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

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

JLab HallA/C Collaboration Meeting
June 28, 2019

Jefferson Lab
Exploring the Nature of Matter

University of New Hampshire

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

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

Tritium Experiment Group:

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

**E12-14-009 Elastic –not scheduled

Run Summary

Fall 2018

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

RHRS: QE scan

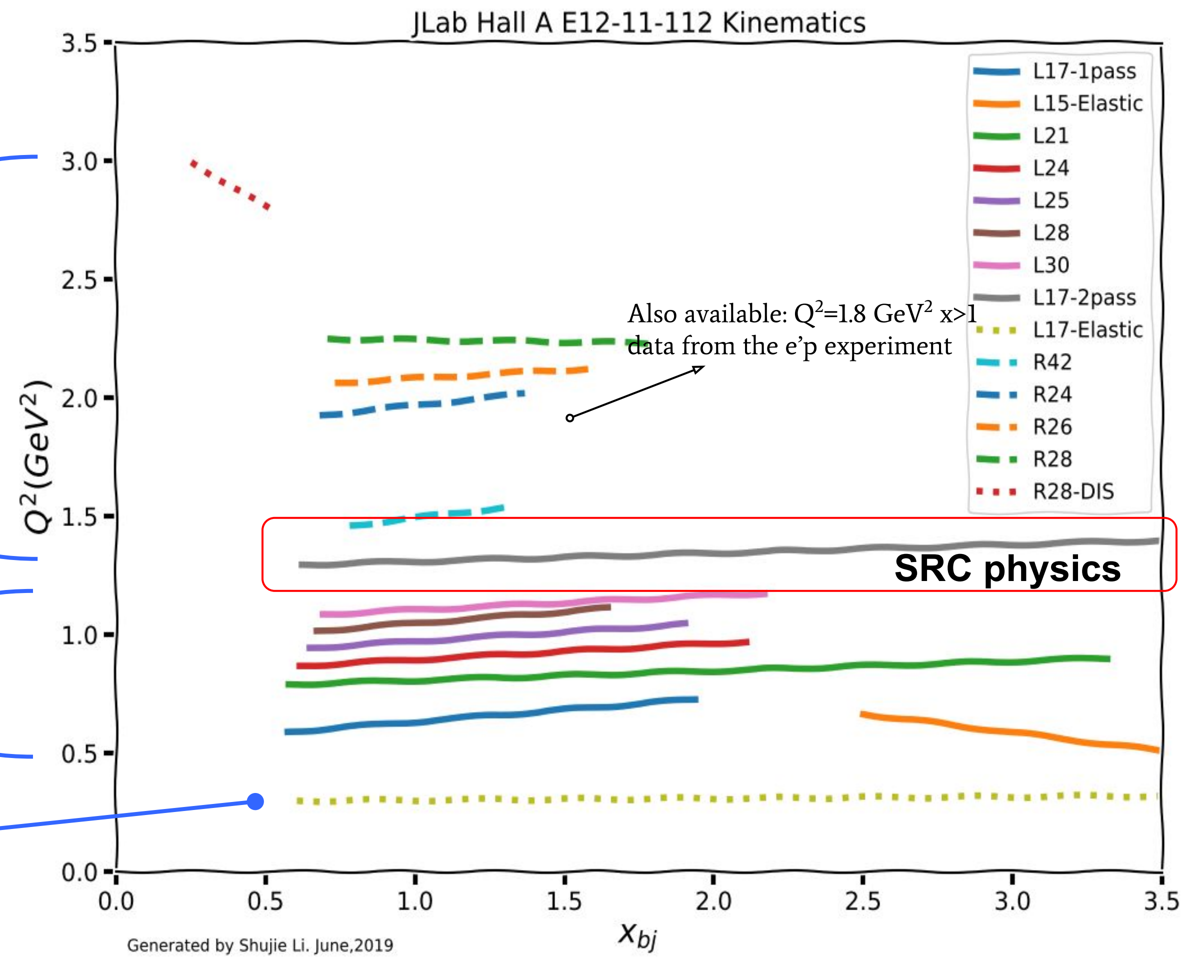
May 2018:

QE scan with 2.2 GeV beam

Dec 2017:

Commissioning

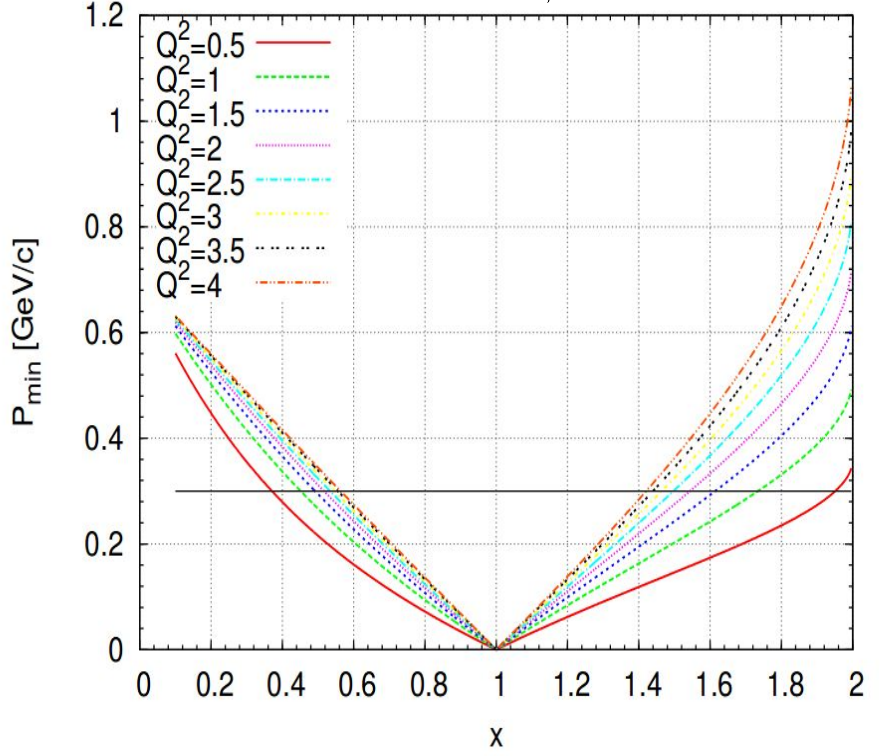
Target “boiling” study (also QE data at Q2=0.4 GeV2)



Probing 2N SRC at x>1

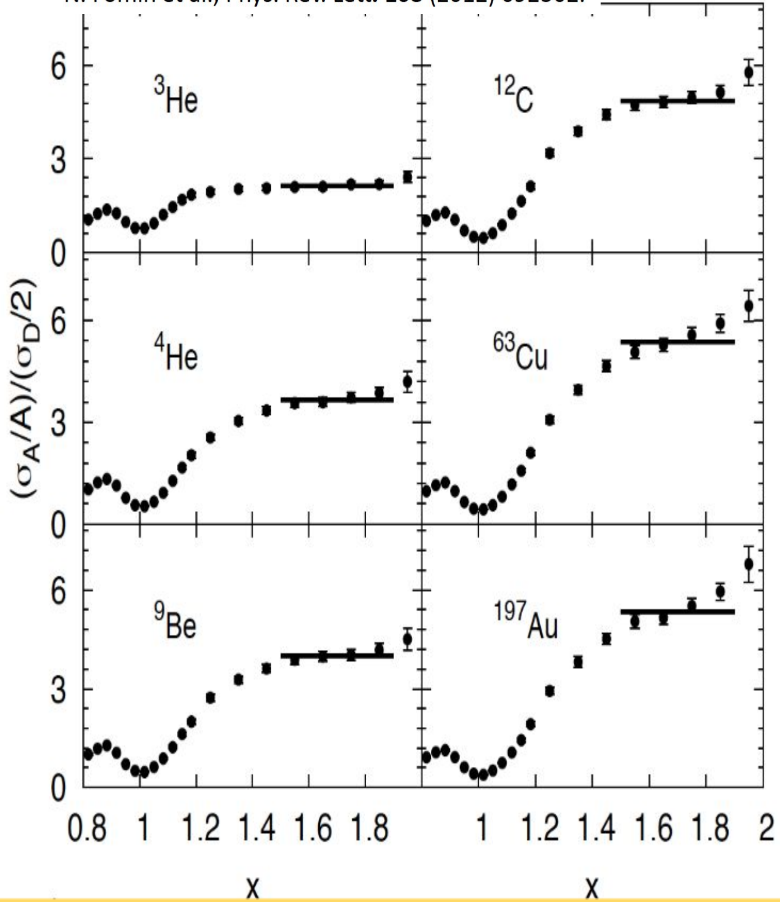
In inclusive (e,e') quasi-elastic scattering, high momentum nucleons dominate the $x = Q2/2m\nu > 1$ kinematics

