Isospin dependence in 2N SRC from tritium at x>1

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

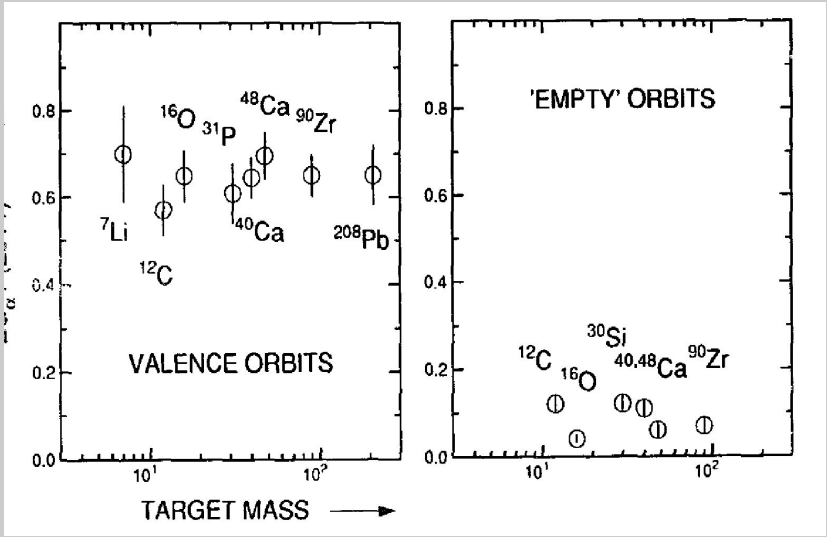
JLAB Hall A/C Summer Meeting
July 16, 2020

BERKELEY LAB

Jefferson Lab
Exploring the Nature of Matter

Nucleons in Nuclei:

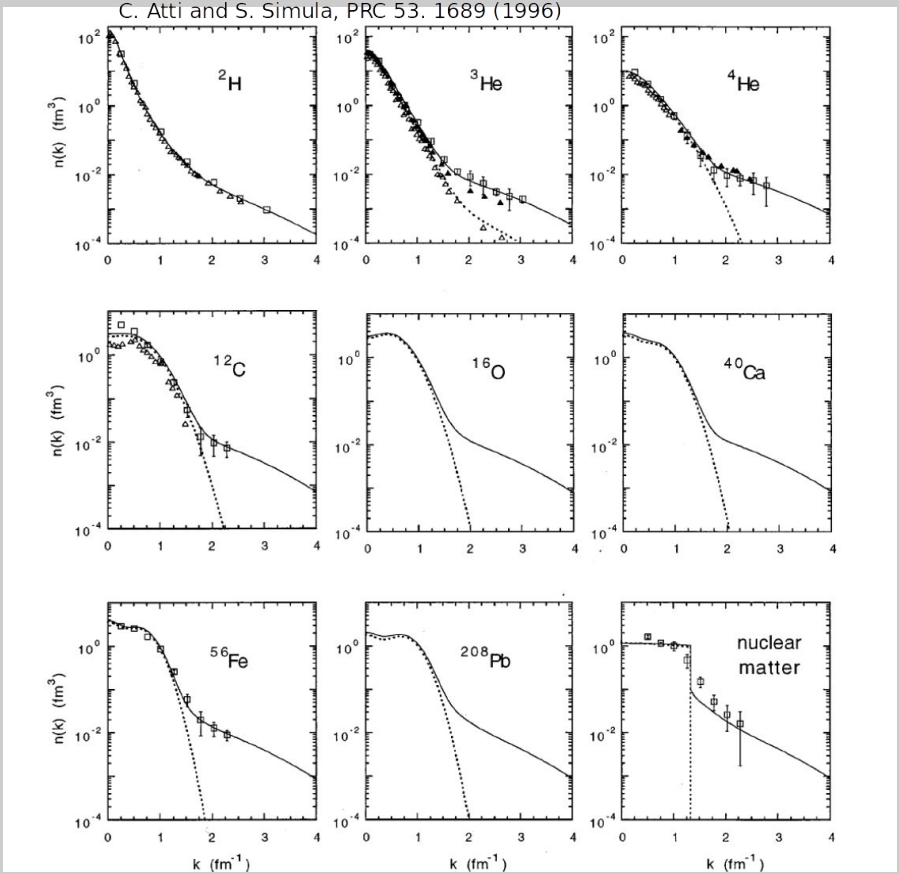
Beyond Shell Model



- 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)



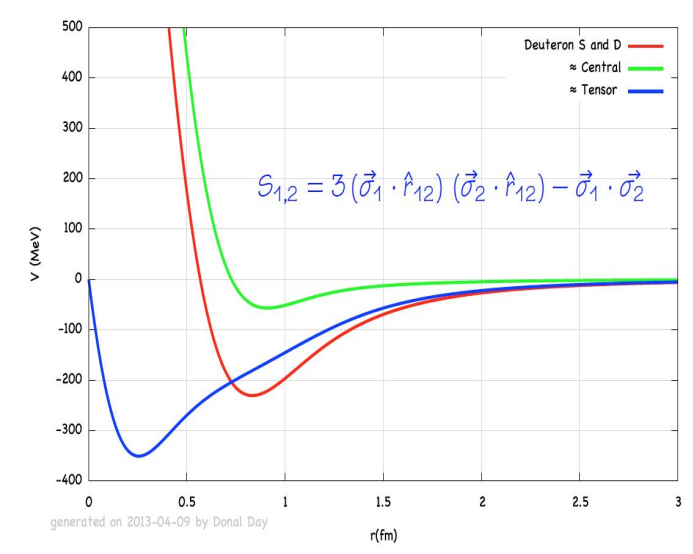
- High momentum nucleons in different nuclei

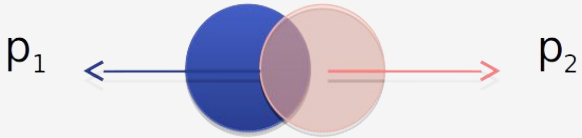
Nucleon-Nucleon Short Range Correlation (SRC)

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.





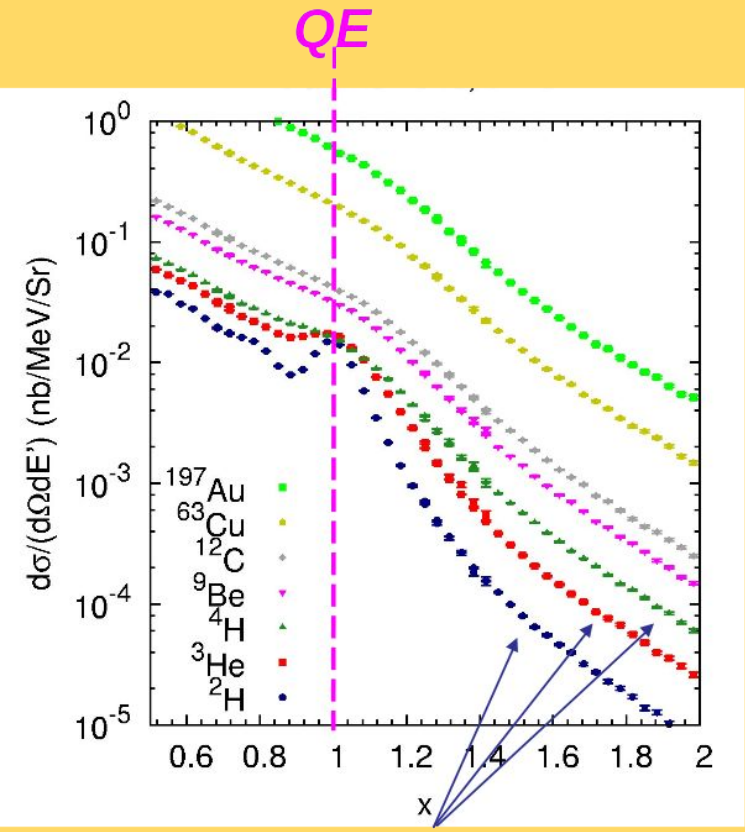
$p_1 + p_2 \rightarrow 0$

Large back-to-back momentum

Probing 2N SRC at x>1

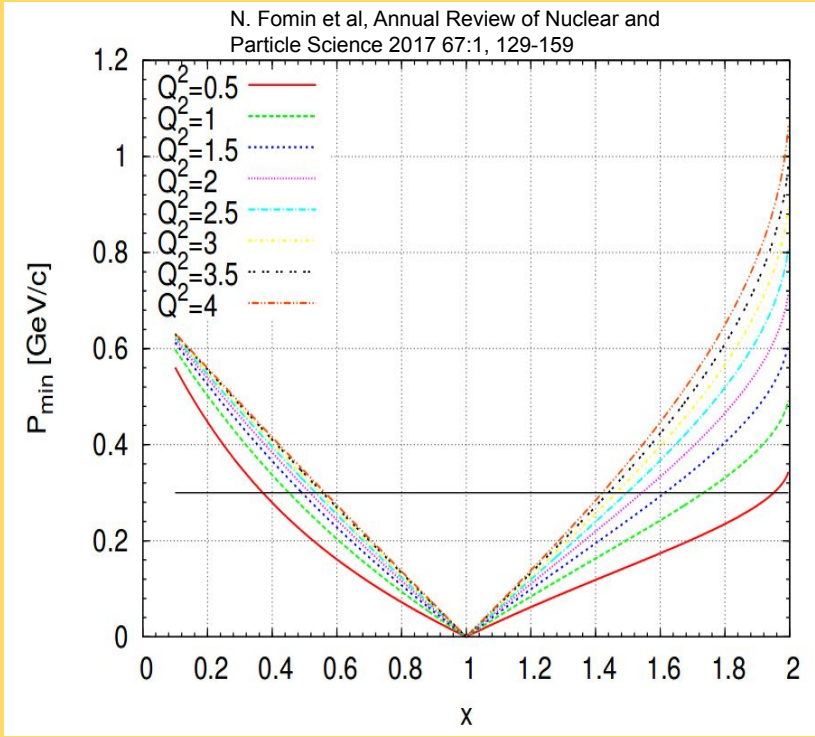
Inclusive electron scattering:

- high statistics
- background suppressed at high Q2



High momentum tails should yield constant ratio if SRC-dominated

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

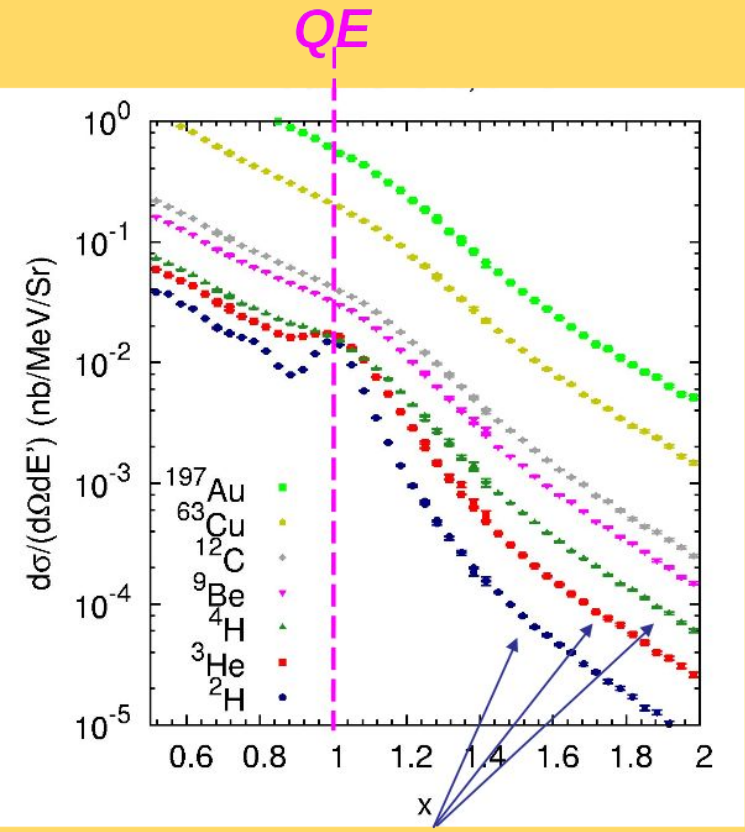


In inclusive (e,e') quasi-elastic scattering, high momentum nucleons dominate the x = Q2/2mν > 1 kinematics

