

EMC Effect for A=3

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November 30, 2018

Outline

1 EMC Effect

2 MARATHON

- Setup
- Run Period

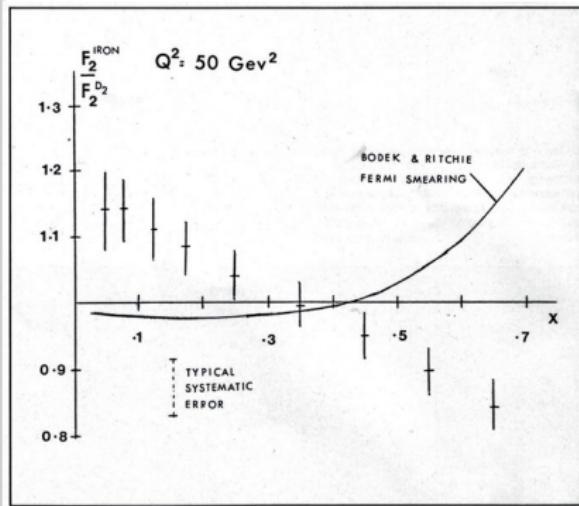
3 Analysis

EMC Effect

European Muon Collaboration's (EMC)
1983 results for the lepton scattering
experiment on Iron and Deuterium.

- Nucleon Structure Functions
- Sea-Quark Distributions
- Gluon Distributions
- Expected $F_A = NF_2^N + ZF_2^P$
- Because the binding energies of the nucleons are several orders of magnitude smaller than the momentum transfer for an interaction in DIS region
- Fermi interaction causing differentiation at high momentum transfer.

Figure: EMC data of F_2^{Fe}/F_2^D from 1982 [Higinbotham D., 2013].





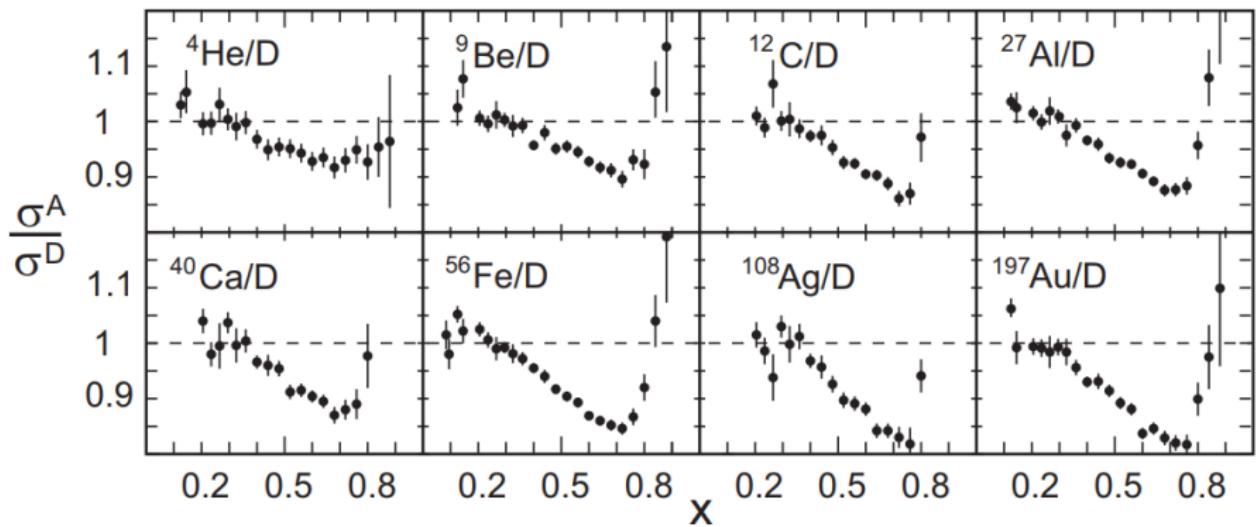
EMC Effect

European Muon Collaboration:

- Nuclear F2 structure function per nucleon different than that of deuterium
- Quark distribution functions modified in the nuclear medium
- Defined the magnitude of the EMC effect as the slope of the $\frac{A}{D}$ per nucleon cross section ratio from 0.3 to 0.7 in x.
- Current Explanations
 - ▶ Binding effects beyond nucleon Fermi motion
 - ▶ Enhancement of pion field with increasing A
 - ▶ Influence of possible multi-quark clusters
 - ▶ Change in the quark confinement scale in nuclei
- No unique/universally accepted theory for explanation of the EMC effect up to date.

EMC Effect

Figure: SLAC experiment E139 [J. Gomez et al., 1994].



EMC Effect

Figure: JLab experiment "EMC in light Nuclei" [J.Seely, A. Daniel et al].

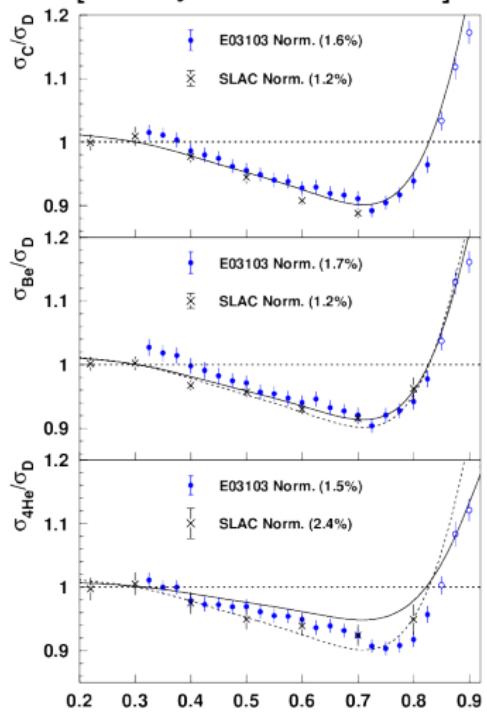
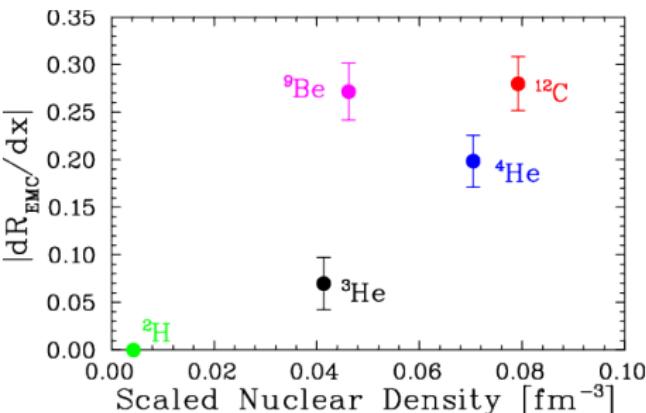
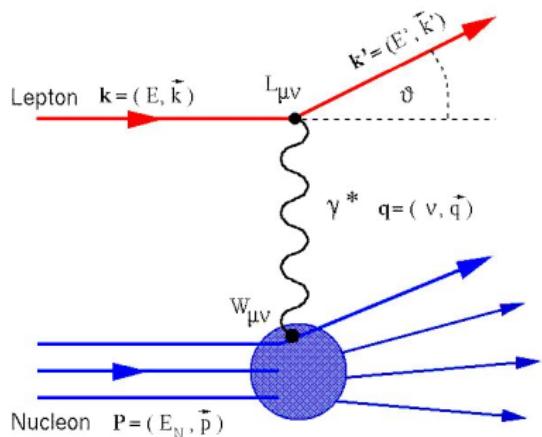


Figure: EMC as a function of Nuclear Density [J.Seely, A. Daniel et al].



