solvignon, John Arrington, Donal Day, Douglas Higinbotham, Zhihong Ye
Students:
Shujie Li, Nathaly Santiesteban, Leiqaa Kurbany

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.



Offshell elastic xsection

2 np pairs + 1 pp pairs

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

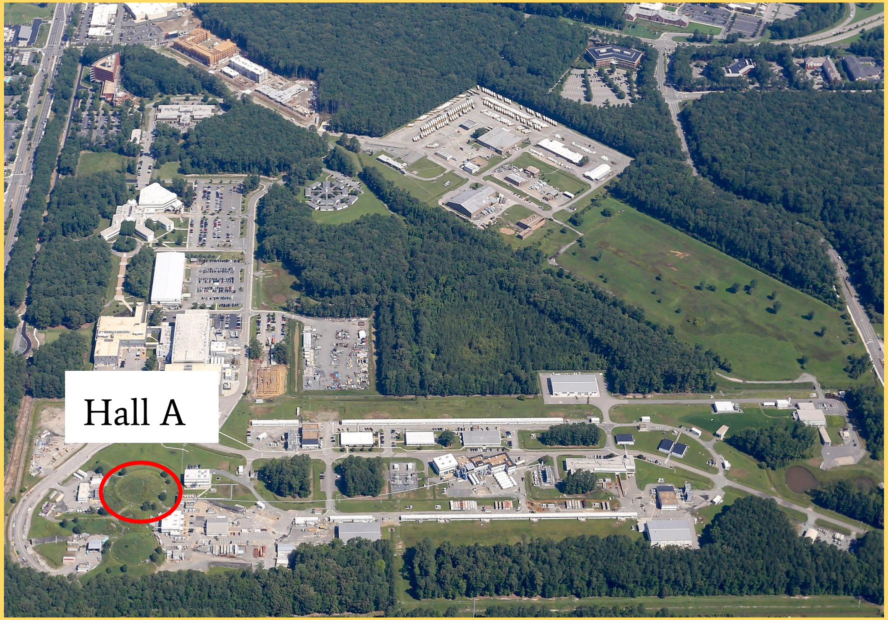
Fraction of a np or pp pair with high momentum (“enhancement factor”)

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

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

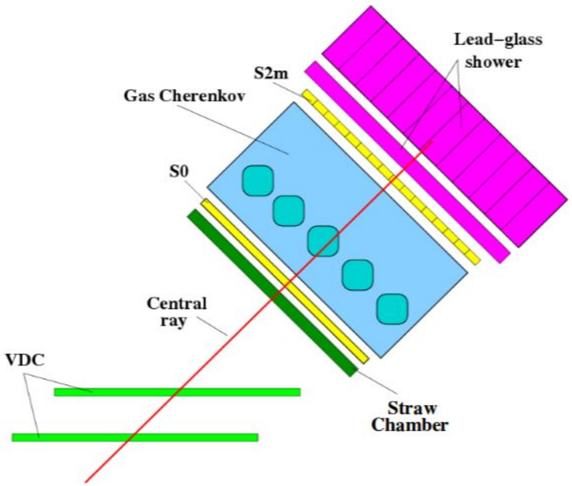
Tritium Family Experiments:

2017.12: Commissioning
2018.2-2018.5: E12-11-103 MARATHON
2018.4 E12-14-011 e'p
2018.5 : E12-11-112 x>1 (inclusive SRC) 2.2 GeV beam
2018.9-11 : E12-11-112 x>1 (inclusive SRC) 4.3 GeV beam
2018.11: E12-17-003 e'K

