Inclusive Short-range Correlation Measurements with 3H and 3He at Jefferson Lab

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JLab Hall A Collaboration Meeting

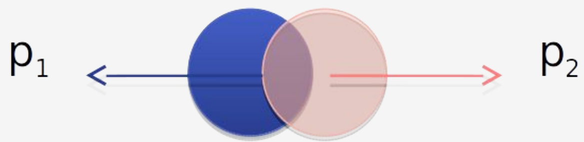
Jan 30, 2020

Jefferson Lab
Exploring the Nature of Matter

University of New Hampshire

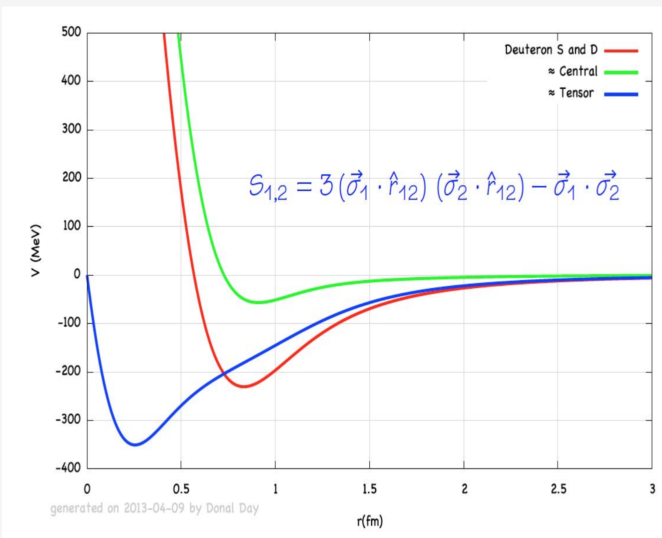
Nucleon-Nucleon Short Range Correlation (SRC)

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.

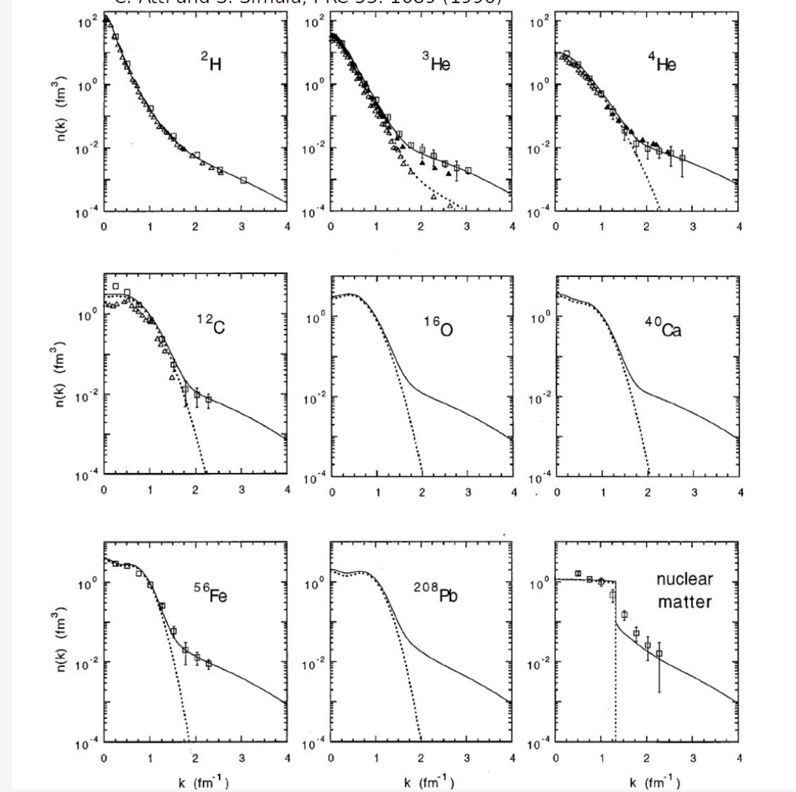


$p_1+p_2 \rightarrow 0$

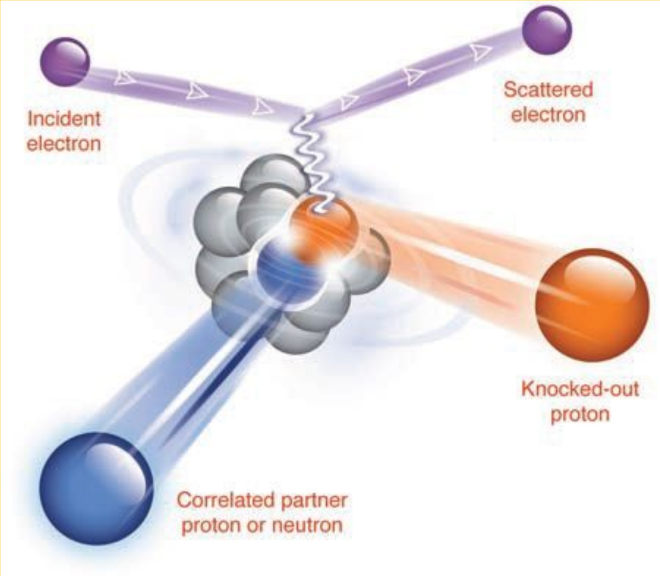
Large back-to-back momentum



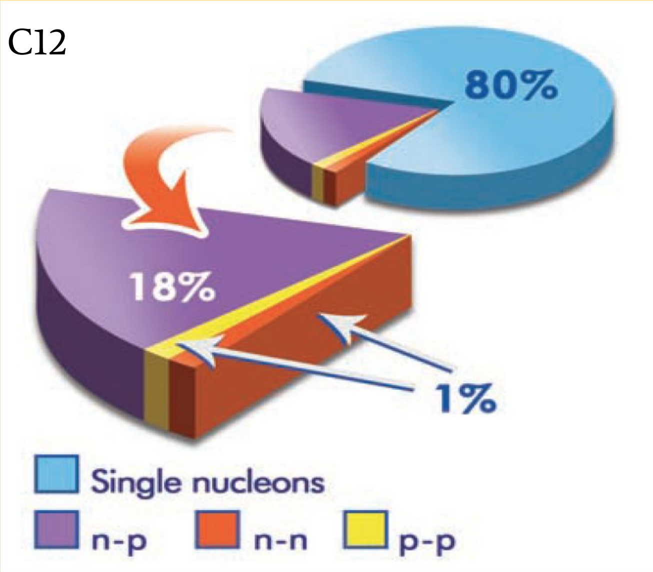
C. Atti and S. Simula, PRC 53. 1689 (1996)



SRC in Exclusive Scattering



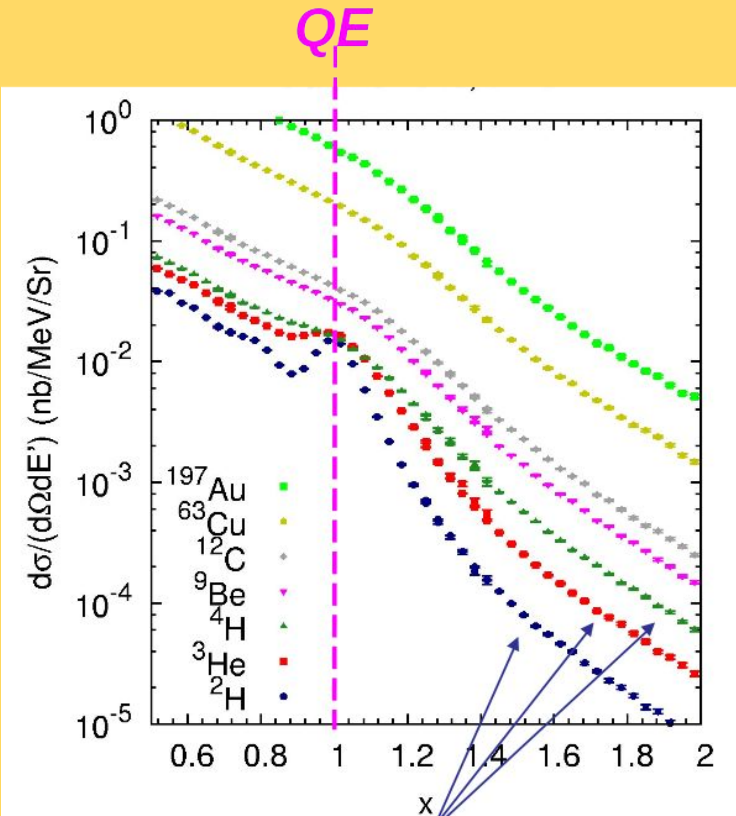
Subedi et al, Science 320, 1476 (2008)