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



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

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



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)

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:

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

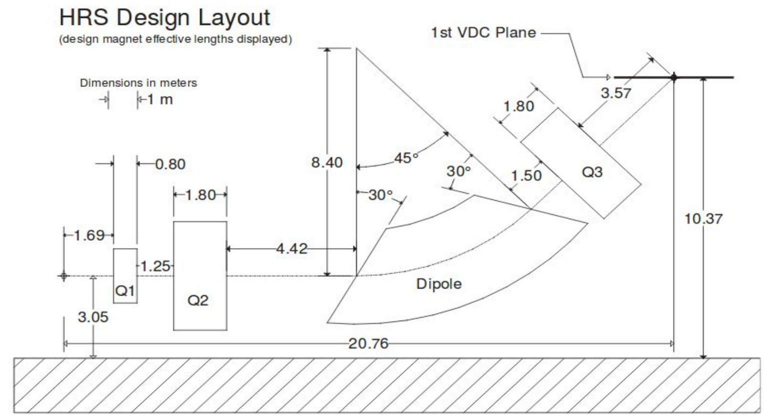
no isospin preference:

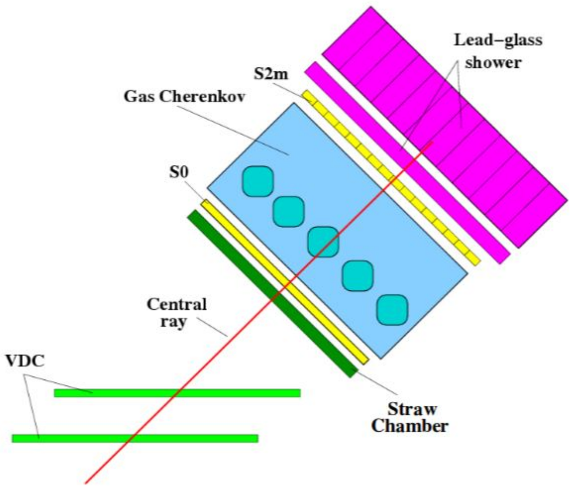
$$\frac{\sigma_{^3H}}{\sigma_{^3He}} = \frac{2\sigma_{nn} + \sigma_{pp}}{\sigma_{nn} + 2\sigma_{pp}} \xrightarrow{\sigma_p \sim 3\sigma_n} 0.7$$

Jefferson Lab, Hall A

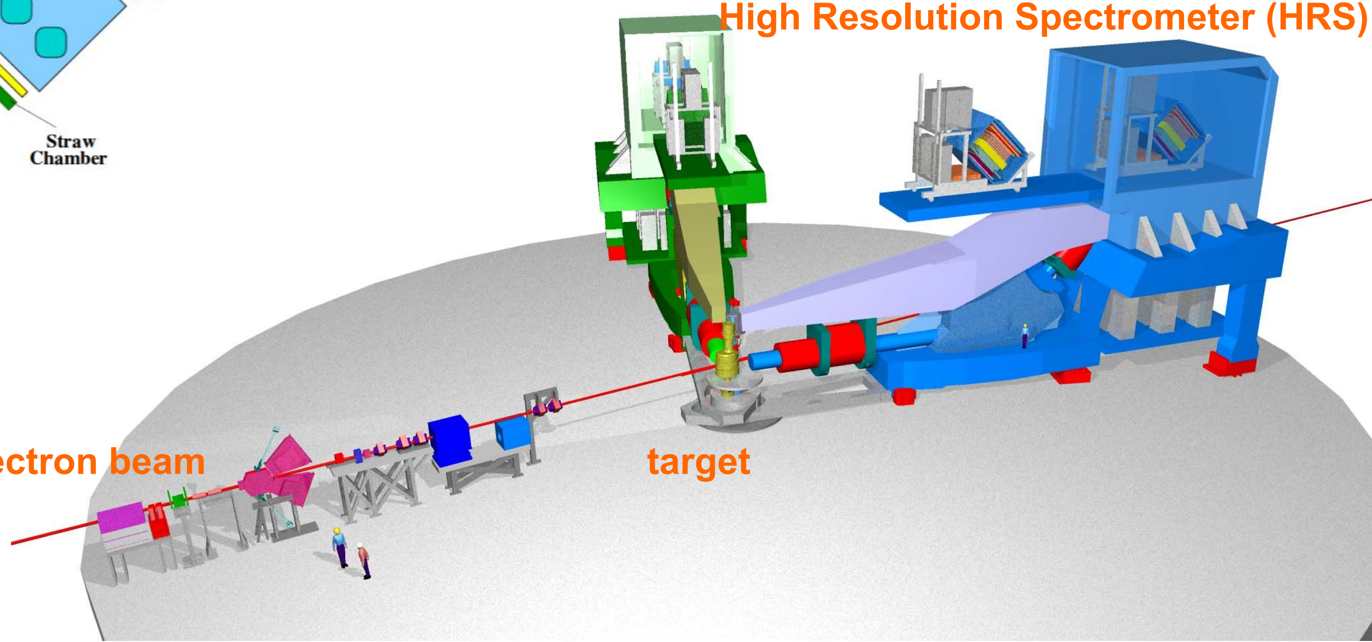
Experiment Configuration

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

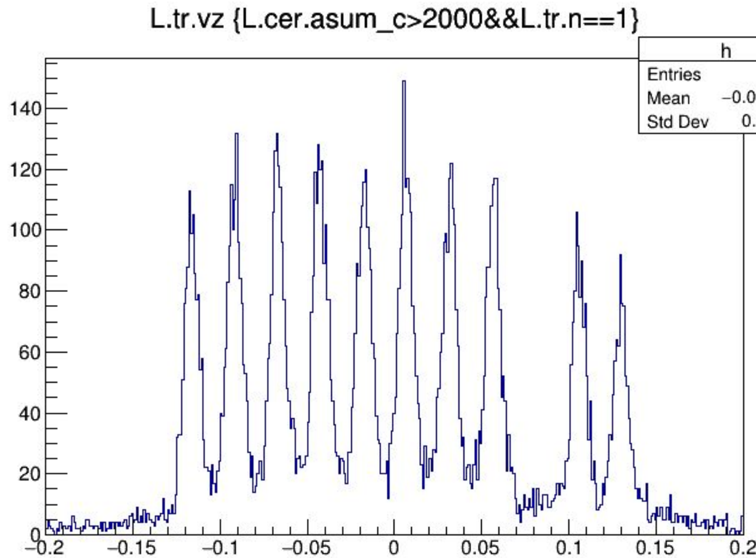


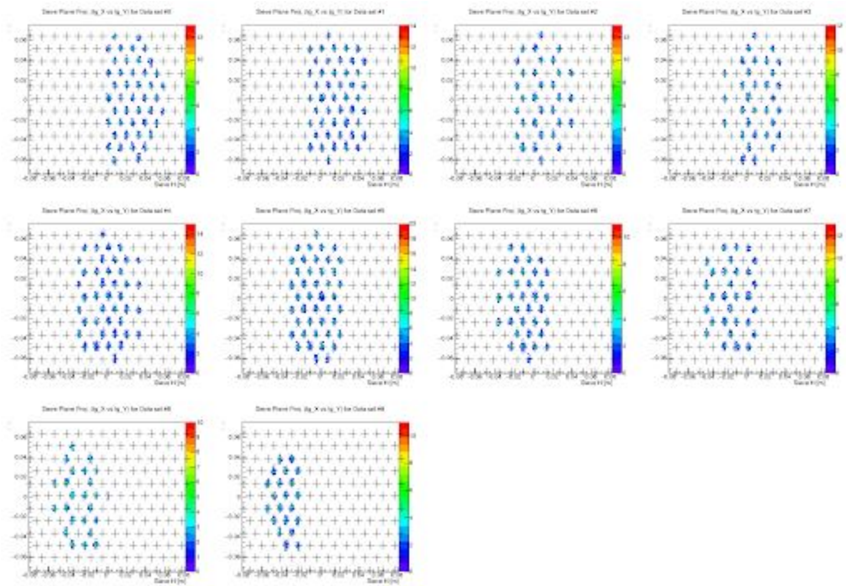


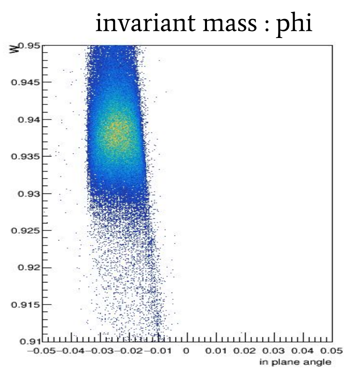
Beam energy: 4.3 GeV
Momentum : 3.54, 3.82 GeV
Angle : 20.88, 17 degree
Q^2 : 1.8, 1.4 GeV^2