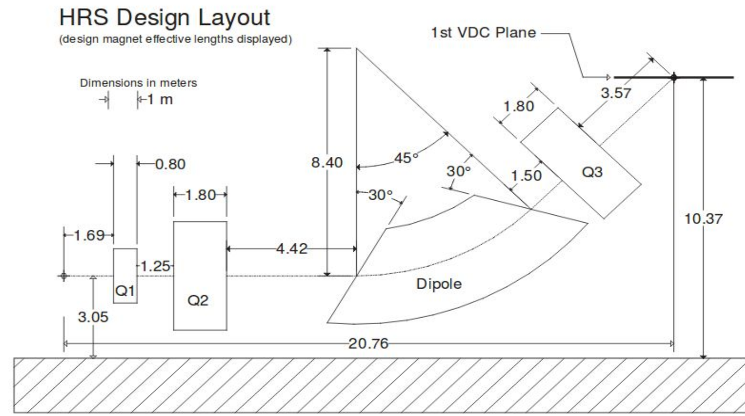


Jefferson Lab, Hall A

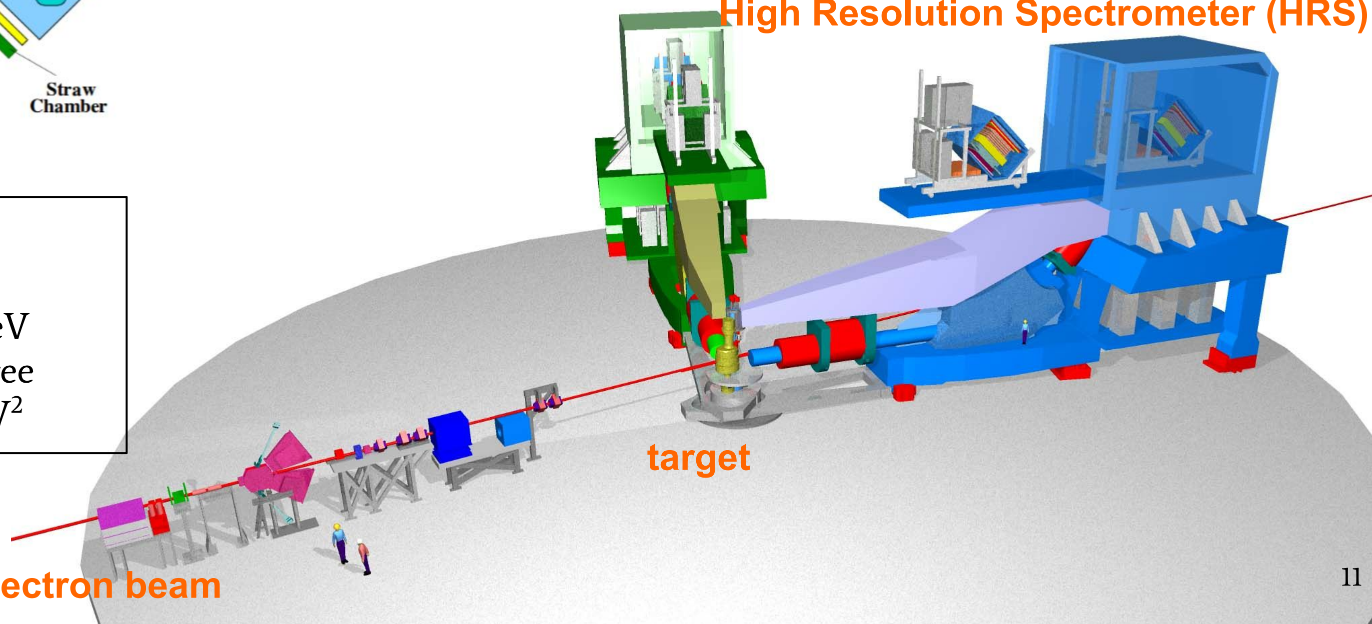
Inclusive (e,e’) scattering



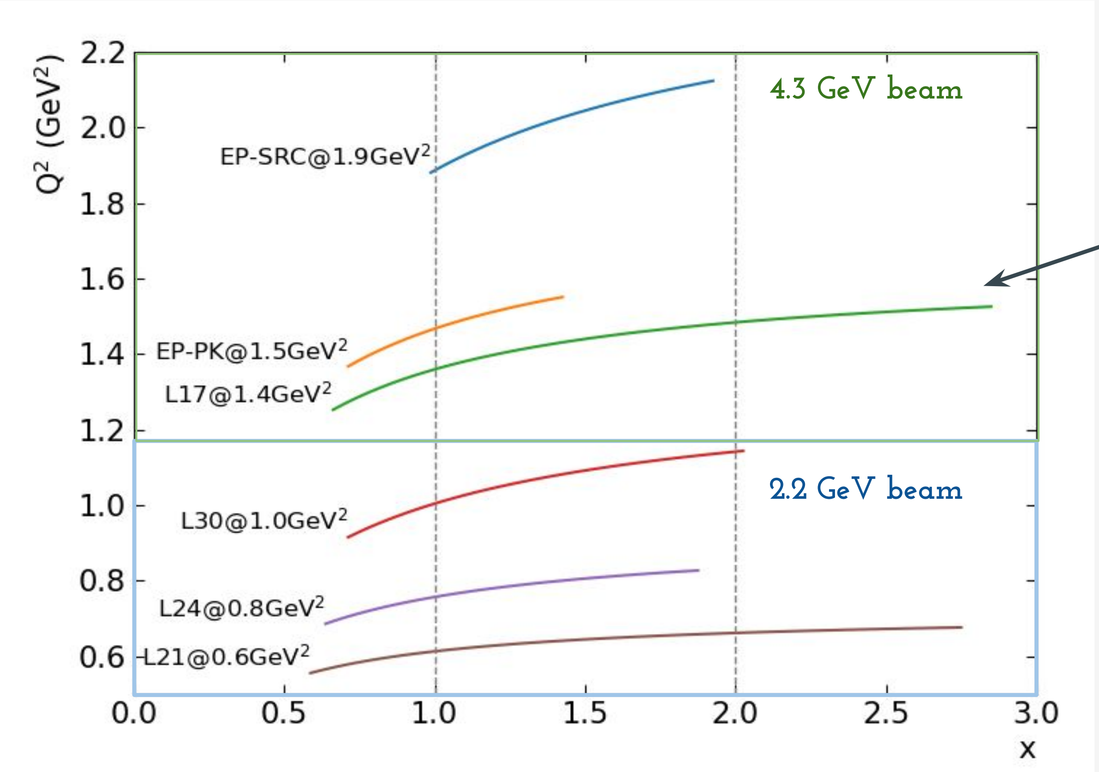
J. Alcorn et al. / Nuclear Instruments and Methods in Physics Research A 522 (2004) 294–346



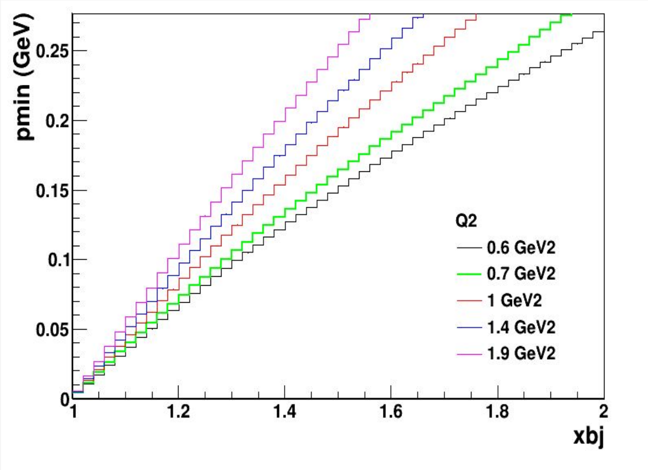
Primary kinematics:
Beam energy: 4.3 GeV
Momentum : 3.54 , 3.82 GeV
Angle : 20.88 , 17 degree
Q^2 : 1.9 , 1.4 GeV^2



x>1 Kinematics:

