

# EMC Effect for A=3

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# Outline

1 EMC Effect

2 MARATHON

- Setup
- Run Period

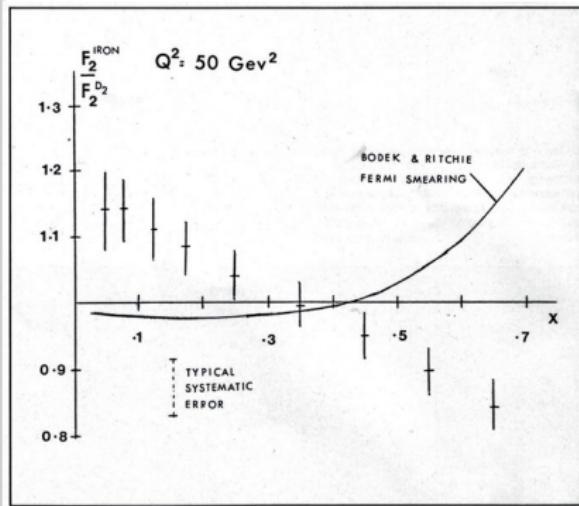
3 Analysis

# 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].





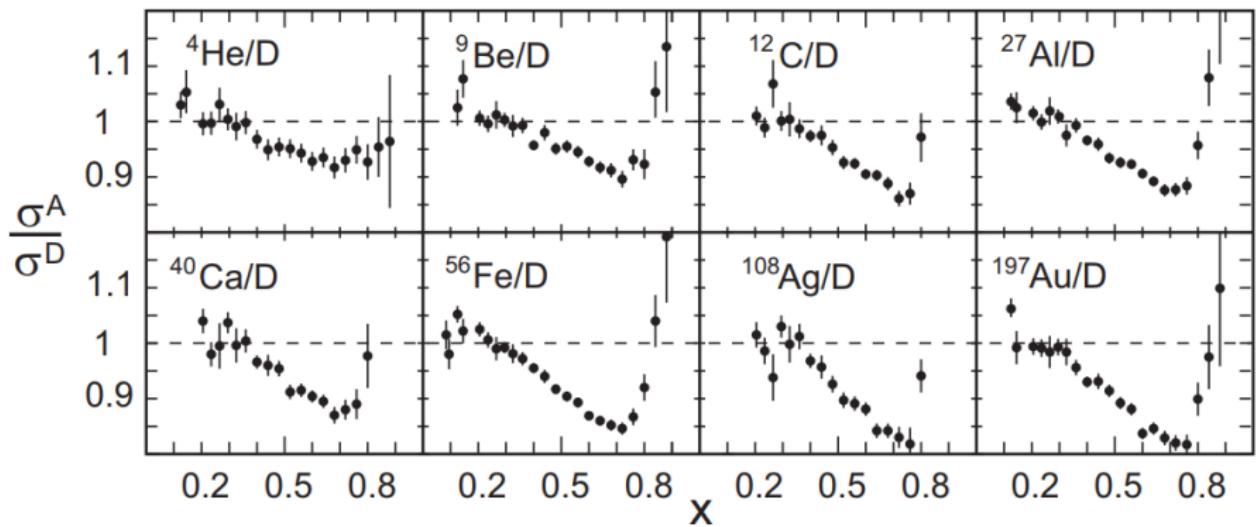
# EMC Effect

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 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].

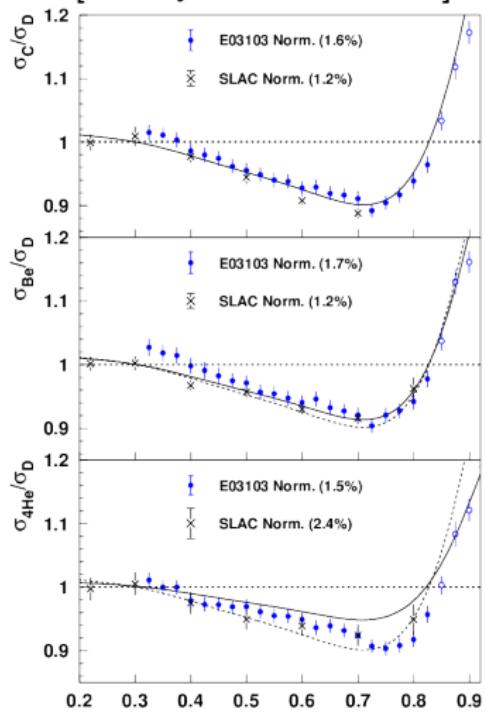
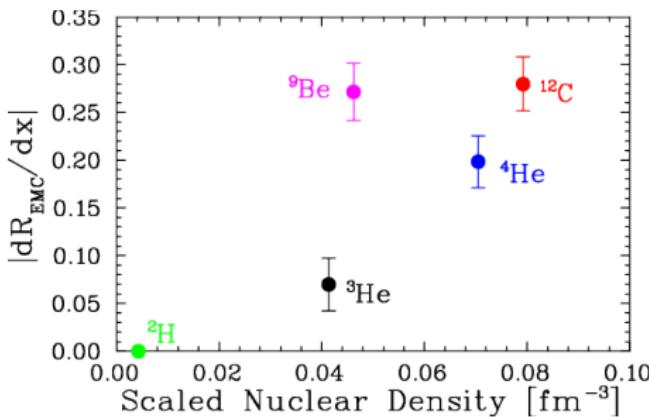
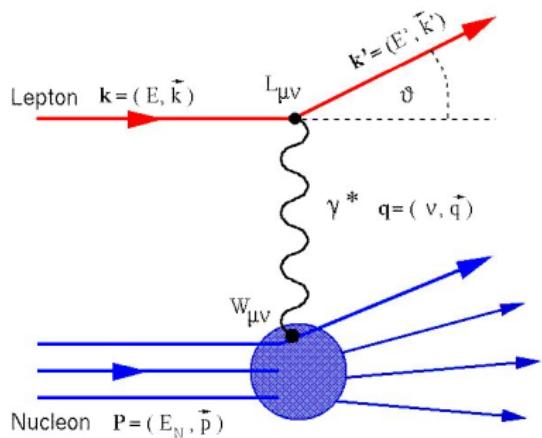


Figure: EMC as a function of Nuclear Density [J.Seely, A. Daniel et al].