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

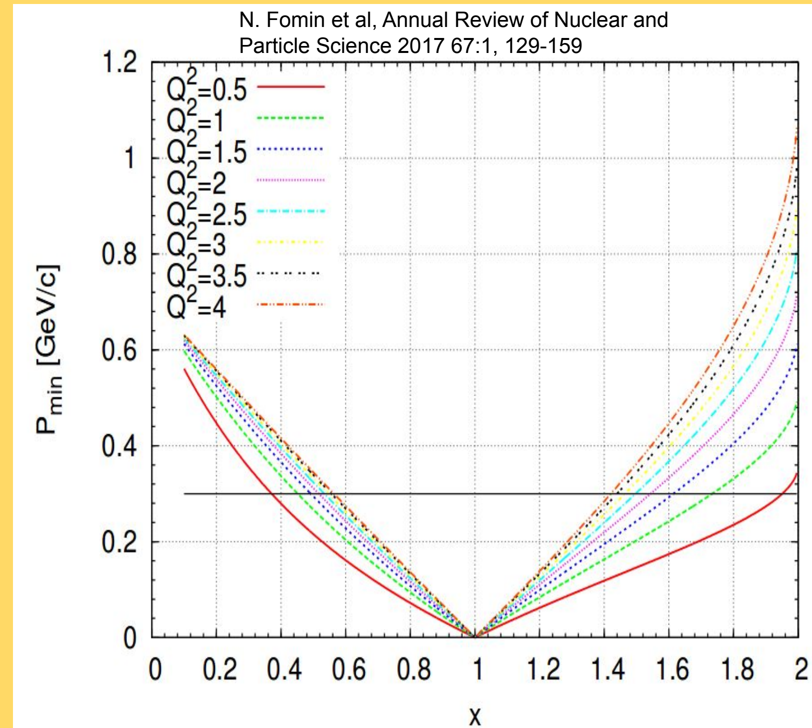
Probing 2N SRC at x>1

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



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

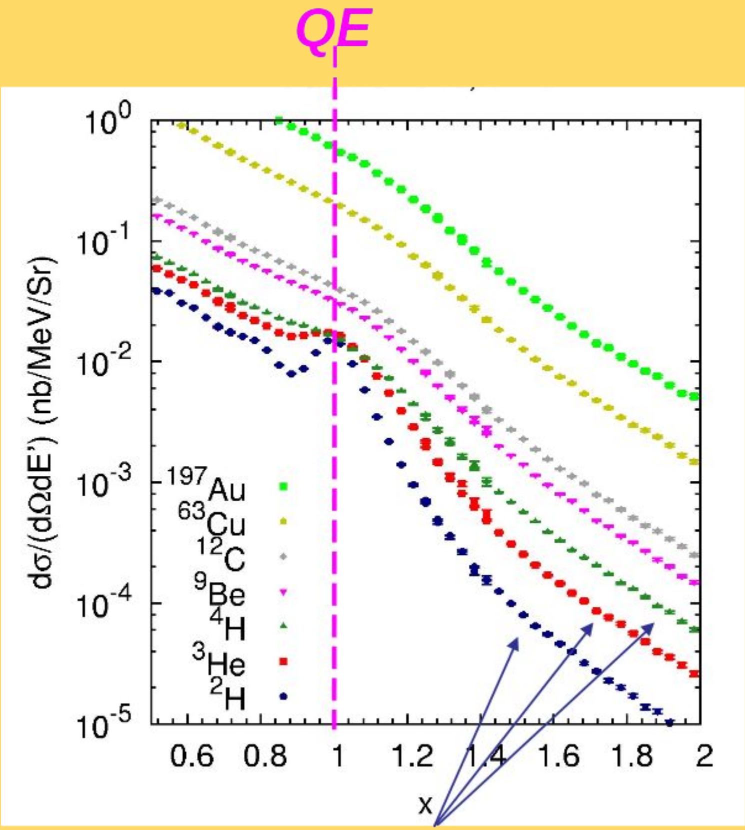
N. Fomin, et al., PRL 108 (2012) 092052



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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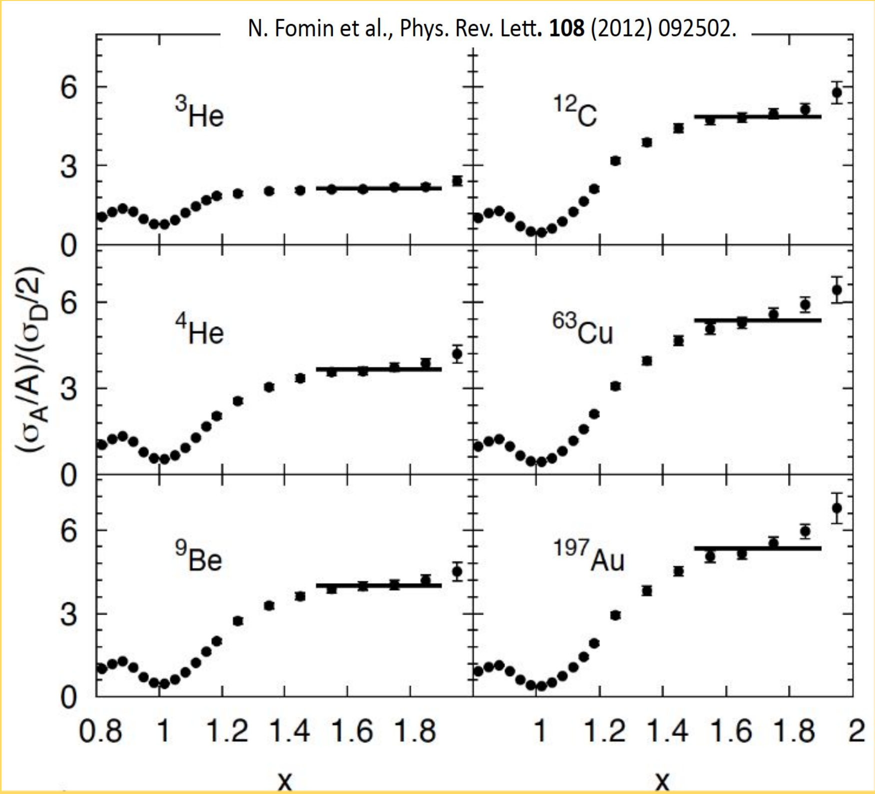


The x>1 plateau of A/D cross section ratios give the percentage of deuteron-like high momentum pairs in each nucleus

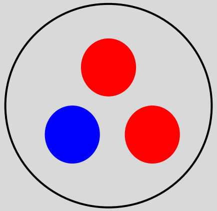
Jefferson Lab E12-11-112 (Hall A) :

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.

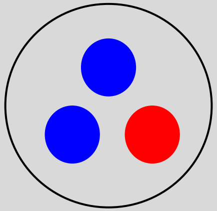


np pair dominates:

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

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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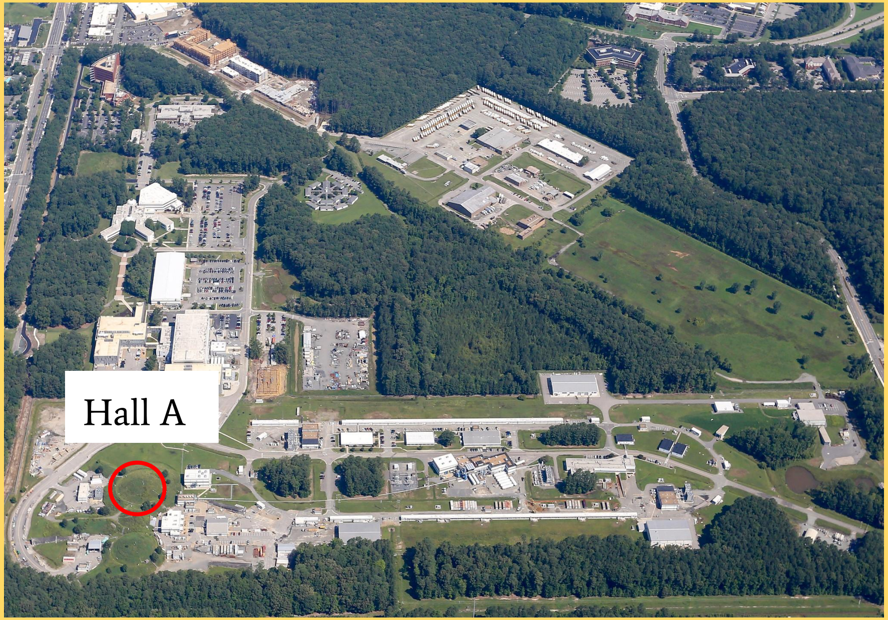


Tritium Family Experiments:

2017.12: Commissioning
2018.2-2018.5: E12-11-103 MARATHON
2018.4 E12-14-011 e'p (exclusive SRC)
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

More to explore

Fall 2018

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

RHRS: QE scan

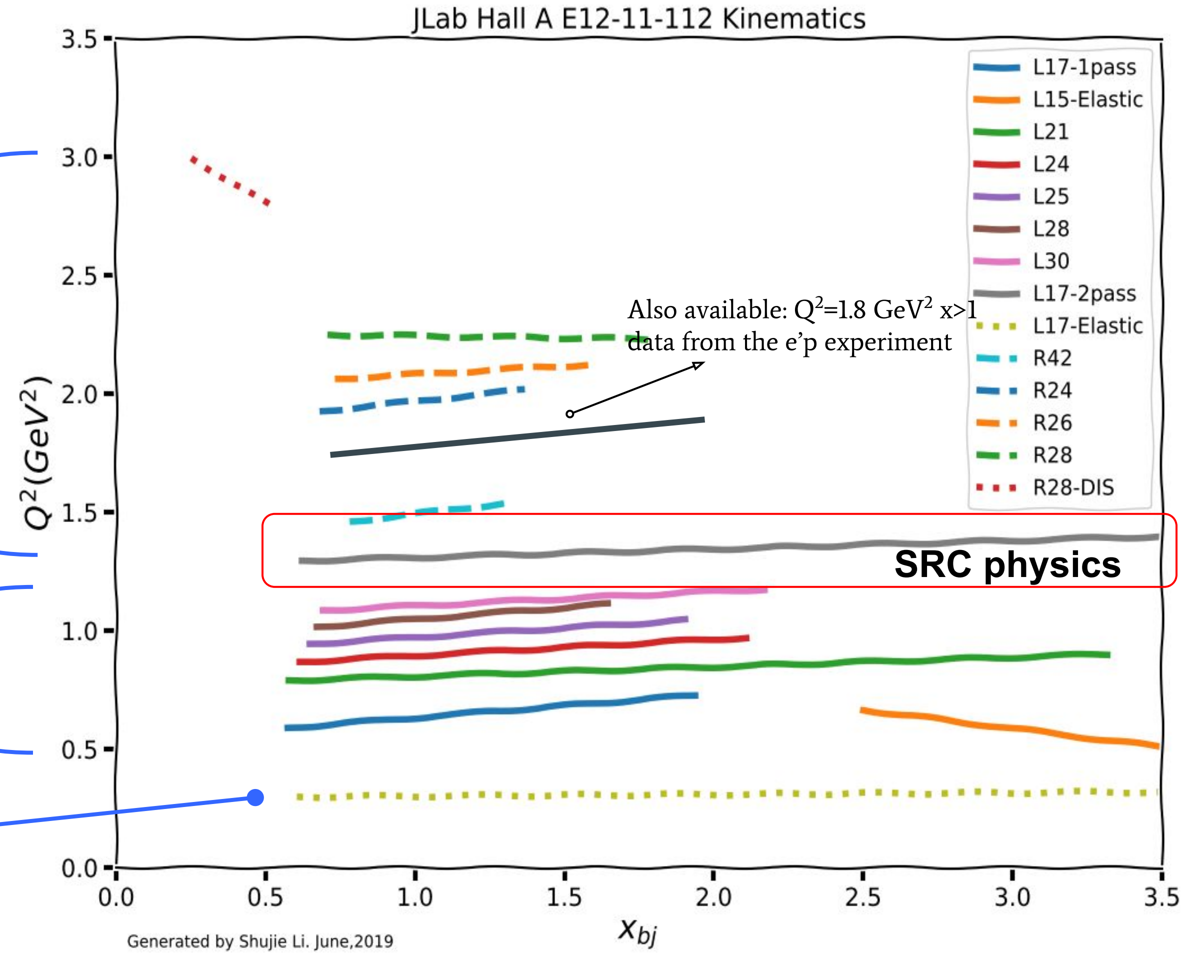
May 2018:

QE scan with 2.2 GeV beam

Dec 2017:

Commissioning

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



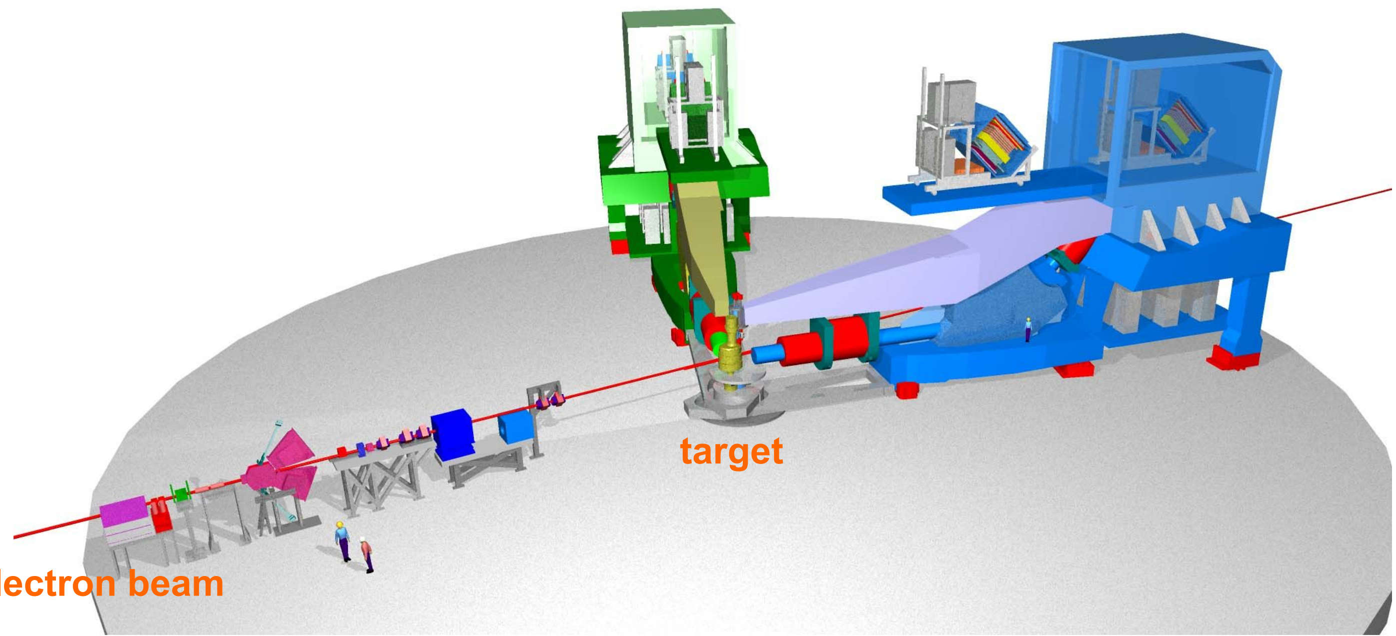
Jefferson Lab, Hall A

Experiment Configuration

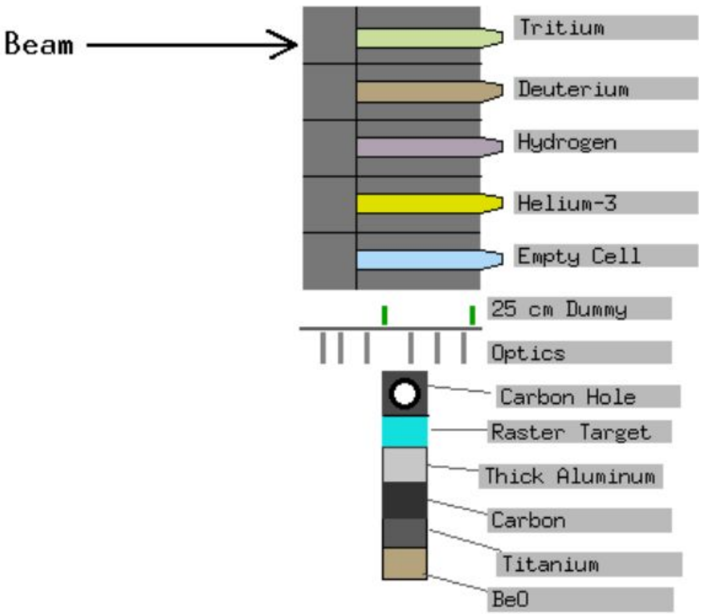
Beam energy:	4.3 GeV		
Momentum :	3.54	,	3.82 GeV
Angle :	20.88	,	17 degree
Q^2 :	1.8	,	1.4 GeV^2

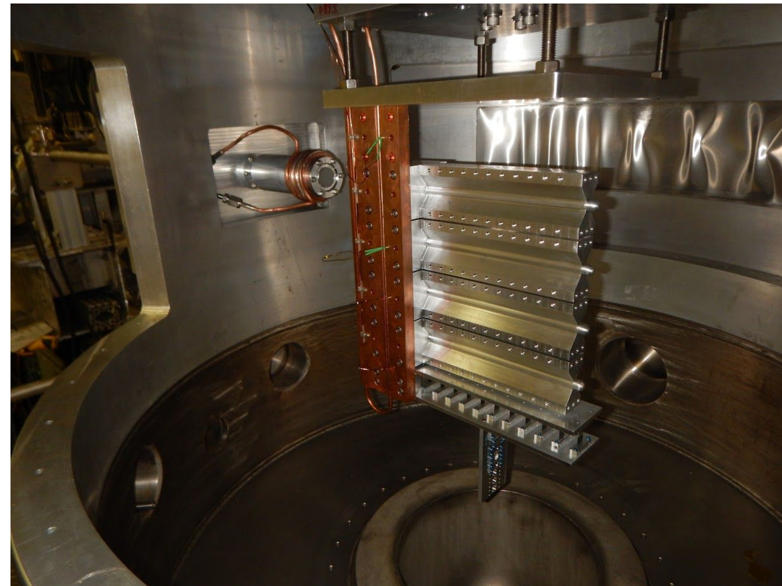
High Resolution Spectrometer (HRS)

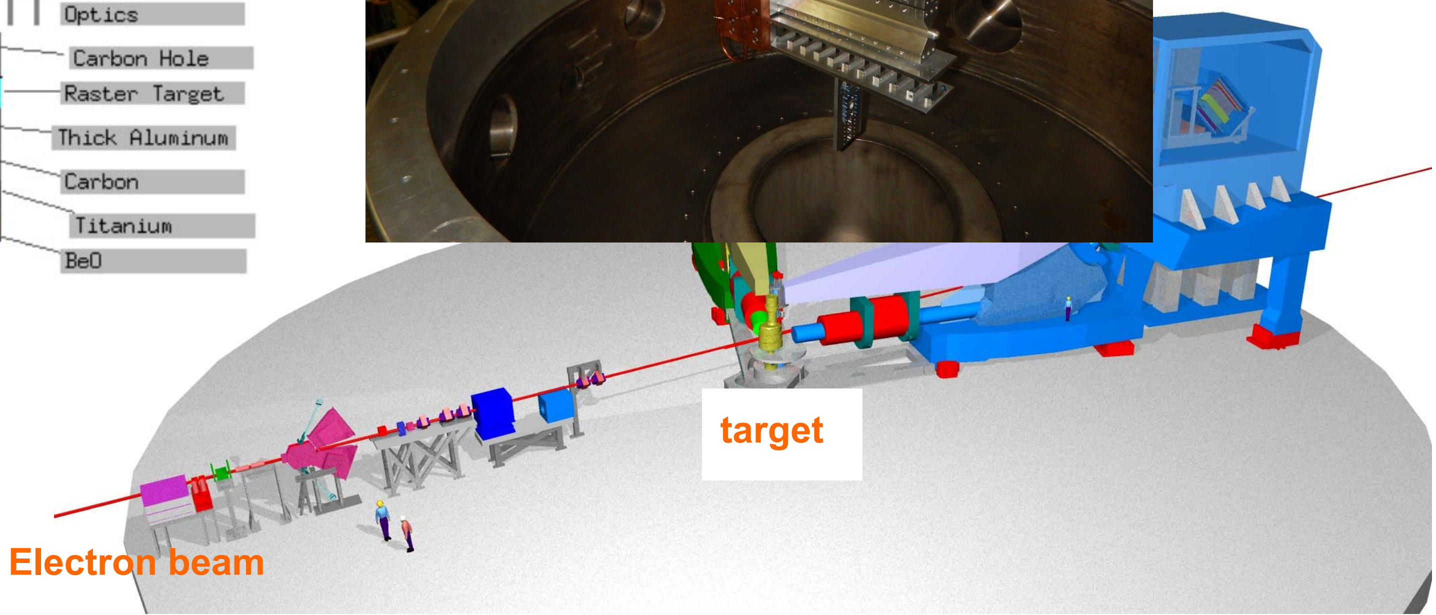
Solid angle:	6 msr
Momentum resol:	1e-4
Momentum range:	+/- 4.5% wrt central ray



The Gas Target System:

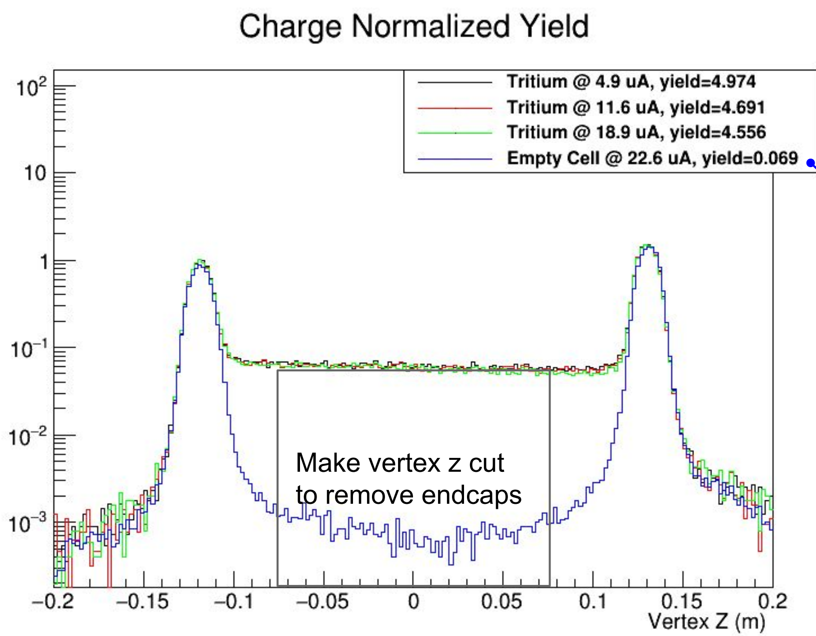






The Gas Target System: special handling

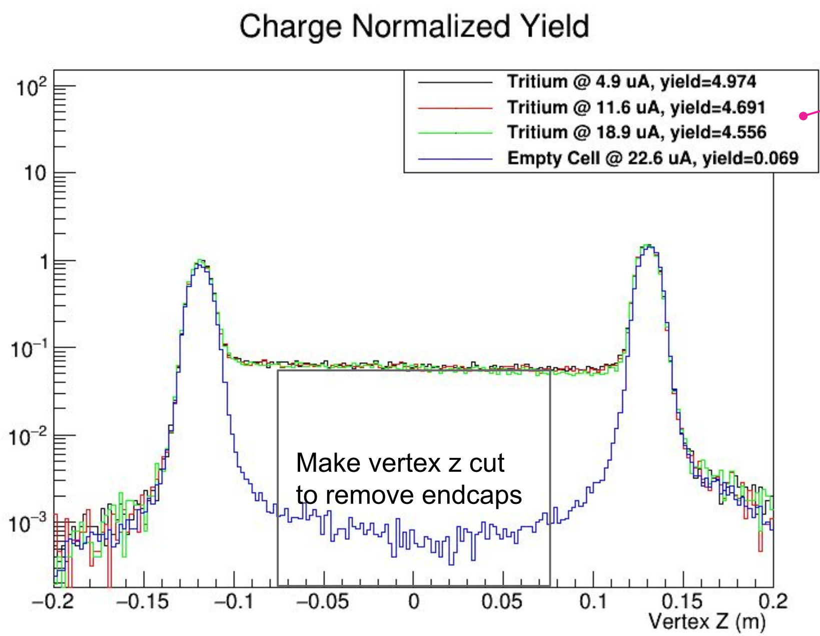
- Maximum current = 22.5 uA on gas cells to minimize the risk of gas leak.
- Endcap(75mg/cm2 Aluminum) being mis-reconstructed into thin gas body (77mg/cm2 Tritium)
- "Boiling": gas density change along beam path



