EMC Effect for A=3

Jason Bane

University of Tennessee

jbane1@vols.utk.edu

November 23, 2018

Outline

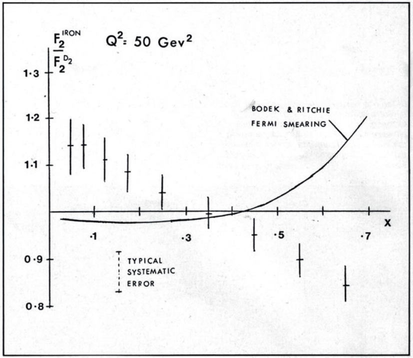
1. EMC Effect
2. MARATHON
   - Setup
   - Run Period
3. Analysis

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 then 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].



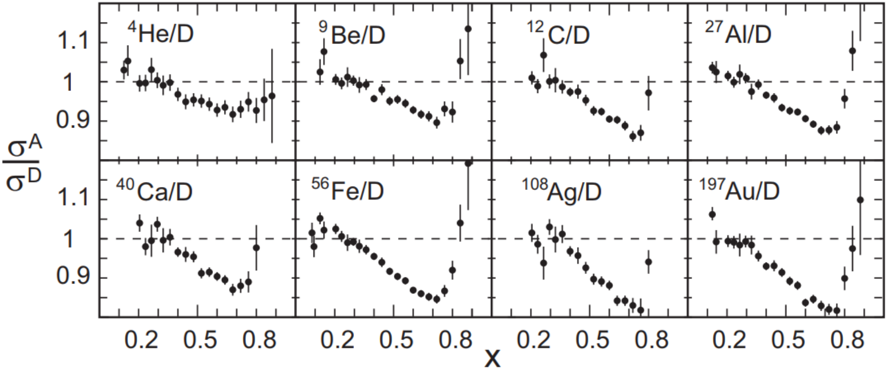
EMC Effect

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].

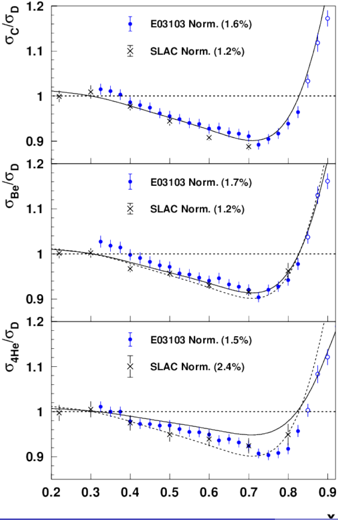
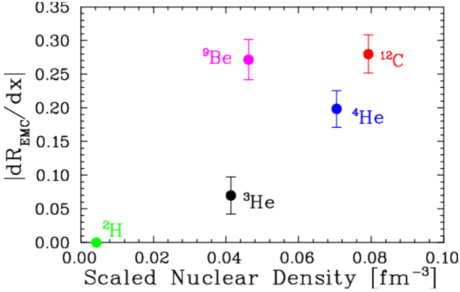
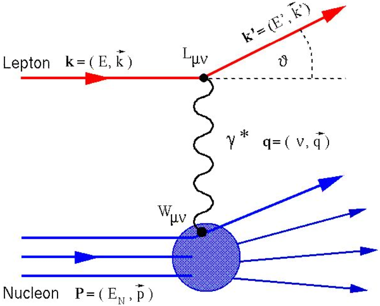


Figure: EMC as a function of Nuclear Density [J.Seely, A. Daniel et al].