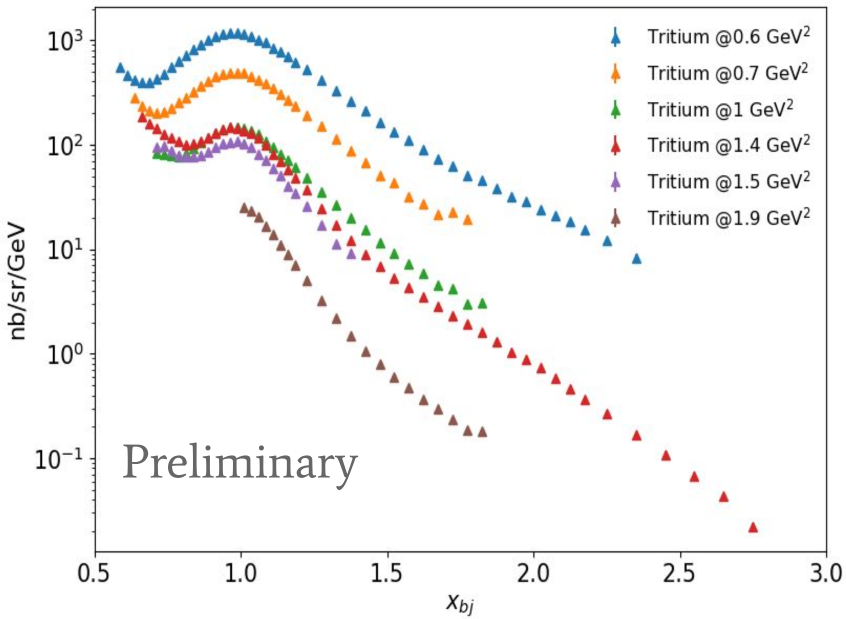


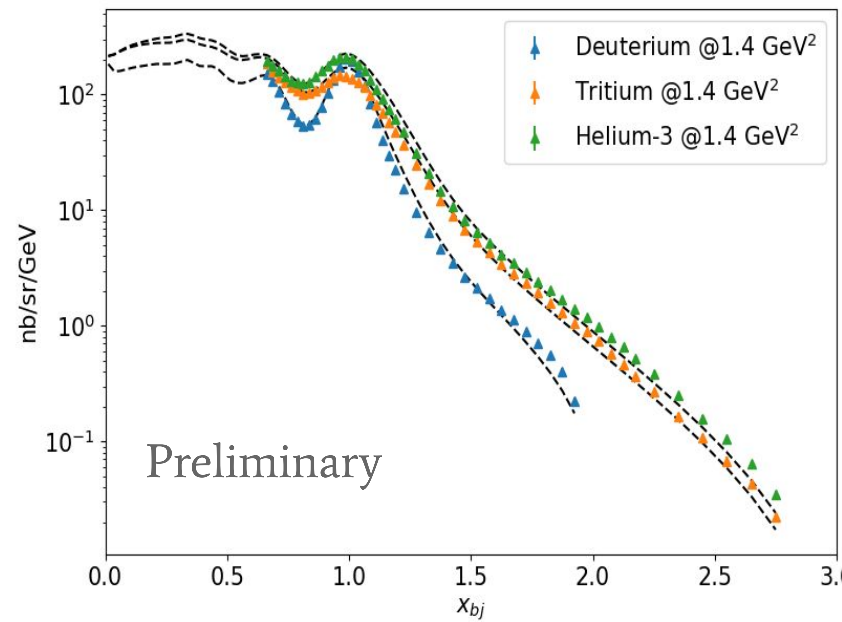
2018 fall data with 2nd tritium cell, affected by the hydrogen contamination



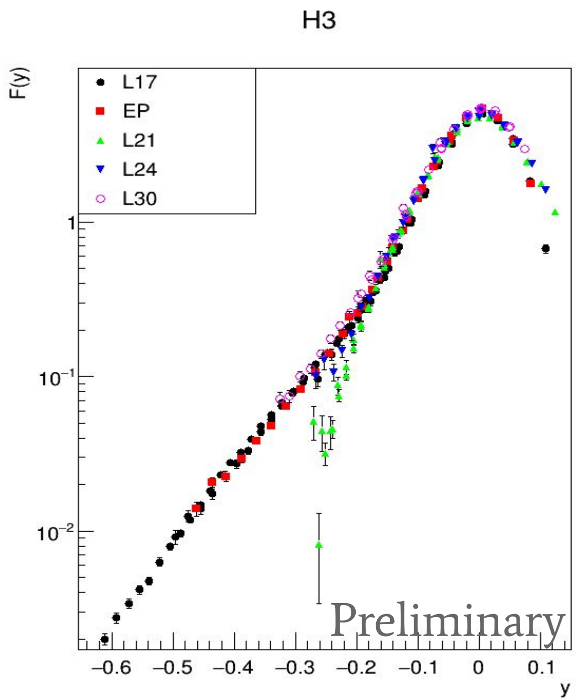
p_min: Minimum momentum of the struck nucleon in deuteron