Scaled by $\frac{(A-1)}{A}$

Deep Inelastic Scattering (DIS)

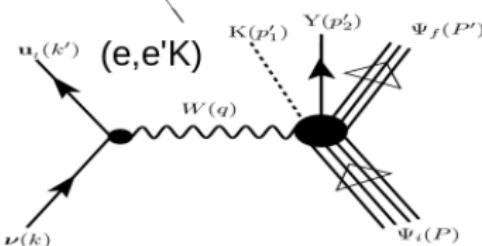
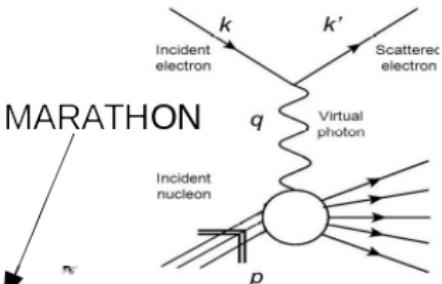
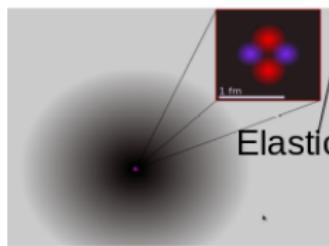
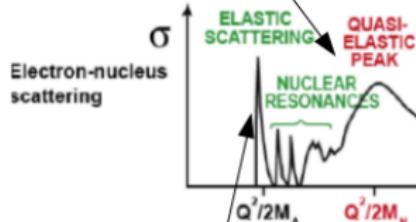
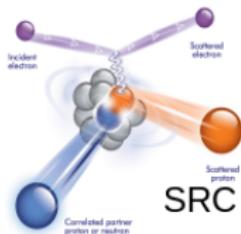


- Momentum Transfer

$$Q^2 \equiv 4EE' \sin^2 \frac{\theta}{2}$$
- Bjorken X (X_{bj}/x) = $\frac{Q^2}{2\nu M}$
- $\sigma_{eN} = \frac{\alpha^2}{eE^2 \sin^4(\frac{\theta}{2})} \left[\frac{F_2}{\nu} \cos^2 \frac{\theta}{2} + \frac{2F_1}{M} \sin^2 \frac{\theta}{2} \right]$
- Invariant Mass

$$W^2 = 2M\nu + M^2 - Q^2$$
- $W^2 > 4 \rightarrow \text{DIS}$

Tritium Experiments



MARATHON

MeAsurement of F_2^n/F_2^p , d/u RAtios and $A = 3$ EMC Effect in Deep Inelastic Electron Scattering off the Tritium and Helium MirrOr Nuclei.

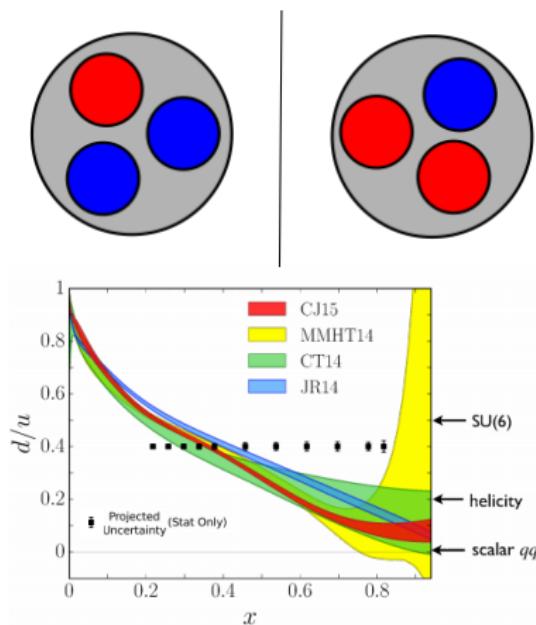
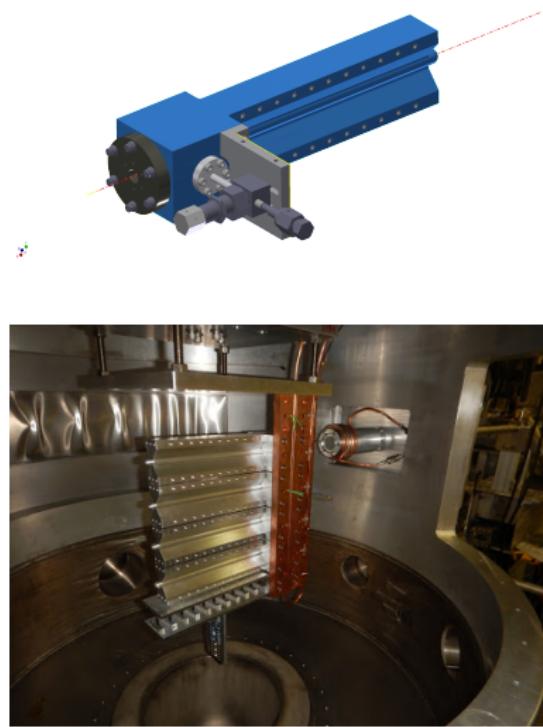


Figure: d/u quark distribution ratios

Tritium Target Cell

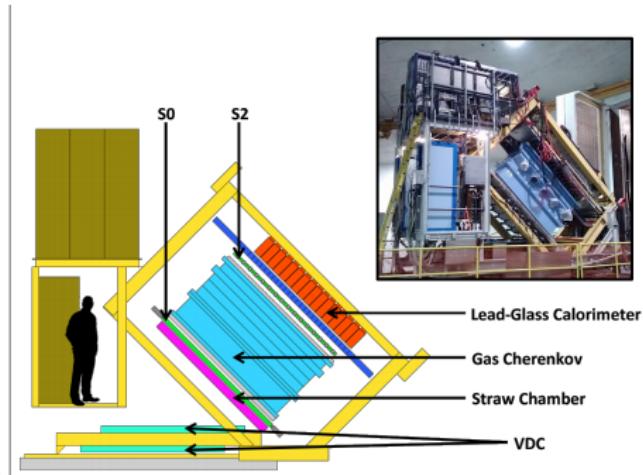
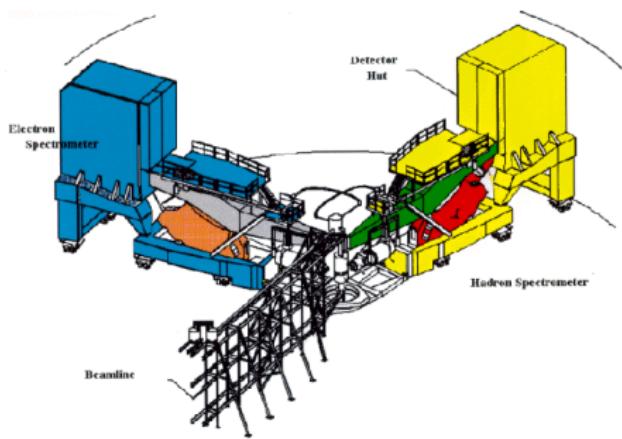
First tritium target at JLab

- Thin Al entrance and exit windows 0.01 inches
- 1090Ci of Tritium (0.1 g)
- 25 cm long
- Tritium Cell was filled in Savannah River
- 40 kelvin Helium is used to cool an attached heat sink

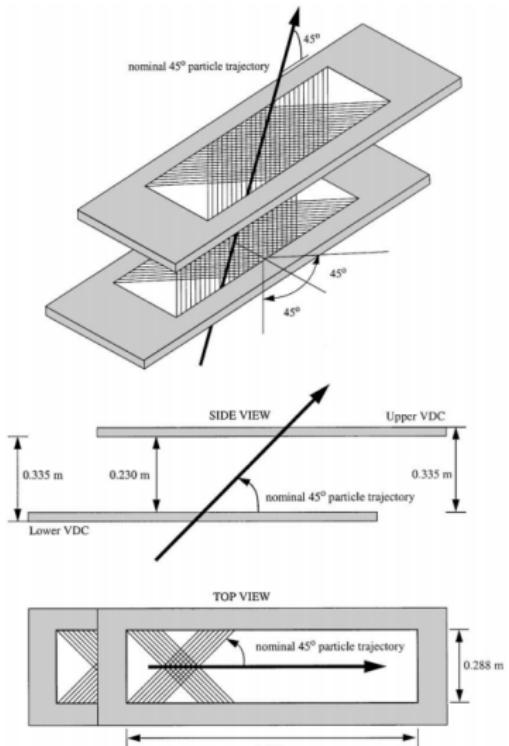


Hall A & The HRSs

Use CEBAF(Continues Electron Beam Facility) to provide 10.6 GeV beam for electron scattering.