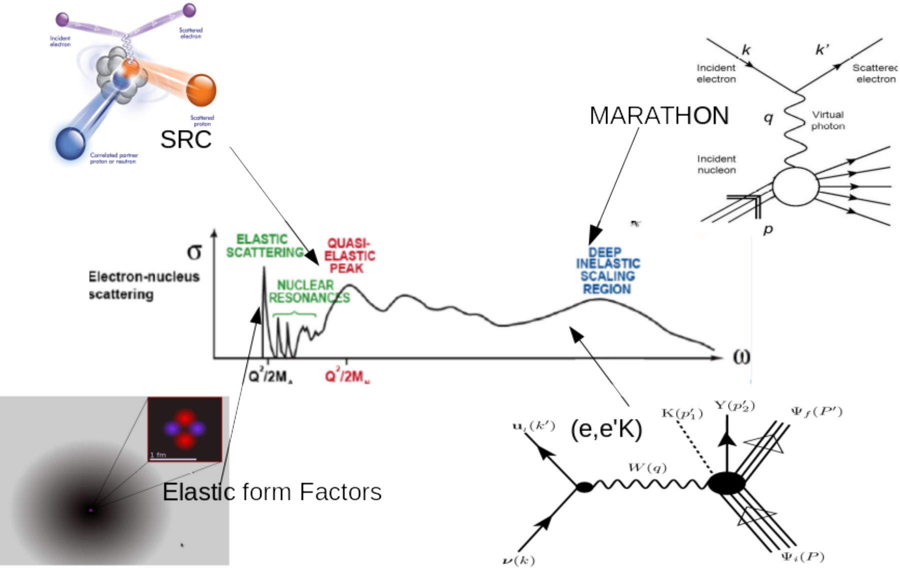


Deep Inelastic Scattering (DIS)



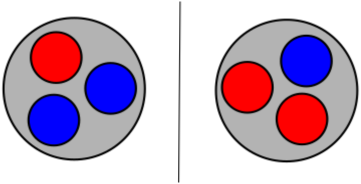
- Momentum Transfer $Q^2 \equiv 4EE' sin\frac{\theta}{2}$
- Bjorken X $(X_{bj}/x) = \frac{Q^2}{2\nu M}$
- $\sigma_{eN} = \frac{\alpha^2}{eE^2 sin^4(\frac{\theta}{2})}[\frac{F_2}{\nu} cos^2\frac{\theta}{2} + \frac{2F_2}{M} sin^2\frac{\theta}{2}]$
- Invariant Mass $W^2 = 2M\nu + M^2 - Q^2$
- $W^2 > 4 \rightarrow$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

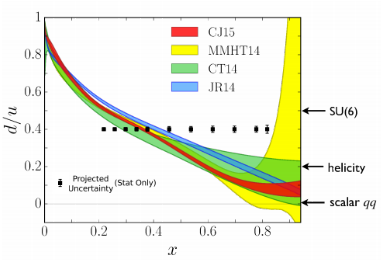
Tritium Experiments



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.



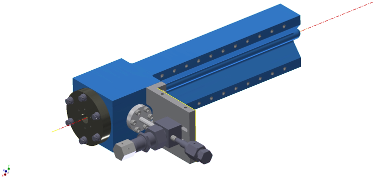


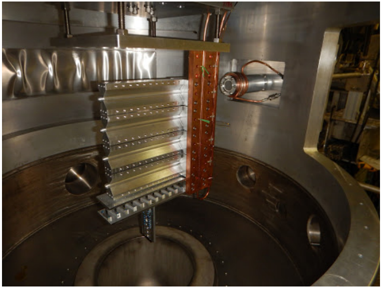
- Lightest and simplest mirror system
  - Number of protons in ^3H = neutrons in ^3He
- Differences in the nuclear effects are small
- Improve the current measurement and understanding of Fn2 to F p2 ratio
- Restrict the assumptions and parameters made in the model calculations of the down to up quark distribution ratio

Tritium Target Cell

First tritium target at JLab

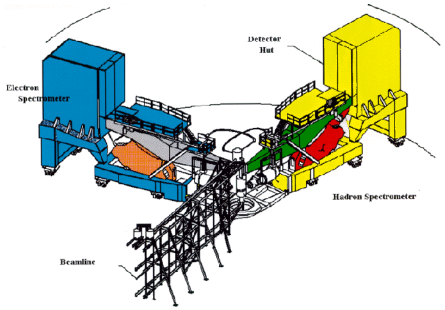
- Thin Al entrance and exit windows 0.01 inches
- 1090Ci of Tritium (0.1 g)
- 25 cm long
- Tritium Cell was filled in Savannah River
- 40 kelvin Helium is used to cool an attached heat sink

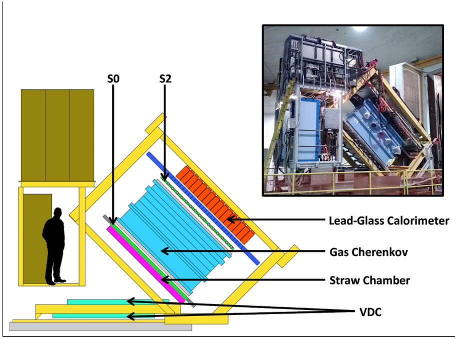




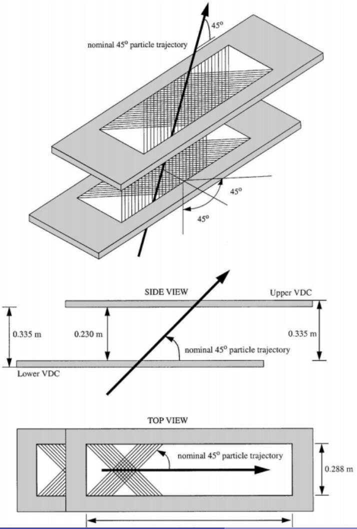
Hall A & The HRSs

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





Vertical Drift Chamber(VDC)