Probing 2N SRC at x>1

Inclusive electron scattering:

- high statistics
- background suppressed at high Q2



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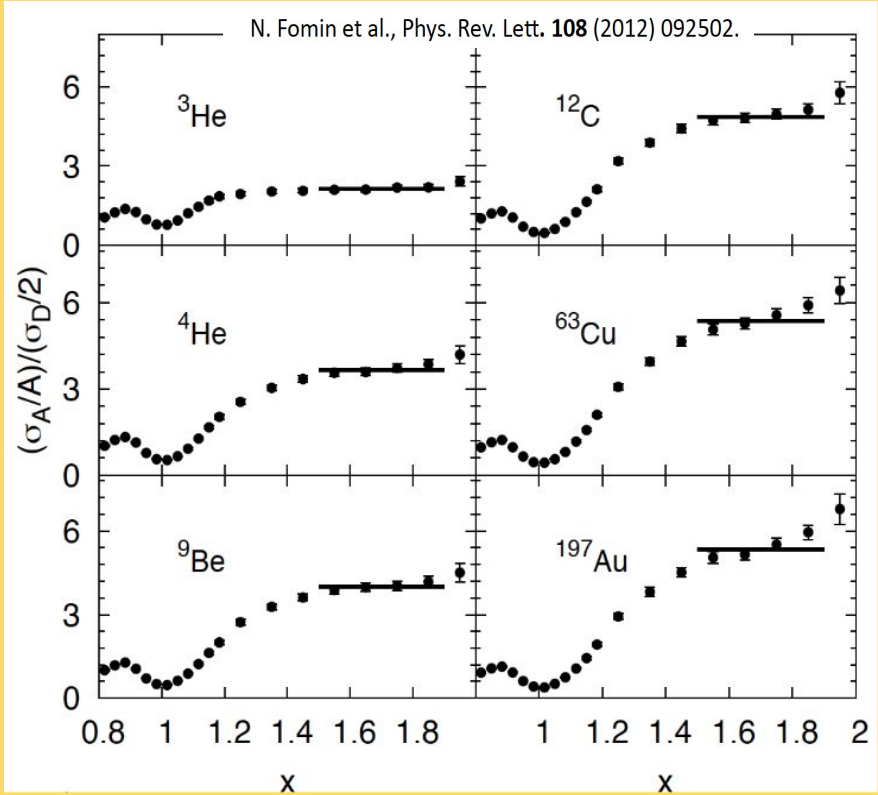
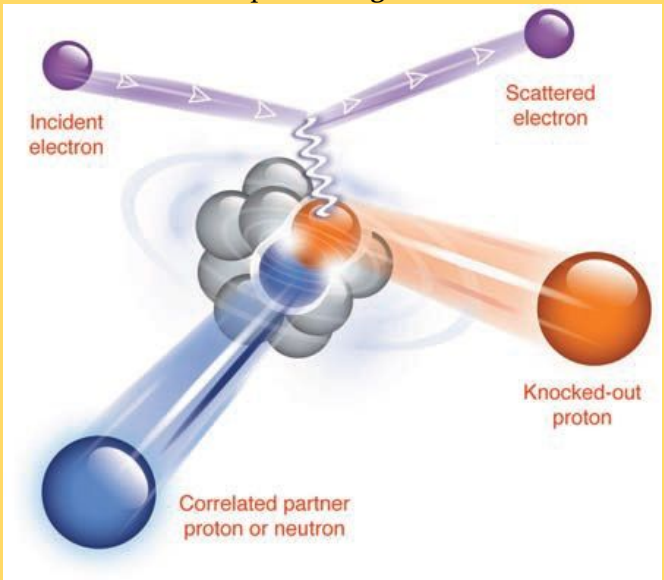
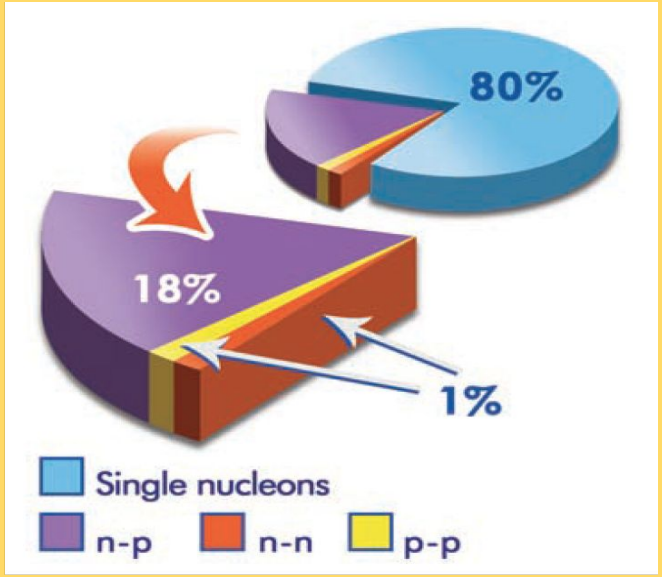


The x>1 plateau of A/D cross section ratios give the percentage of deuteron-like high momentum pairs in each nucleus

SRC in Exclusive Scattering

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





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

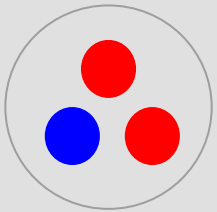
Jefferson Lab E12-11-112 (Hall A) :

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), Tyler Kutz (Stony Brook), 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.

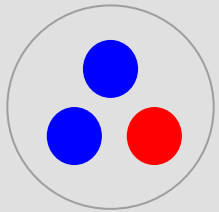


np pair dominates:

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

no isospin preference:

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



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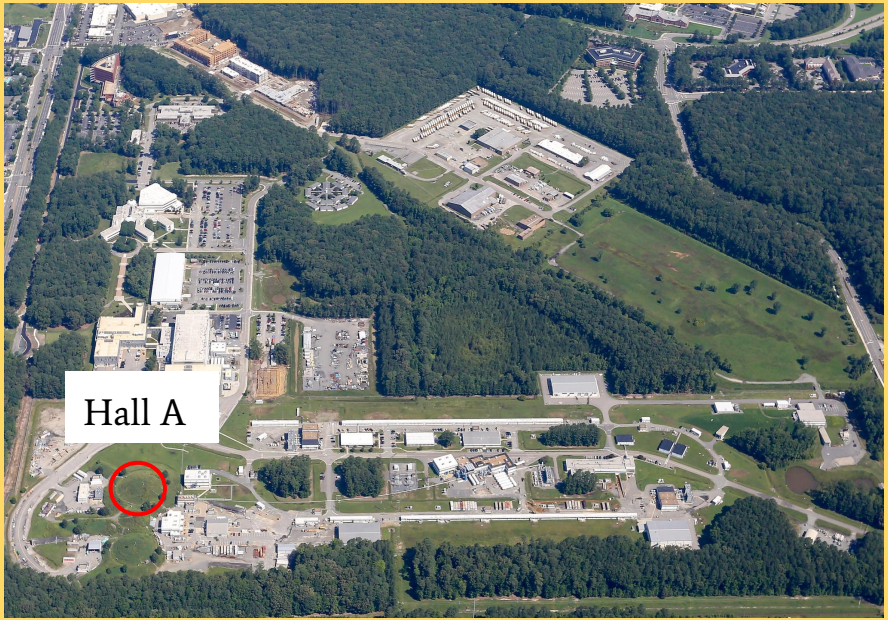


Tritium Family Experiments:

2017.12: Commissioning
2018.2-2018.5: E12-11-103 MARATHON
2018.4 E12-14-011 e'p (exclusive SRC)
Cruz-Torres, R., Li, S., et al. Physics Letters B, 797, 134890
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

Kinematics:

Fall 2018

LHRS: Dedicated NN and 3N SRC study (1<xbj<3) with 4.3 GeV beam

RHRS: QE scan

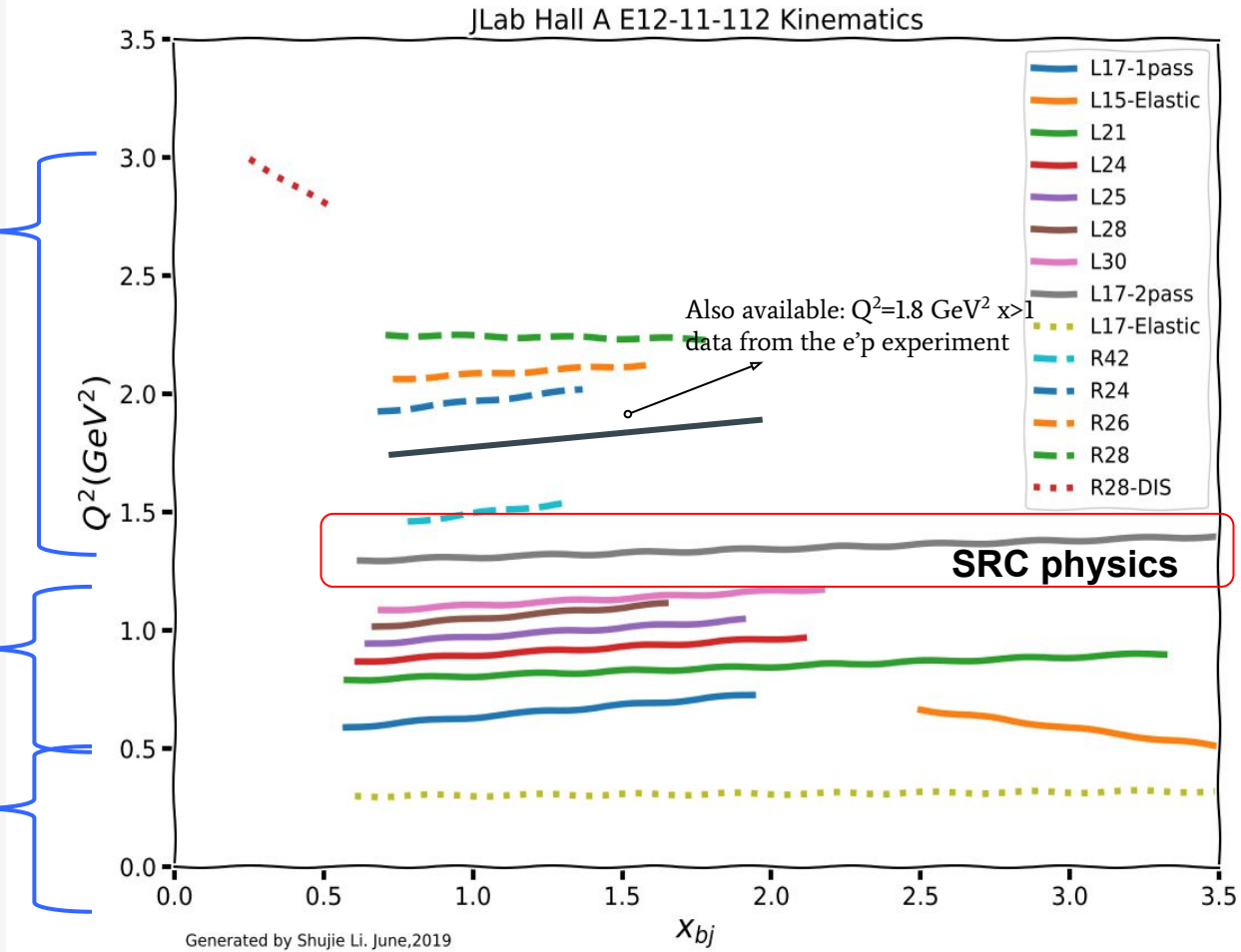
May 2018:

QE scan with 2.2 GeV beam

Dec 2017:

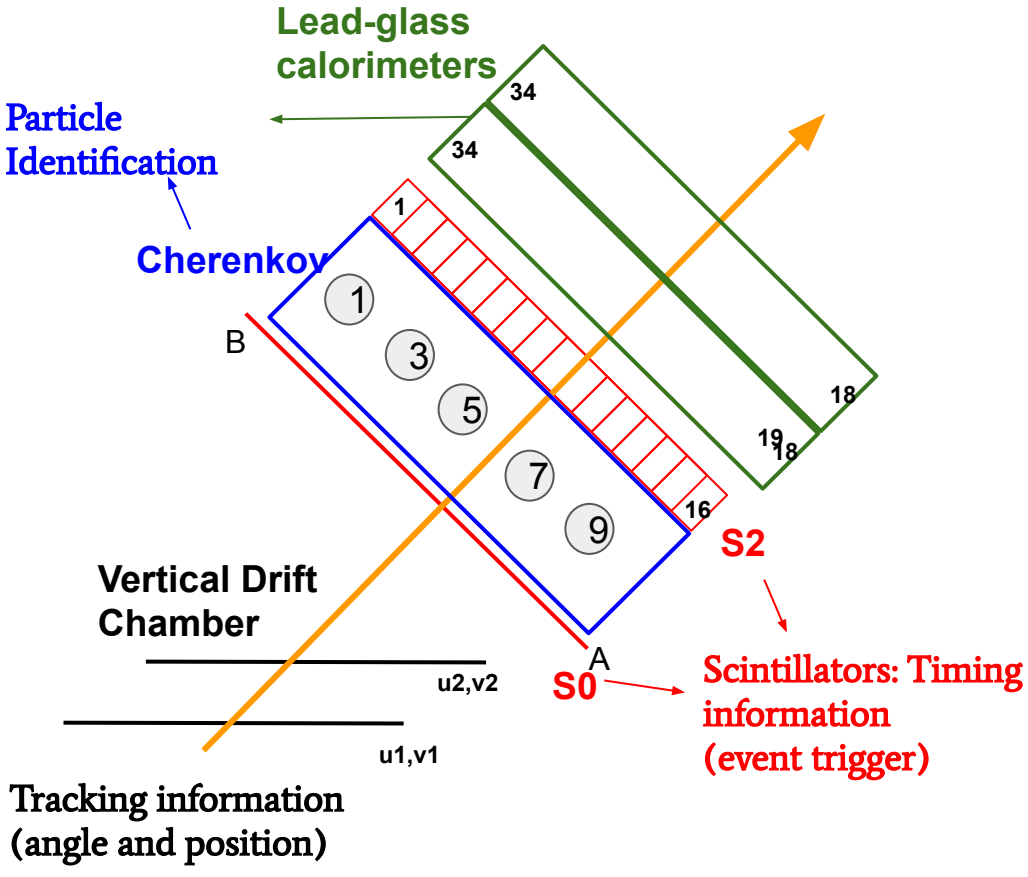
Commissioning

Target “boiling” study (also QE data at Q2=0.4 GeV2)

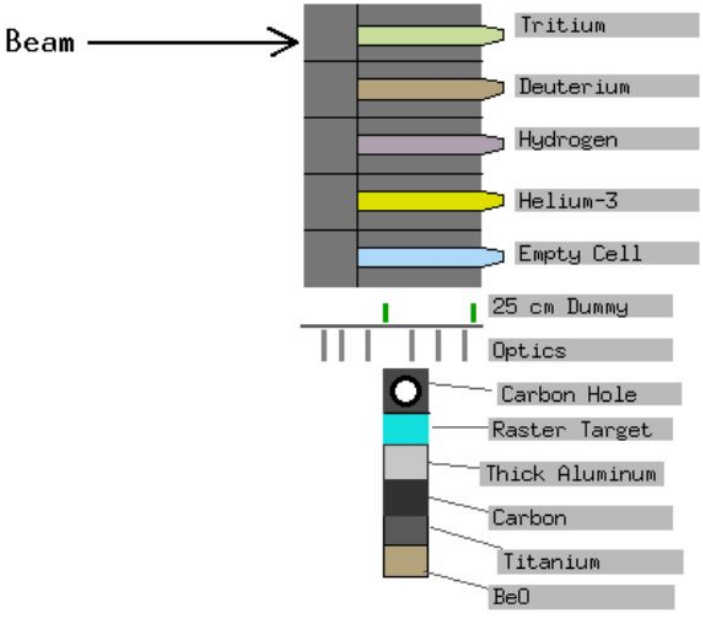


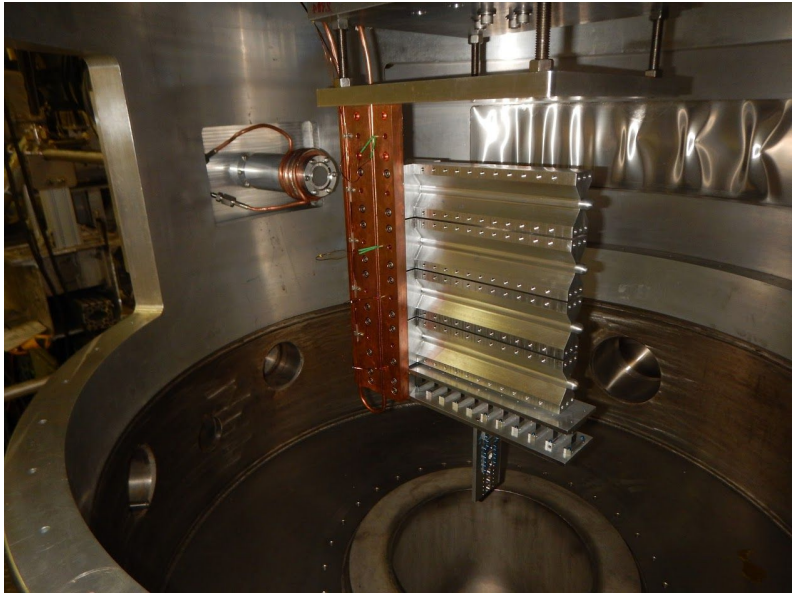
Jefferson Lab, Hall A

Detector Package:



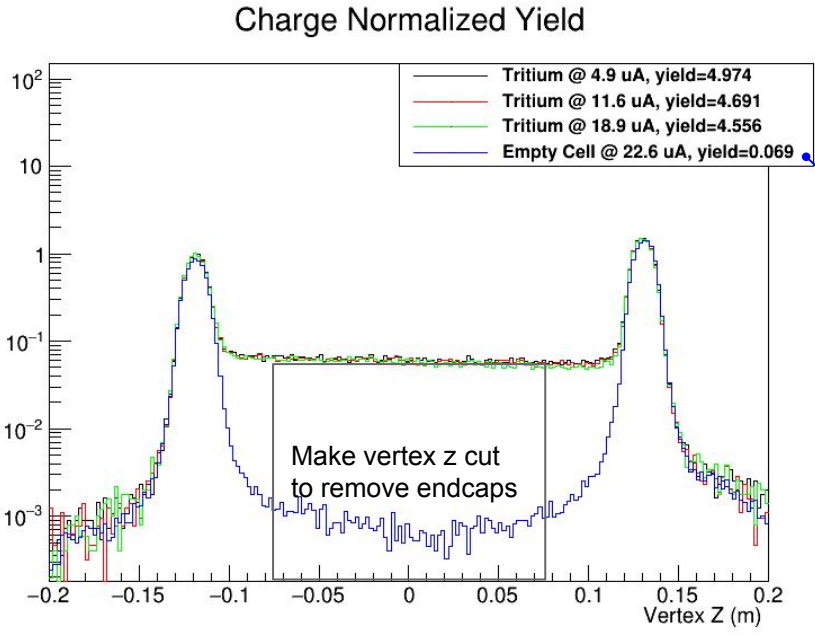
The Gas Target System:





The Gas Target System: special handling

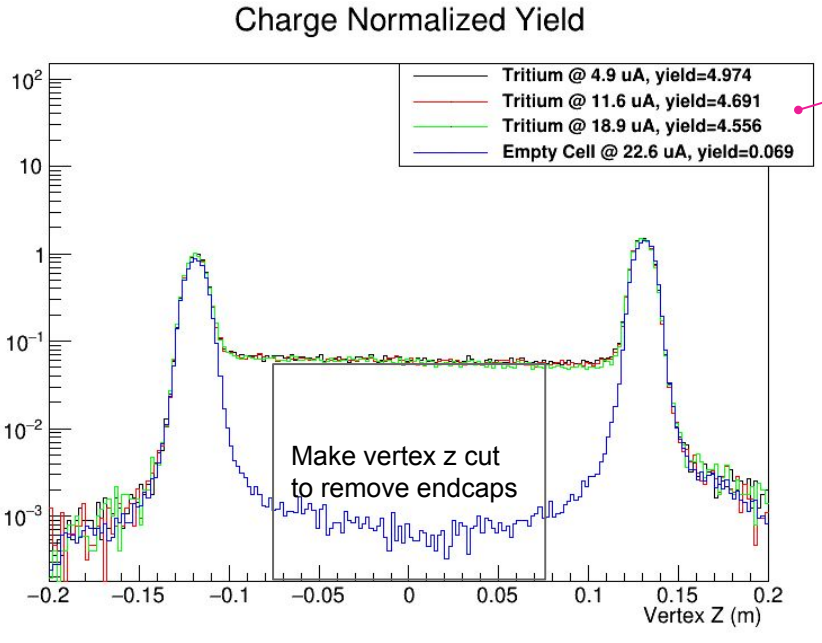
- Maximum current = 22.5 uA on gas cells to minimize the risk of gas leak.
- Endcap(75mg/cm2 Aluminum) being mis-reconstructed into thin gas body (77mg/cm2 Tritium)
- "Boiling": gas density change along beam path



The endcap contamination (after vertex cut) varies from less than 0.1% to 10% depends on spectrometer angle and kinematics.