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

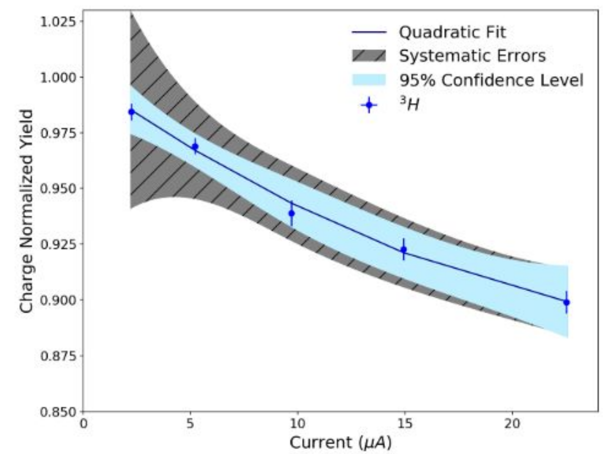
The Gas Target System: special handling

- ❖ 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)



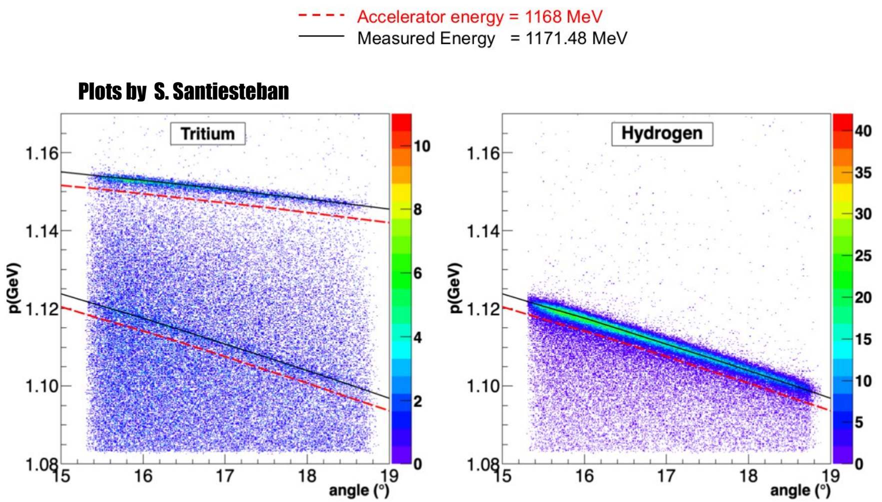
The Tritium density reduced by ~ 10 percent at 22.5 uA

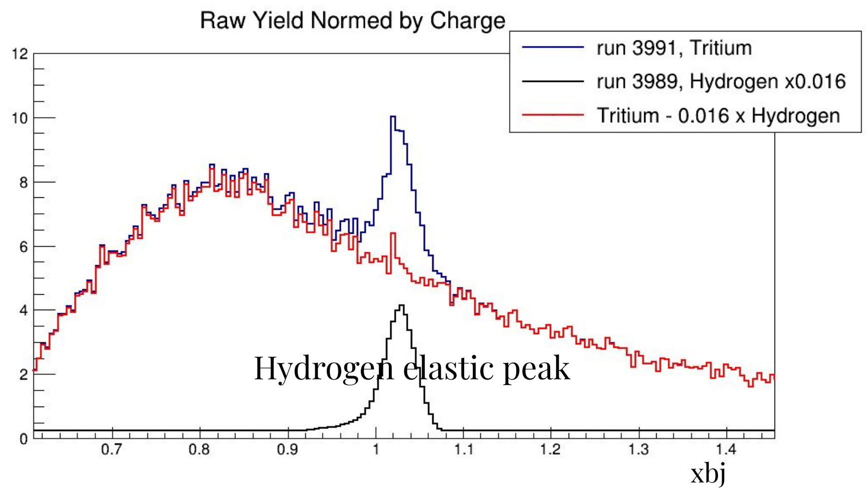
S. Santiesteban et al. ,
https://doi.org/10.1016/J.NIMA.2019.06.025

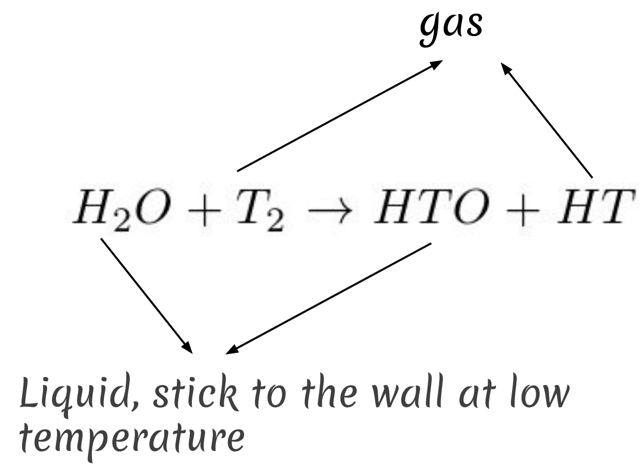


The Gas Target System:

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





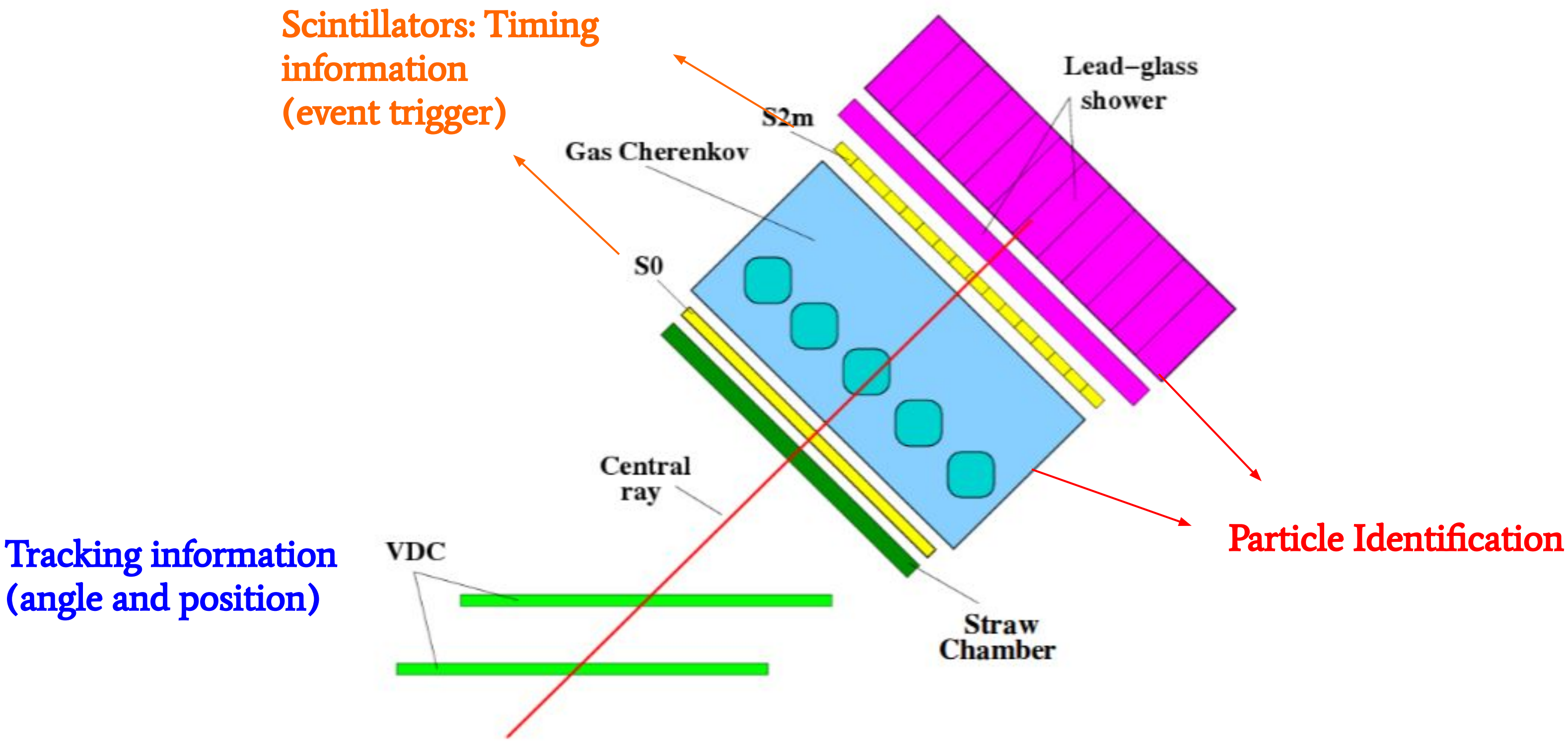


Tritium replaced by hydrogen:
1.6% * 0.0708 g/cm2 * 3 (H2O->HTO) / 0.0851g/cm2 = 4.0 %

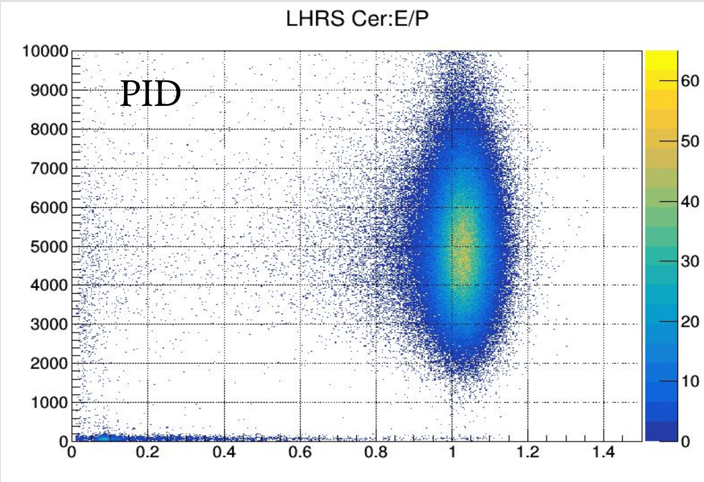
Remained tritium density:
0. 0851 g/cm2 * (1-4%) ⇒ 0.0817 g/cm2 ??