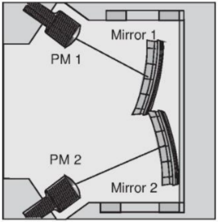


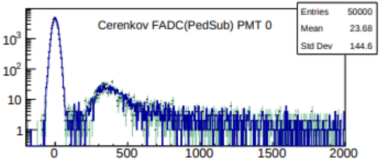
Tracking Detector

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

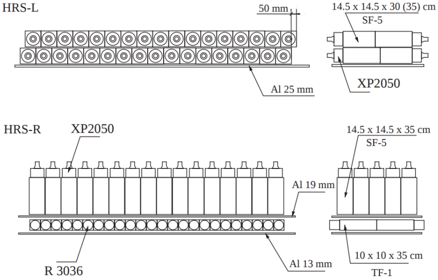


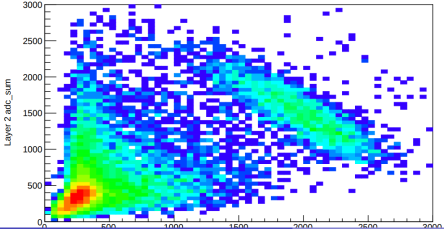


PID Detector

- 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





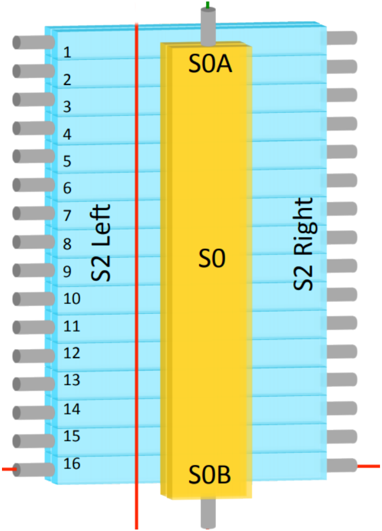
PID Detector

- 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 Chernenkov, pion suppression above $2\frac{GeV}{c}$ of a factor of 2e5 [J. Alcorn et al.]

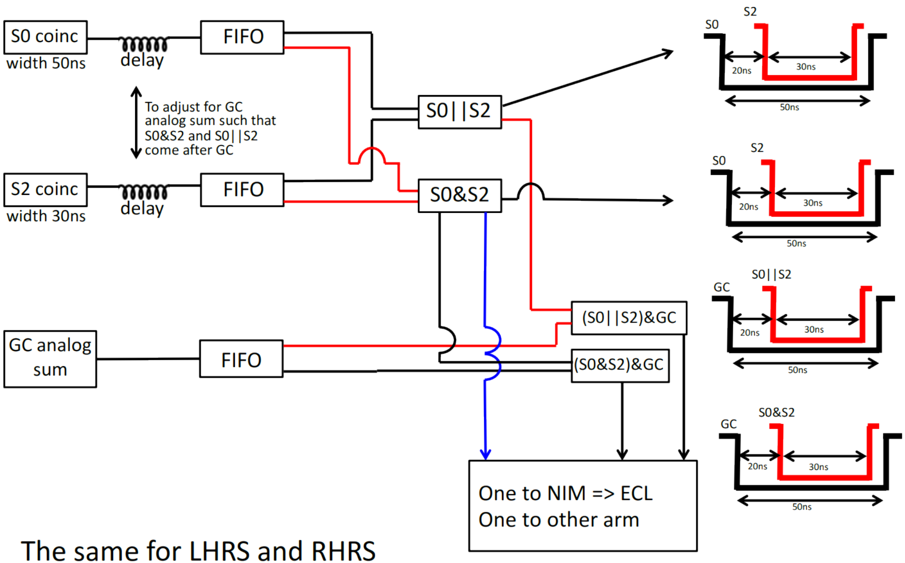
Scintillators

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.]



