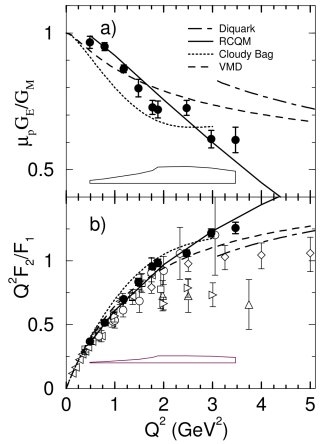
Counting Electrons in Hall A

Okay, but how do you actually DO it?

Evan McClellan

June 13, 2018

Experimental Nuclear Physics



Jones et. al. (1999)

Input

- An idea
- Millions of Dollars
- Tens of thousands of expert-hours

Output

- $a \pm \sigma_a$

Even Theorists Can Do It!

PR12-14-012

Measurement of the Spectral Function of ^{40}Ar through the $(e, e'p)$ reaction

Proposal to the

Jefferson Lab Program Advisory Committee PAC 42

July 2014

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JLAB-PHY-18-2656

SLAC-PUB-17200

First Measurement of the Ti(e, e')X Cross Section at Jefferson Lab

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(The Jefferson Lab Hall A Collaboration)

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[17]*University of Virginia, Charlottesville, Virginia, 22908, USA*
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To probe CP violation in the leptonic sector using GeV energy neutrino beams on argon targets, precise models of the complex underlying neutrino and antineutrino-argon interactions are needed. The E12-14-012 experiment at Jefferson Lab Hall A was designed to study electron scattering on both argon ($N = 22$) and titanium ($Z = 22$) nuclei using GeV energy electron beams. Here we report the first experimental study of electron-titanium scattering as double differential cross section at beam energy $E = 2.222$ GeV and electron scattering angle $\theta = 15.541$ deg, measured over a broad range of energy transfer, spanning the kinematical regions in which quasielastic scattering and delta production are the dominant reaction mechanisms. The data provide valuable new information needed to develop accurate theoretical models of the electromagnetic and weak cross sections of these complex nuclei in the kinematic regime of interest to neutrino experiments.

Disclaimers

This talk:
Inclusive, unpolarized DIS with electrons in Hall A
Some tritium target specific details

Deep-Inelastic Scattering Cross Sections

$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\cos^2\left(\frac{\theta}{2}\right)\left[\frac{F_2}{\nu} + \frac{2F_1}{M}\tan^2\left(\frac{\theta}{2}\right)\right]$$

$$\nu = E - E'$$

$$Q^2 = 4EE'\sin^2\frac{\theta}{2}$$

$\frac{d\sigma}{d\Omega dE'}$: Probability of θ, E' given E

$$F_1 = \frac{1}{2}\sum_i e_i^2 q_i(x) \quad \text{(bjorken limit)}$$

$$F_2 = x\sum_i e_i^2 q_i(x) \quad \text{(bjorken limit)}$$

Deep-Inelastic Scattering Cross Sections

Counting (Statistics) | Measurement (Systematics) | Interpretation (Physics)

$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\cos^2\left(\frac{\theta}{2}\right)\left[\frac{F_2}{\nu} + \frac{2F_1}{M}\tan^2\left(\frac{\theta}{2}\right)\right]$$

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$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\cos^2\left(\frac{\theta}{2}\right)\left[\frac{F_2}{\nu} + \frac{2F_1}{M}\tan^2\left(\frac{\theta}{2}\right)\right]$$

Count Electrons

$\sigma_{\text{stat}} \approx \sqrt{N}$

(PID, target thickness, beam charge, ...)