Absolute Cross Sections and Momentum Distribution



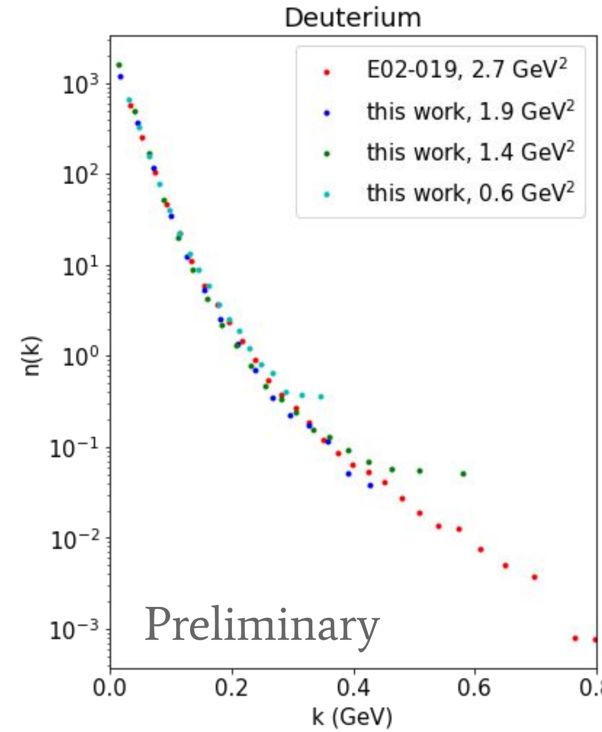


Absolute Cross Sections and Momentum Distribution



F(y) ~ longitudinal momentum distribution

$$\sigma_{QE} = F(y)(Z\widetilde{\sigma}_p + N\widetilde{\sigma}_n)\left(\frac{q}{\sqrt{M^2 + (y+q)^2}}\right)^{-1}$$



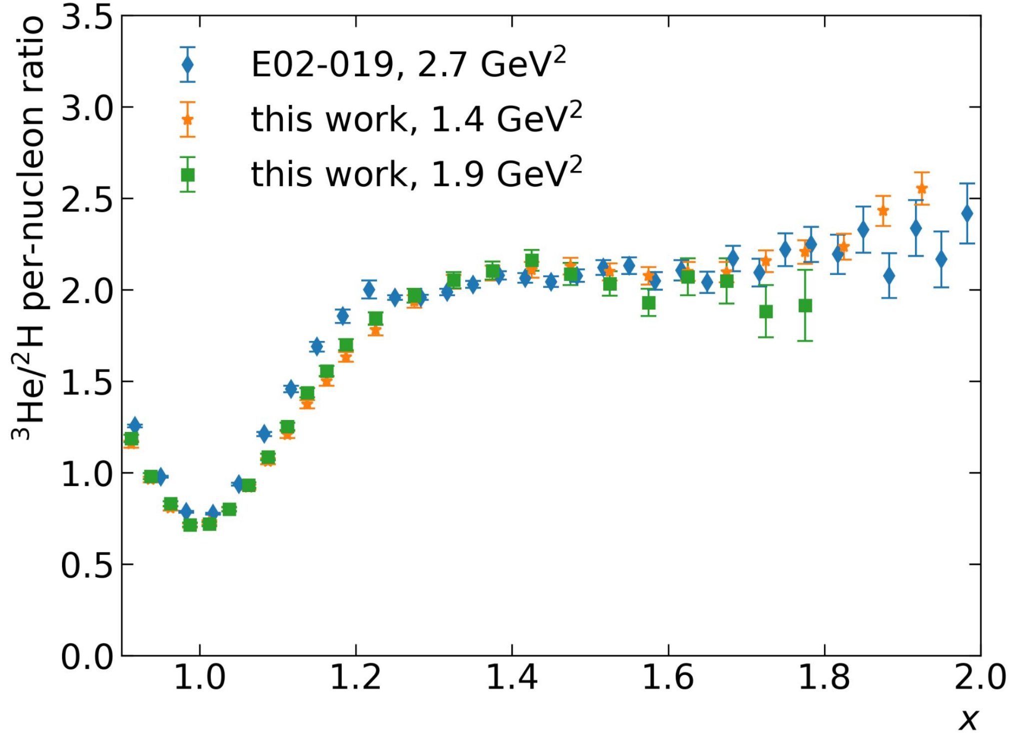
$$\frac{dF(k)}{dk} \approx -2\pi k n(k)$$

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	0.8-1.4%	
Hydrogen Contamination		0.5%	0	0.5%	
Total		*2.0-4.2%*	*0.6-13%*	*0.8-1.5%*	*0.4-1.8%*

x>1 cross section ratio (from yield ratio):