Vertical Drift Chamber(VDC)

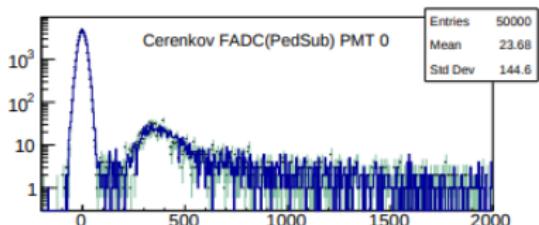
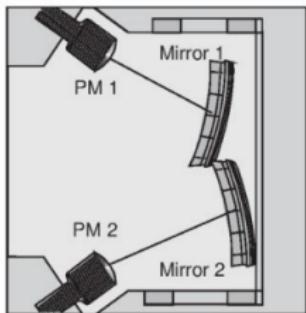


Tracking Detector

A dual VDC system is used to provide precise angular reconstruction of particle trajectories.

- U/V angle $\pm 45^\circ$
- 368 wired per plane
- 4.2mm spacing between wires
- Online Efficiency determined by nearest neighbor method [J. Alcorn et al.]

Gas Cherenkov

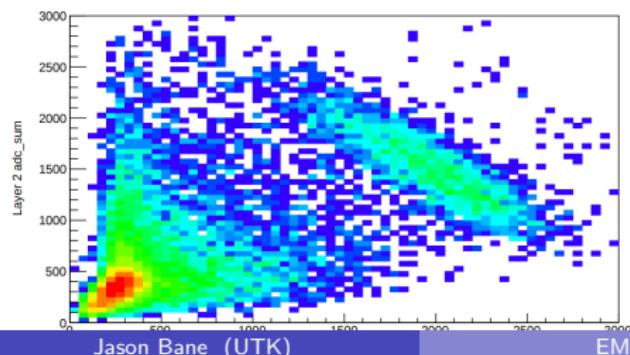
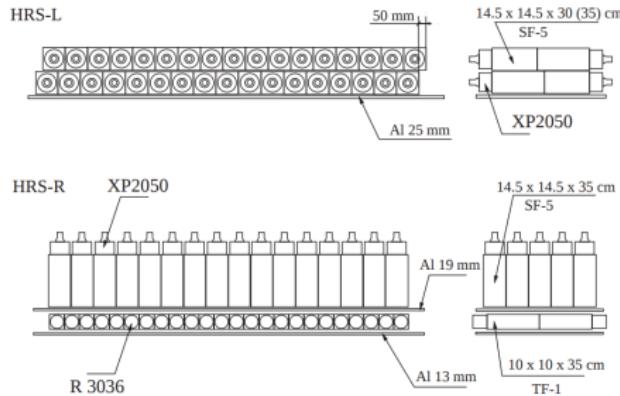


PID Detector

- Filled with CO_2
- Index of refraction of 1.00041 and operated at 1 atm
- Electron threshold of 0.017 $\frac{GeV}{c}$
- Pion/proton threshold of 4.8/32 $\frac{GeV}{c}$
- 1.5/1 m radiator length of left/right arm [J. Alcorn et al.]



Calorimeter



Jason Bane (UTK)

EMC A=3

November 30, 2018 14 / 42

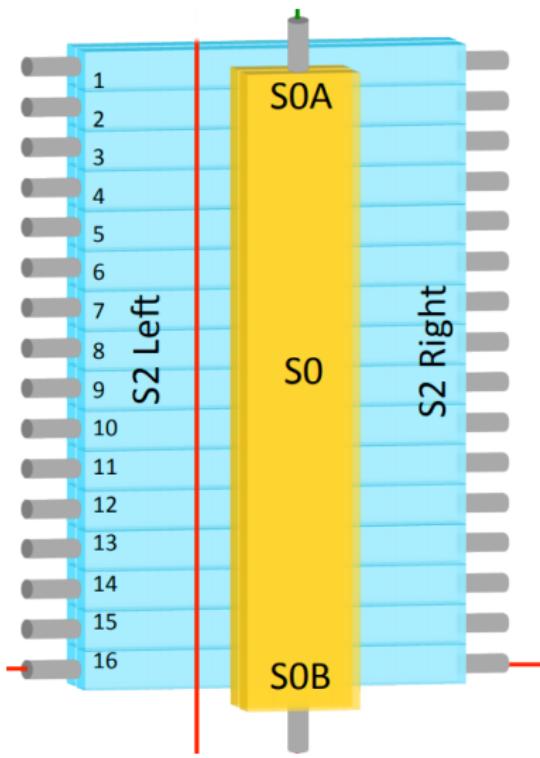
PID Detector

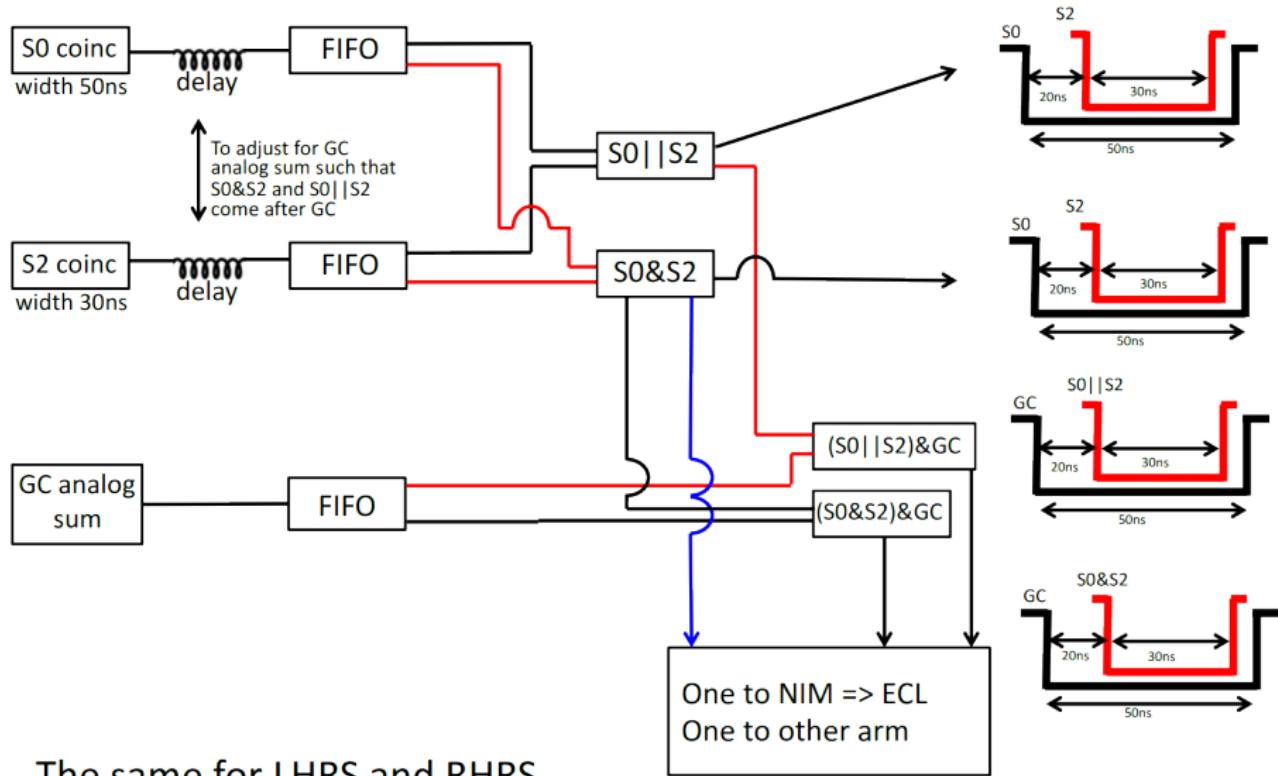
- Two layers of lead glass
- LHRs - Both layers are stacked perpendicular to beam direction.
 - ▶ 34 Blocks, 34 blocks
- RHRs - First layer perpendicular, second layer is parallel
 - ▶ 48 Blocks, 80 blocks
- With Cherenkov, pion suppression above $2 \frac{\text{GeV}}{c}$ of a factor of 2e5 [J. Alcorn et al.]