# Deep Inelastic Scattering (DIS)

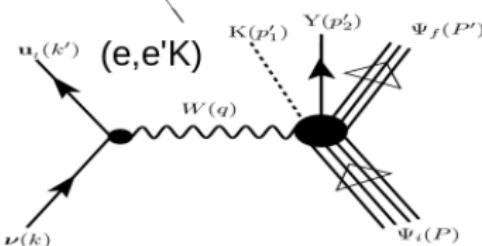
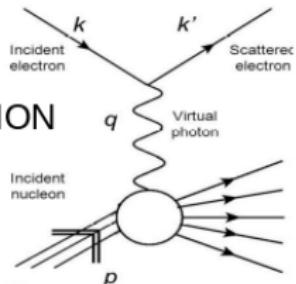
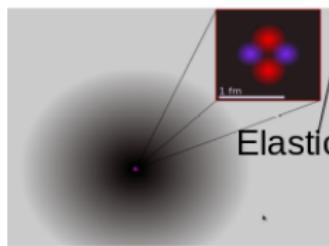
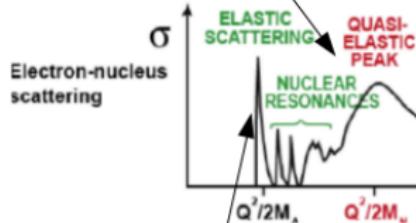
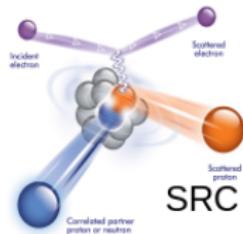


- Momentum Transfer  

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

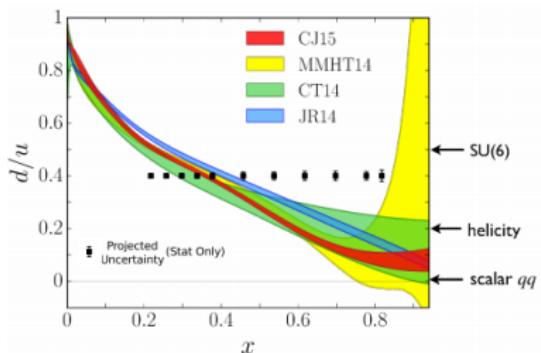
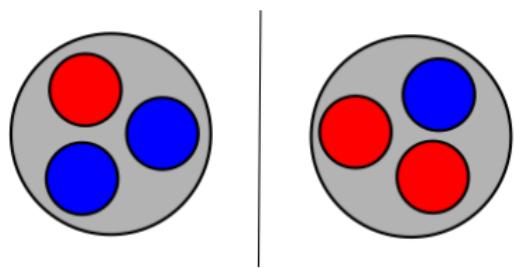
$$W^2 = 2M\nu + M^2 - Q^2$$
- $W^2 > 4 \rightarrow \text{DIS}$

# 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.

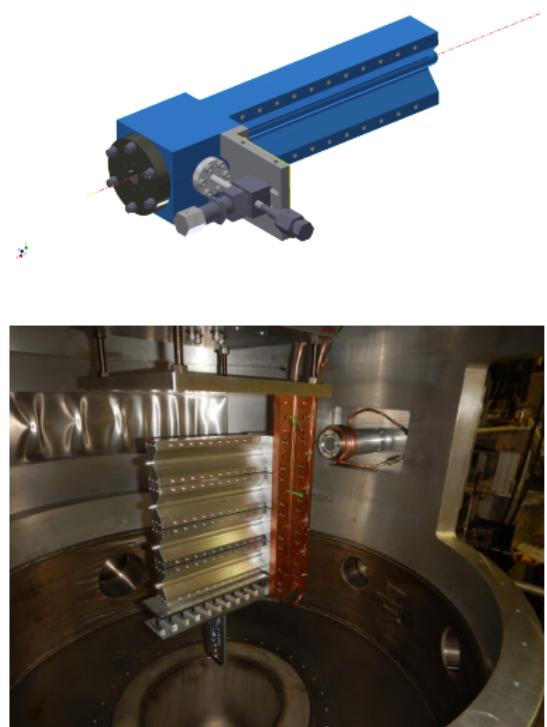


- Lightest and simplest mirror system
  - ▶ Number of protons in  ${}^3H$  = neutrons in  ${}^3He$
- Differences in the nuclear effects are small
- Improve the current measurement and understanding of  $F_{n2}$  to  $F_{p2}$  ratio
- Restrict the assumptions and parameters made in the model calculations of the down to up quark distribution ratio

# Tritium Target Cell

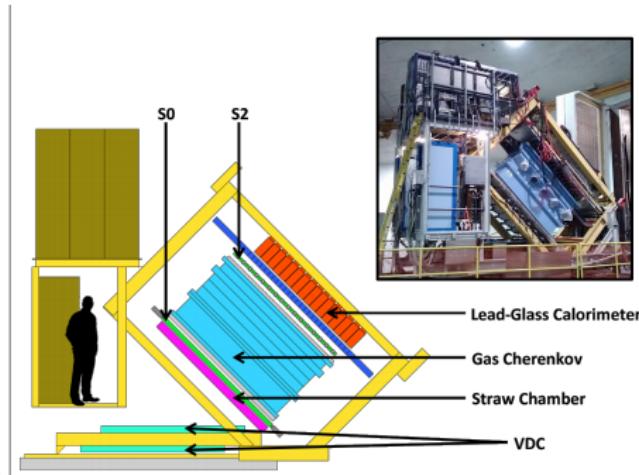
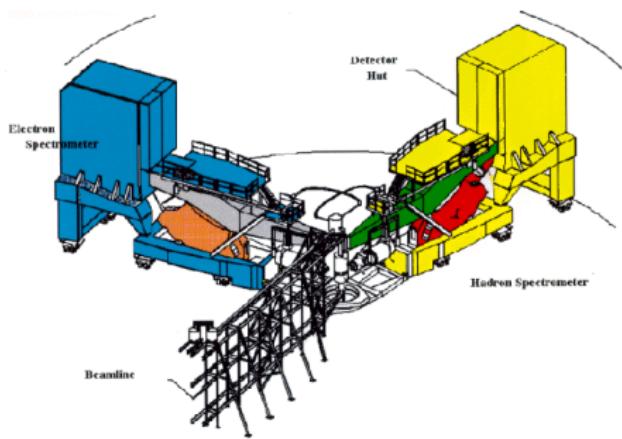
First tritium target at JLab