Calibration result: 3He/2H ratio from E02-019

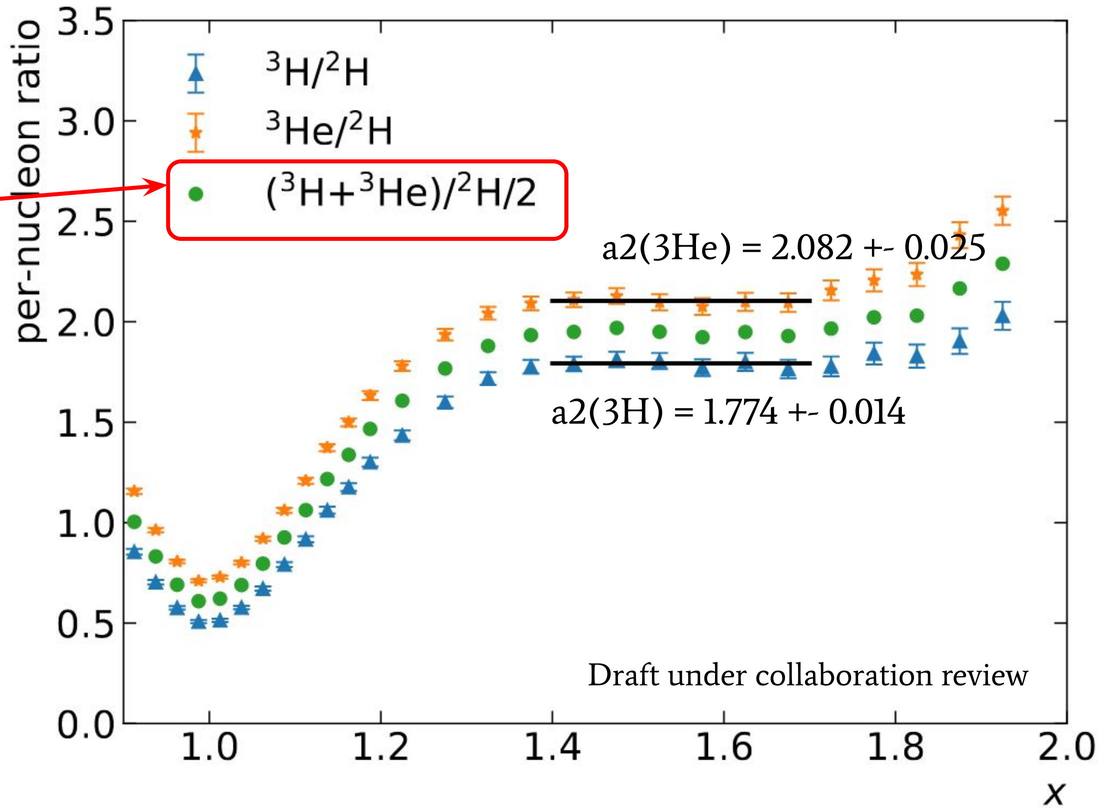


* E02-019 data from N. Fomin, PhysRevLett.108.092502

x>1 cross section ratio (from yield ratio):

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

To be compared with EMC ratio from MARATHON



3H/3He ratio from (e,e’):

Combined results of data from 2 experiments:

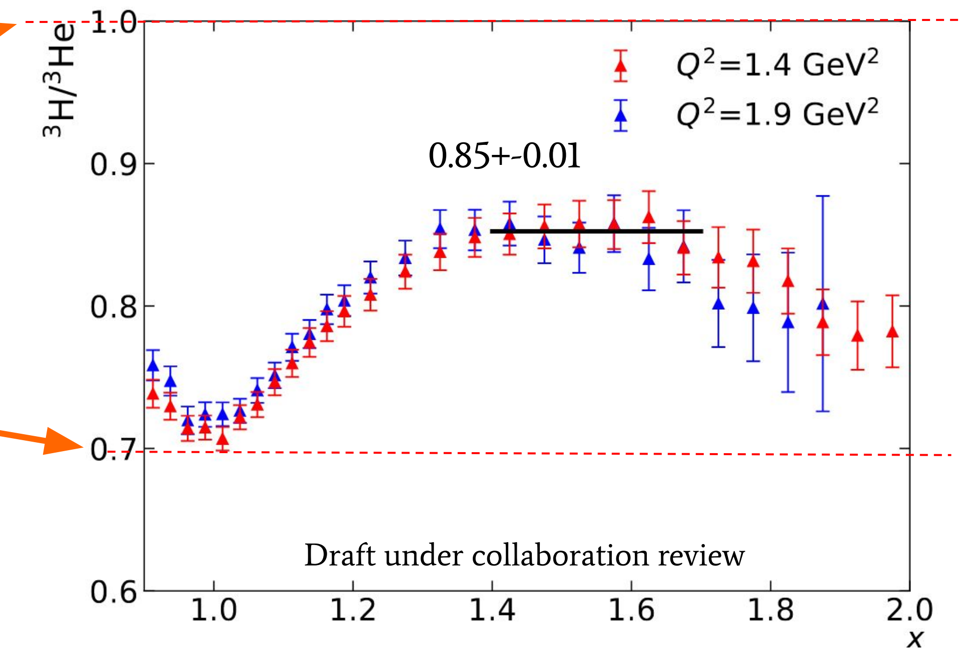
- 1.4 GeV2 data from inclusive SRC: 0.854+-0.011
- 1.9GeV2 data from the exclusive SRC 0.845+-0.010

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 isospin 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 A=3 nuclei

- The off-shell elastic cross section ratio of proton to neutron at Q2=1.4-1.9 GeV2 is p/n ~ 2.55

$$\frac{\sigma(3H)}{\sigma(3He)} = \frac{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_n \cdot p_0}{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_p \cdot p_0} = 0.85$$

⇩

p1/p0 = 2.2+-0.18

⇩

*Ratio of np/pp SRC pairs in A=3 nuclei = 2*p1/p0 =4.39*

np → T=1 and T=0 np pairs

pp → T=0

Ratio of high momentum n/p in Tritium

n/p = (4.4+2*1) : (4.4)

⇒ 3:2 v.s. 2:1 in mean-field

Ratio of high momentum n/p in Helium-3

n/p = 4.4 : (4.4+2*1)

==> 2:3 v.s. 1:2 in mean-field

Isospin dependence in A=3 nuclei and more

- The off-shell elastic cross section ratio of proton to neutron at Q2=1.4-1.9 GeV2 is p/n ~ 2.55

$$\frac{\sigma(3H)}{\sigma(3He)} = \frac{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_n \cdot p_0}{2(\sigma_n + \sigma_p)\cdot p_1 + 2\sigma_p \cdot p_0} = 0.85$$