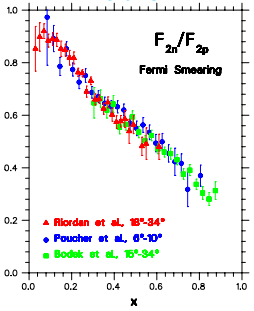
Measure:

E_{beam}

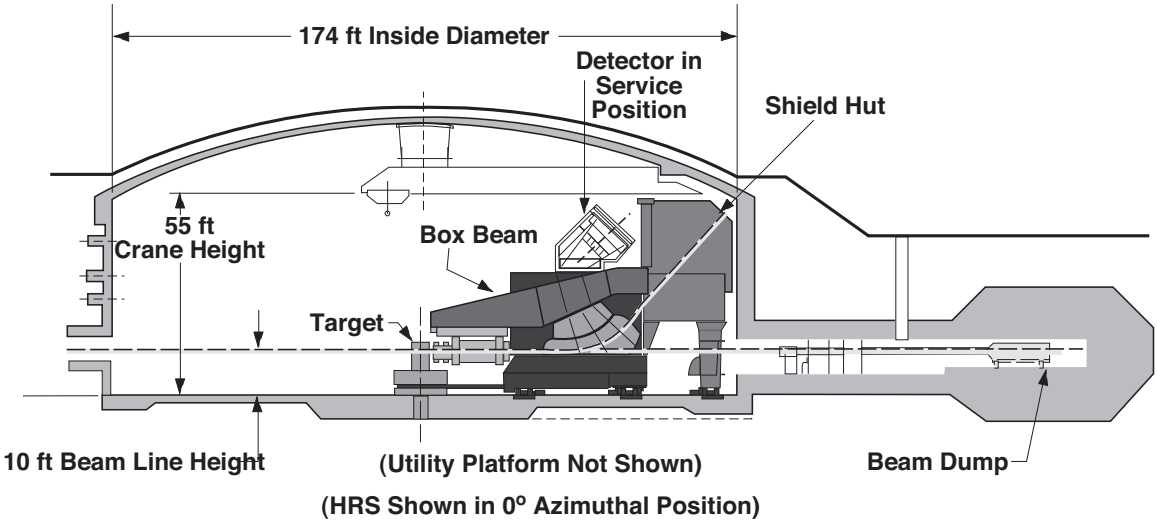
E' (momentum)

θ

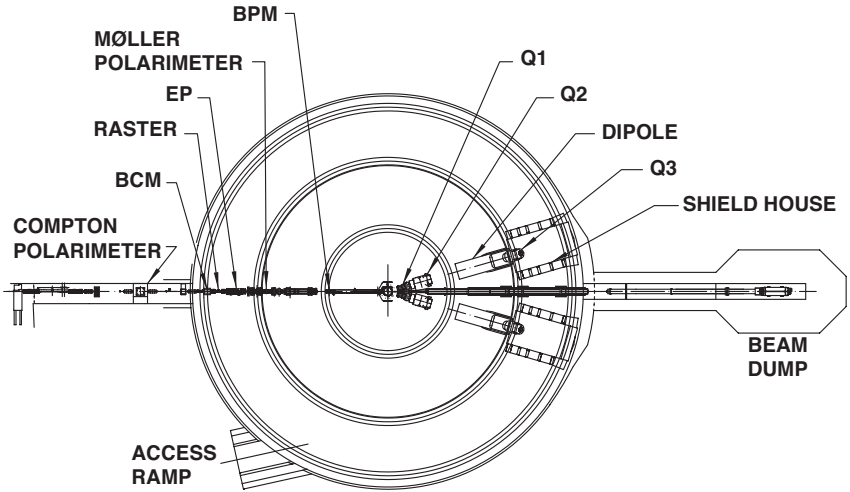
Publish



Electron Scattering Experiments Hall A



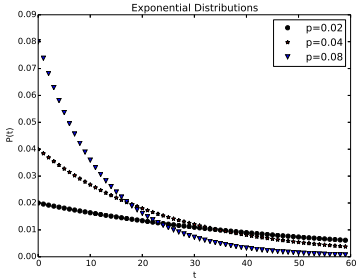
Electron Scattering Experiments in Hall A



Counting Statistics

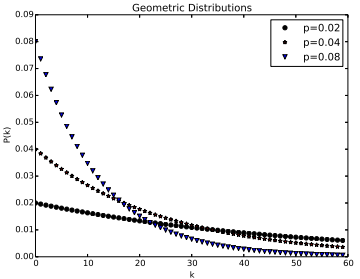
Consider the time interval between successive events

Continuous (Radioactivity)



$$P(t) = \lambda e^{-\lambda t}$$

Discrete (Dice Rolling)