Scintillators

Triggering Detector

- Two Scintillating light detectors
 - ▶ S0 large acceptance and low resolution
 - ▶ S2 16 bars capped by PMTs
- Main source for trigger
- Provide TOF(time of flight) & Used to help identify hadrons [J. Alcorn et al.]



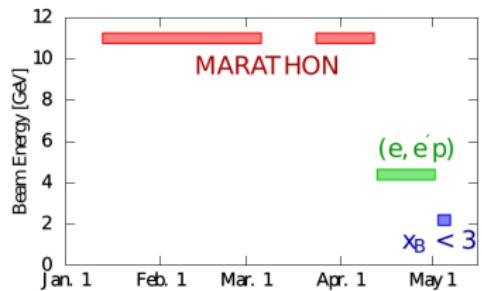
Single Arm Triggers ($S_0 \& S_2$); $(S_0 \& S_2) \& GC$; $(S_0 \mid\mid S_2) \& GC$ 

The same for LHRS and RHRs

Figure: By Florian Hauenstein

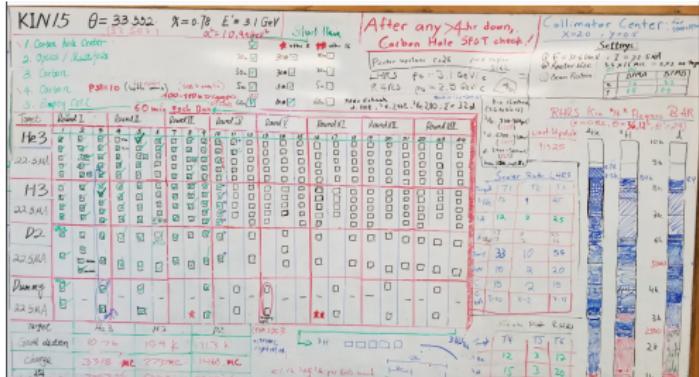


The Run Period



Rey Torres

- Ran from January 11th to April 12th of 2018.
- Gaseous Tritium, Deuterium, Helium-3, and Hydrogen
- Single Carbon Foil, Carbon foil with hole, and multi-foil
- Rotated through targets to achieve equal statics and reduce the impact of unforeseen circumstances



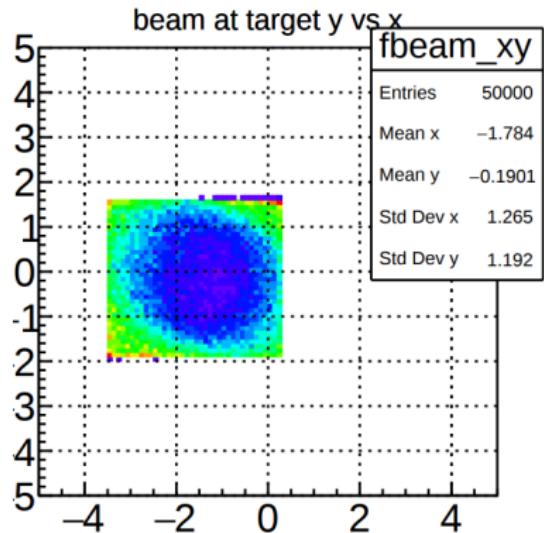
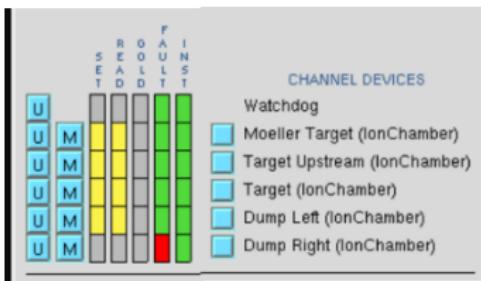
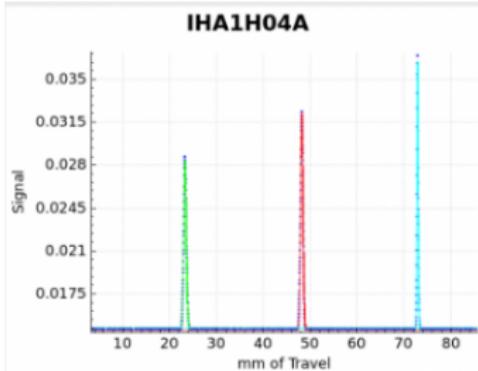


Major Miscues

- Right Arm Dipole failed on January 11th
 - ▶ Return the dipole to functionality the following day
 - ▶ 01/13 - Dipole failed again, causing a chain reaction with the Left arm
 - ▶ Solution could not be found quickly
 - ▶ Change of Kinematic plan to use single HRS.
 - ▶ Recovered RHRSS on 01/16 - Set to take data at theta of 36.12° , x of 0.82
- A Transformer Failed on March 5th
 - ▶ Recovered on March 23rd
 - ▶ Spring run Period extended by 18 days
 - ▶ MARATHON took opportunistic data during recovery period

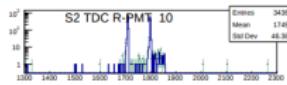
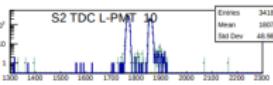
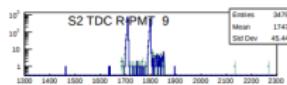
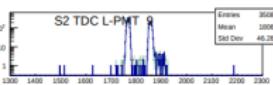
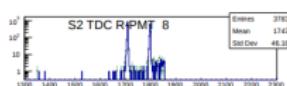
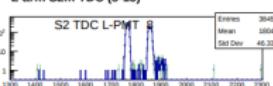
Tritium Safety Requirements

- Harp and BPM Check!
- Ion Chamber functionality test
- Beam Center
- Raster Size calibration.

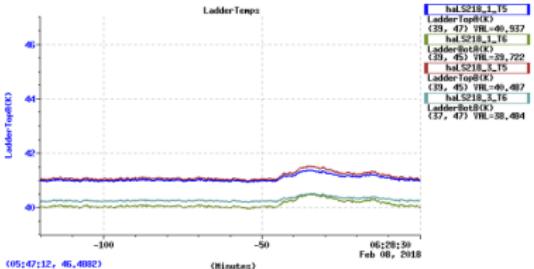


Run #1894

L-arm S2m TDC (8-15)



T1	$1.27e+01$	T2	$2.99e+00$	T3	$2.49e+01$
(S0/S2)R	$3.01e+03$	L1A_Remote	$2.30e+01$	Clock_RHRS	$1.02e+03$
Sh-Sum	$3.37e+01$	(S0/S2)L	$2.48e+03$	S2L	$2.80e+03$
(S0/S2)R	$3.01e+03$	ADC_gate	$3.47e+01$	L1A	$1.76e+03$



Shift Crew Task

- Monitor Detector plots
- Record and observe event frequency
- Observe target response including the temperature sensor attached to the target ladder.