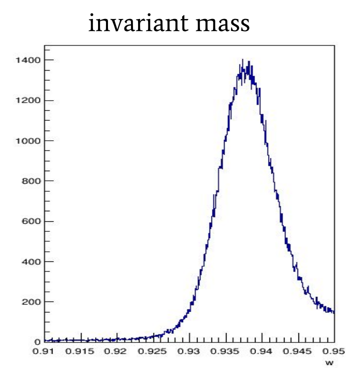


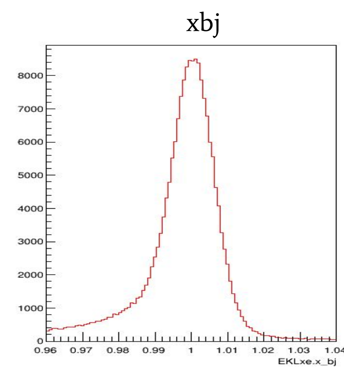
Optics Calibration correct for Q1 saturation











LHRS PID: electron/pion discrimination

Kinematics (Run 100684):

Ebeam = 4.3 GeV

Angle = 17 . 8 degree,

p0 = 3.543 GeV

Electrons:

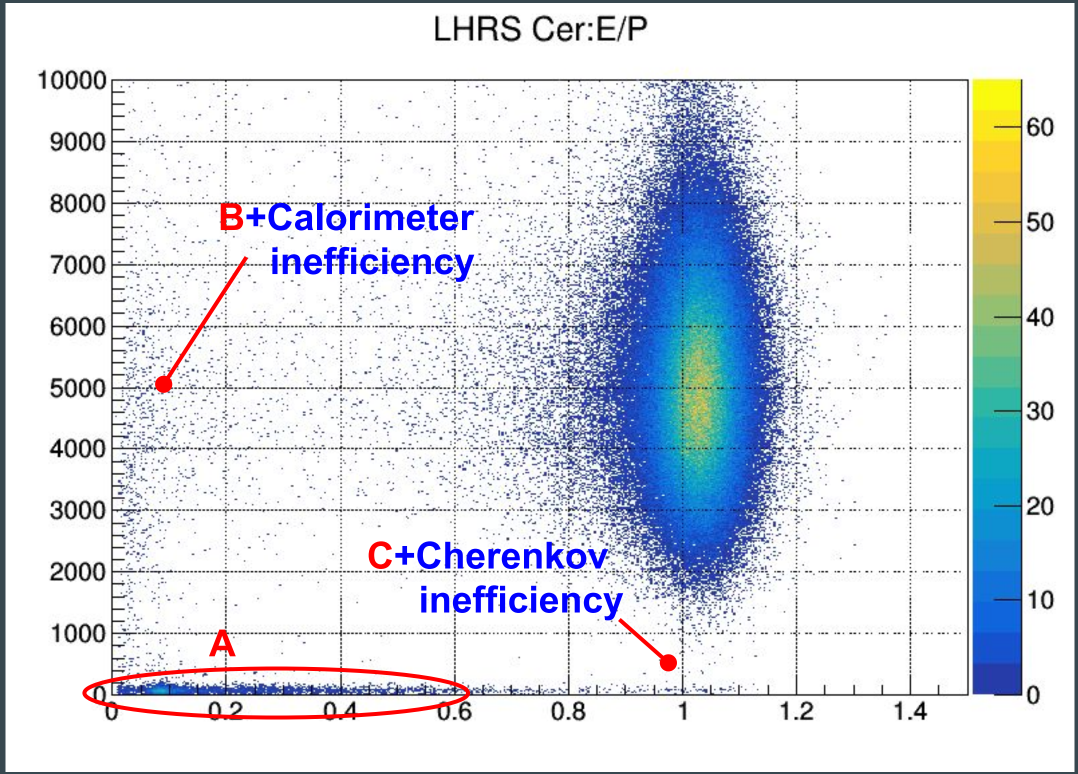
large Cerenkov and calorimeter signals

Pion contaminations:

A. π^- :
   No Cerenkov signal,
   small energy deposit in calorimeter

B. π^- knock out electron (ionization) before/in Cerenkov:
   Cerenkov triggered,
   small calorimeter signal

C. $\pi^- n \to \pi^0 p \to \gamma\gamma$:
   No Cerenkov signal,
   large calorimeter signal



- **The combination of B(C) and detector inefficiency is less than 0.1% => detector inefficiency alone << 0.1%**

Trigger Efficiency

Production Trigger!

LHRS:
T1: S0 && S2
T2: (S0 && S2) && Cer
T3: (S0 || S2) && Cer

Cerenkov trigger efficiency
Scintillators (s0, s2) trigger efficiency

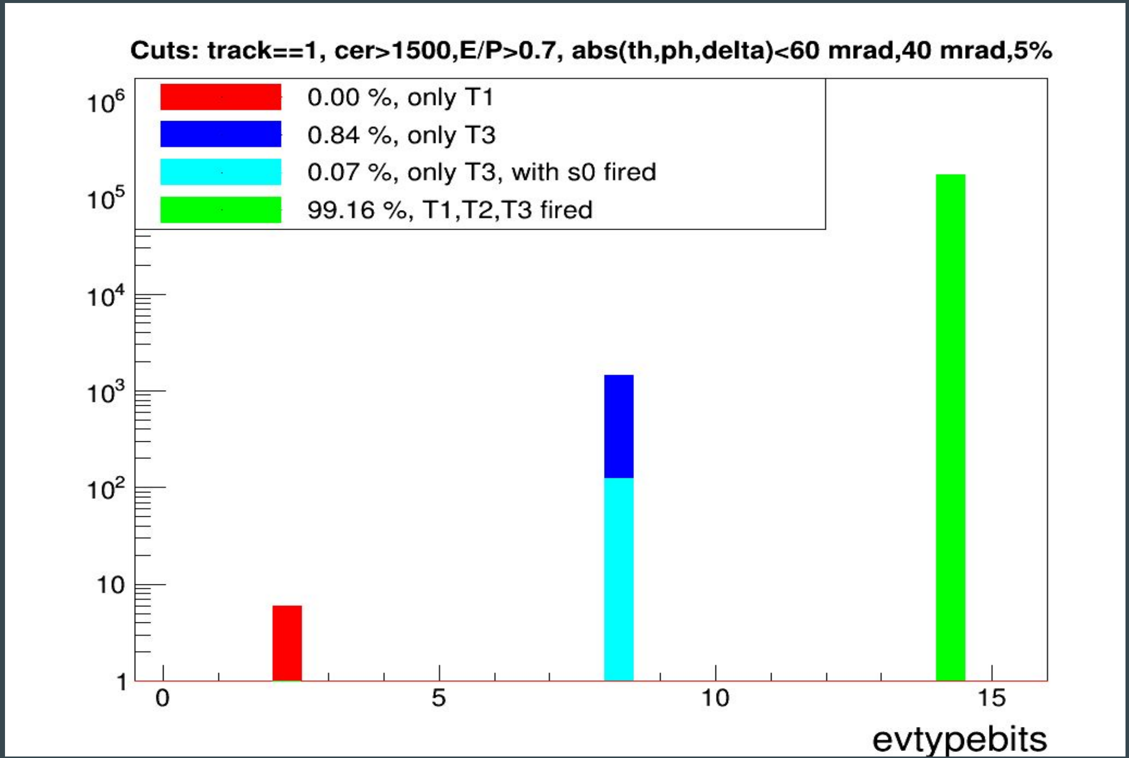
Run 100684, events passed PID and one-track cuts