⇩

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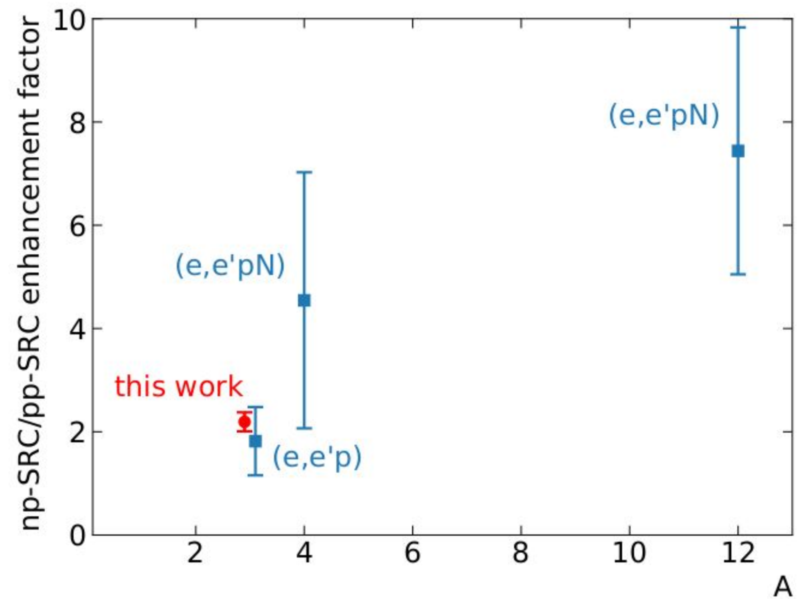
⇩

*Ratio of np/pp SRC pairs in A=3 nuclei = 2*p1/p0 =4.39*

np → T=1 and T=0 np pairs

pp → T=0

Phys. Rev. Lett. 124, 212501 (2020)
I. Korover et al., Phys. Rev. Lett.113, 022501 (2014)
R. Shneoret al., Phys. Rev. Lett.99, 072501 (2007)

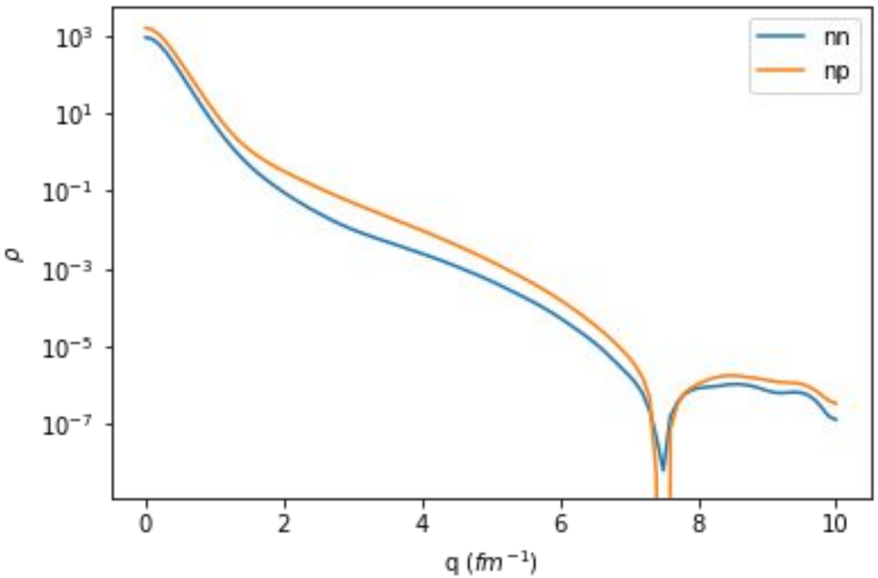


$$exclusive\ \frac{\#(3H)}{\#(3He)} = \frac{2\cdot p_1}{2\cdot p_1 + 2\cdot p_0}$$

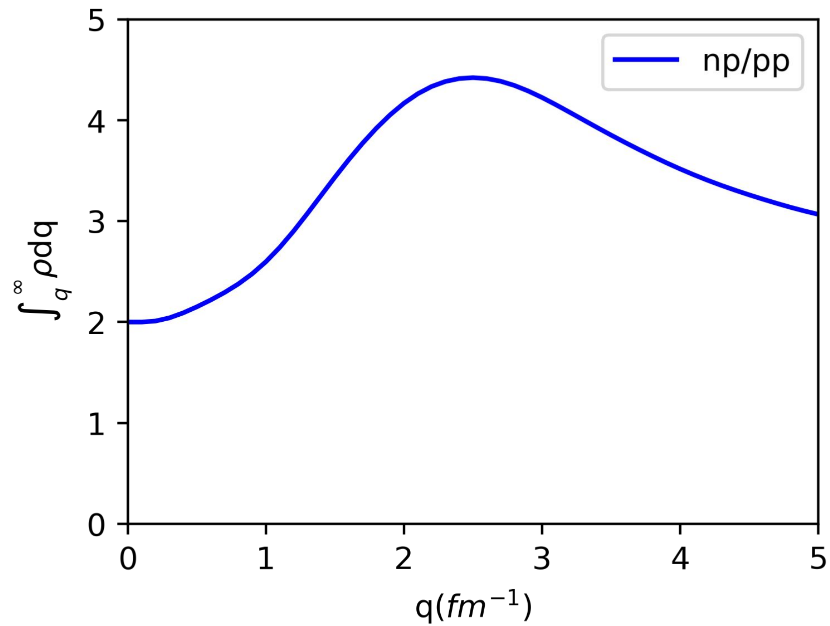
Momentum distribution in 3H

Wiringa, Schiavilla, Pieper, and Carlson: Phys. Rev. C 89, 024305 (2014)