- 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

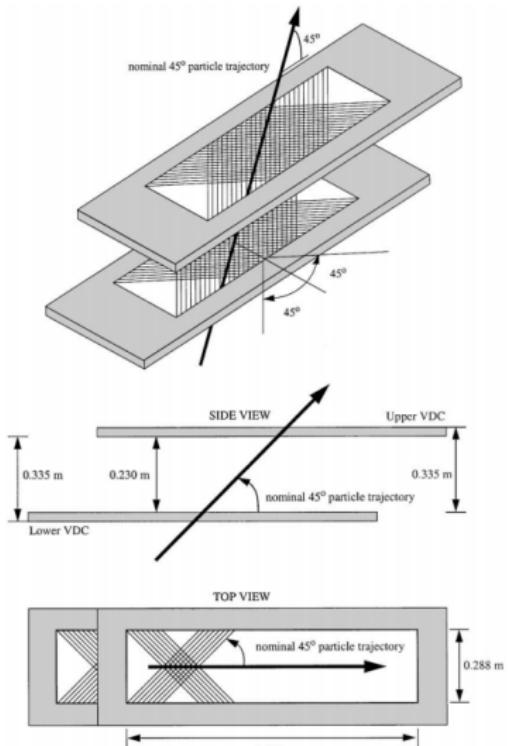


# Hall A & The HRSs

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



# Vertical Drift Chamber(VDC)

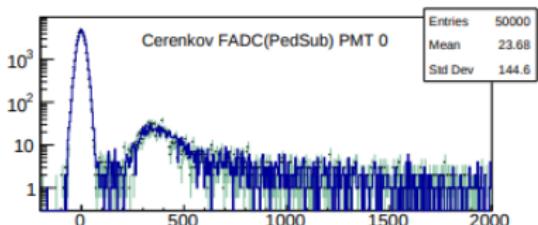
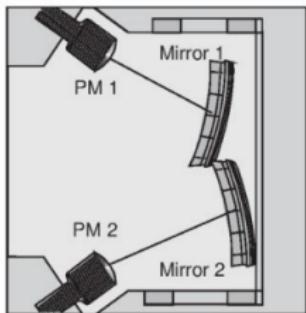


## Tracking Detector

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

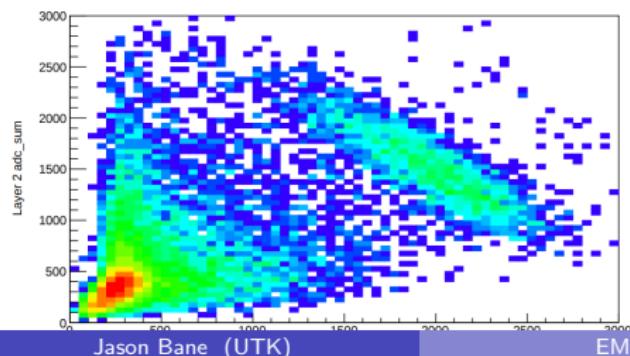
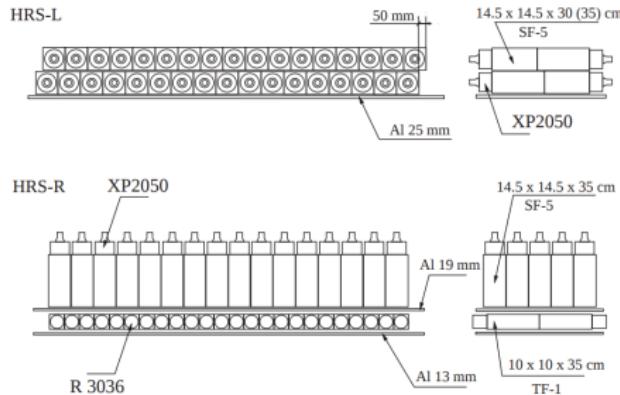