Evtypebits =

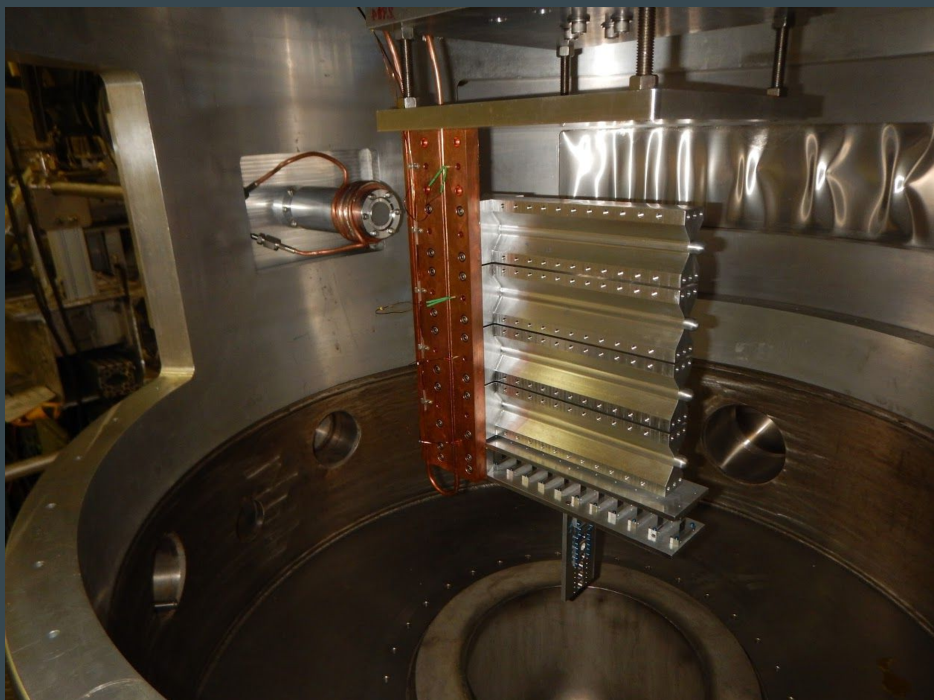
2 -> only T1
-> Cerenkov trigger inefficient

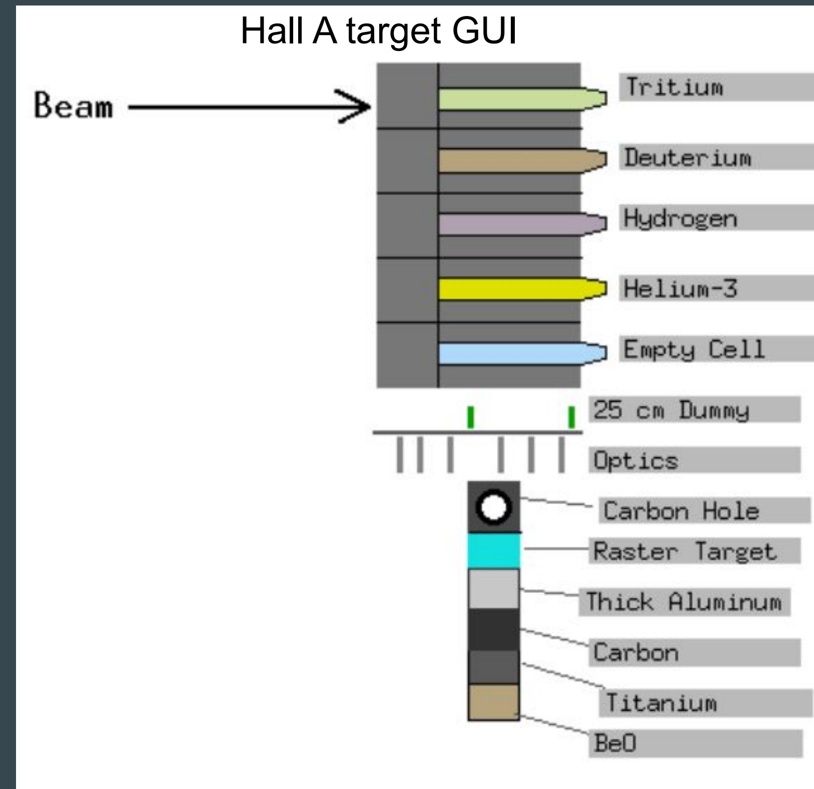
8 -> only T3
-> S0 or S2 triggers inefficient

14 -> T1 + T2 + T3
-> good



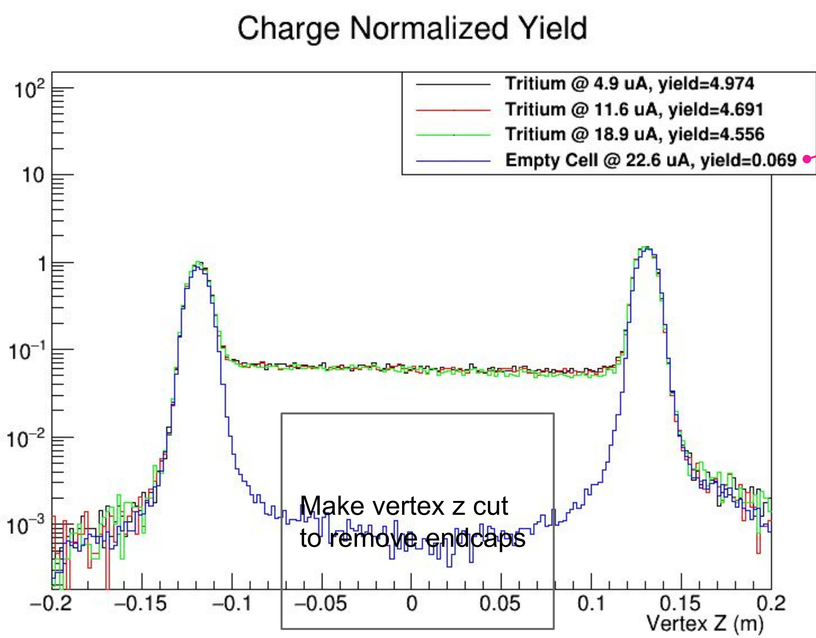
The Gas Target System:





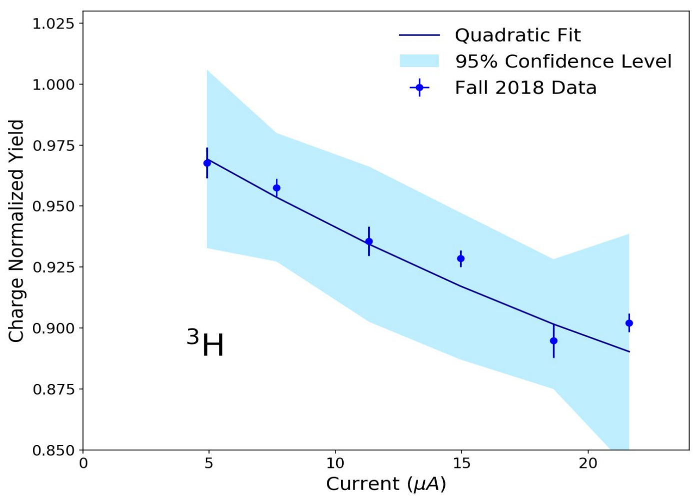
The Gas Target System: special handling

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



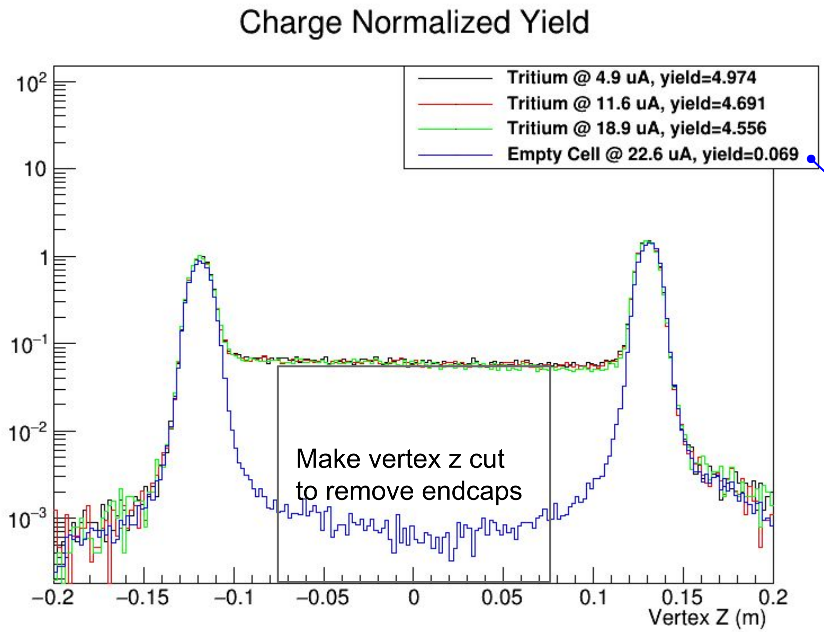
The Tritium density reduced by ~ 10 percent at 22.5 uA