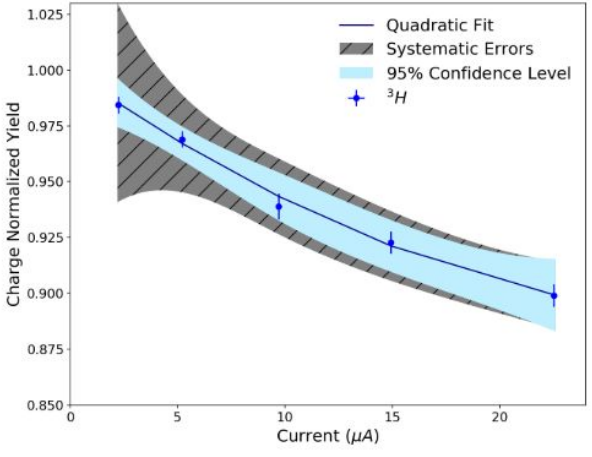
The Gas Target System: special handling

- 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 (84mg/cm2 Tritium)
- "Boiling": gas density change along beam path (after reached equilibrium which takes less than 1 second)



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



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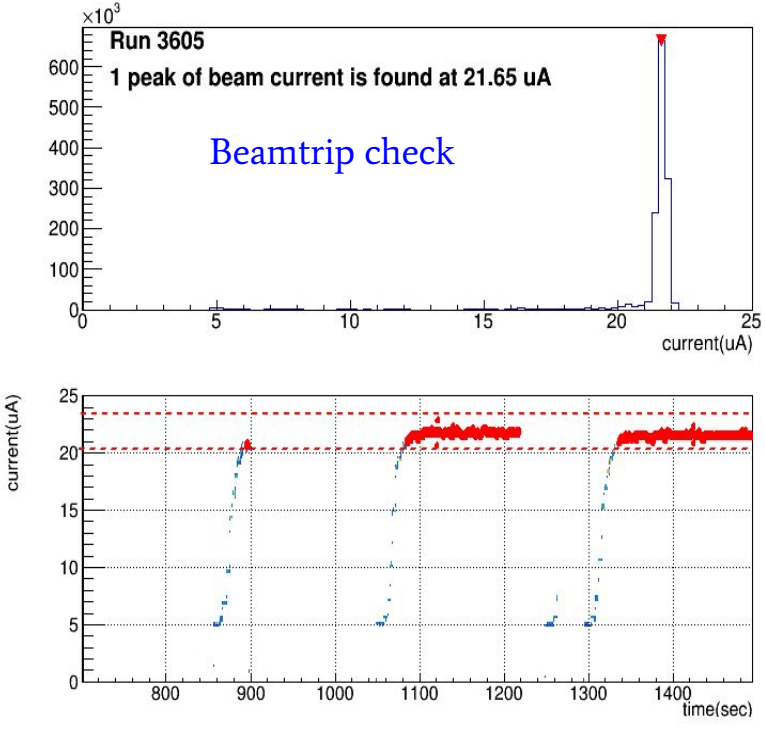
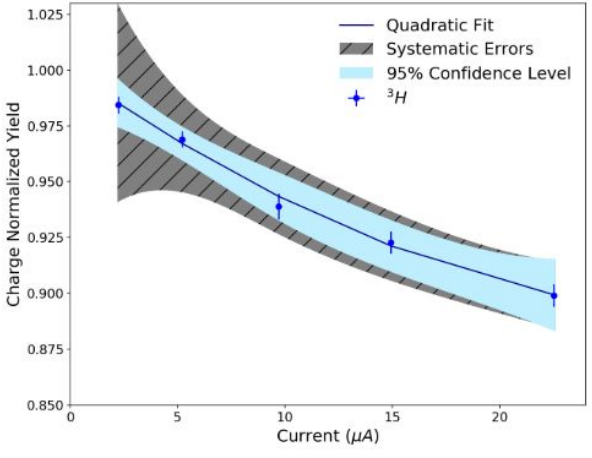


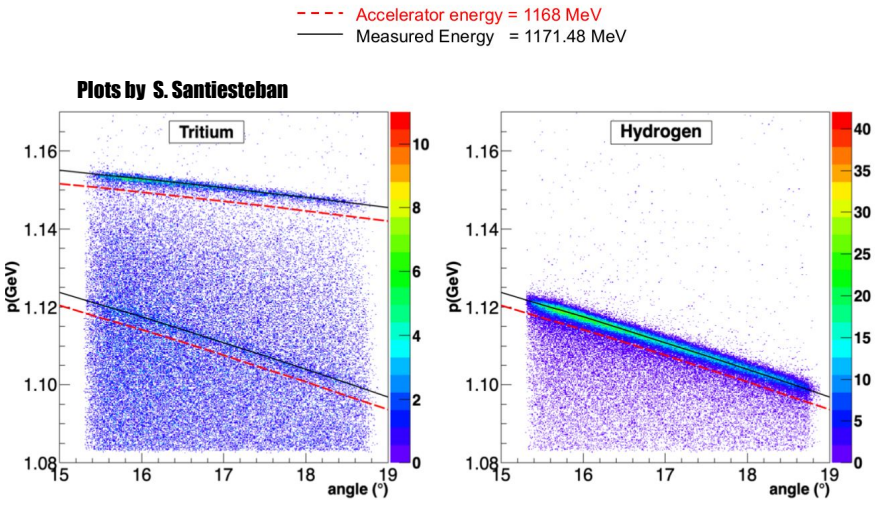
Only data from stable beam around 22 uA are used for this analysis

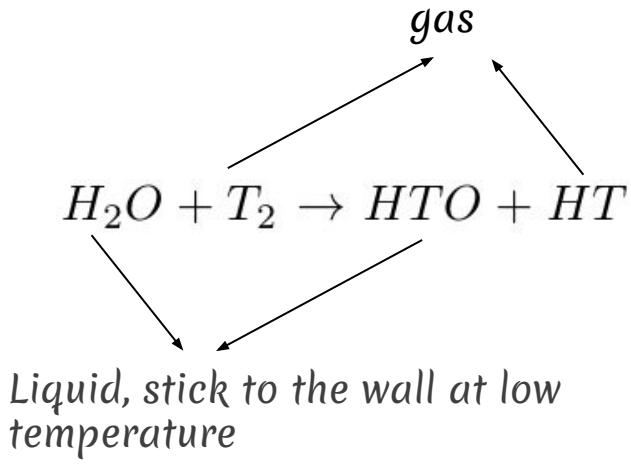
S. Santiesteban et al. ,
https://doi.org/10.1016/J.NIMA.2019.06.025

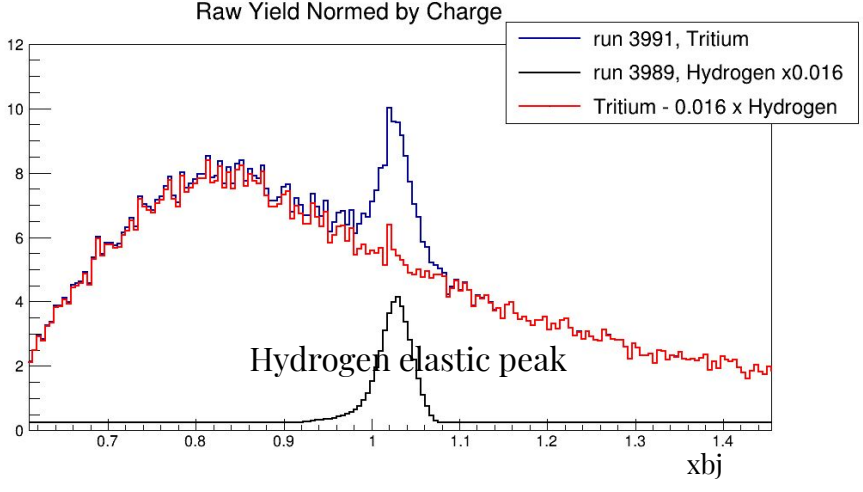


The Gas Target System:

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







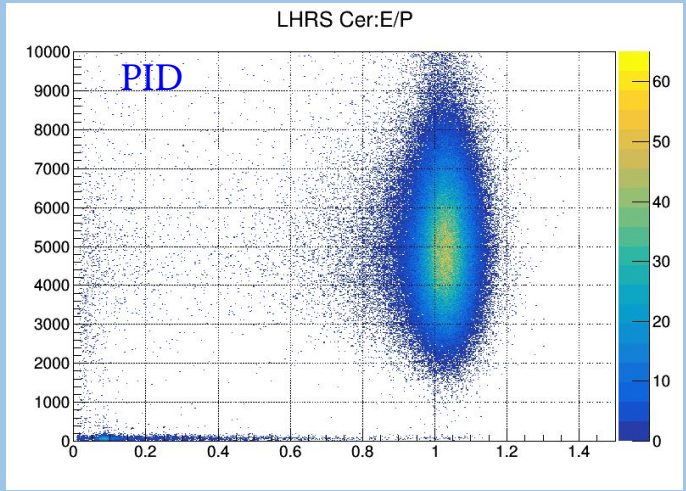
Tritium replaced by hydrogen:
1.6% * 0.0708 g/cm2 * 3 (H2O->HTO) / 0.0851g/cm2 = 4.0 %

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

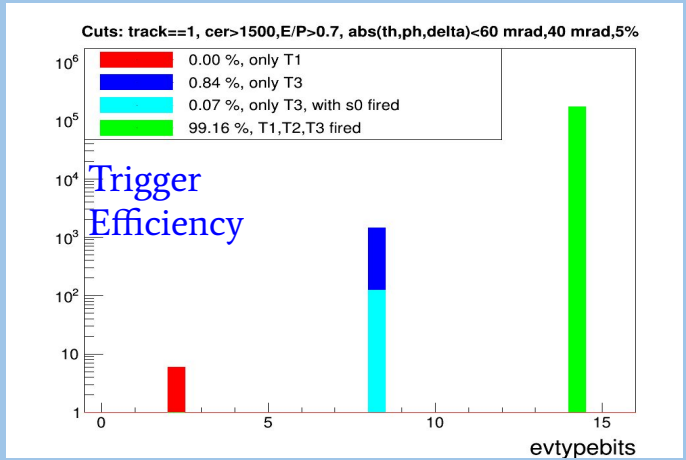
In this analysis: use 2+- 2 %

Data Processing

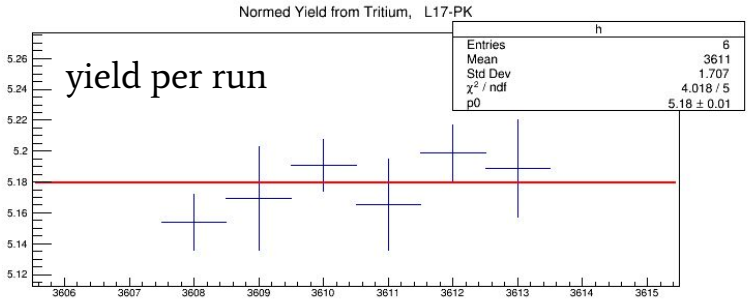
- **Calibrations:**
  - Beam current and energy (Nathaly Santiesteban)
  - Beam position (Jason Bane and Tyler Hague)
  - HRS pointing and optics reconstruction
  - Vertical Drift Chamber
  - Cherenkov
  - Scintillator timing (Tong Su)
  - Calorimeter (Nathaly Santiesteban)
  - Tritium Decay (Tyler Kutz)