## PID Detector

- 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

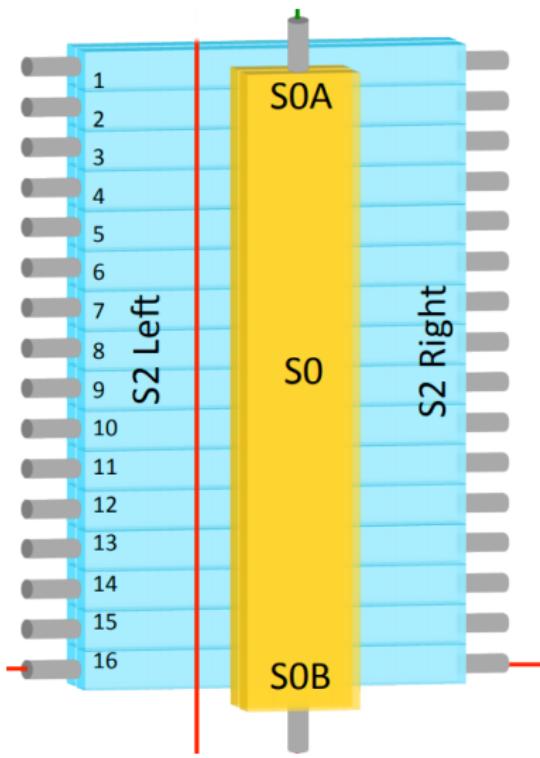
## PID Detector

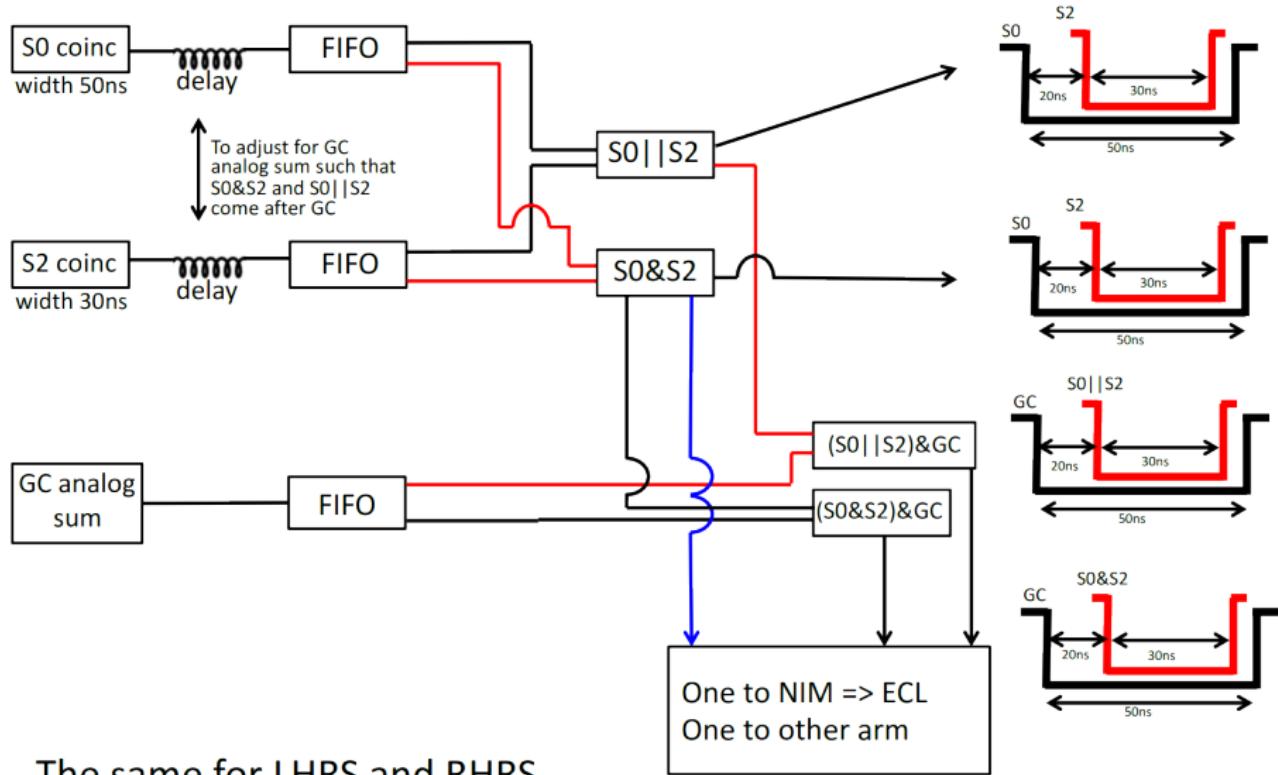
- Two layers of lead glass
- LHRs - Both layers are stacked perpendicular to beam direction.
  - ▶ 48 Blocks, 80 blocks
- RHRs - First layer perpendicular, second layer is parallel
  - ▶ 34 Blocks, 34 blocks
- With Cherenkov, pion suppression above  $2 \frac{\text{GeV}}{c}$  of a factor of 2e5 [J. Alcorn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



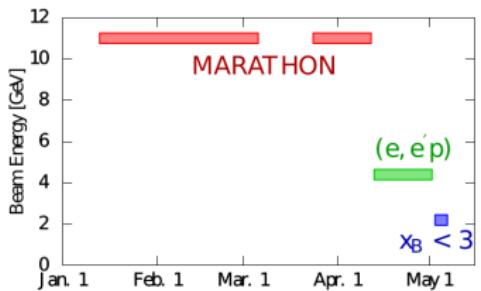
Single Arm Triggers ( $S_0 \& S_2$ );  $(S_0 \& S_2) \& GC$ ;  $(S_0 \mid\mid S_2) \& GC$ 