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



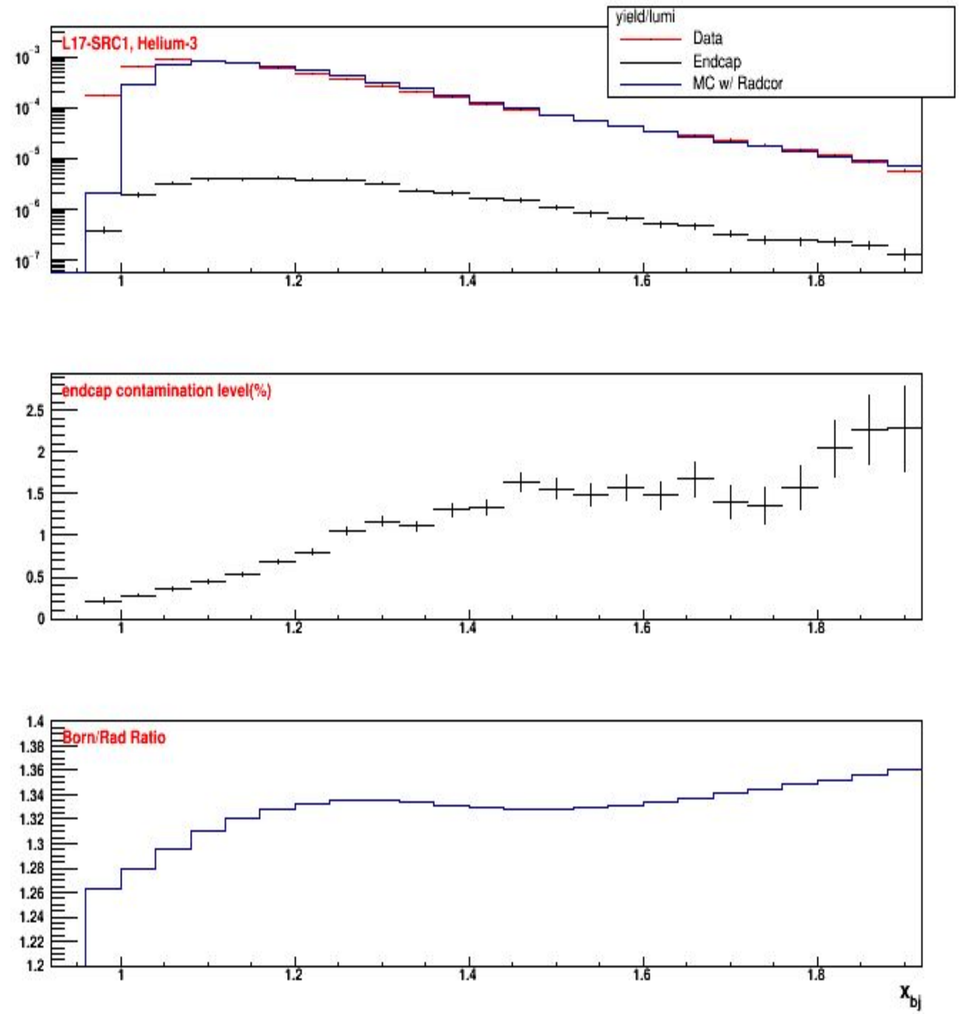
The Gas Target System: special handling

- 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



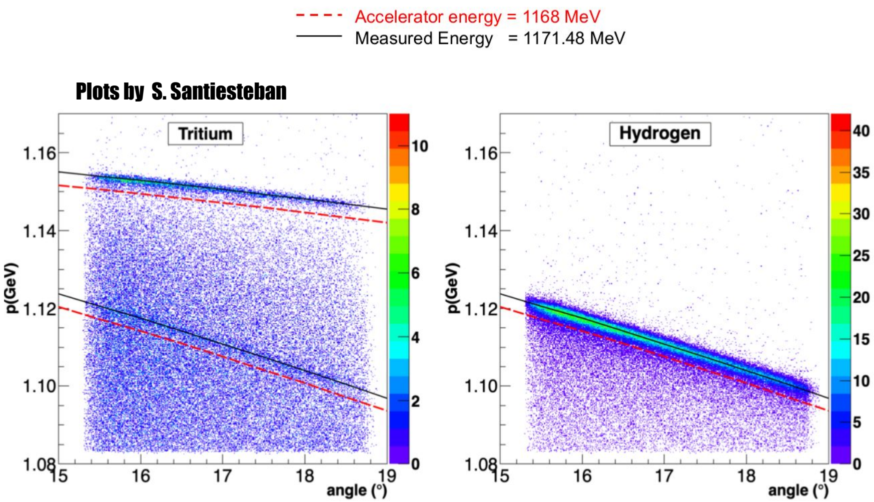
The endcap contamination (after vertex cut) varies from less than 0.1% to 10% depends on spectrometer angle and kinematics.

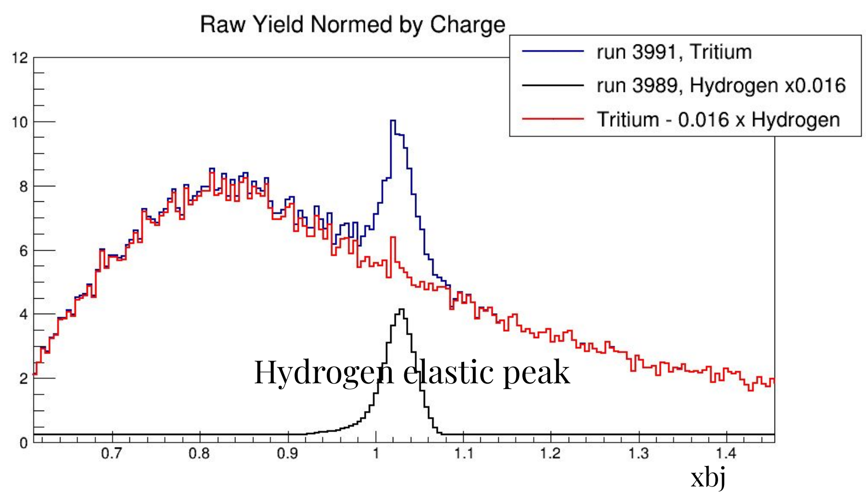
Endcap Contamination

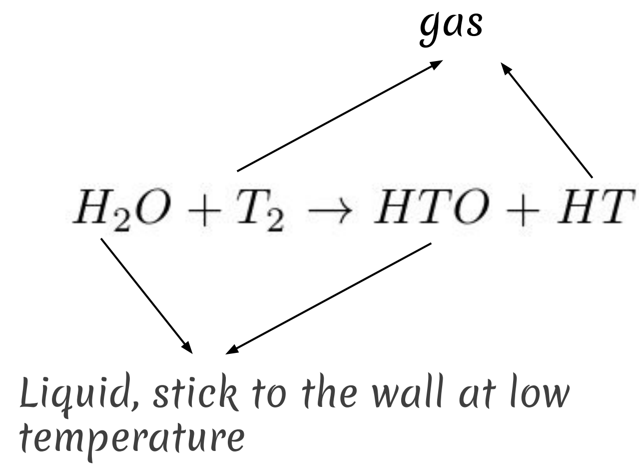


The Gas Target System:

Hydrogen in the 2nd Tritium cell (used in the fall 2018)







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 %

Extract Yield from Data

For a given good production run i, periods of data with stable currents are first identified. Then for events from each good current (allow $1.5uA$ fluctuation) we calculated the following quantities:

- C_i : raw good electron counts per x_{bj} bin,
- PS_i : the prescale factor for the production trigger,
- LT_i : the computer livetime in fraction for the production trigger,
- eff_i : the product of all efficiencies including trigger, tracking, cut efficiencies,
- Q_i : charge with stable beam current,
- ρ_l : effective area density of the target (g/cm^2). For a gas cell it should represent the amount of gas after vertex z cut (target length cut),
- $Boiling_i$: the ratio of the effective gas target density at given beam current comparing to no beam. See the boiling study for details.