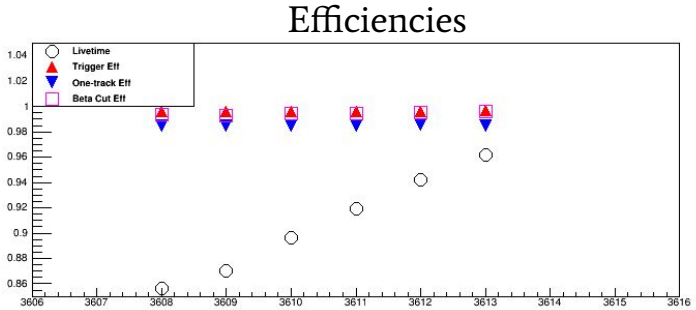


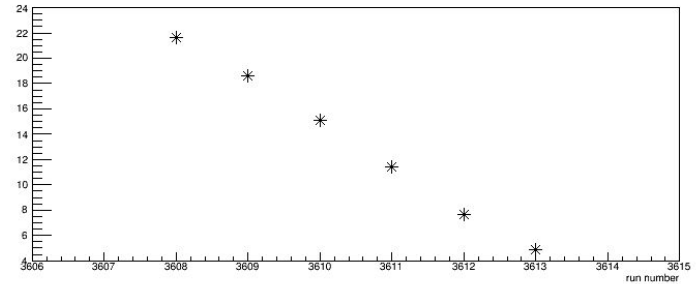
- **Data quality check:**
  - Trigger efficiency
  - Detector efficiency
  - Tracking efficiency
  - Beam quality check
  - Deadtime calculation
  - Run condition check



Cross Section Extraction



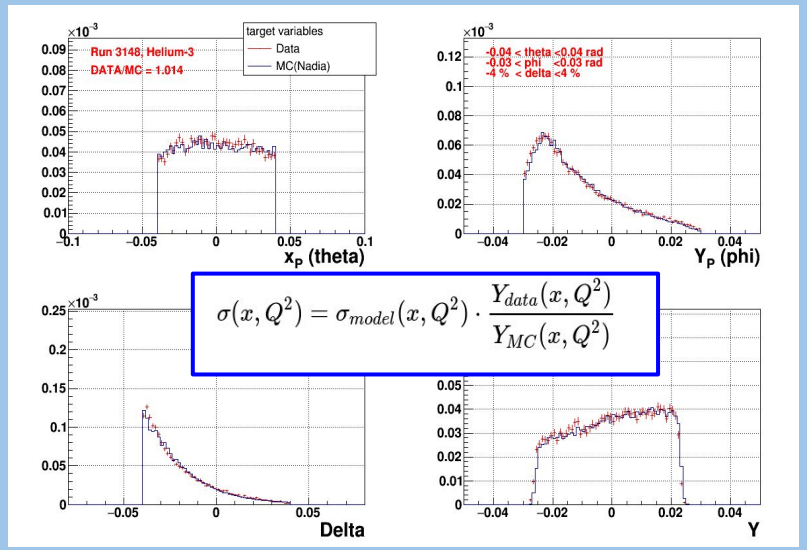




"Yield" extracted from data

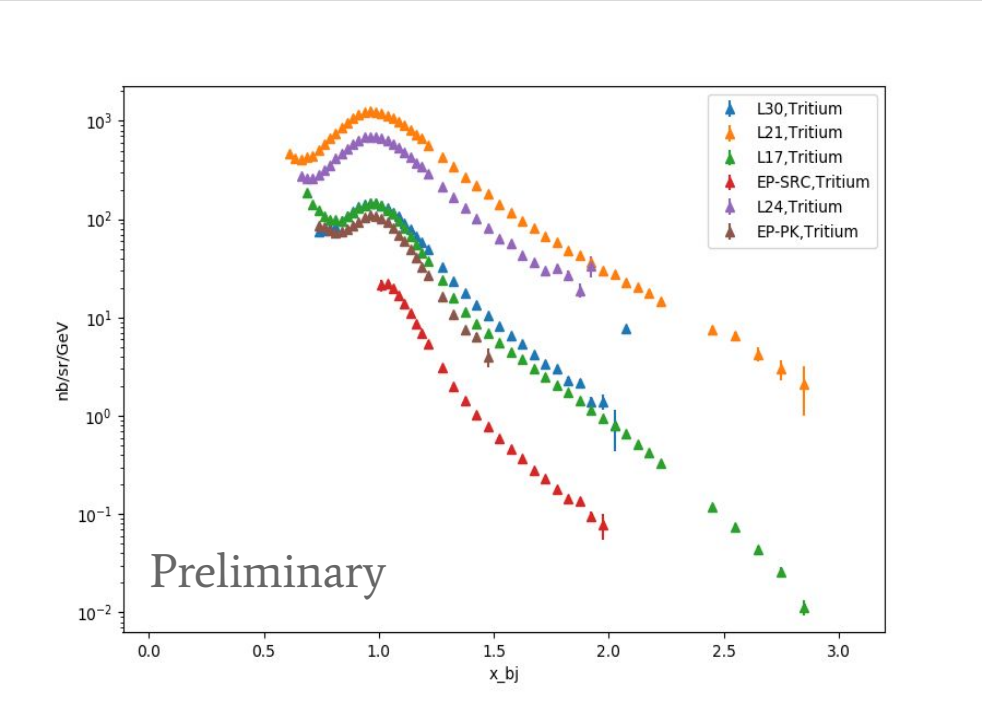
$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\#\text{ of events}}{Q \cdot \rho_l / M_A \cdot \text{efficiencies}} \frac{A(\Omega, E')}{\Delta\Omega\Delta E'}$$

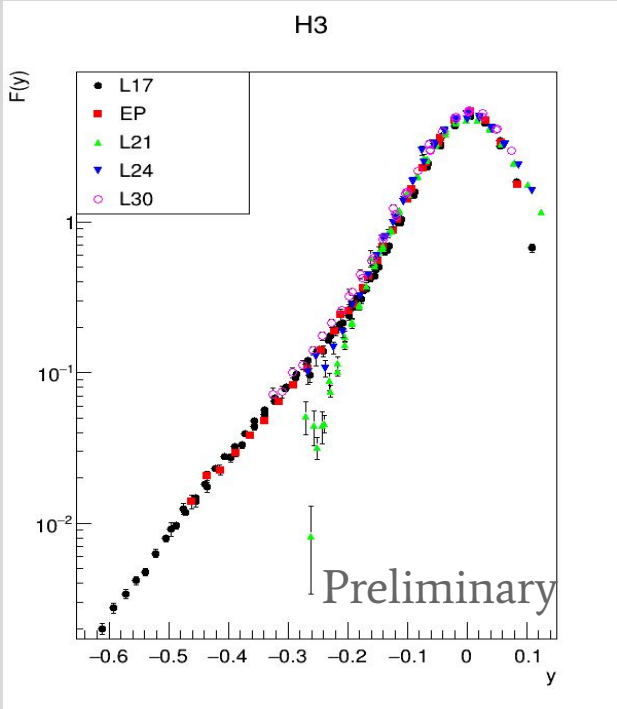
"HRS Acceptance effect" included in Monte-Carlo Simulation



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

Tritium Absolute Cross Sections

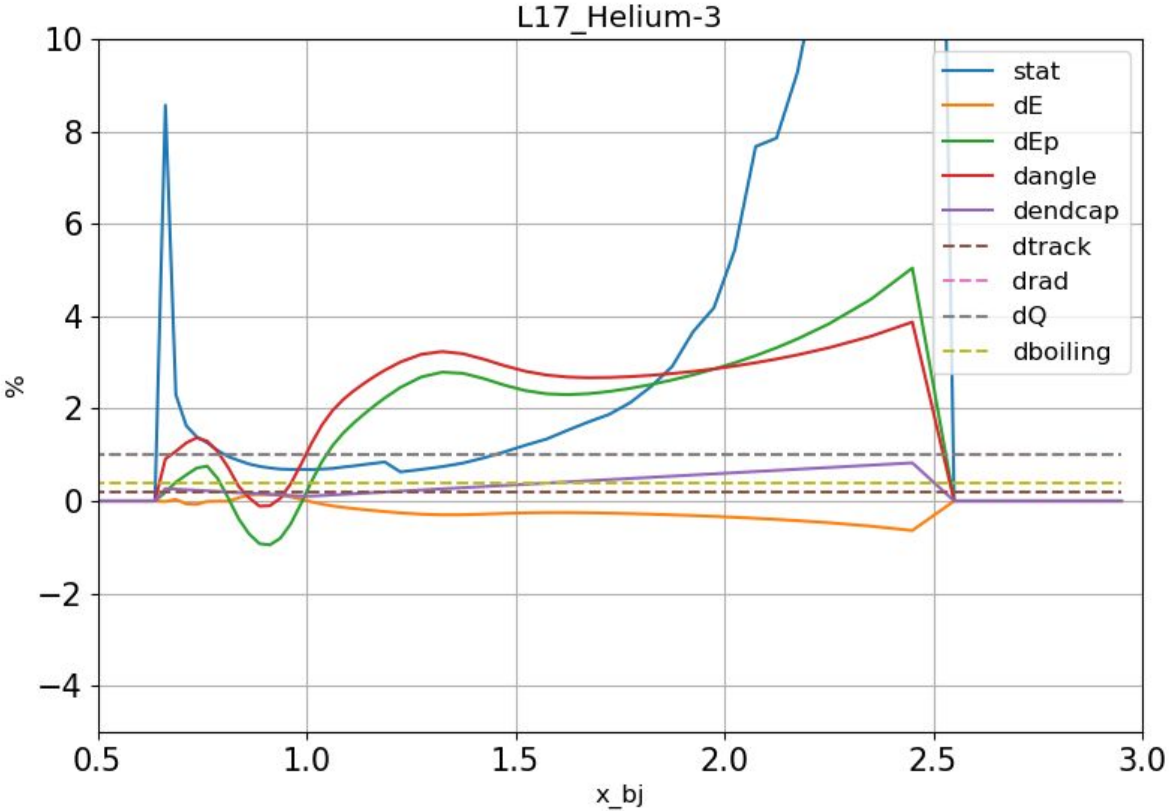




F(y) ~ longitudinal momentum distribution

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

Uncertainties



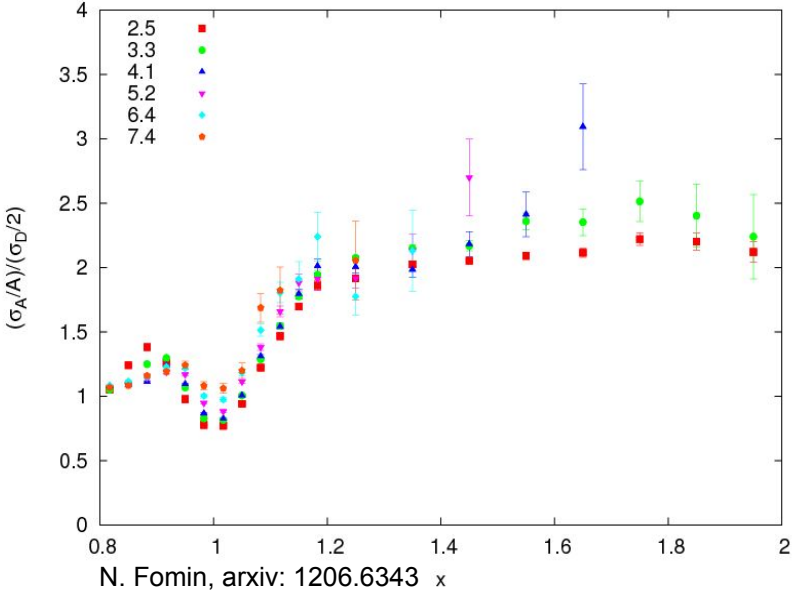
Uncertainties

		Absolute XSection		Yield Ratios	
Sources	**Uncertainties**	**norm**	**ptp**	**norm**	**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:

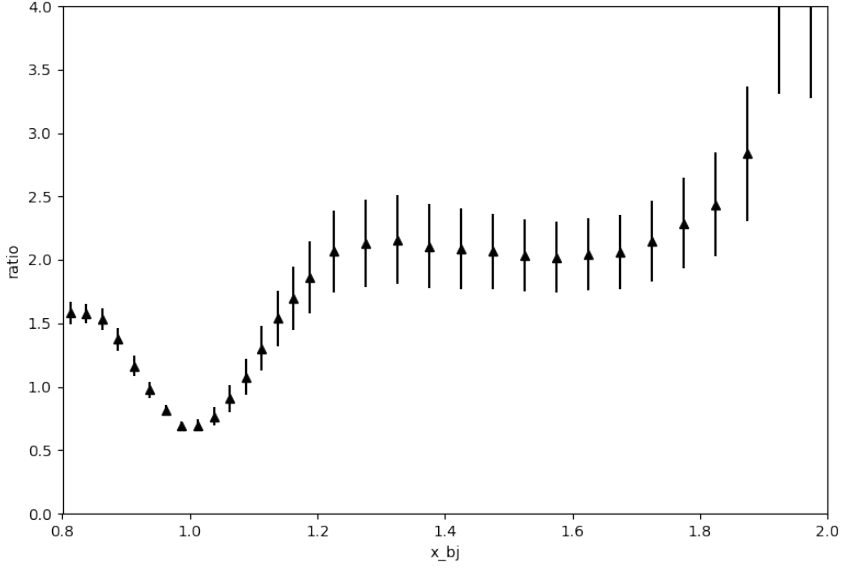
Calibration result: 3He/2H ratio

JLAB Hall C E02-119



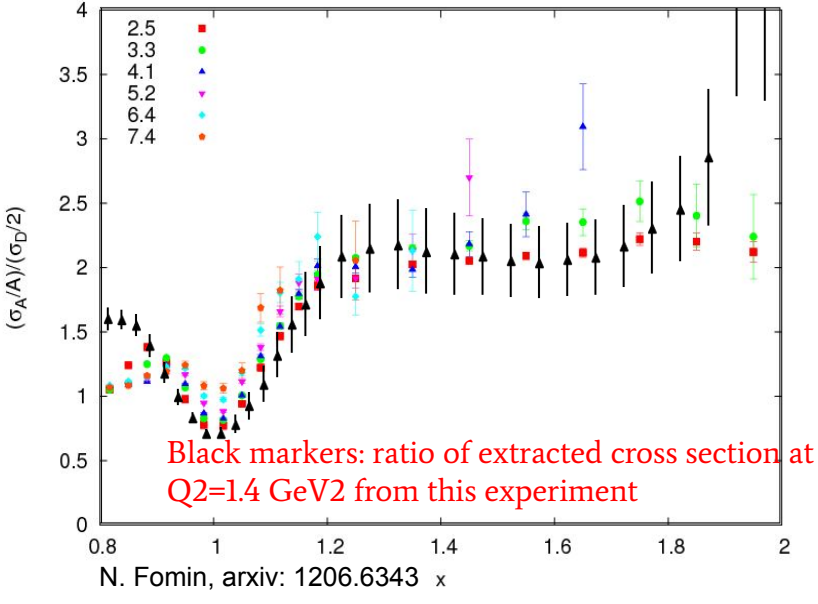
N. Fomin, arxiv: 1206.6343

This experiment:
ratio of extracted cross section at Q2=1.4 GeV2



x>1 cross section ratio:

Calibration result: 3He/2H ratio



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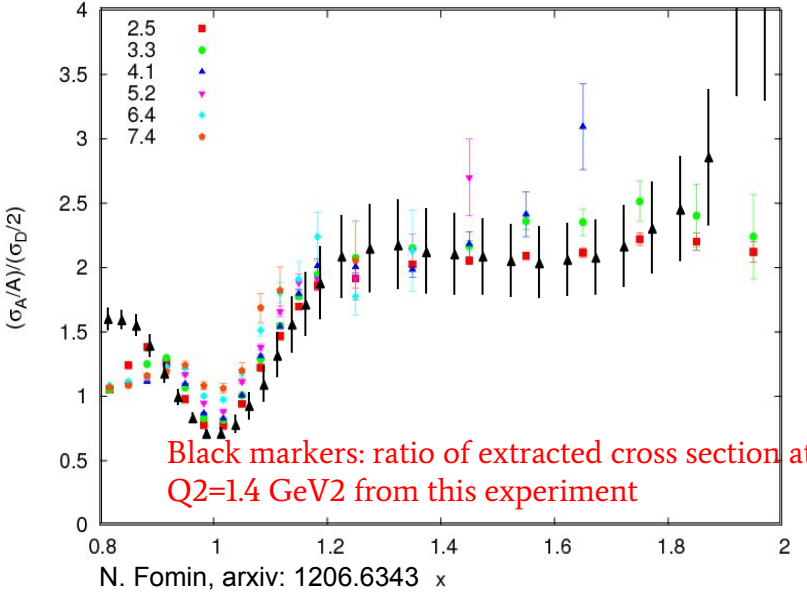
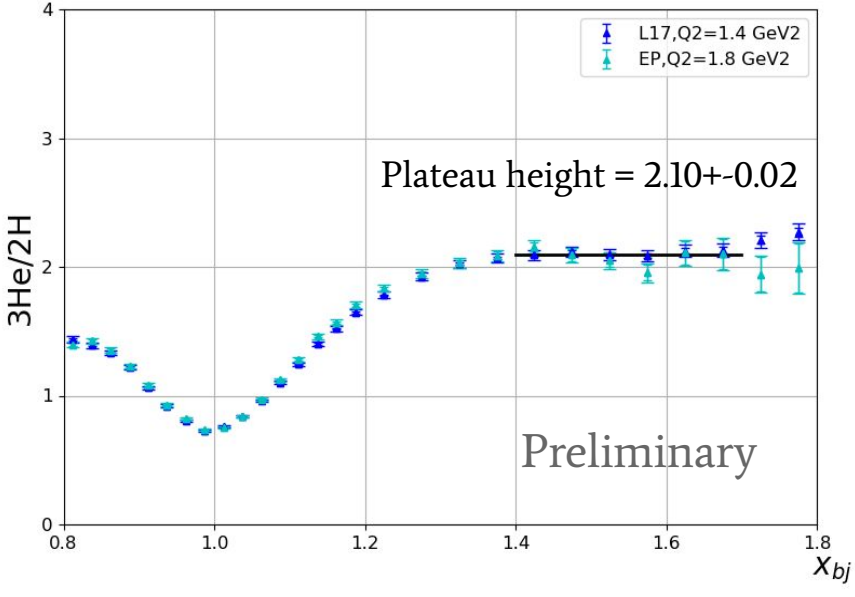
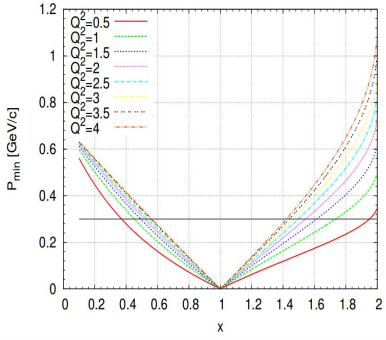


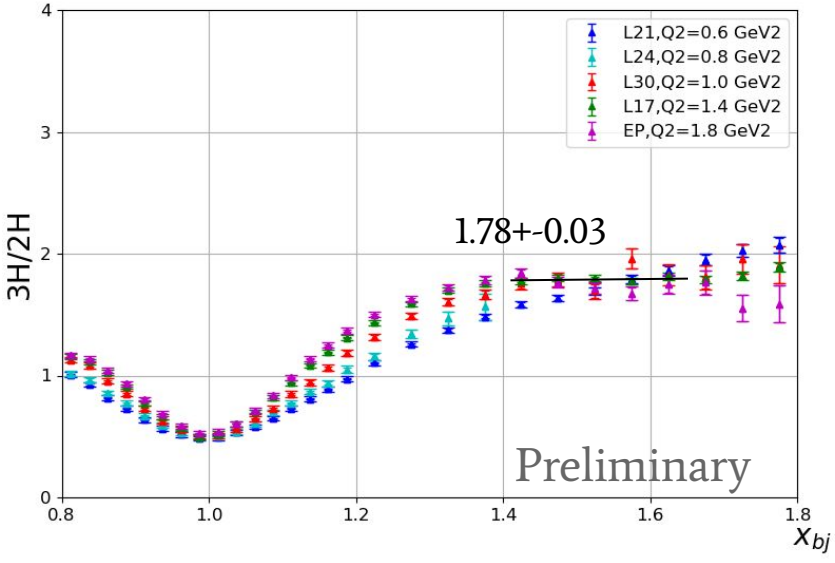
Xsection ratio from yield ratio method

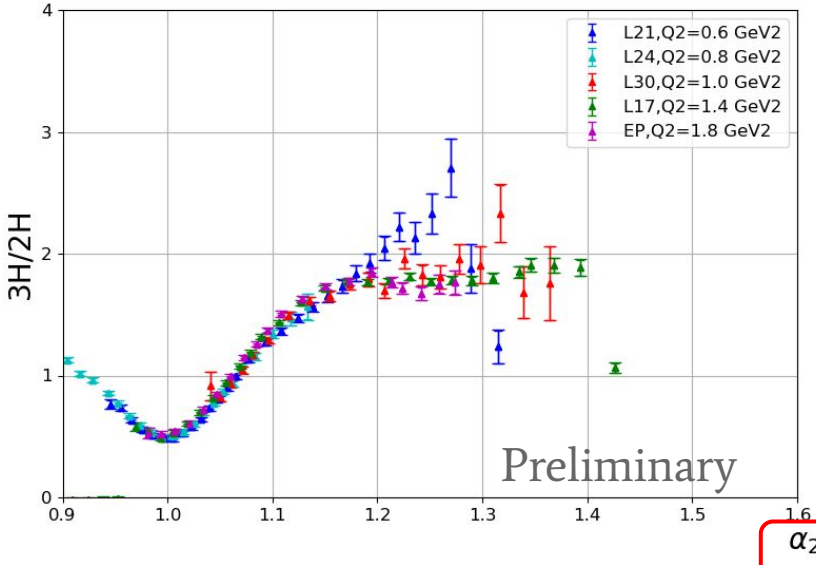


x>1 cross section ratio:

Q2 dependence on 3H/2H ratio



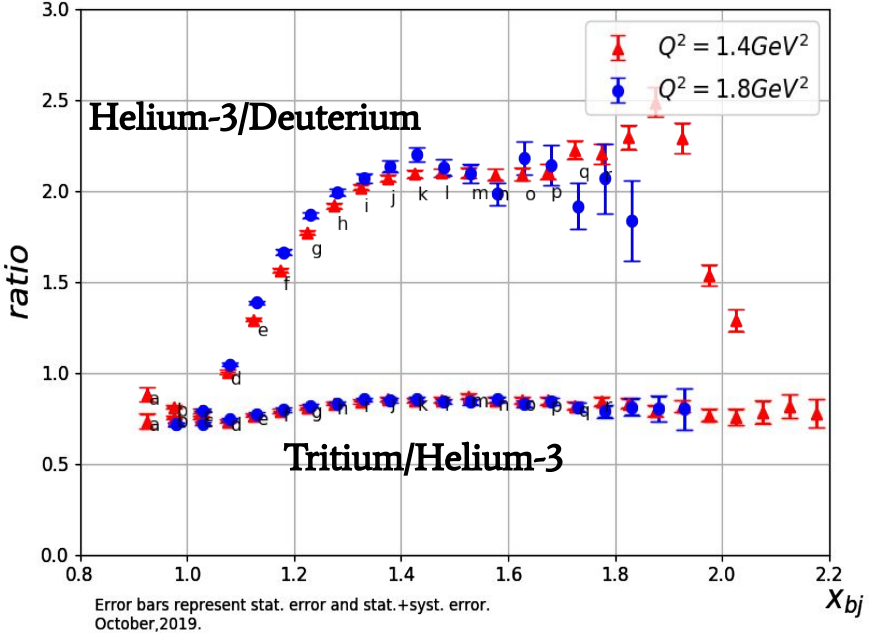


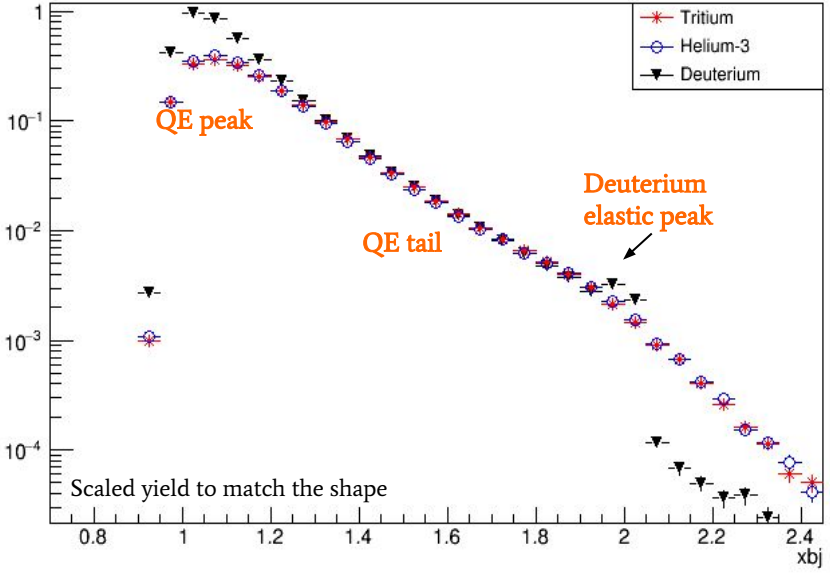


Light cone variable:

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

x>1 cross section ratio:





x>1 cross section ratio:

Combined results of data from 2 experiments:

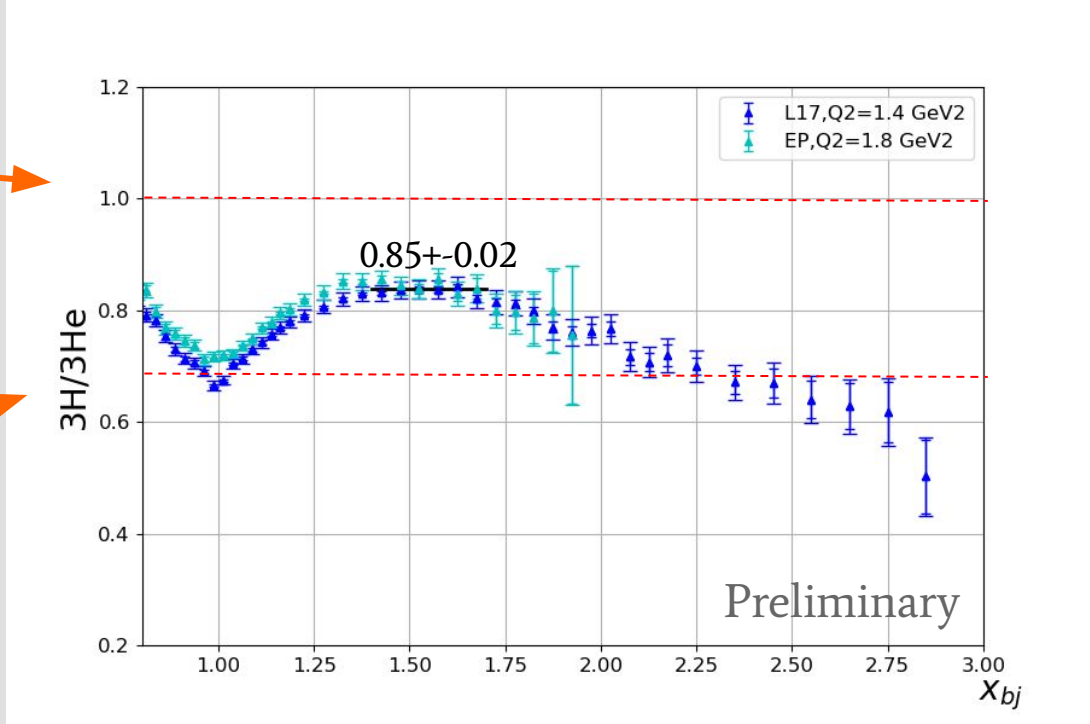
- 1.4 GeV2 data from this experiment
- 1.8 GeV2 data from the exclusive SRC

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

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



Understand the Results:

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 elastic cross section ratio of proton to neutron at Q2=1.4 GeV2 is p/n ~ 2.8

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

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

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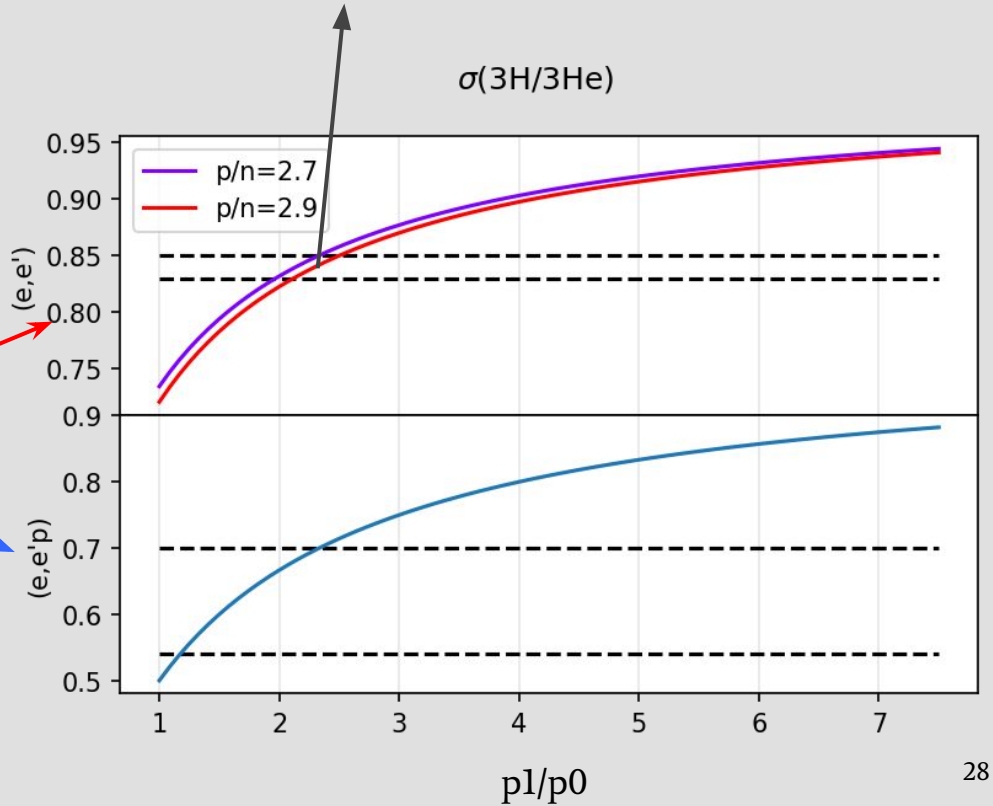
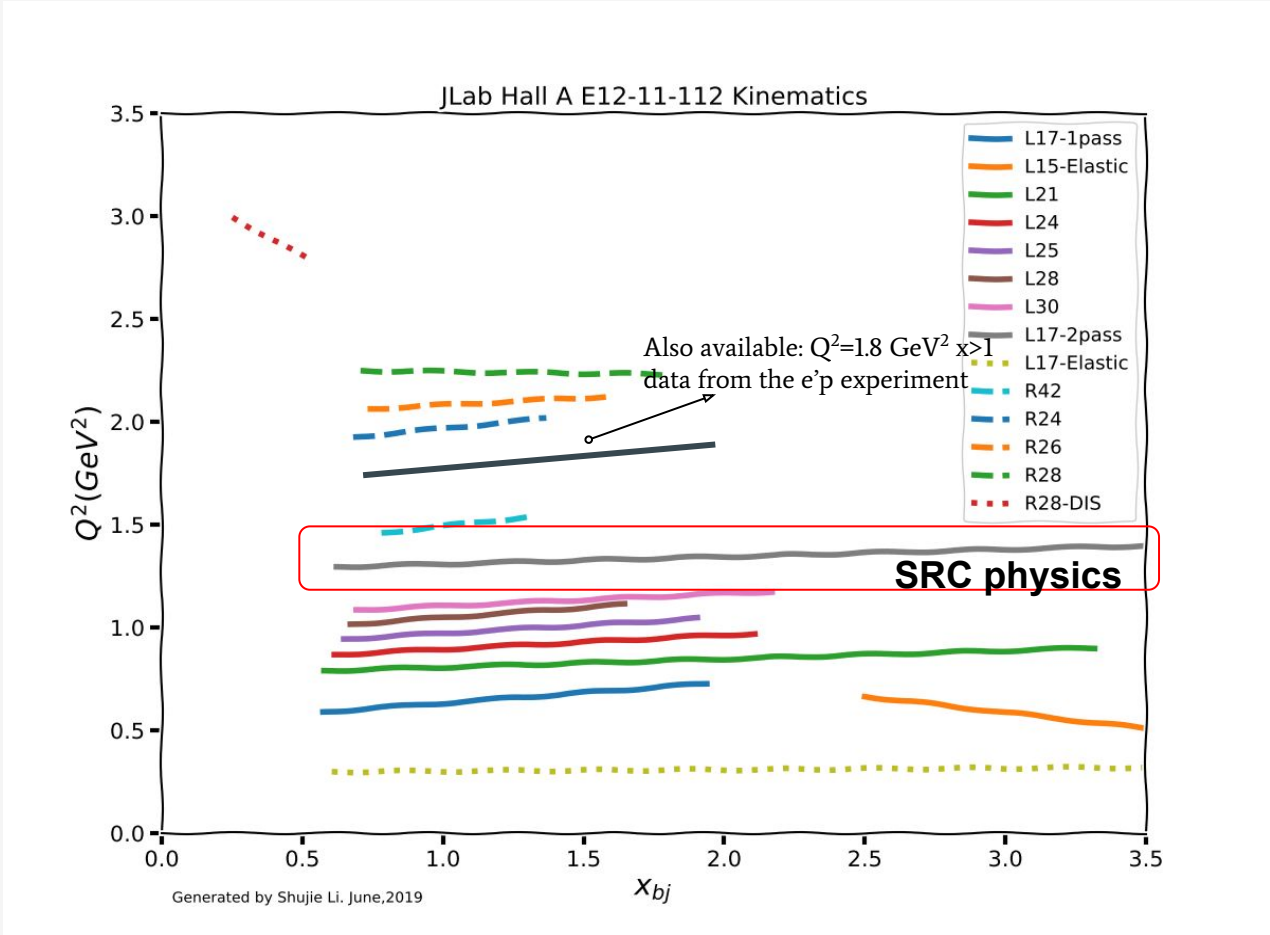
*Ratio of np/pp SRC pairs in A=3 nuclei = 2*p1/p0 = 4.4*