The same for LHRS and RHRs

Figure: By Florian Hauenstein

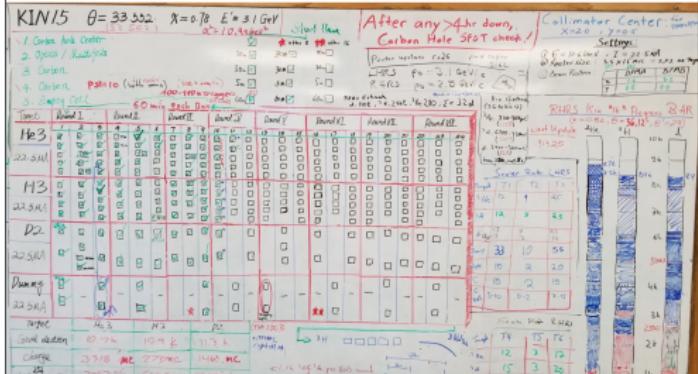


# The Run Period



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



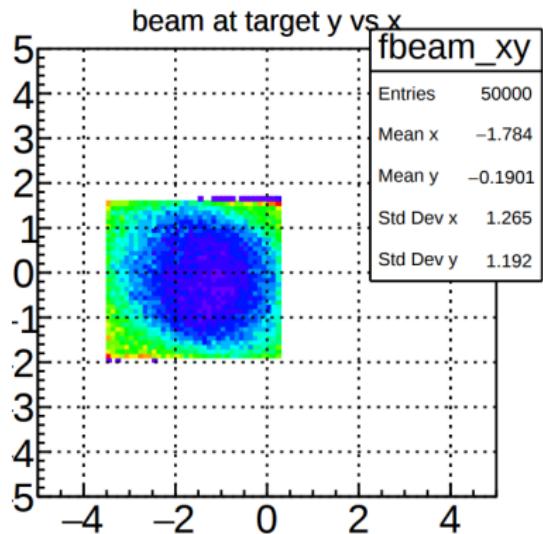
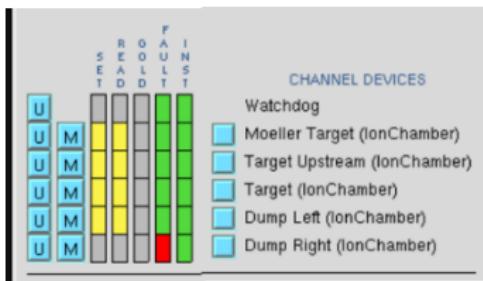
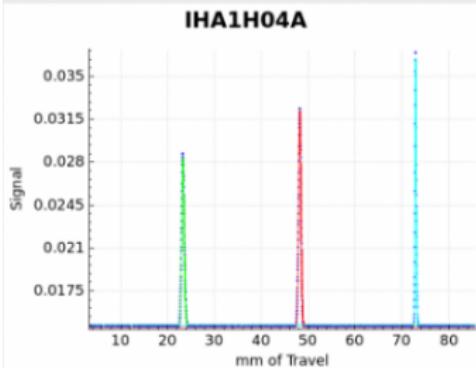


# Major Miscues

- 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  $36.12^\circ$ , 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

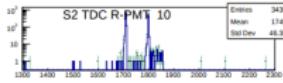
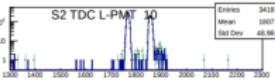
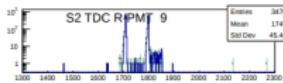
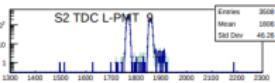
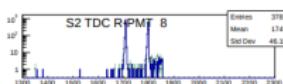
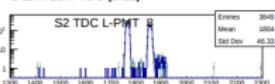
## Tritium Safety Requirements

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

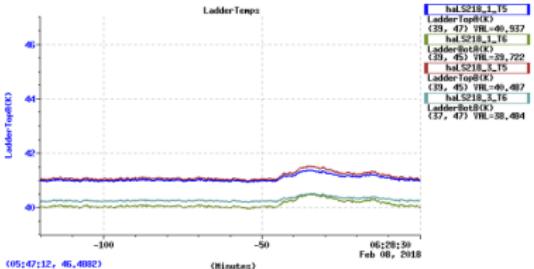


Run #1894

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

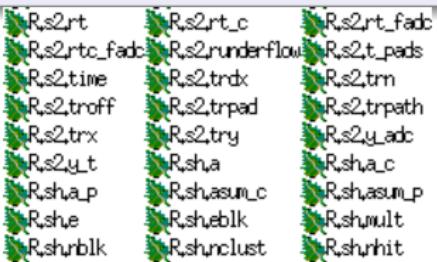
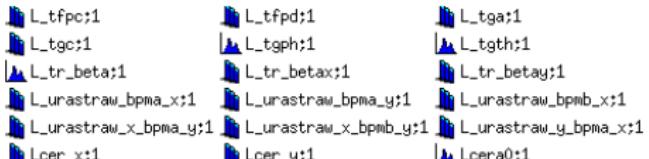
- Cross section extraction through Data to Monte Carlo ratio method
- Application of Nuclear Corrections
- Compare Cross Section of A=3 Nuclei to that of Deuterium to calculate EMC effect