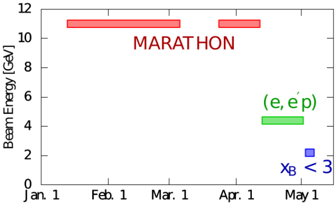
Single Arm Triggers (S0&S2); (S0&S2)&GC; (S0||S2)&GC



The same for LHRS and RHRS

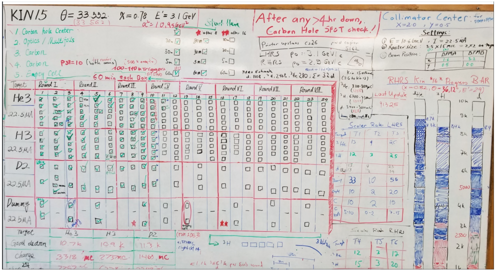
Figure: By Florian Hauenstein

The Run Period



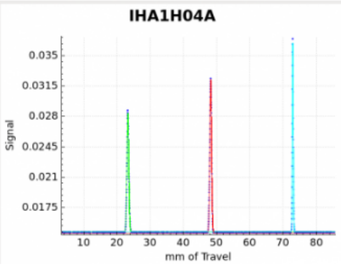
Rey Torres

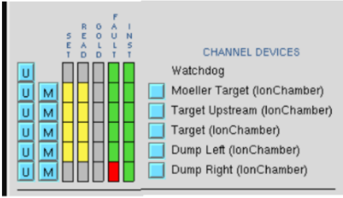
- Ran from January 11th to April 12th of 2018.
- Gaseous Tritium, Deuterium, Helium-3, and Hydrogen
- Single Carbon Foil, Carbon foil with hole, and multi-foil
- Rotated through targets to achieve equal statics and reduce the impact of unforeseen circumstances



Major Miscues

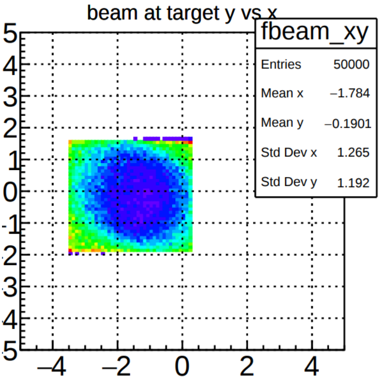
- Right Arm Dipole failed on January 11th
  - Return the dipole to functionally the following day
  - 01/13 - Dipole failed again, causing a chain reaction with the Left arm
  - Solution could not be found quickly
  - Change of Kinematic plan to use single HRS.
  - Recovered RHRS on 01/16 - Set to take 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





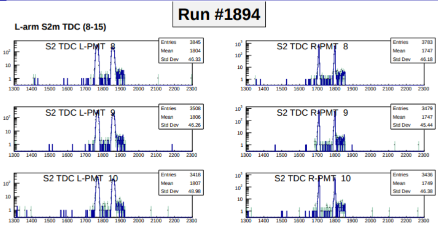
Tritium Safety Requirements

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

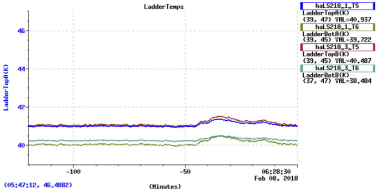


Shift Crew Task

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



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



Analysis

Data Analysis Task

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

Monte Carlo Analysis

- Monte Carlo Tunning
  - 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

```
*************************************************
*                                               *
*            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]
```

The Hall A Analyzer

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

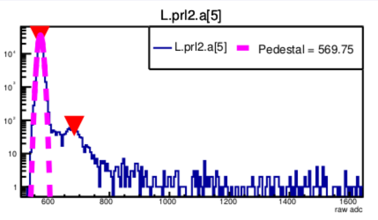
- THaRasterBeamClass
- THaCherenkov
- THaTrackingDetector
- Tri_Beam_Eloss
- TriBCM
- TriFADCBPM

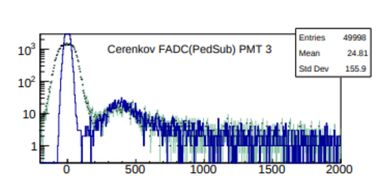
L_tfpc;1	L_tfpd;1	L_tga;1
L_tgc;1	L_tgph;1	L_tgth;1
L_tr_beta;1	L_tr_betax;1	L_tr_betay;1
L_urastraw_bpma_x;1	L_urastraw_bpma_y;1	L_urastraw_bpmb_x;1
L_urastraw_x_bpma_y;1	L_urastraw_x_bpmb_y;1	L_urastraw_y_bpma_x;1
Lcer_x;1	Lcer_y;1	Lcera0;1