Analysis

Data Analysis Task

- Data decoding
- Online analysis
- Full detector calibrations
- Detector efficiencies
- Systematic Studies

Monte Carlo Analysis

- Monte Carlo Tuning
 - ▶ Offsets
 - ▶ Target Parameters
 - ▶ Reconstruction functions
- Event weighting
- Acceptance studies

- Cross section extraction through Data to Monte Carlo ratio method
- Application of Nuclear Corrections
- Compare Cross Section of A=3 Nuclei to that of Deuterium to calculate EMC effect

Data Decoding

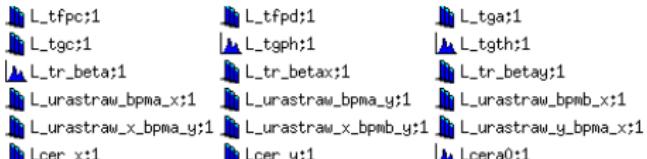
The Hall A Analyzer

```
*****
* W E L C O M E to the *
* H A L L A C++ A N A L Y Z E R *
*
* Release 1.7.0-devel      May 01 2018 *
* Based on ROOT 6.08/00     Nov 4 2016 *
*
* For information visit   *
* http://hallaweb.jlab.org/podd/ *
*****
analyzer [0] ■
```

- An object-oriented, modular framework built on top of ROOT.
- Use modular classes to build a detector package
- Libraries to calculate physics variables

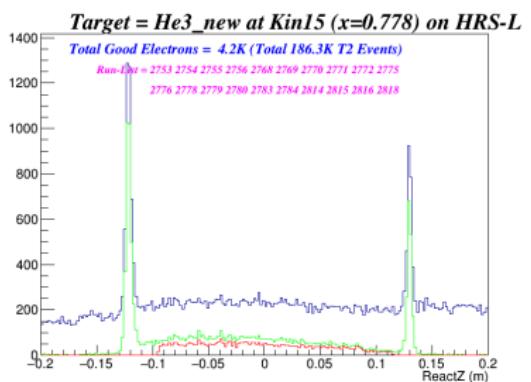
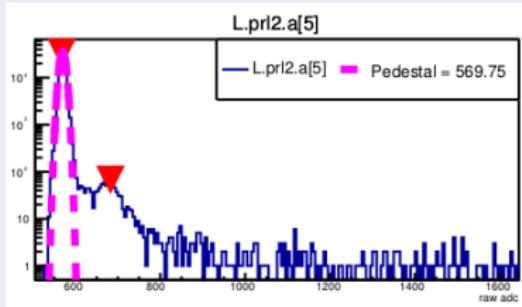
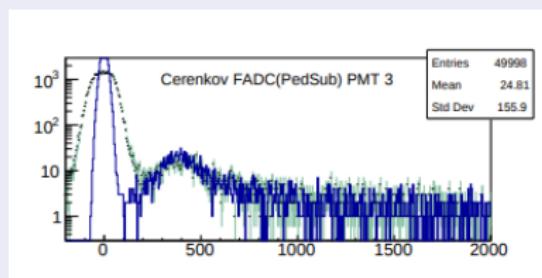
- THaRasterBeamClass
- THaCherenkov
- THaTrackingDetector

- Tri_Beam_Eloss
- TriBCM
- TriFADC BPM



Online Analysis

- Quick Calibrations
- Electron Counts
- Comparable plots for detector checks



Detector Calibrations

Figure: BCM calibration

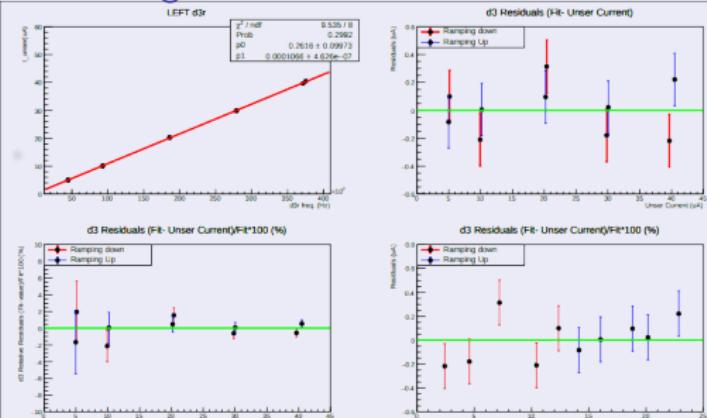
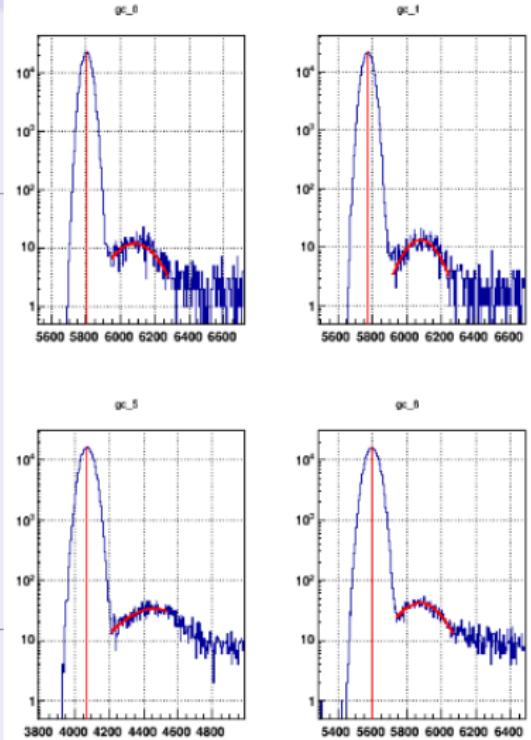


Figure: Gain and Pedestal calibration



Detector Calibrations

Figure: Beta calibration

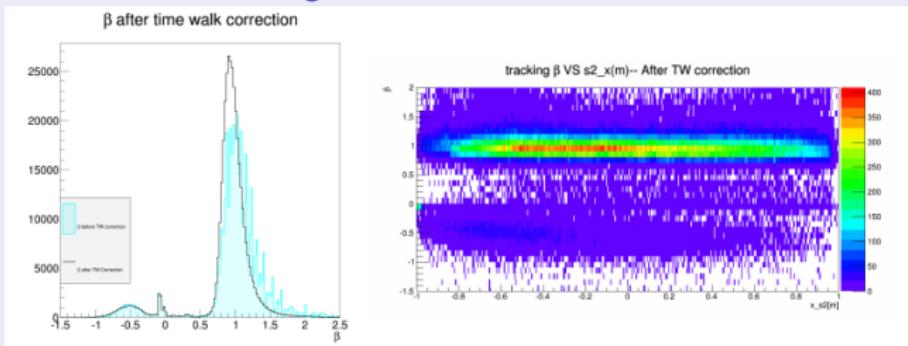
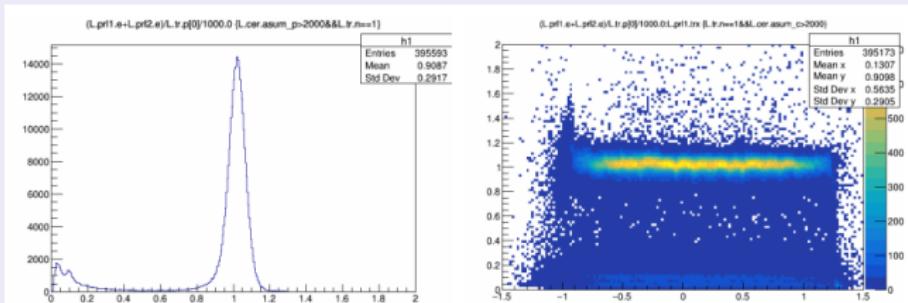