# Data Decoding

## The Hall A Analyzer

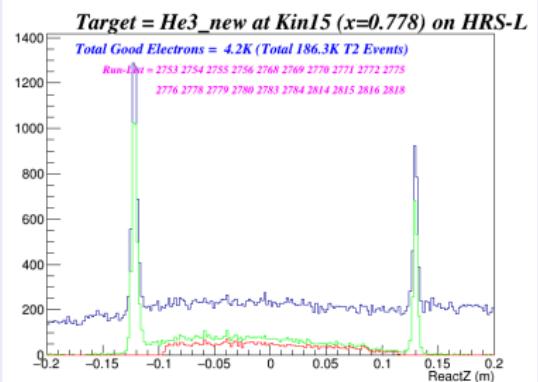
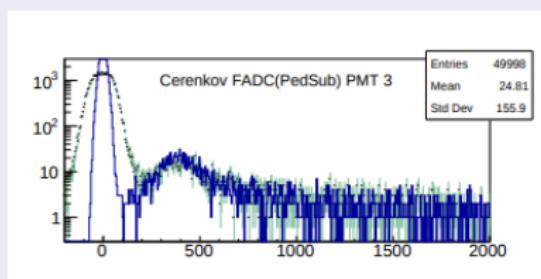
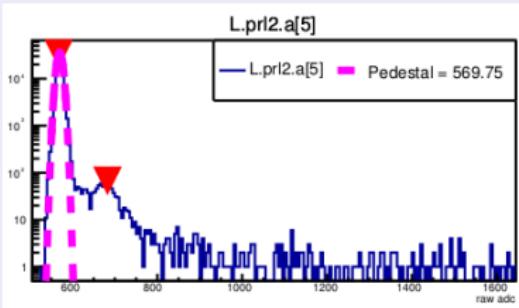
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* W E L C O M E to the *
* H A L L A C++ A N A L Y Z E R *
*
* Release 1.7.0-devel      May 01 2018 *
* Based on ROOT 6.08/00     Nov 4 2016 *
*
* For information visit   *
* http://hallaweb.jlab.org/podd/ *
*****
analyzer [0] ■
```

- 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
- TriFADCBPM



# Online Analysis

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



# Detector Calibrations

Figure: BCM calibration

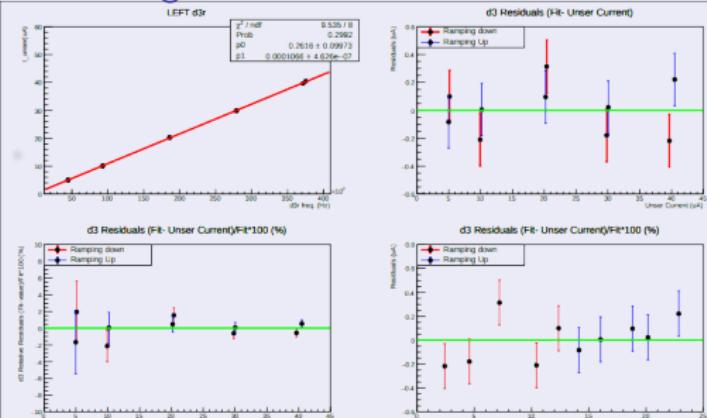
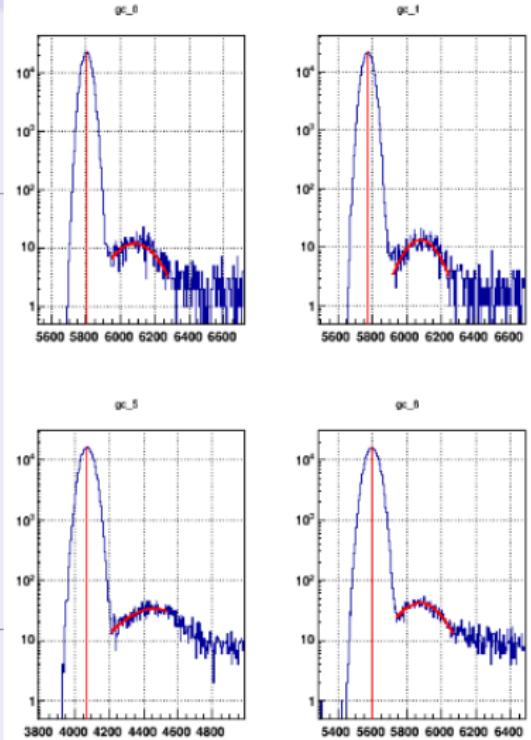


Figure: Gain and Pedestal calibration



# Detector Calibrations

Figure: Beta calibration

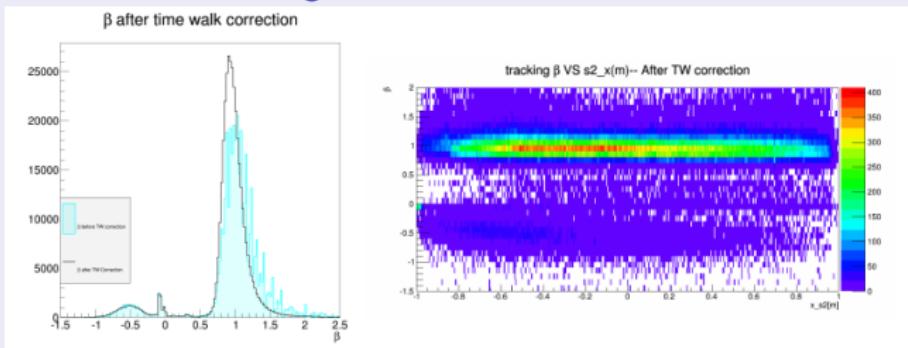
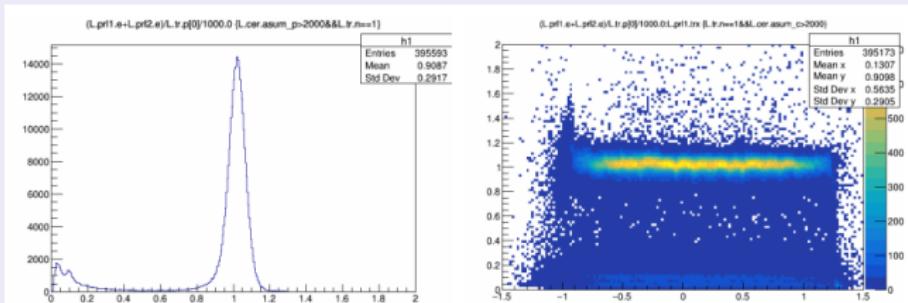


Figure: Calorimeter Energy Calibration



# BPM Calibration

Figure: Harp Scan

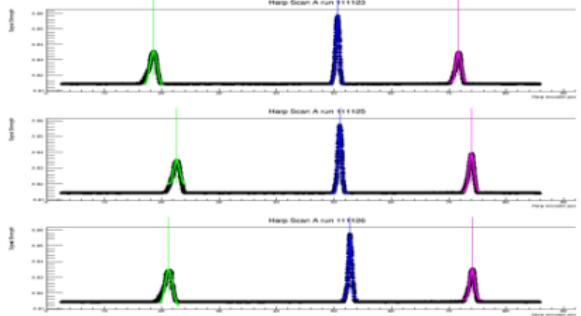


Figure: BPM pedestals