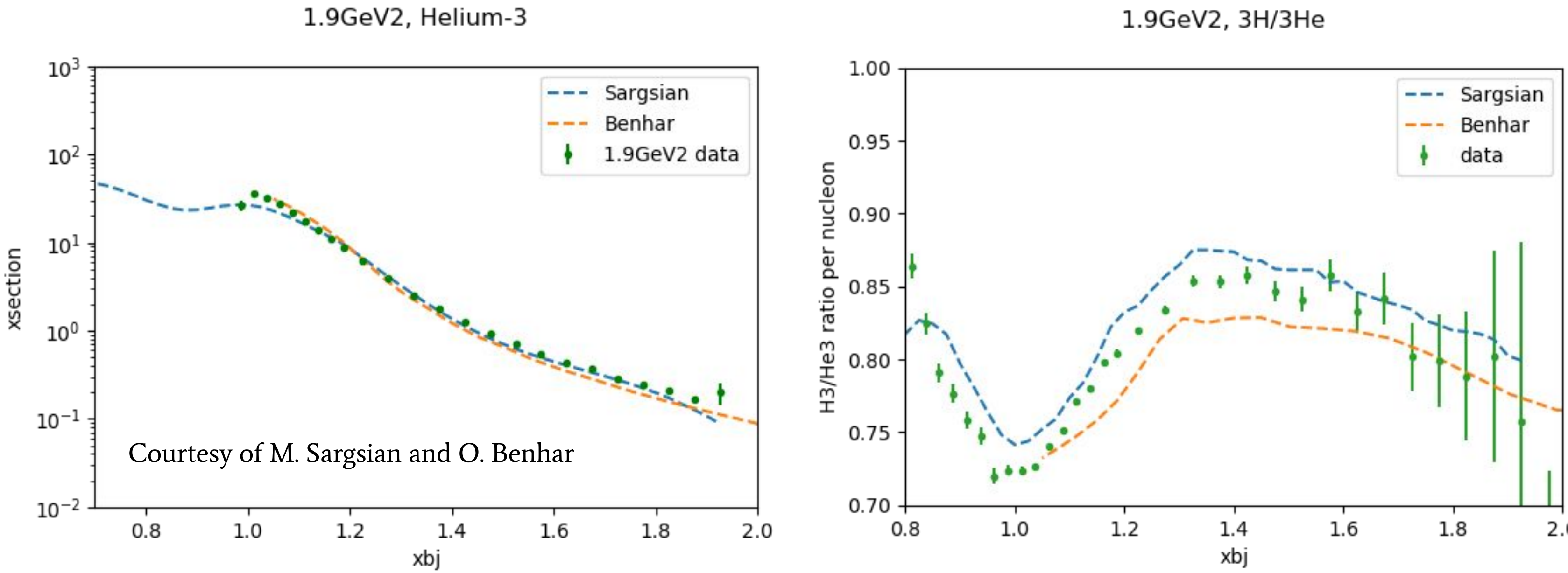
Momentum distribution from AV18



np/pp ratio from simple integration



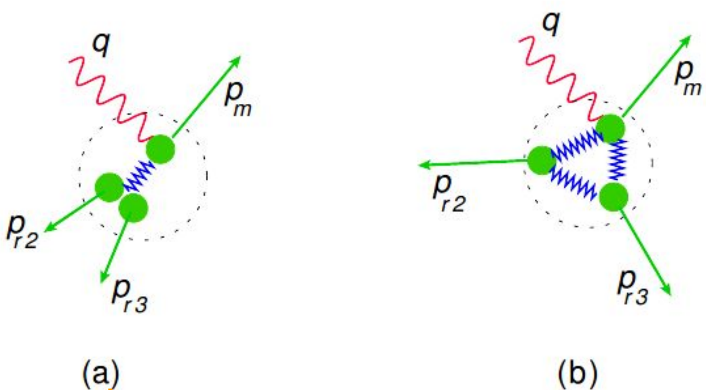
Cross Section Calculation



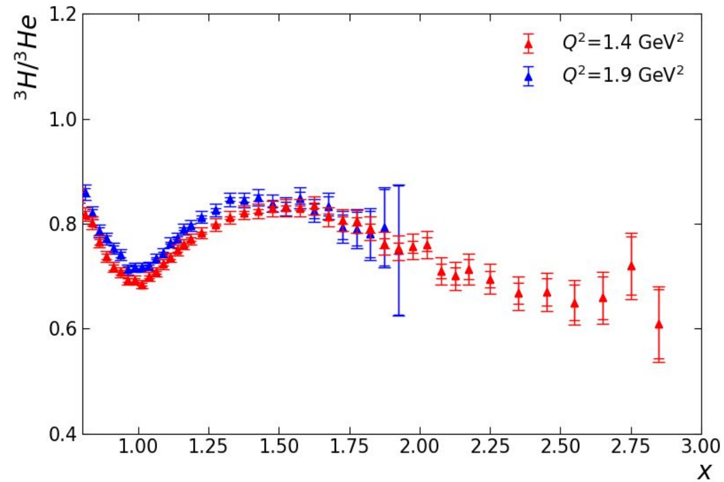
Towards 3N-SRC

Thanks M. Sargsian for useful discussions

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

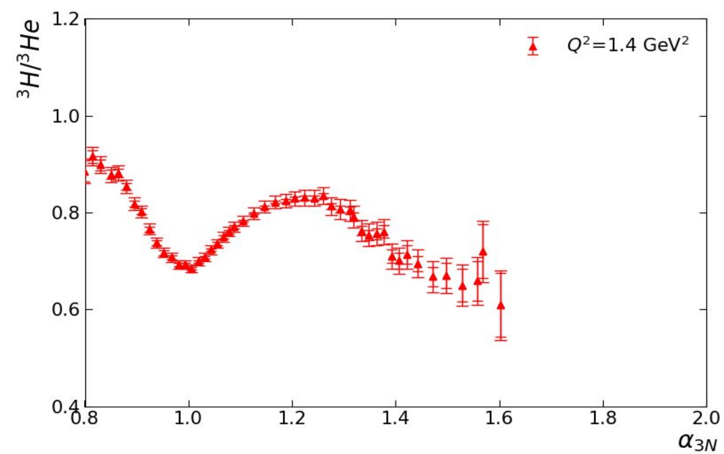


D. Day, et al., arXiv:1803.07629

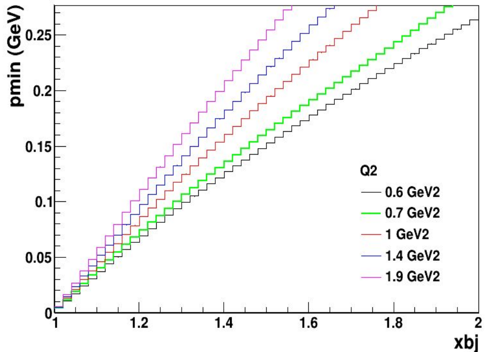


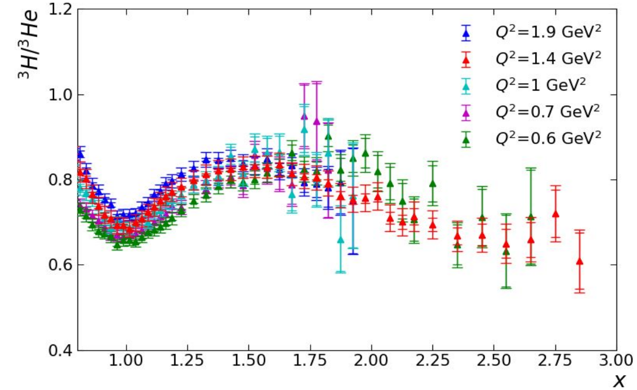
Dominant channel:

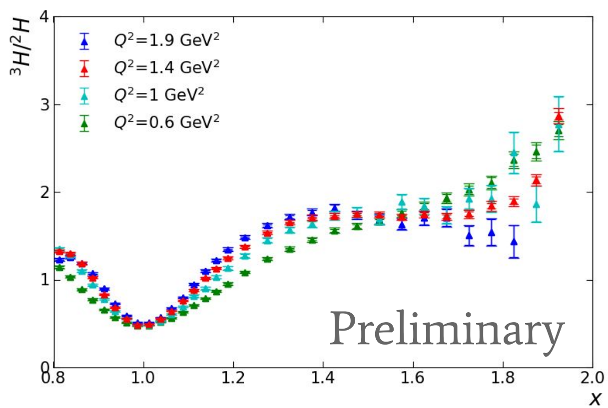
$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{2\sigma_{nn} + \sigma_{pp}}{\sigma_{nn} + 2\sigma_{pp}} \xrightarrow{\sigma_p \sim 3\sigma_n} 0.7$$

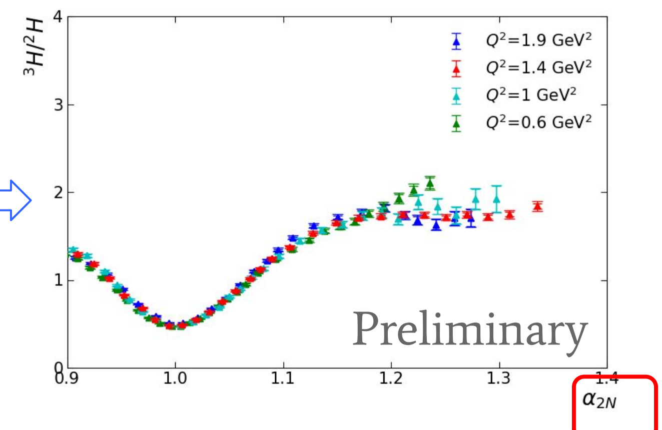


Mean-field to SRC transition









Light cone variable:

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

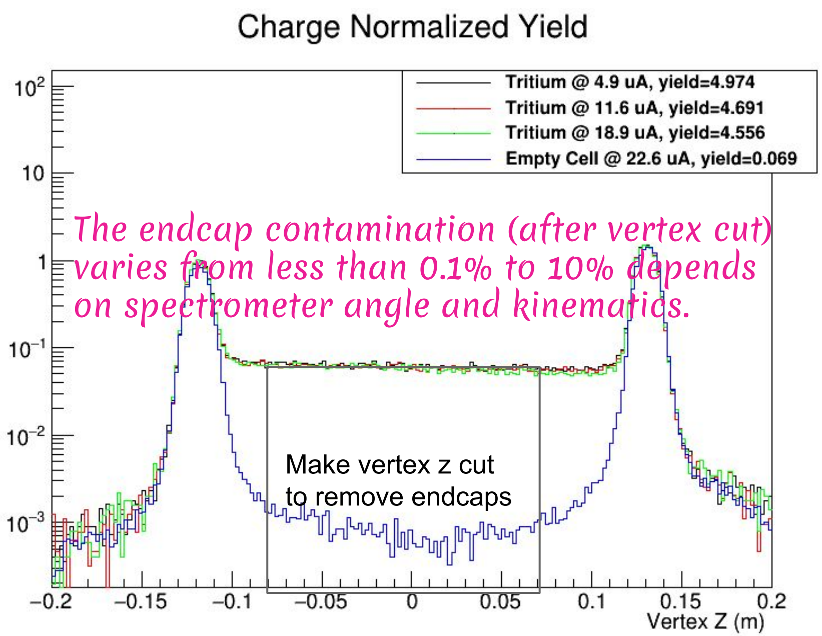
Acknowledgement

- 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 !

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