Figure: Calorimeter Energy Calibration



BPM Calibration

Figure: Harp Scan

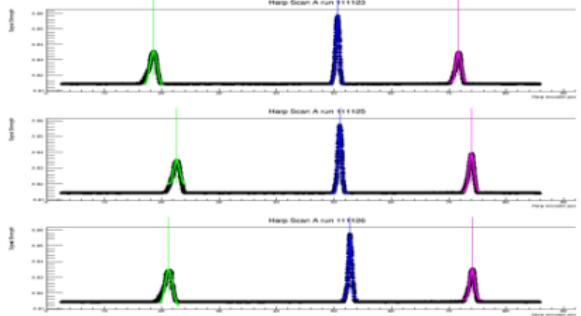


Figure: BPM pedestals

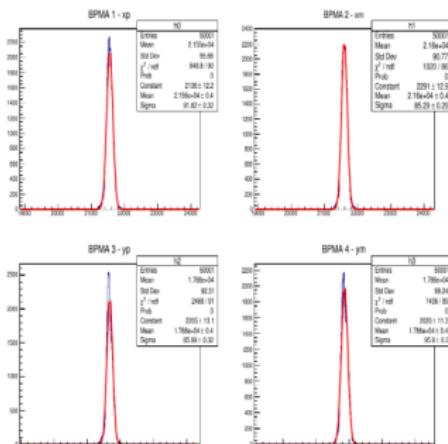
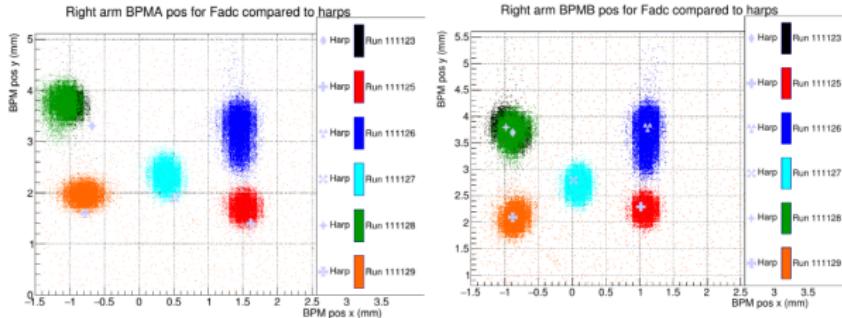


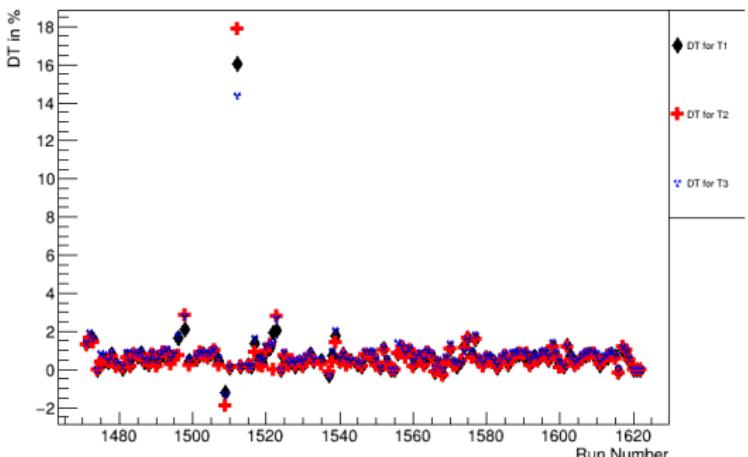
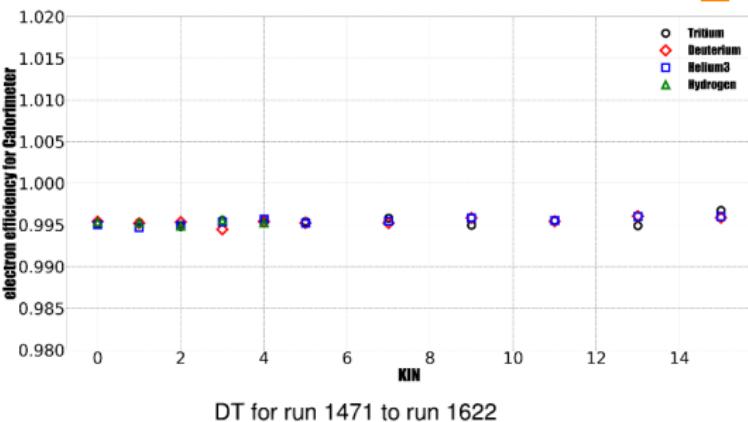
Figure: Before and After





Efficiencies

- Particle ID
- Tracking Efficiency
- Dead Time
- Trigger Efficiency



Systematic Studies

Figure: Density Fluctuations

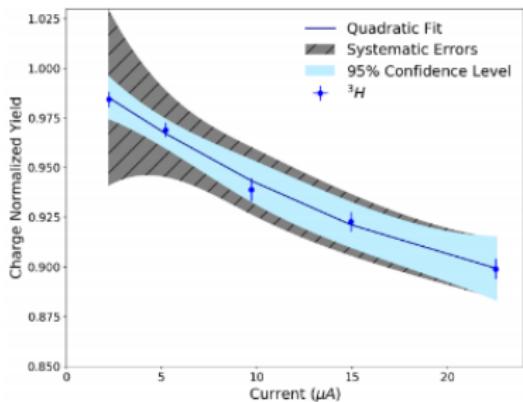


Figure: Tritium beta decay

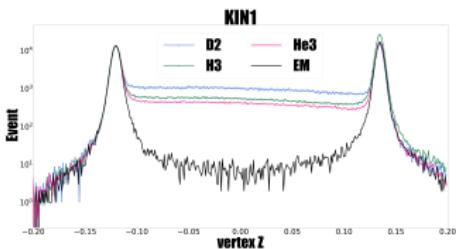
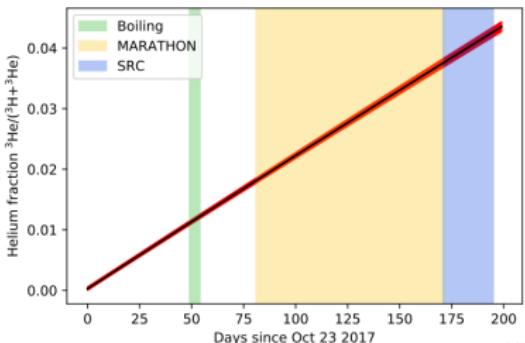


Figure: End Cap Contamination

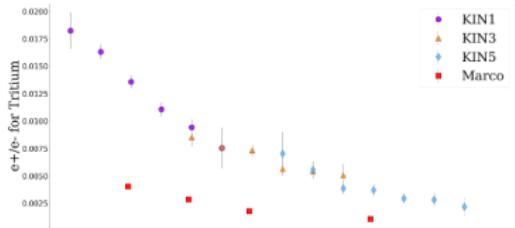
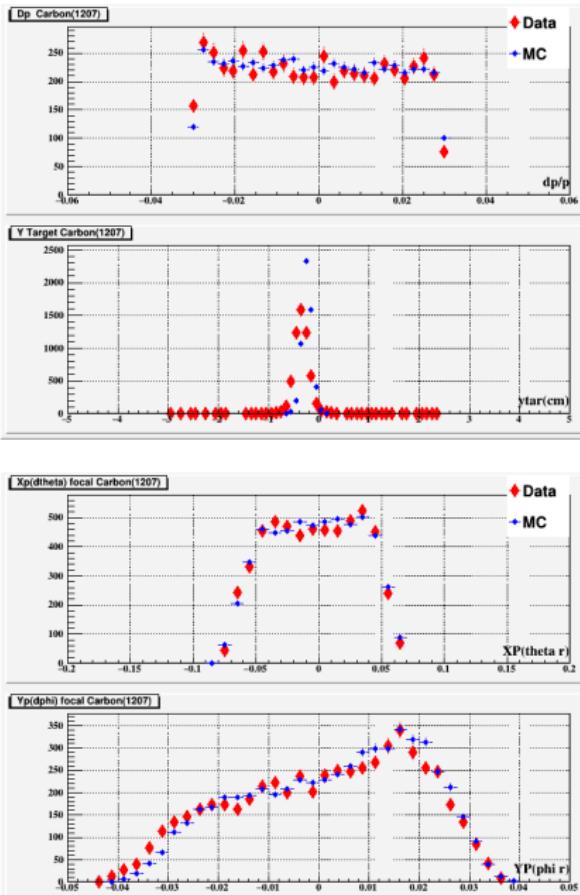