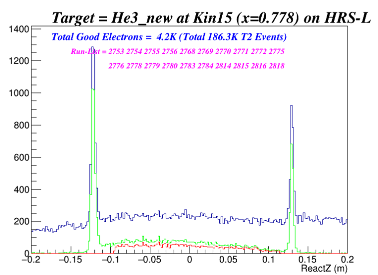
R.s2.rt	R.s2.rt_c	R.s2.rt_fadc
R.s2.rtc_fadc	R.s2.runderflow	R.s2.t_pads
R.s2.time	R.s2.trdx	R.s2.trn
R.s2.troff	R.s2.trpad	R.s2.trpath
R.s2.trx	R.s2.try	R.s2.y_adc
R.s2.y_t	R.sh.a	R.sh.a_c
R.sh.a_p	R.sh.asum_c	R.sh.asum_p
R.sh.e	R.sh.eblk	R.sh.mult
R.sh.nblk	R.sh.nclust	R.sh.nhit

Online Analysis

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







Detector Calibrations

Figure: BCM calibration

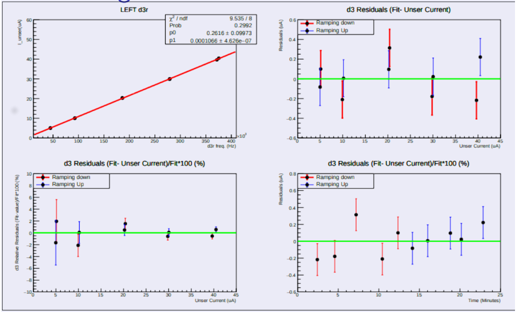
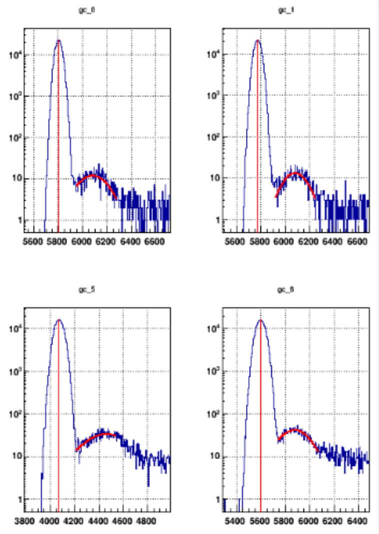


Figure: Gain and Pedestal calibration



Detector Calibrations

Figure: Beta calibration

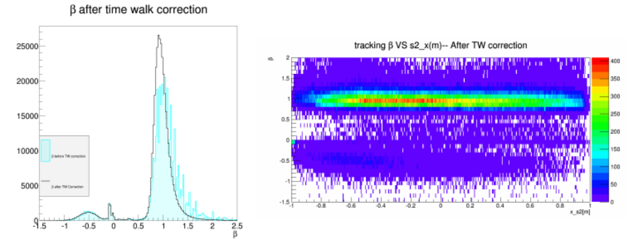
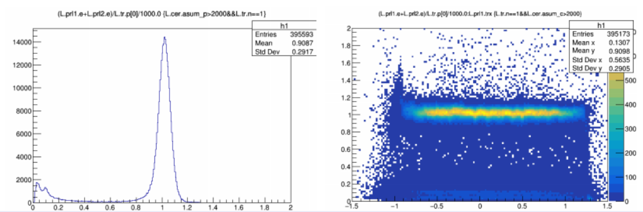