The yield for this run

$$Y_i = \frac{\#\ of\ observed\ events}{Effective\ Luminosity} = \frac{C_i}{Q_i \cdot \rho_l \cdot Boiling_i \cdot eff_i \cdot LT_i / PS_i}$$

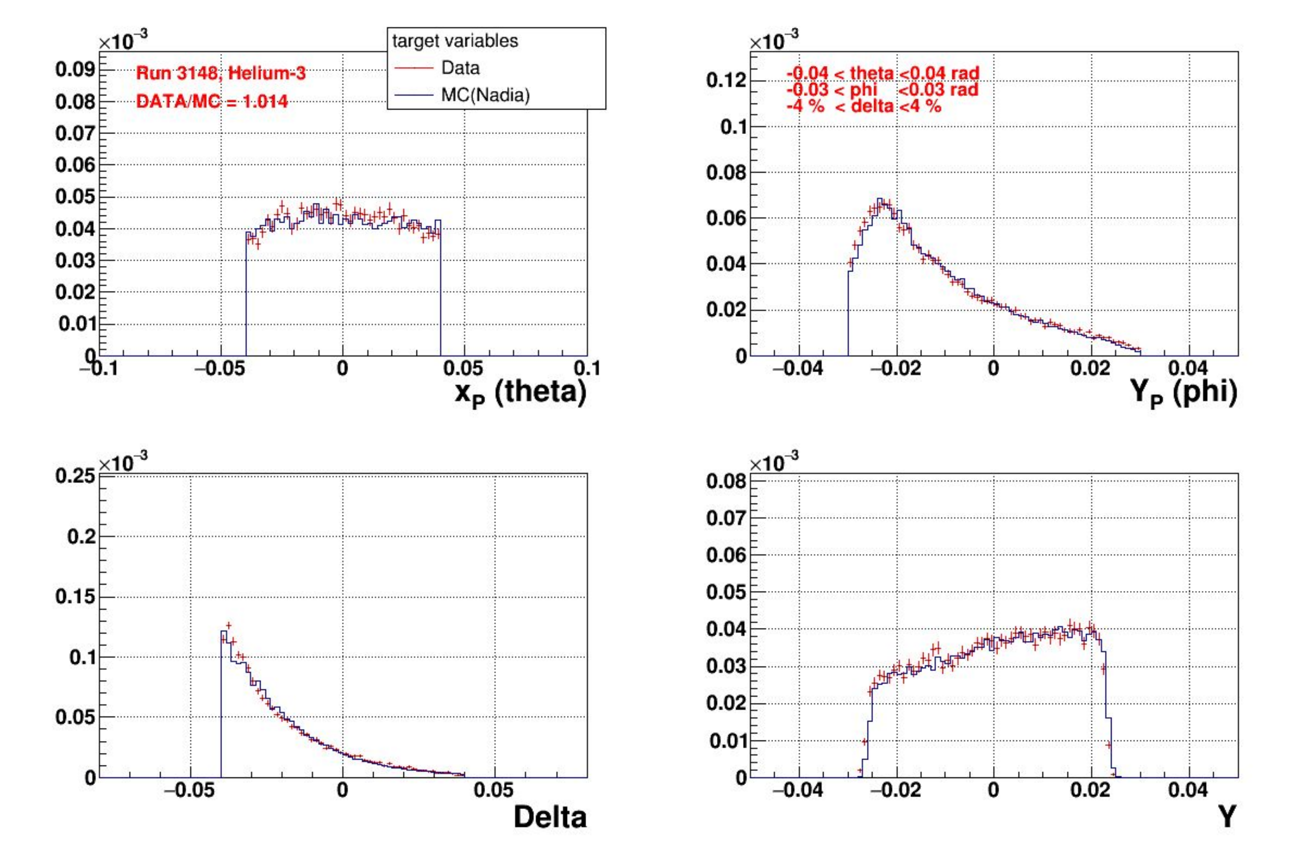
with $\frac{1}{\sqrt{C_i}}$ as the fractional statistical uncertainty.

The overall yield of a given kinematics is the weighted arithmetic mean of all good production runs under this kinematics:

$$Y_{overall} = \frac{\sum_i C_i}{\sum_i Q_i \cdot \rho_l \cdot Boiling_i \cdot eff_i \cdot LT_i / PS_i}$$

with a fractional statistical uncertainty of $\frac{1}{\sqrt{\sum_i C_i}}$.

Compare Data vs MC Simulation



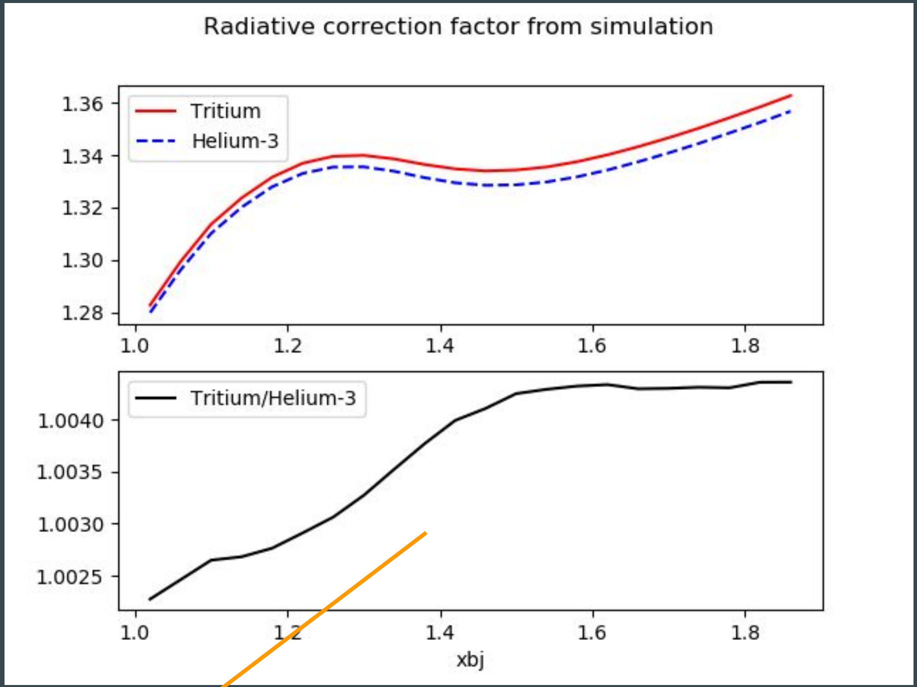
Radiative Corrections

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%

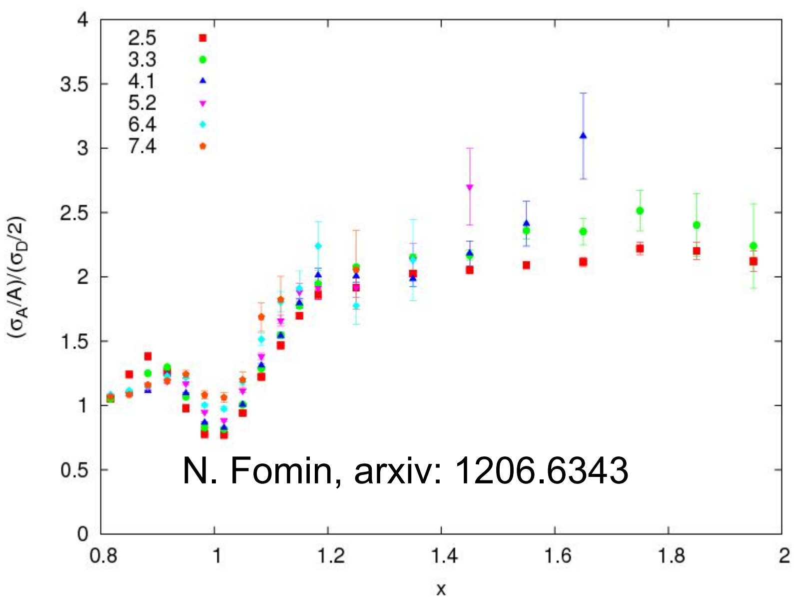
Normalization: 1.4-2.5%

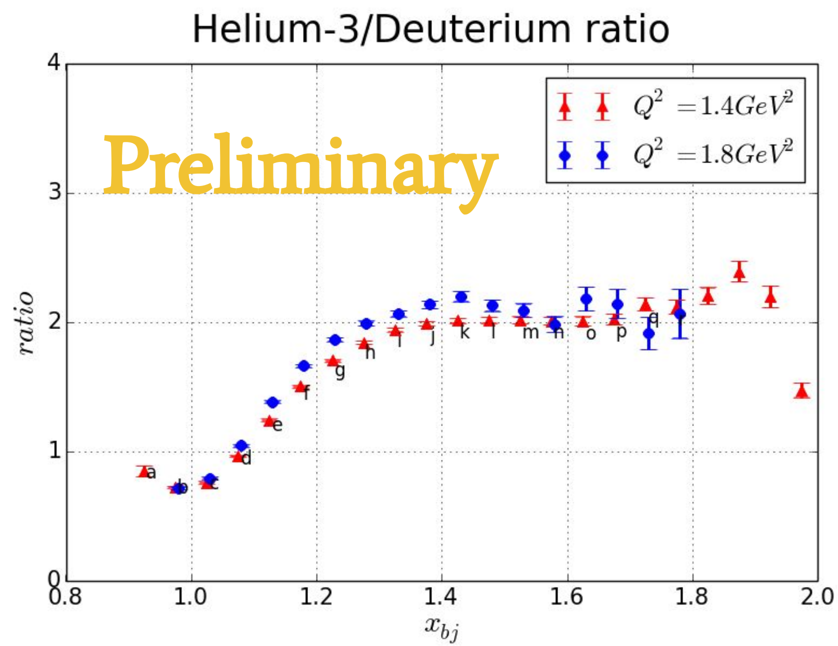
SRC Analysis Status:

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





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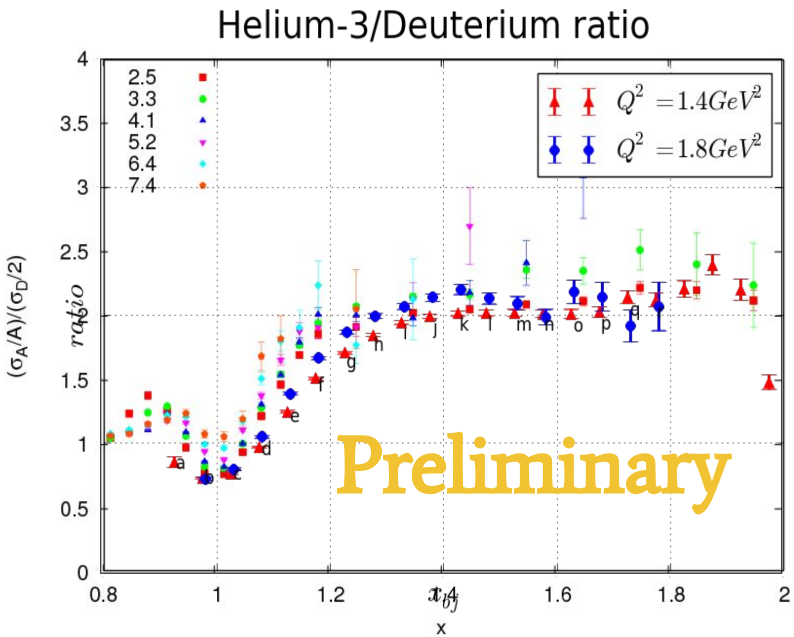
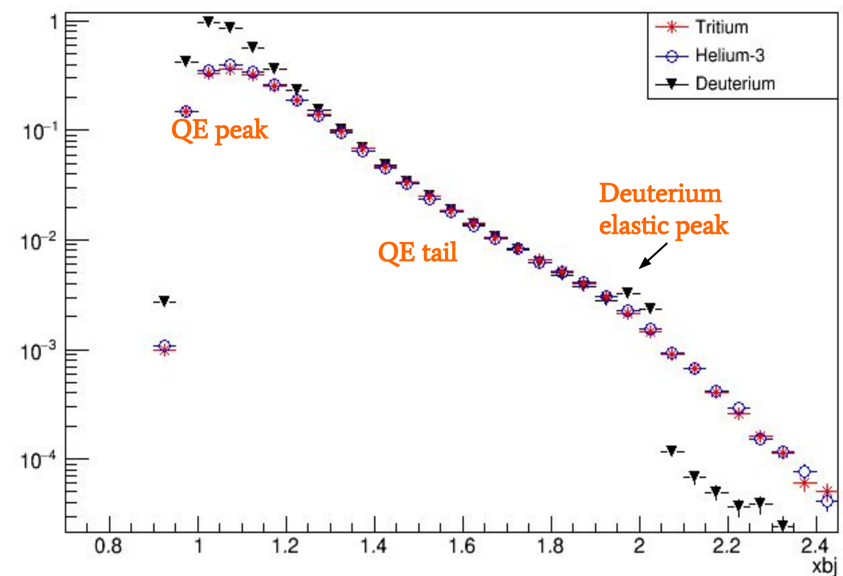


Scale yield to match the shape



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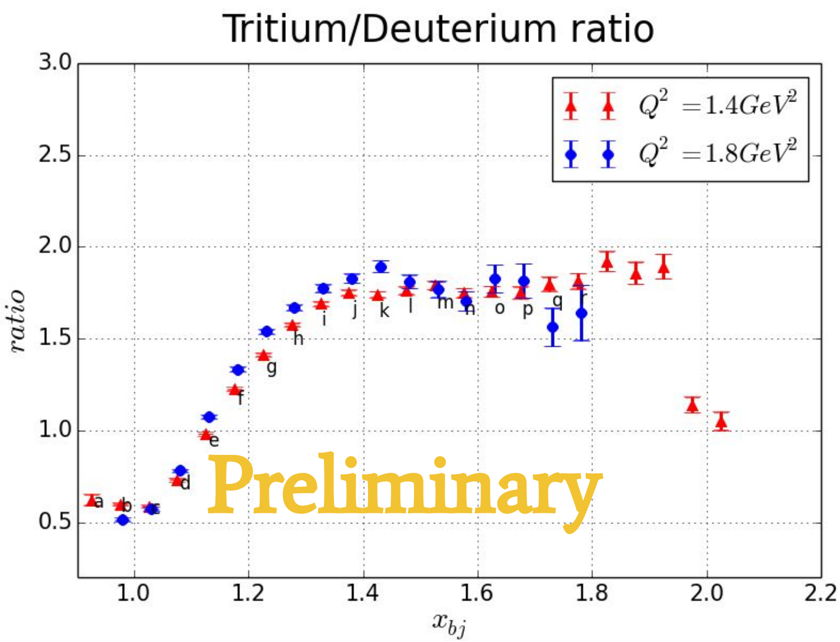

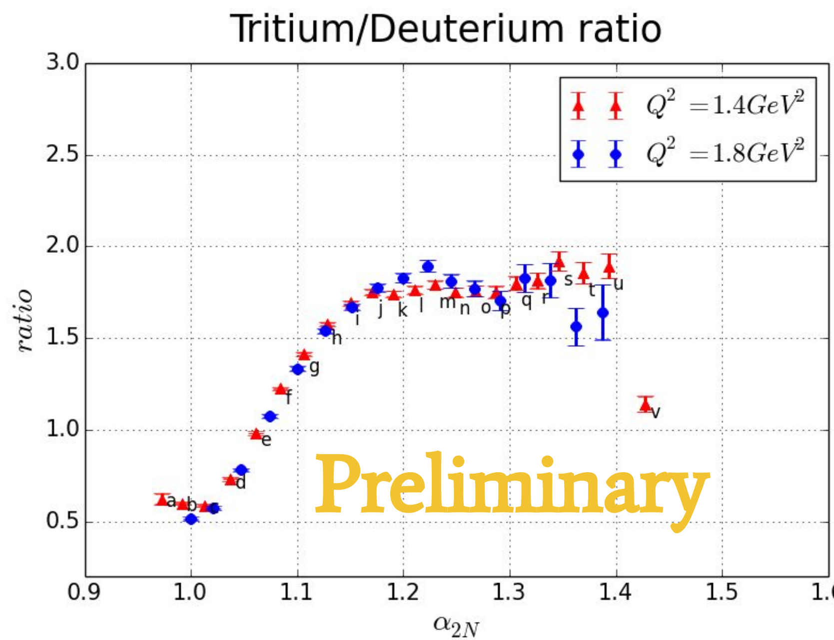

Light cone variable:

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

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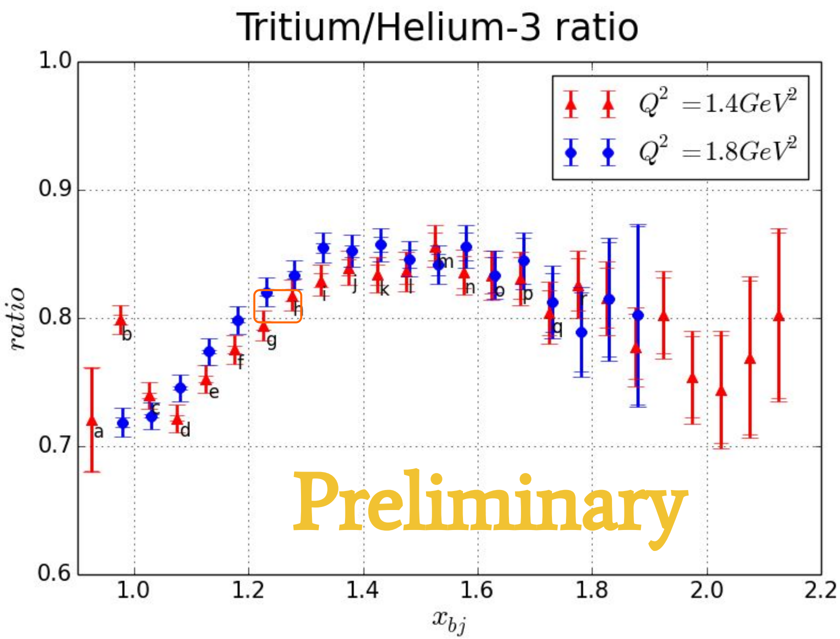