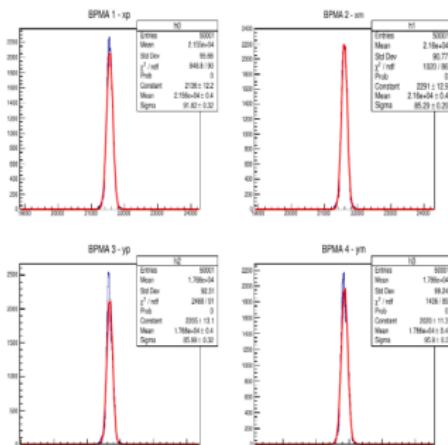
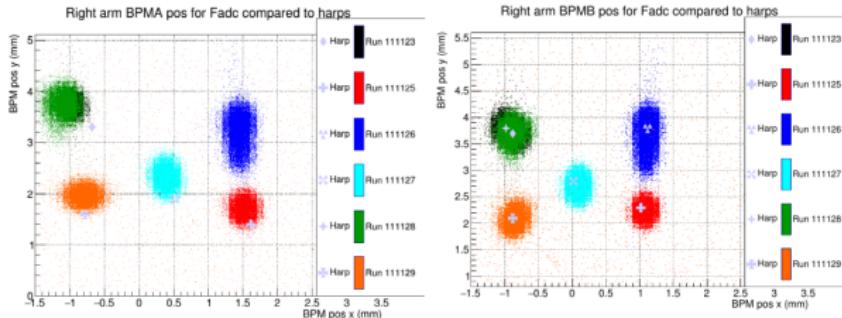


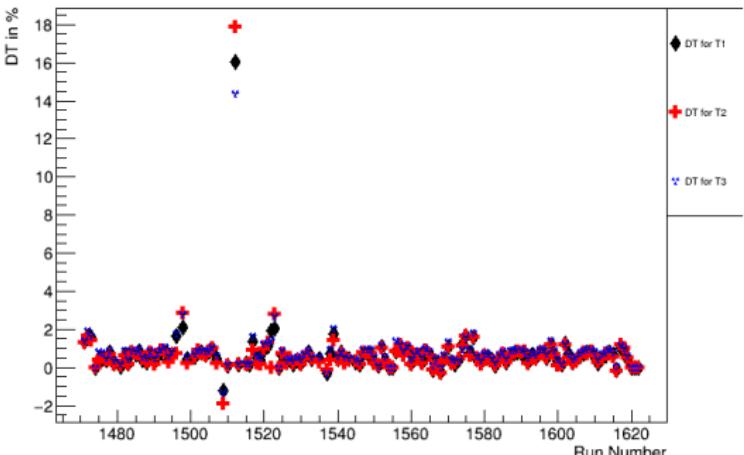
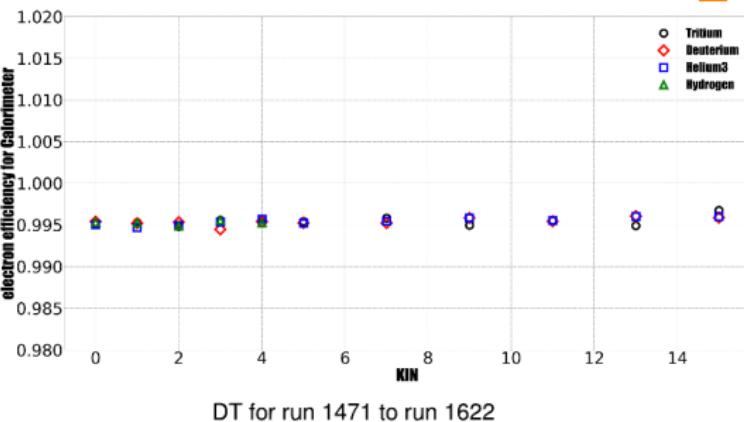
Figure: Before and After





# Efficiencies

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



# Systematic Studies

Figure: Density Fluctuations

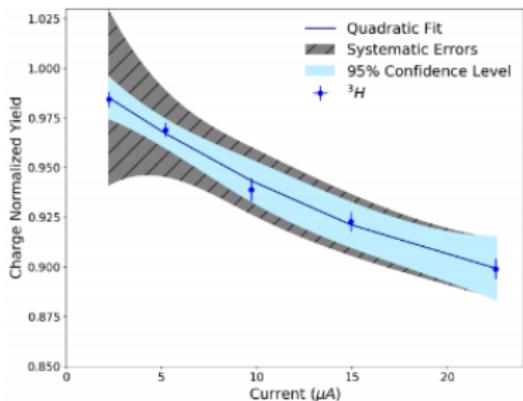


Figure: Tritium beta decay

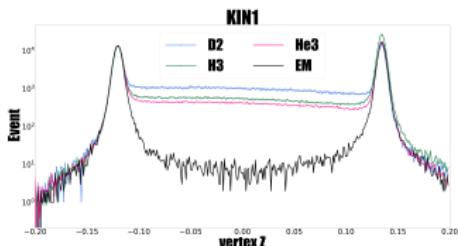
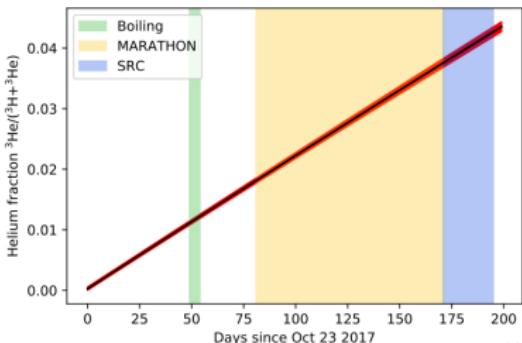


Figure: End Cap Contamination

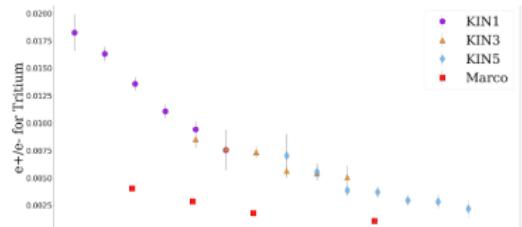
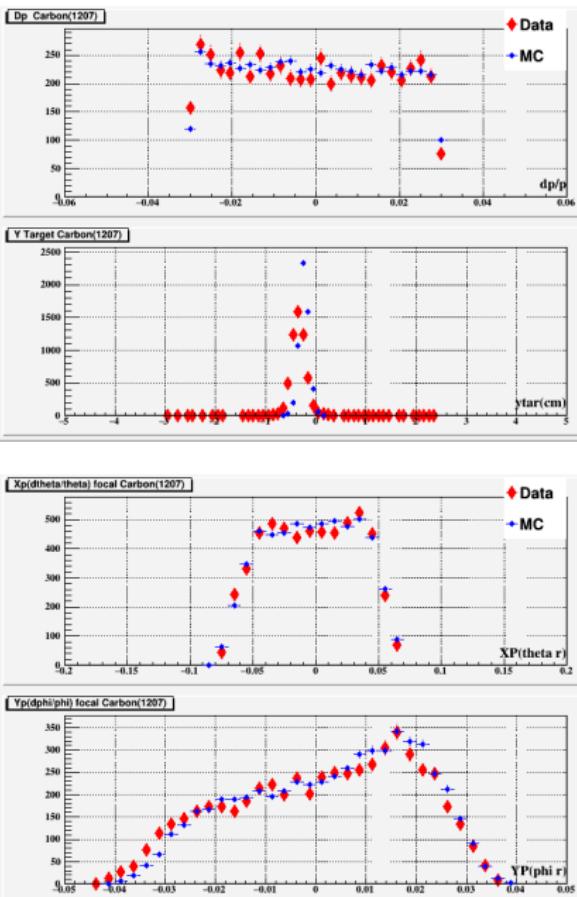


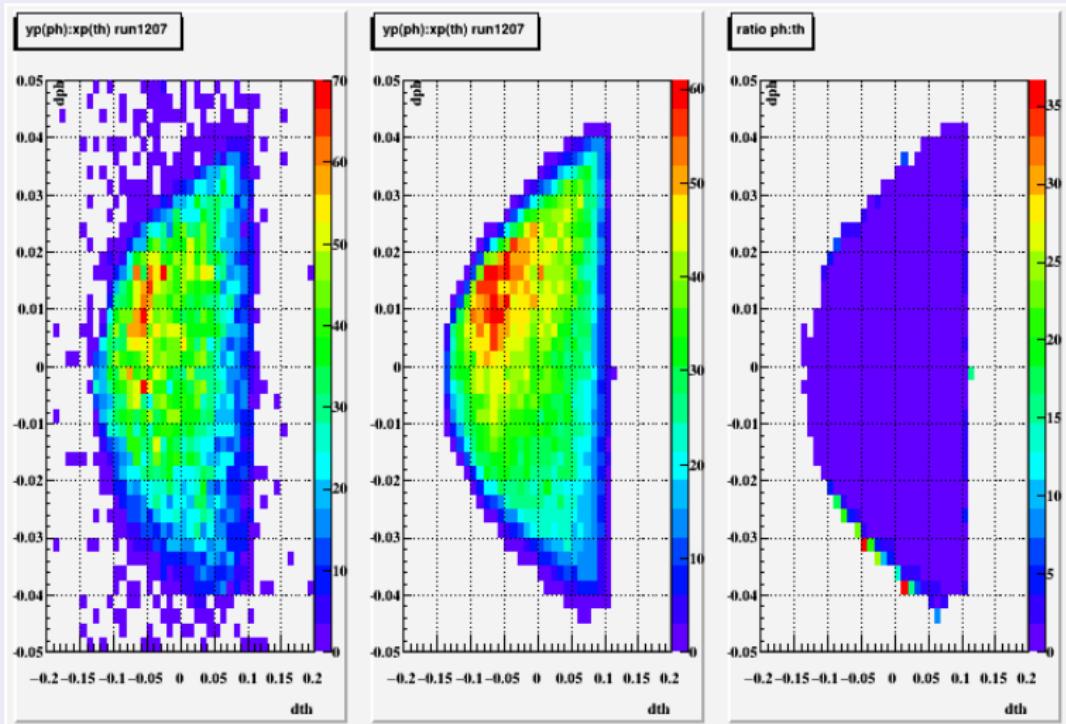
Figure: Charge Symmetric background

## 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 Bodek Fit [A. Bodek and U.K. Yang]
  - ▶ Quasi elastic and elastic



# 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
- $(\Delta E' \Delta \Omega)$  = Phase space
- $\epsilon$  = efficiencies
- $A(E'\theta)$  = Acceptance

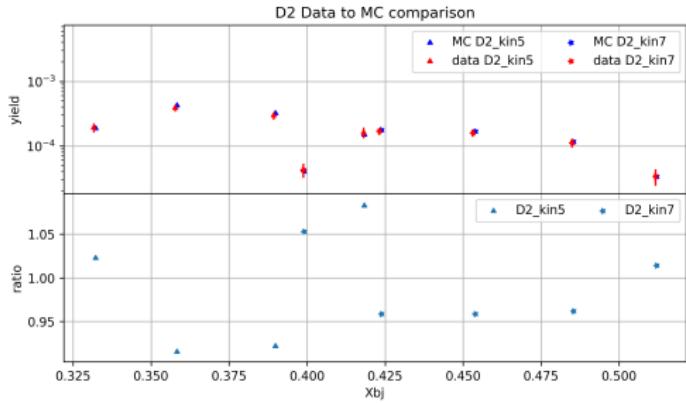
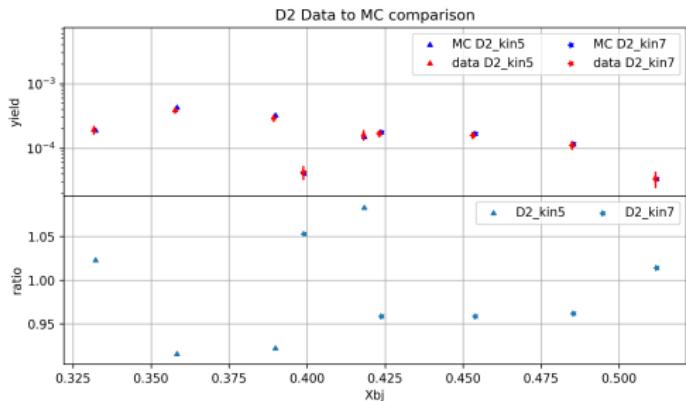
$$Yield_{data} = \frac{(N_e - BackGround)}{Efficiency} = L * \sigma^{data} * (\Delta E' \Delta \Omega) * A(E'\theta)$$

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

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

- Generate 1 Million events per run
- Use enough runs to average 10k events per bin





## Timeline

- Calibrations
- Monte Carlo Tuning  $\approx 85\%$
- Detector Efficiencies  $\approx 50\%$ 
  - PID is done
  - 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
- February 2019
- WIP
- February 2019
- Feb. - March 2019
- May-June 2019
- July 2019
- July - August 2019
- August -Sept. 2019
- **Graduate**



# References

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The EMC effect still puzzles after 30 years  
*Cern Courier* April 2013.
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*Phys. Rev D* 49 (1994) 4348
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New Measurements of the EMC Effect in Very Light Nuclei  
[\*nucl-ex/0904.4448\*](https://arxiv.org/abs/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.* Fall (2002)

# The End

# backup