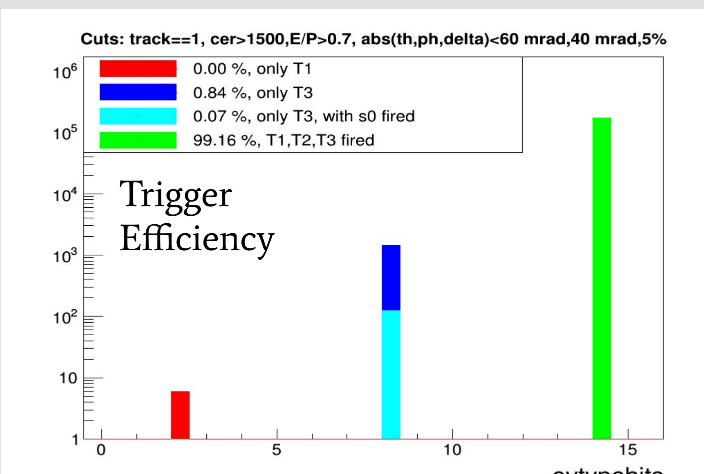
In this analysis: use 2+- 2 %

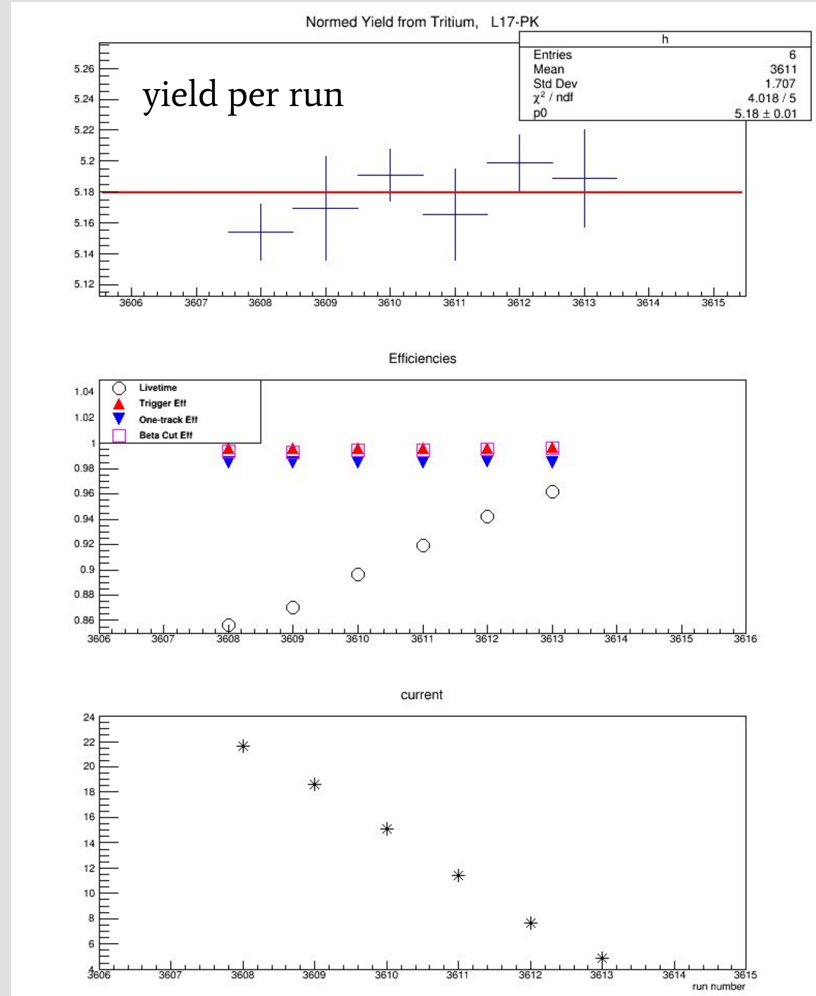
Detector Package:



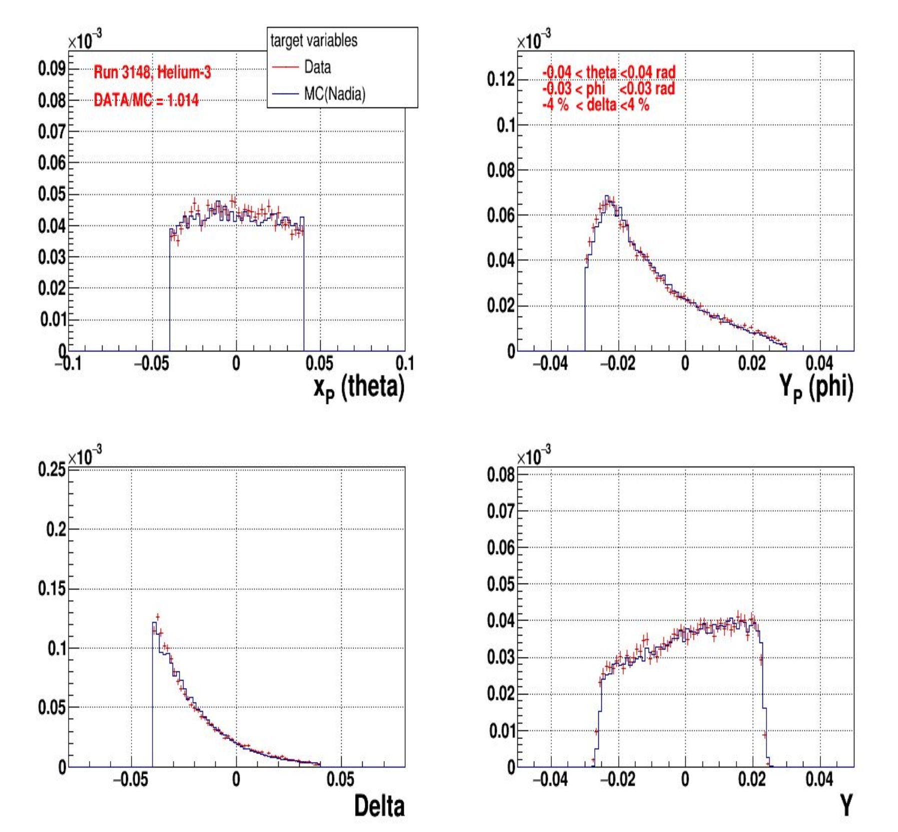
Data Quality Check

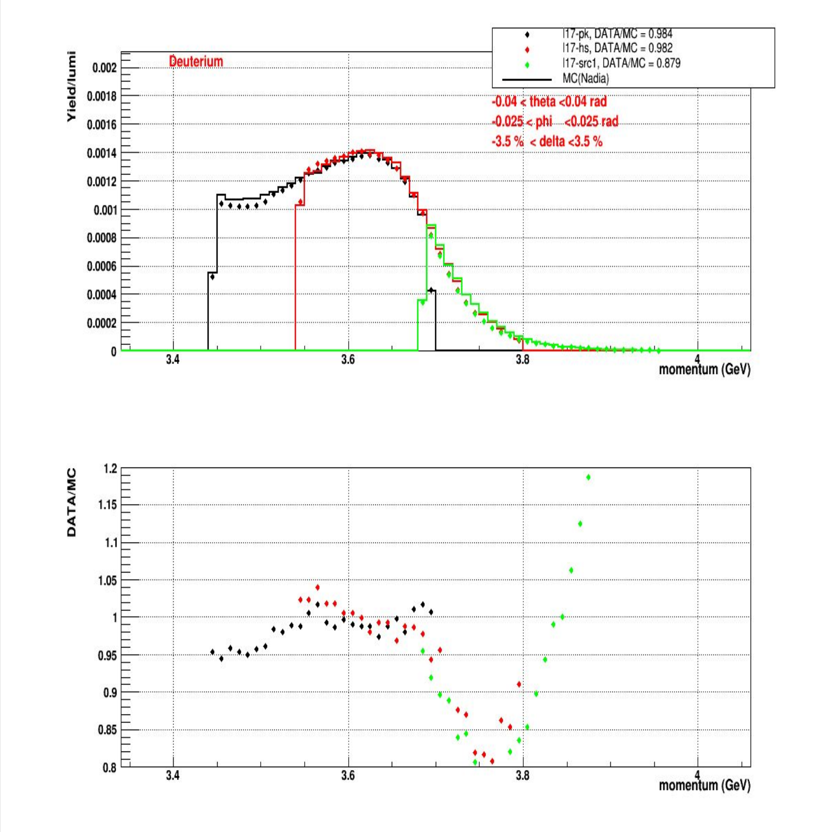






Compare Data vs Monte-Carlo Simulation





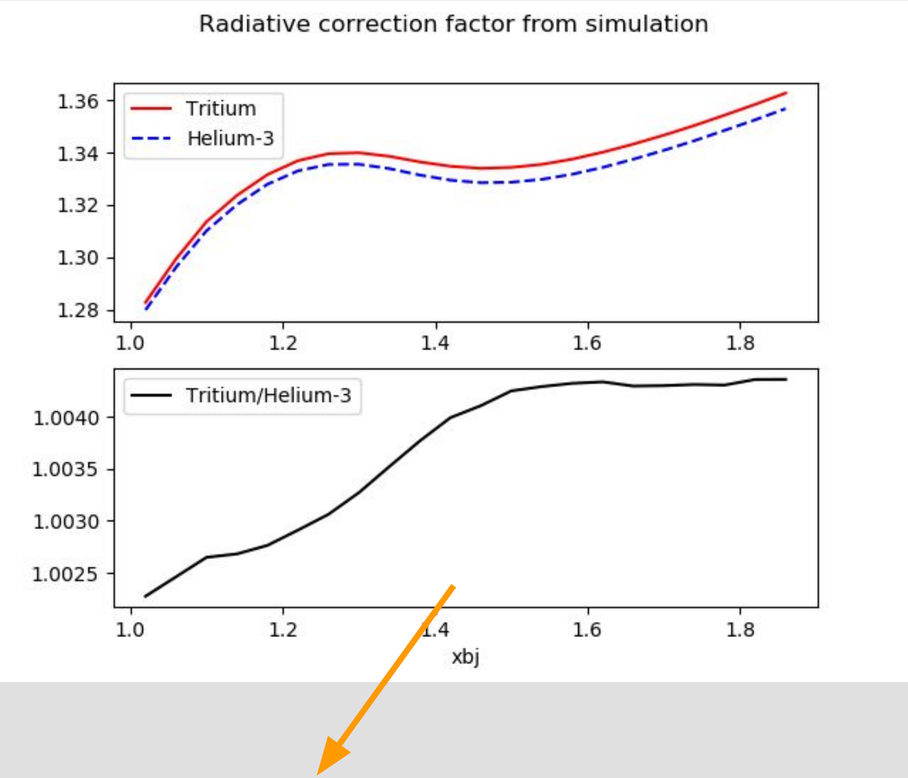
Radiative Corrections

Gas body:

negligible radiative effect

Endcap:

- Material:
  - Aluminum (rad. Length = 8.897 cm)
- Thickness:
  - Upstream: 0.257mm
  - Downstream : 0.276mm



Radiative correction almost cancelled in ratio. Calculated with XEMC model (Peaking approximation method for QE)
https://userweb.jlab.org/~yez/XEMC/

Uncertainties (Preliminary!)