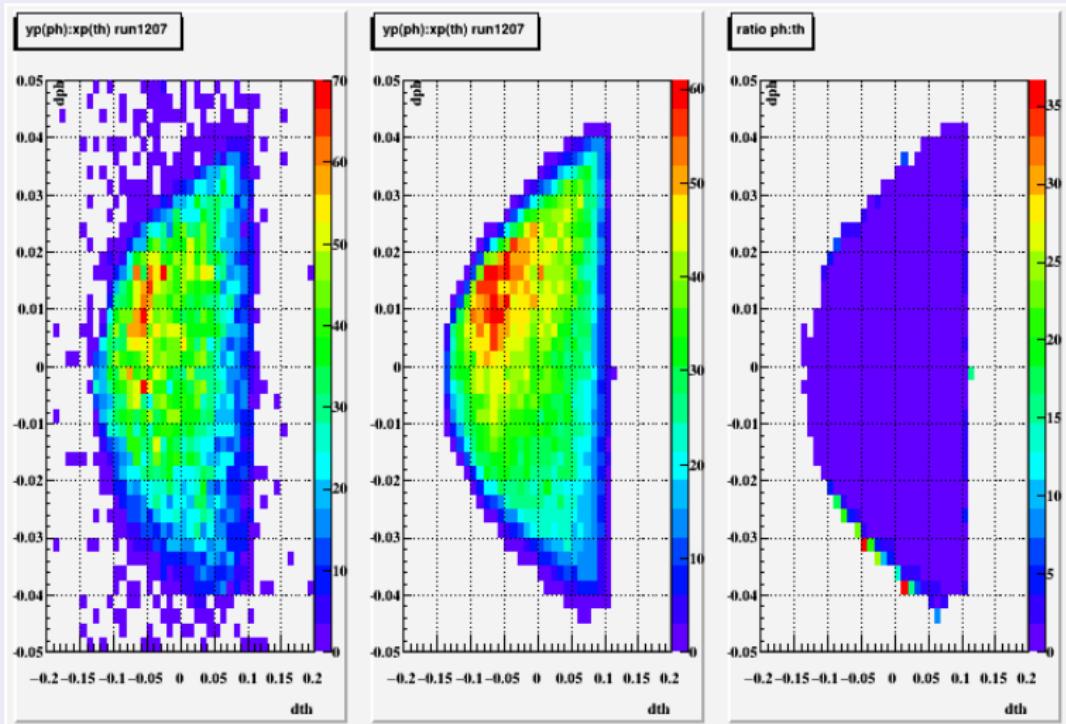
Figure: Charge Symmetric background

Monte Carlo

- Generate events in target space
- Pass through detector aperture
- Use optics matrix to project back to target from focal plane.
- Tune Simulation to match detector response
- Adjust initial parameters
- Use model to weight events
 - ▶ Deep Inelastic and resonance region from Bodek Fit [A. Bodek and U.K. Yang]
 - ▶ Quasi elastic model of F1F2QE09 [P. Bosted and E. Christy]



Acceptance Studies



- Determine where the acceptance is understood the best
- Use comparison plots to make efficient fiducial cuts.



Cross Section

$$N_e = L * \left(\frac{d\sigma}{d\Omega dE'} \right) * (\Delta E' \Delta \Omega) \epsilon * A(E'\theta) + BackGround$$

- L Luminosity \equiv # of electrons per scattering centers
- $(\Delta E' \Delta \Omega)$ = size of bin
- ϵ = efficiencies
- $A(E'\theta)$ = Acceptance

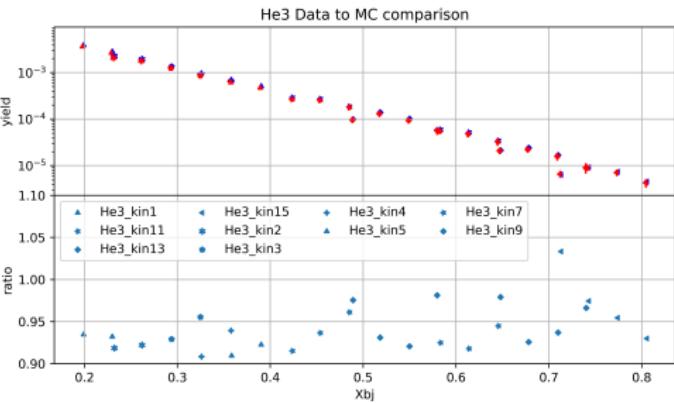
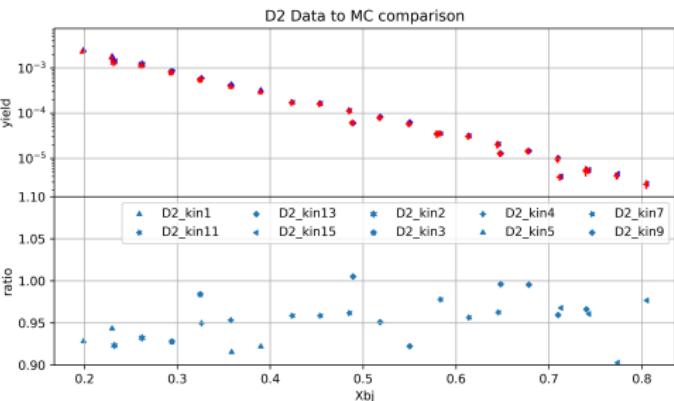
$$Yield_{data} = \frac{(N_e - BackGround)}{Efficiency} = L * \sigma^{data} * (\Delta E' \Delta \Omega) * A(E'\theta)$$

$$Yield_{MC} = L * \sigma^{mod} * (\Delta E' \Delta \Omega) * A(E'\theta)$$

Cross section by Monte carlo ratio method: $\frac{d\sigma}{d\Omega dE'} = \sigma^{mod} * \left[\frac{Yield_{data}(E',\theta)}{Yield_{MC}(E',\theta)} \right]$

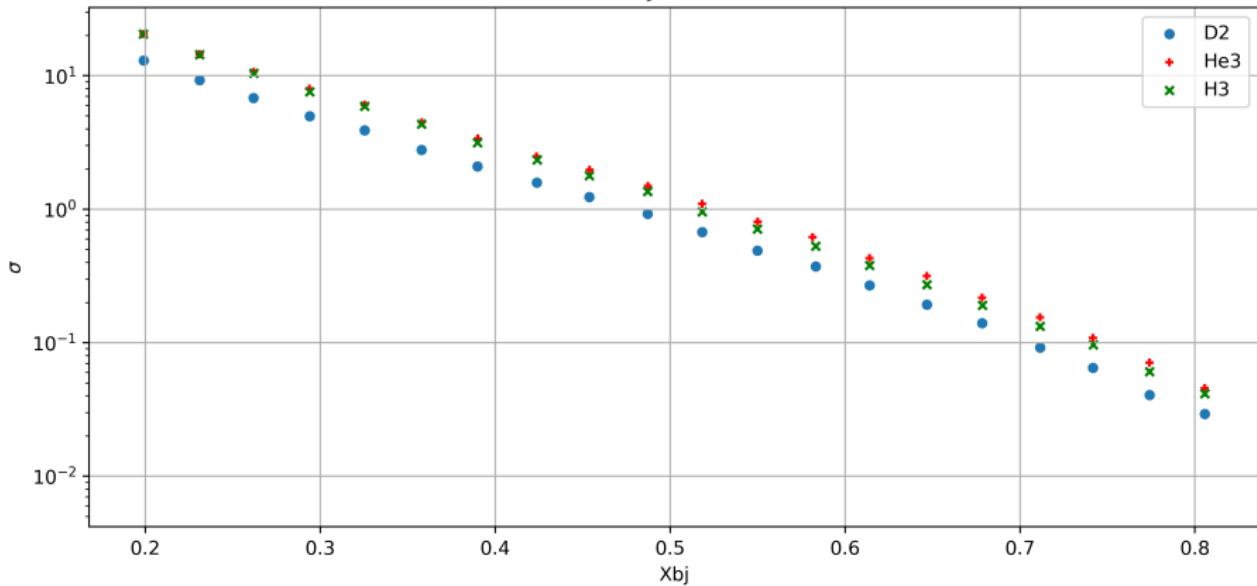
Monte Carlo to Data

- For Deuterium on kin15, we have 66 runs
- Use enough runs to average 10k events per bin
- monitoring the kinematic overlapping region