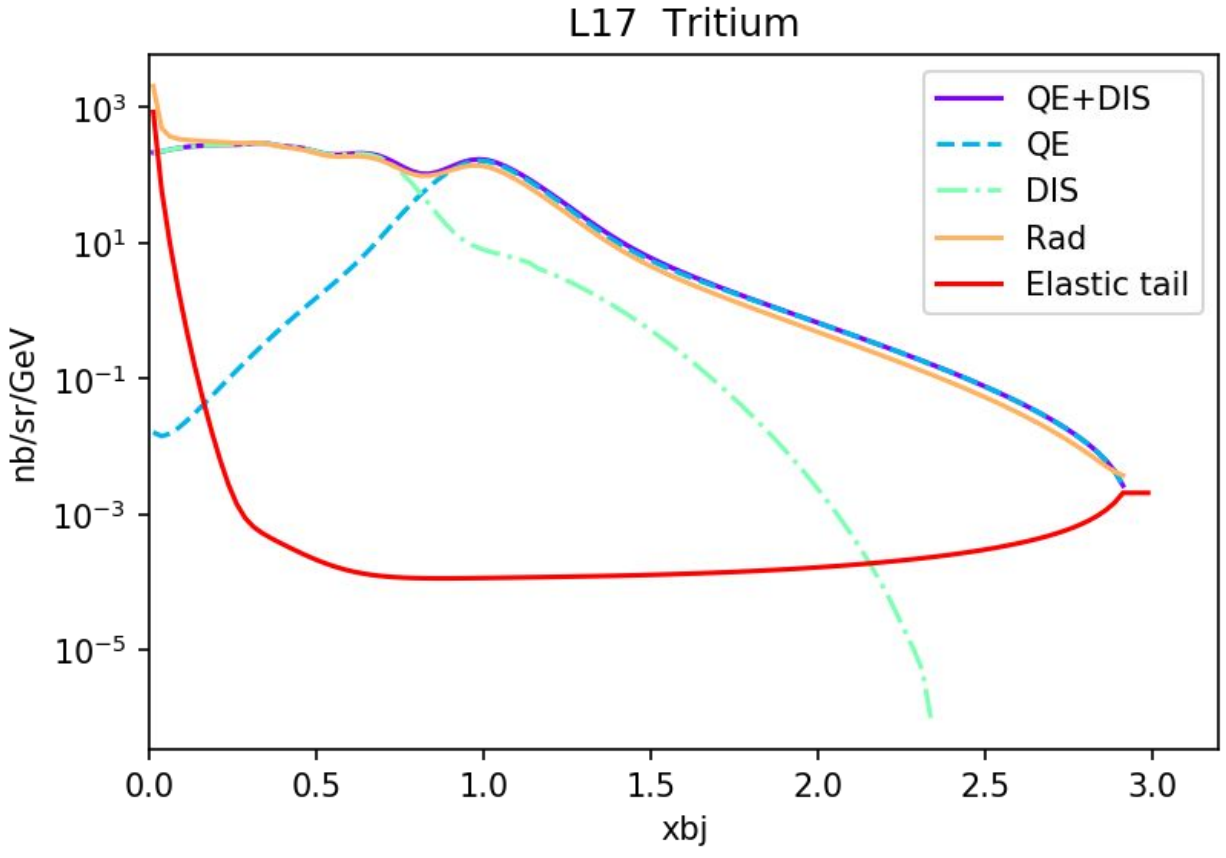


Summary

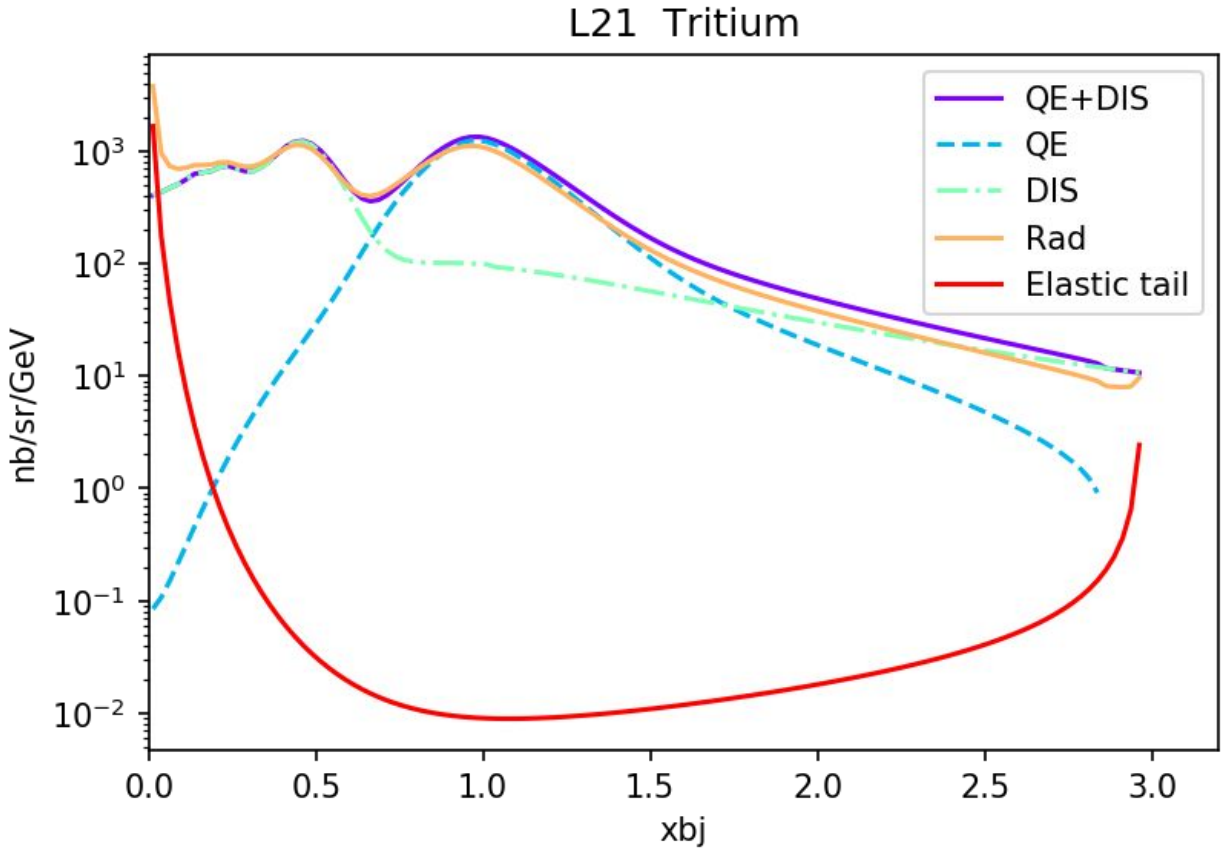
- Deuterium, tritium, helium-3 cross sections and their ratios extracted at 0.8<xbj<3 with Q2=0.6-1.8 GeV2.
- np/pp ratio in A=3 nuclei extracted from the x>1 plateau
- Improve x>1 cross section models
- Compare with theory calculations
- Nuclei Electric form factor (Leiqaa)
- GMn (Nathaly)



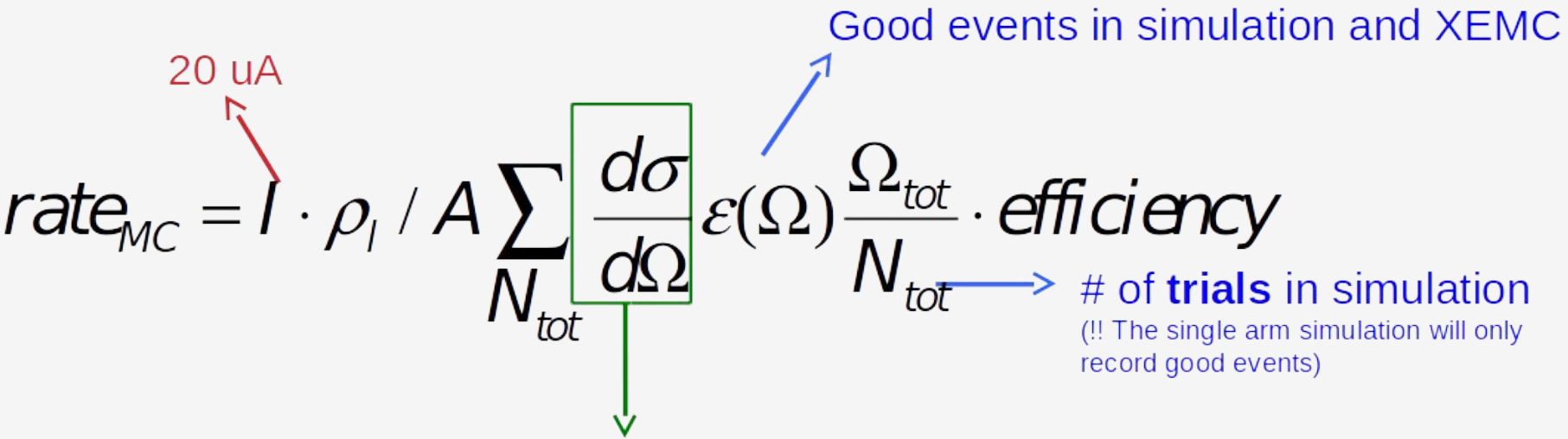
Thank you !


L17 Tritium
QE+DIS
QE
DIS
Rad
Elastic tail
nb/sr/GeV
xbj
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Q2=0.6: Fy model overestimated the tail



Yield (rate) Calculation from Monte-Carlo Simulation



Cross section tables generated from XEMC model:
- from Zhihong
- Included bremsstrahlung radiation
- y-scaling. Use He3 fitting parameter for H3