Quantity	Type	Uncertainty in Absolute Cross Section	Uncertainty in Ratio
Beam Energy	correlated	0	0
Tracking Efficiency	point-to-point	1%	0
Trigger Efficiency	point-to-point	0.50%	0
Endcap Contamination	point-to-point	0.15%-0.75%	0.21%-1.05%
Acceptance	point-to-point		0-1%
Radiative Correction	point-to-point		1%
Charge	normalization	1%	0
Current Induced Density Change	normalization	1%	1.40%
Tritium Decay	normalization	0	0
Hydrogen Contamination	normalization	(2%)	(2%)

Systematic: 1.02-1.7%

Normalization: 1.4-2.5%

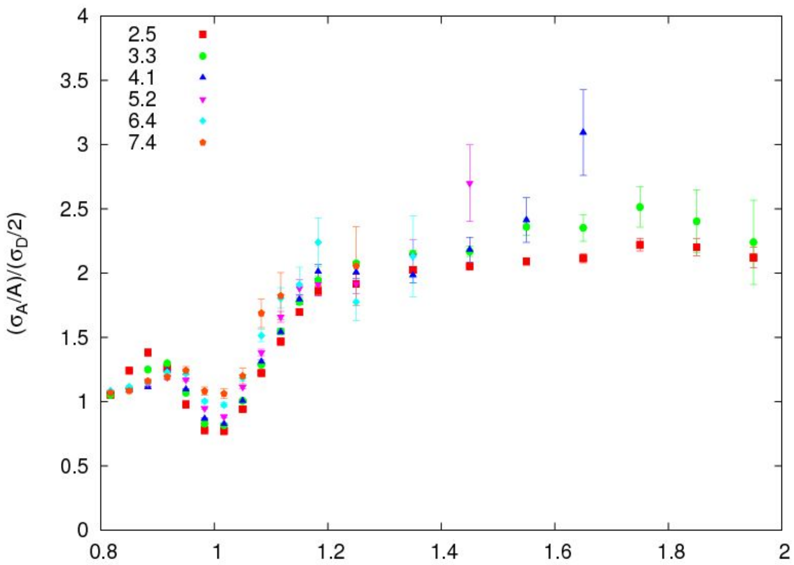
Normalized Yield

$$Y(x,Q^2) = \frac{\sum_i C_i(x,Q^2)}{\sum_i Q_i \cdot \rho_l \cdot eff_i \cdot LT_i / PS_i}$$

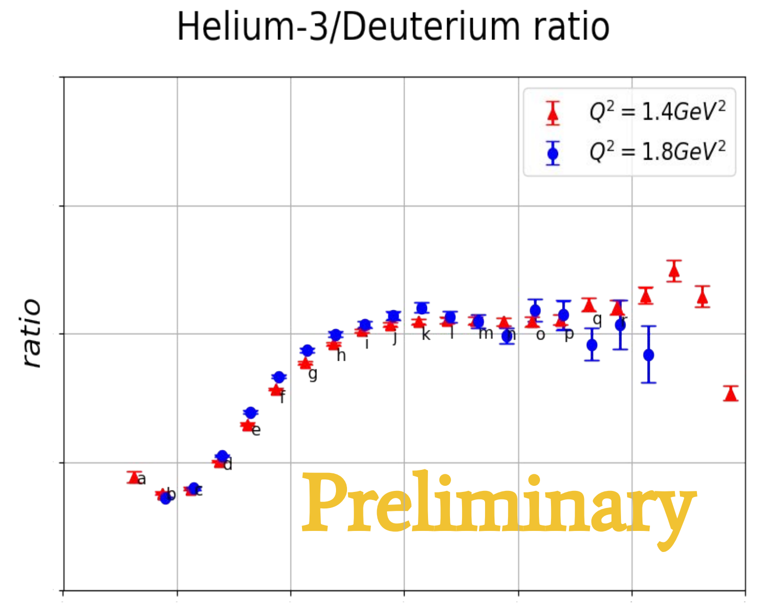
x>1 cross section ratio:

Combined analysis of data from 2 experiments:
- 1.4 GeV2 data from this experiment (red)
- 1.8 GeV2 data from the exclusive SRC (blue)

Calibration result: 3He/2H ratio



N. Fomin, arxiv: 1206.6343



Error bars represent stat. error and stat.+syst. error.
October,2019.

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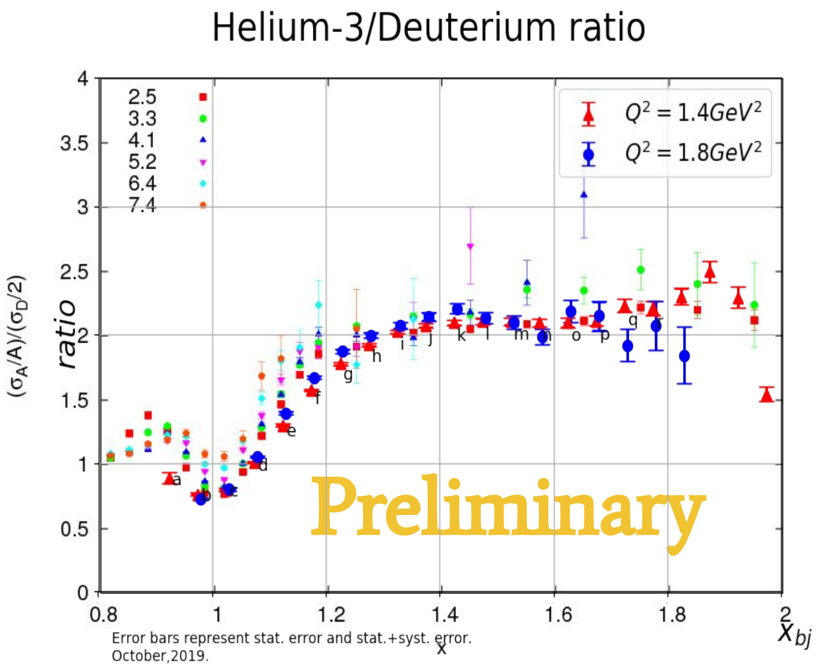

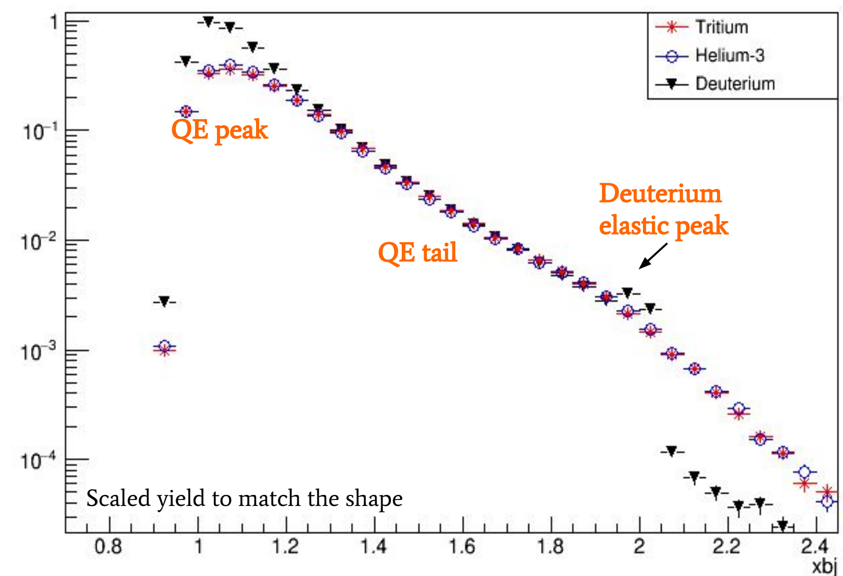

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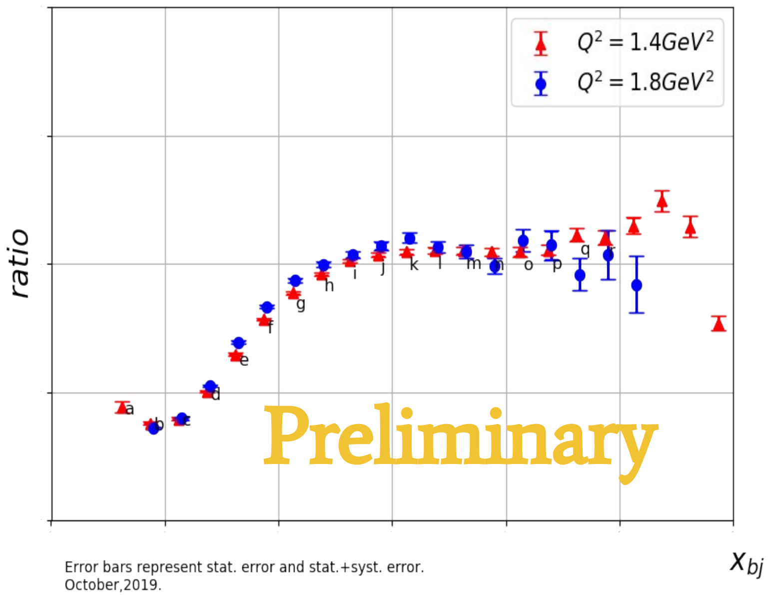
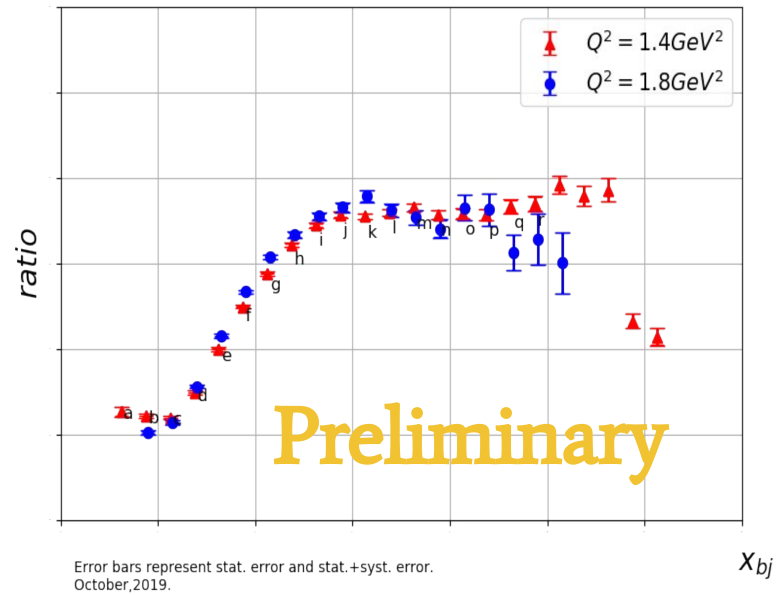
Helium-3 and Tritium to Deuterium ratios