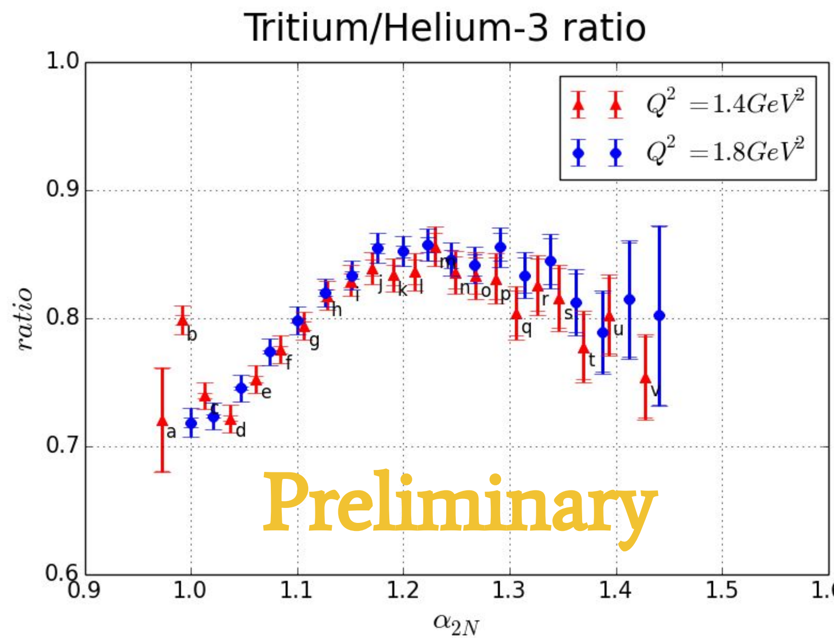

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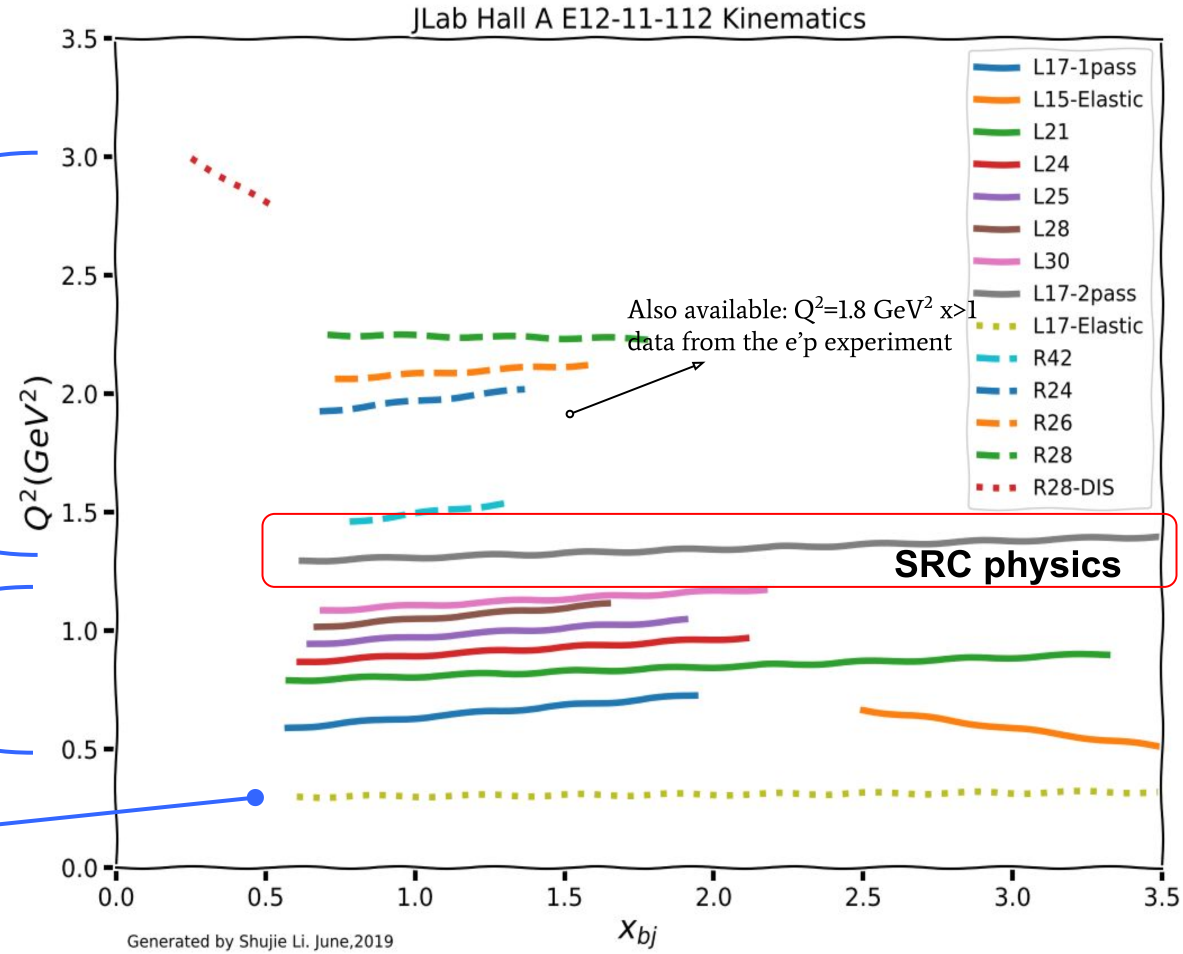


Thanks to:

The tritium group students

Florian, Evan, Meekins

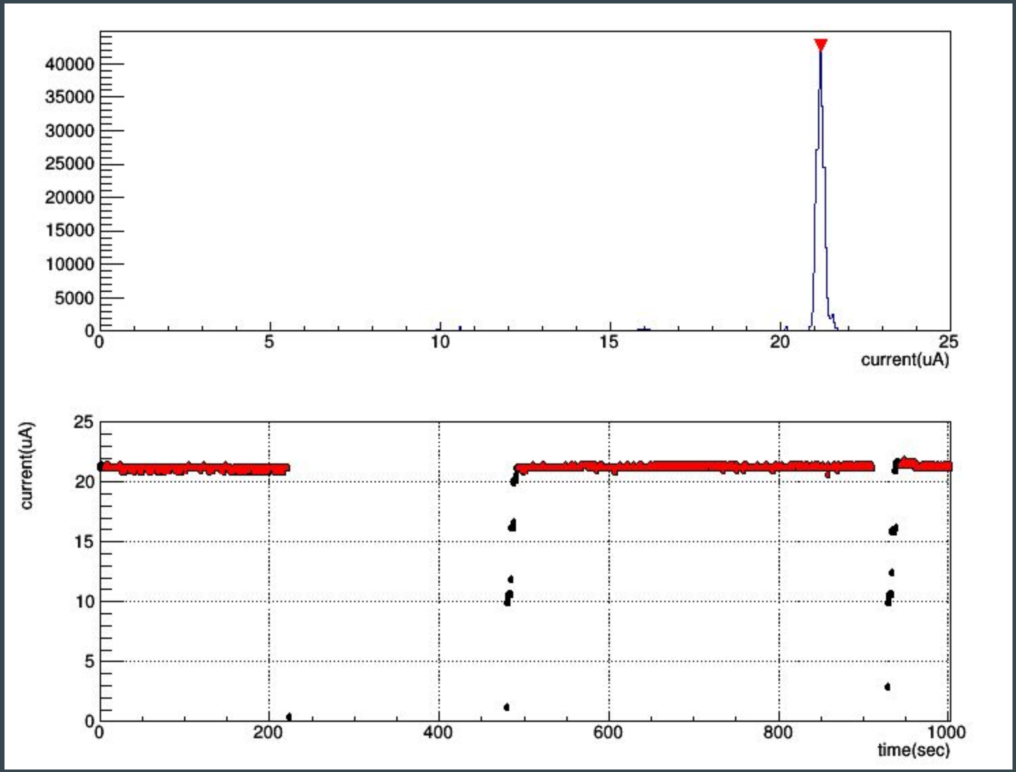
Shift workers

Hall A engineer/tech group

The GMp collaboration

Beam Current and Charge, Livetime:

1. Find beam on currents, loop over fast scaler readout (evLeft/evRight) to find current associated with every TTree event.
2. For each stable beam current, find corresponding events (**+- 1.5 uA**), also discard events within the first **5 seconds** of stable beam, then accumulate charge and raw trigger signals from scaler, and triggered events (DL.bit2) counts
3. Save event list of events passed beamtrip cuts, record corresponding mean current, charge,, and livetime.



Yield (rate) Calculation from Monte-Carlo Simulation

20 uA

$$rate_{MC} = I \cdot \rho_l / A \sum_{N_{tot}} \frac{d\sigma}{d\Omega} \varepsilon(\Omega) \frac{\Omega_{tot}}{N_{tot}} \cdot efficiency$$

Good events in simulation and XEMC

of **trials** in simulation

(!! The single arm simulation will only record good events)

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