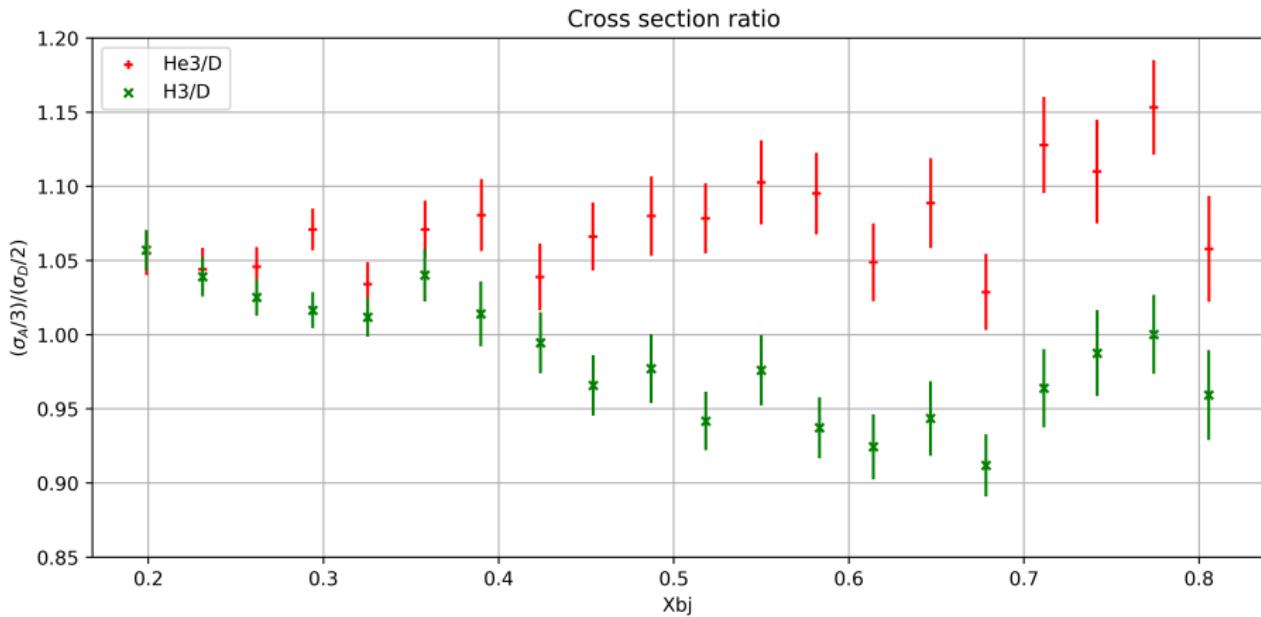


DIS (e, e') Cross section

Cross Section by Monte Carlo Ratio



EMC effect



- Includes statistical error
- Need to add error from systematic studies

Timeline

- Calibrations
- Monte Carlo Tuning $\approx 85\%$
- Detector Efficiencies $\approx 50\%$
 - PID $\approx 90\%$
 - Tracking, Trigger
- Systematic Studies $\approx 50\%$ Need to focus on error estimation.
- Acceptance Studies using Monte Carlo $\approx 75\%$ Finish tuning to move forward
- Extraction of Cross section $\approx 50\%$
- Application of Nuclear Corrections $\approx 5\%$
- Calculation of the EMC effect in A=3 nuclei $\approx 25\%$
- Thesis First Draft $\approx 25\%$
- **Defend by November 1st*!!!!!**
- Done
- January 2019
- January 2019
- WIP
- February 2019
- Feb. - March 2019
- May 2019
- June 2019
- July 2019
- August 2019
- **Graduate**

References



Douglas Higinbotham (2013)

The EMC effect still puzzles after 30 years

Cern Courier April 2013.



J. Gomez et al. (SLAC-E139)

Phys. Rev D 49 (1994) 4348



J.Seely, A. Daniel et al (2013)

New Measurements of the EMC Effect in Very Light Nuclei

nucl-ex/0904.4448.



J. Alcorn et al, (2004)

Basic instrumentation for Hall A at Jefferson Lab

NIM A 522(2004) 294-346



A. Bodek and U.K. Yang

Nuclear Physics B, Procc. Suppl. 112 (2002) 70-76



Bosted & Christy (2008)

Phys. Rev. C 77, 065206 (2008)

The End

BackUp



Data Yield calculation

Included Systematic Corrections

- Positron Correction
- End Cap Contamination
- Radiative Corrections
- Density modification correction.

Included Efficiencies

- Electronic Dead time

Need to implement

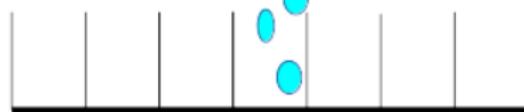
- Pion contamination/PID efficiency
- Trigger efficiency
- Tracking efficiency
- Scintillator efficiency

Binning

Kin 1



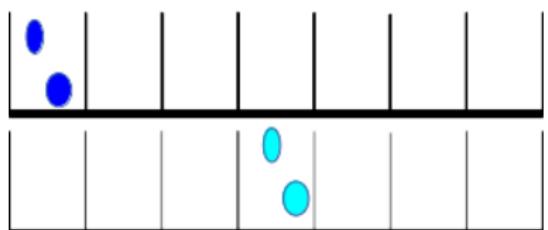
Kin 5



X_{bj}

X_{bj}

Binning



Kin 15



X_{bj}

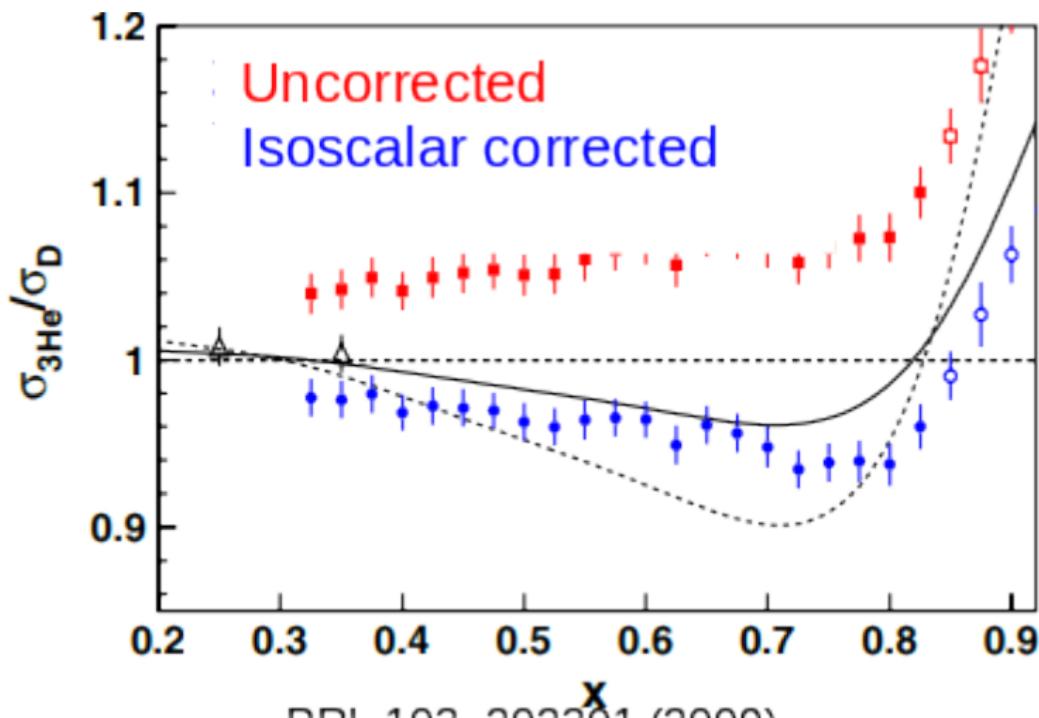


Kin 5



X_{bj}

Isoscaler Corrections



PRL 103, 202301 (2009)