Helium-3/Deuterium ratio



Tritium/Deuterium ratio



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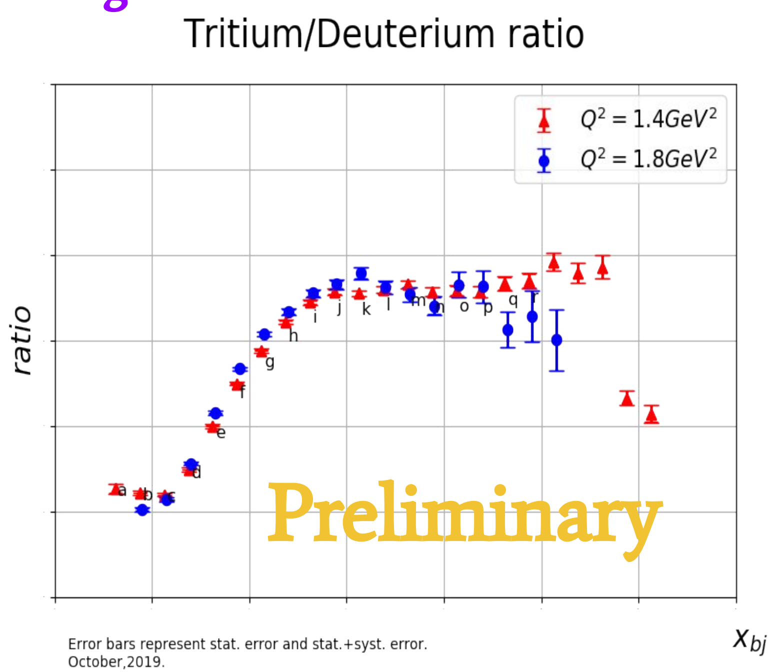
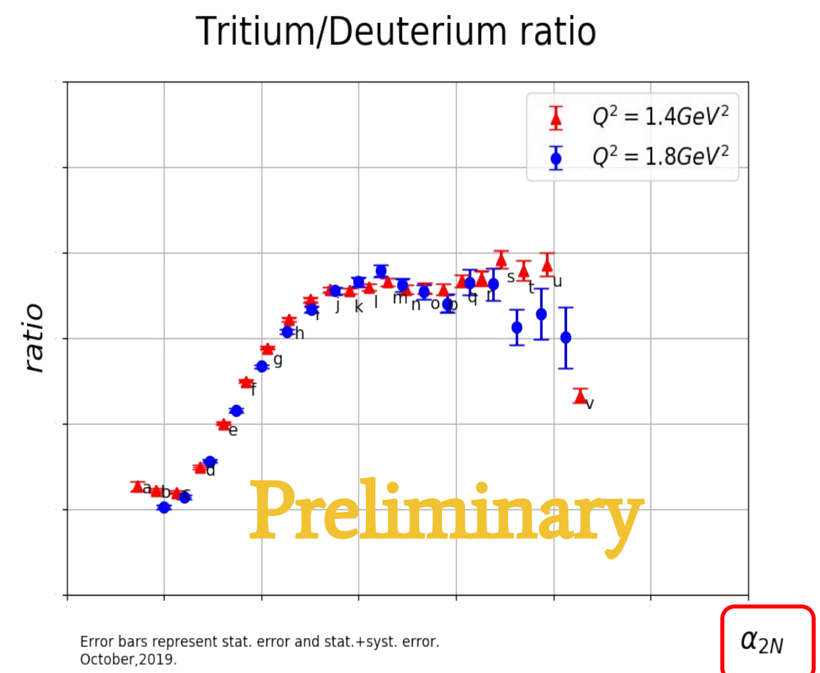
Scaling behaviour

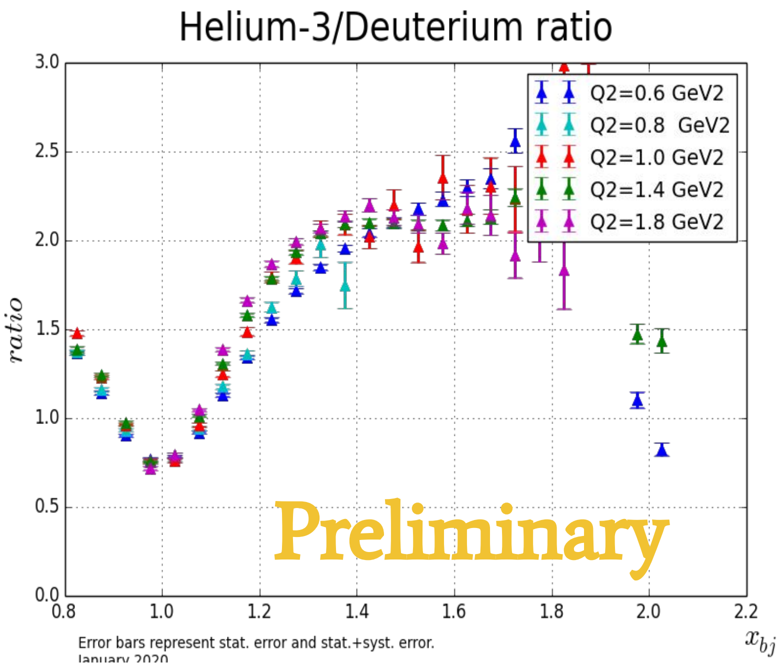


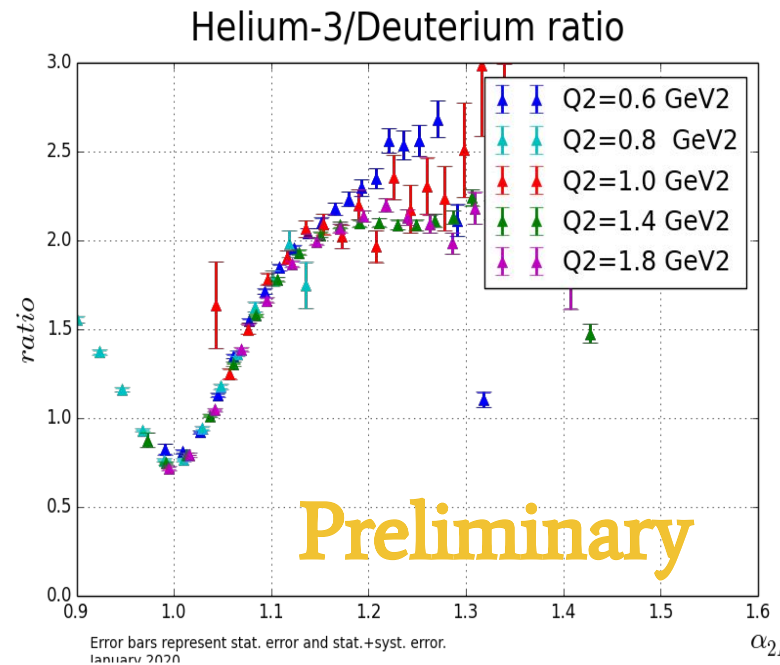


Light cone variable:

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

Q2 Dependence:





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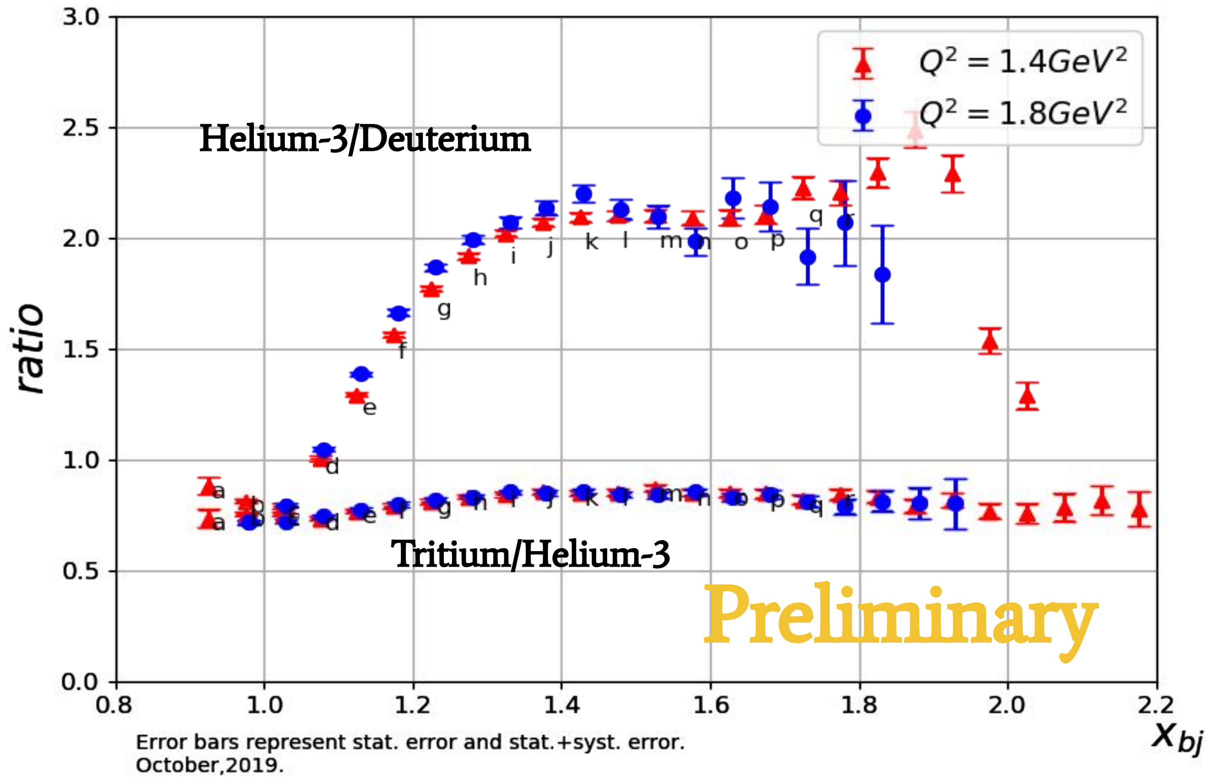

x>1 cross section ratio:

Combined results of data from 2 experiments:

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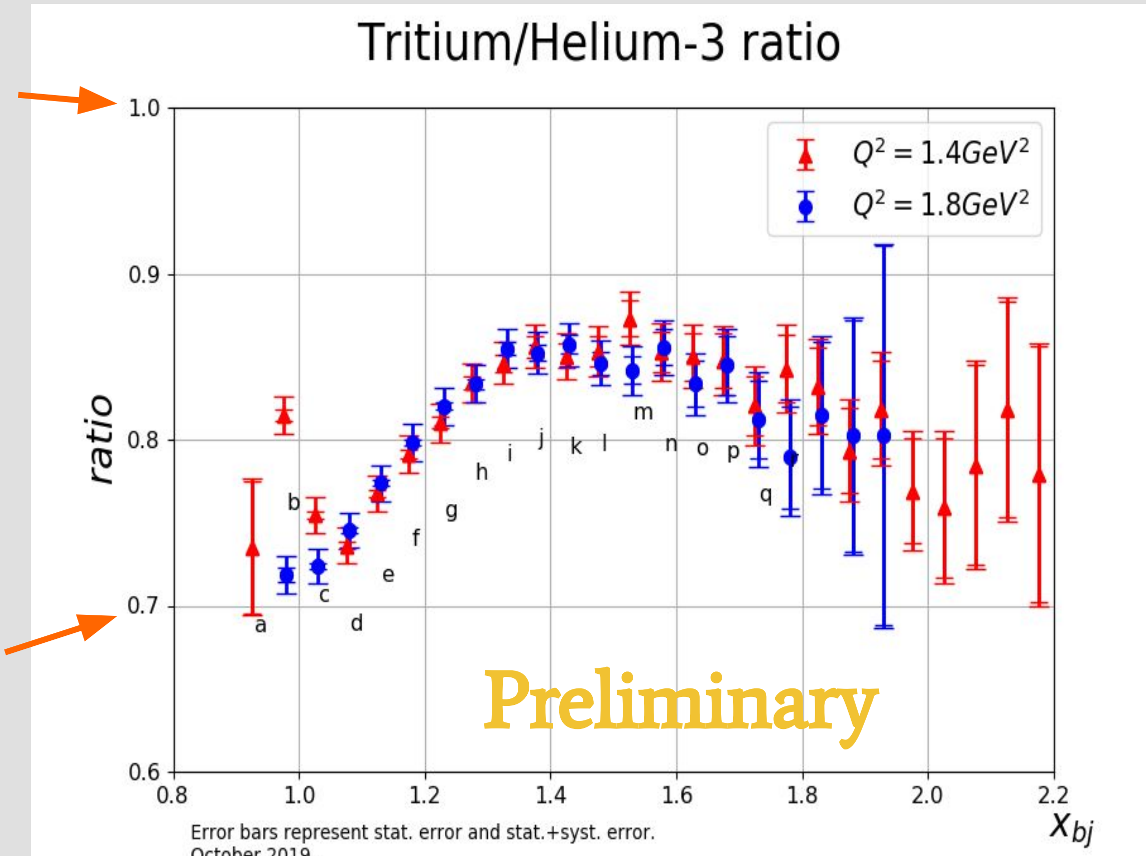
Completely np dominant

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

No isoscalar dependence

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



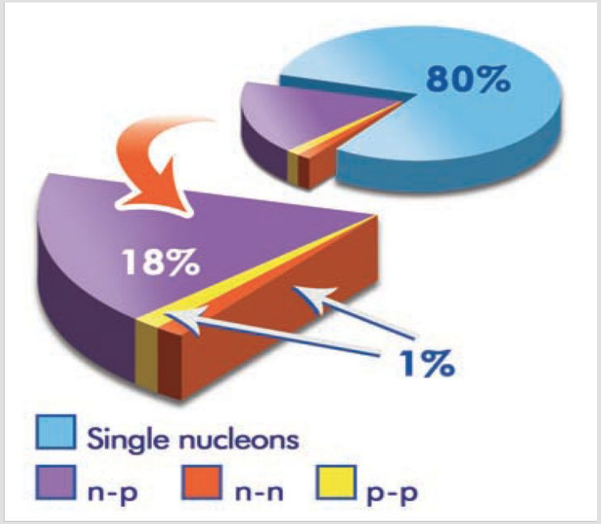
Understand the Results:

Configurations	np	pp	nn
# of pairs	NZ/A/(A-1)	Z(Z-1)/A/(A-1)	N(N-1)/2/A/(A-1)
Probability of finding high momentum pairs	p0	p1	p1
Cross section	$\sigma_n+\sigma_p$	$2\sigma_p$	$2\sigma_n$

$$\sigma_{SRC} = NZ(\sigma_p + \sigma_n)p_0 + N(N-1)\sigma_n p_1 + Z(Z-1)\sigma_p p_1$$

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

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



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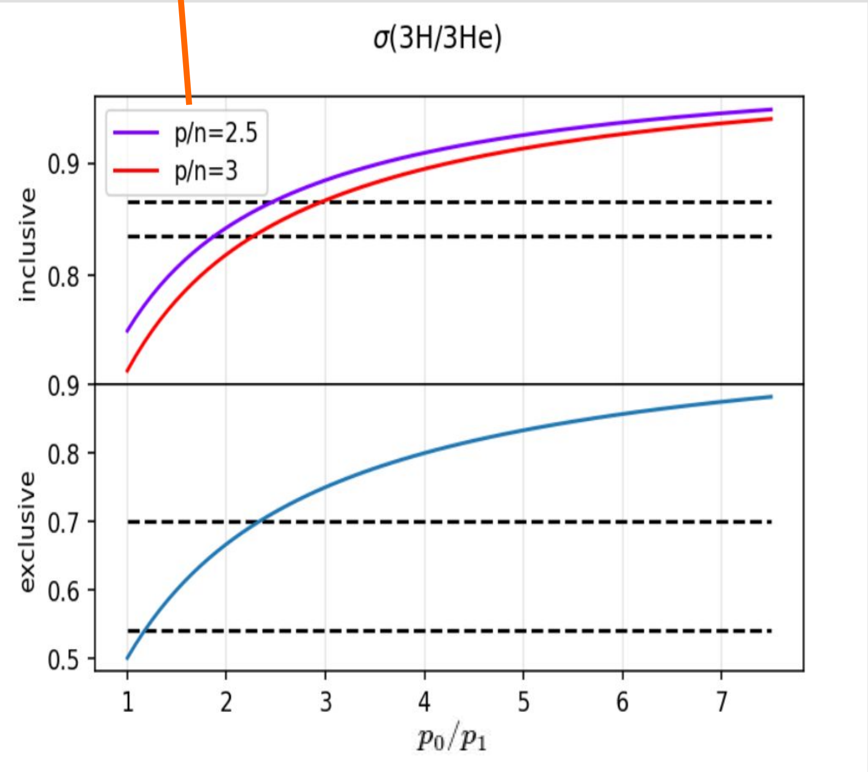
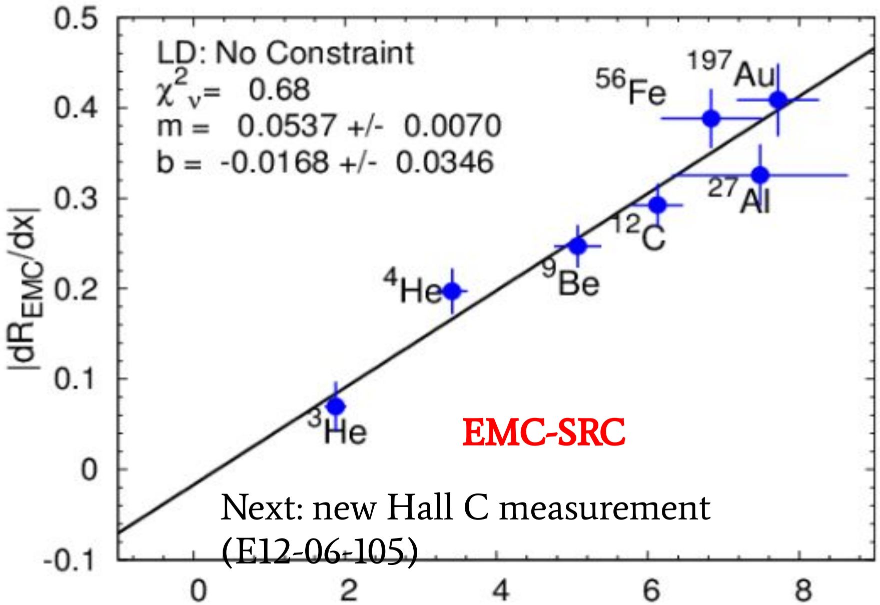
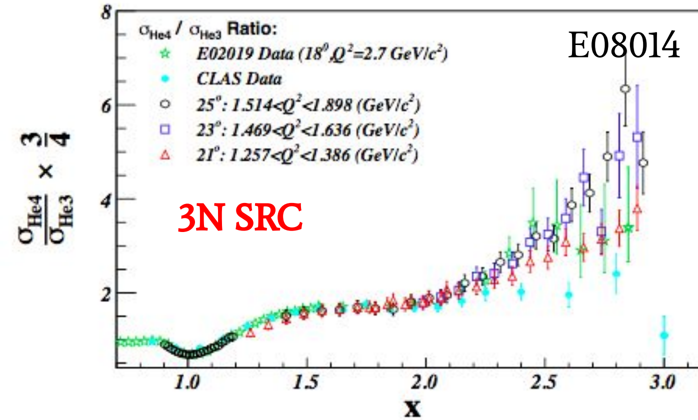
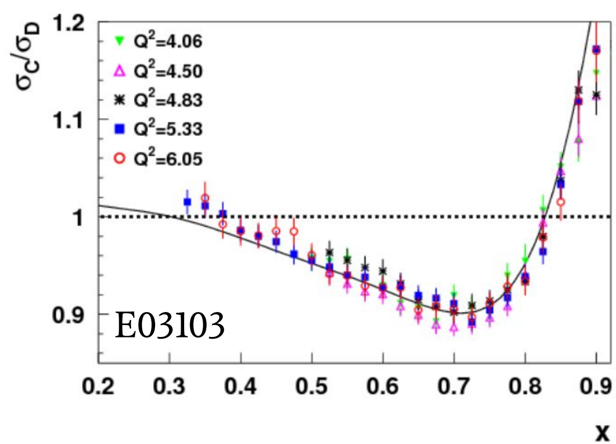
$$exclusive\ \frac{\#(3H)}{\#(3He)} = \frac{2\cdot p_0}{2\cdot p_1 + 2\cdot p_0}$$

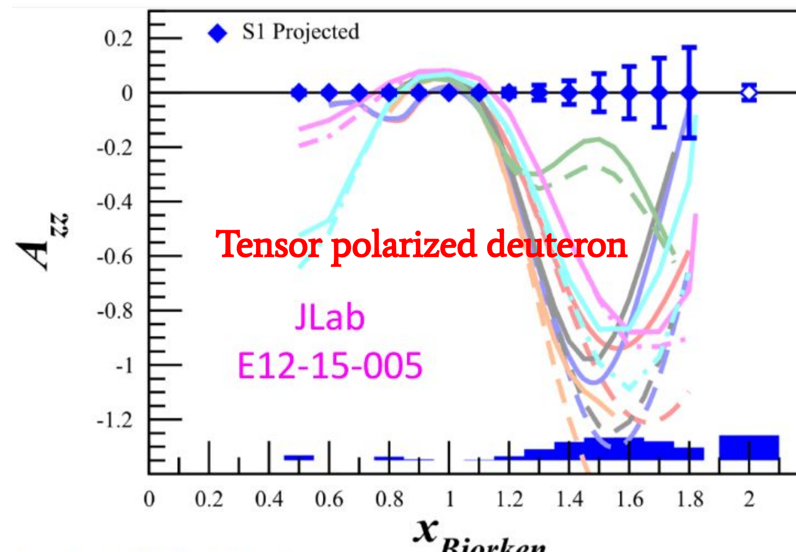
Elastic cross section ratio











E Long, *et al*, JLab C12-15-005

Thank you !