Figure: Calorimeter Energy Calibration



BPM Calibration

Figure: Harp Scan

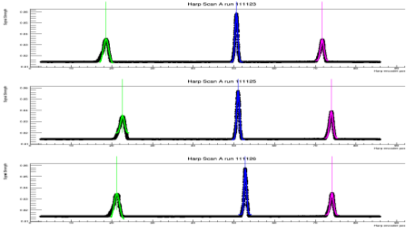


Figure: BPM pedestals

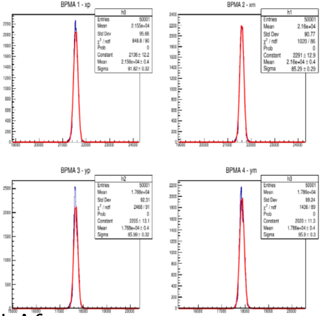
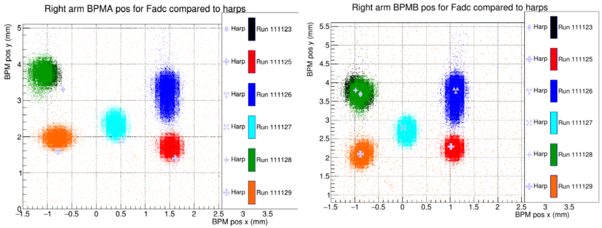
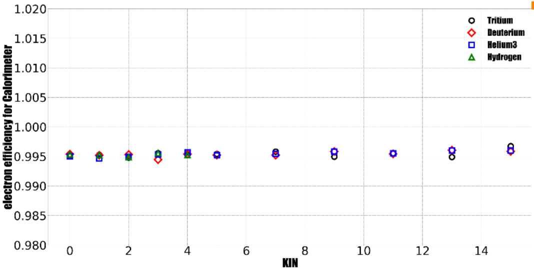


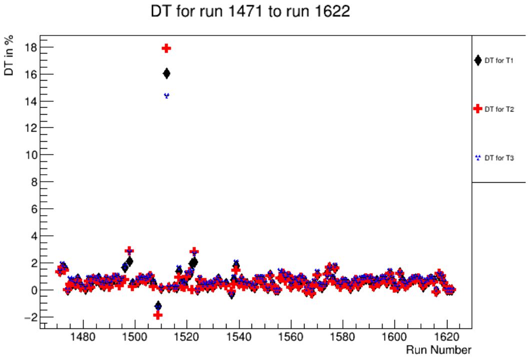
Figure: Before and After



Efficiencies

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





Systematic Studies

Figure: Density Fluctuations

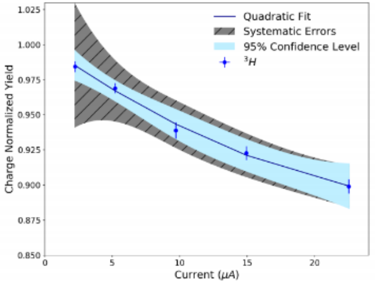
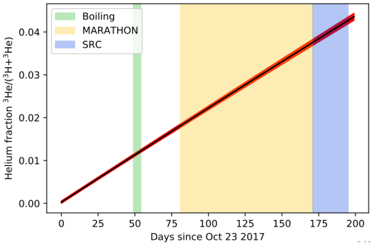


Figure: Tritium beta decay



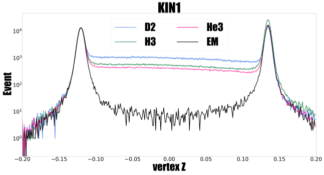


Figure: End Cap Contamination

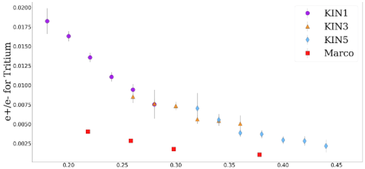
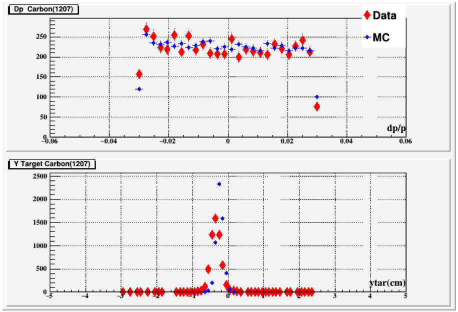
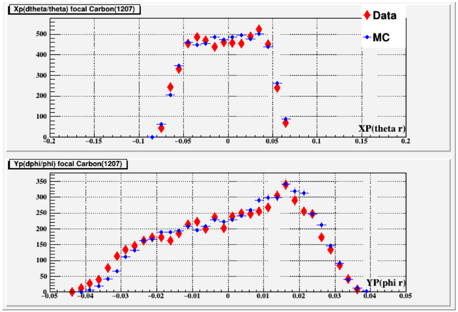


Figure: Charge Symmetric background

Monte Carlo

- Generate events 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





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

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

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

Timeline

- Calibrations
- Monte Carlo Tunning $\approx$ 85%
- Detector Efficiencies $\approx$ 50%
  - PID is done
  - Tracking, Trigger .... WIP
- Systematic Studies $\approx$ 50% Need to focus on error estimation.
- Acceptance Studies using Monte Carlo $\approx$ 75% Finish tunning 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
- February 2019
- Feb. - March 2019
- May-June 2019
- July 2019
- July - August 2019
- August -Sept. 2019
- <u>**Graduate**</u>

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

The End

backup