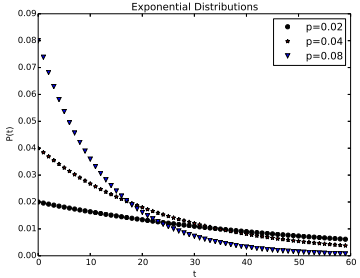
$$P(k) = (1-p)^k p$$

$$\text{Average Interval} = \frac{1}{p}$$

Counting Statistics

Consider the time interval between successive events

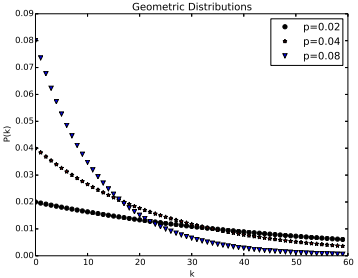
Continuous (Radioactivity with replacement)



$$P(\Delta t) = \lambda e^{-\lambda \Delta t}$$

Average Interval $= \frac{1}{\lambda}$

Discrete (Dice Rolling)



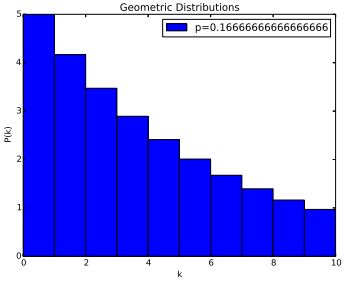
$$P(k) = (1-p)^k p$$

Average Interval $= \frac{1}{p}$

Counting Statistics: Dice-Rolling Demo!

$N = 30$

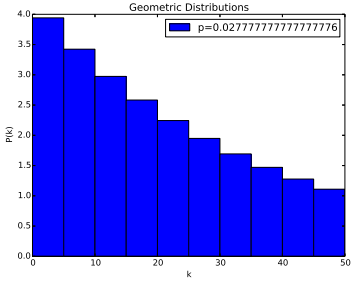
Roll a 1 on one die ($p = \frac{1}{6}$)



$P(k) = (1-p)^k p$

Average Interval = 6

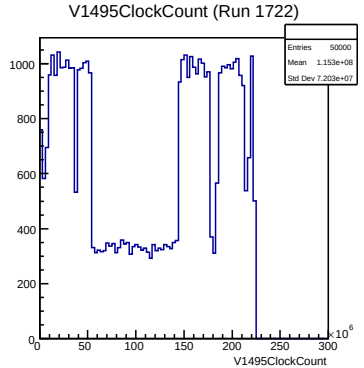
Roll 'snake-eyes' ($p = \frac{1}{36}$)

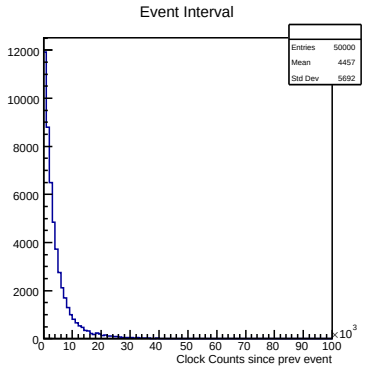


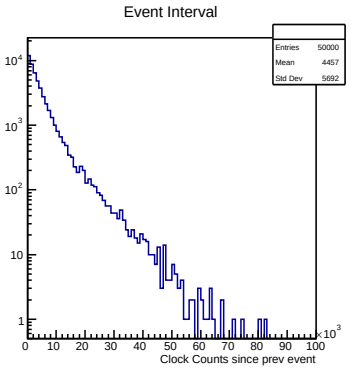
$P(k) = (1-p)^k p$

Average Interval = 36

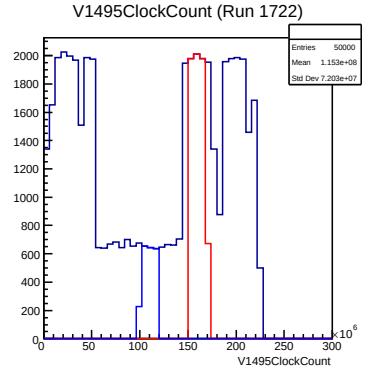
Scattered Electron Counting is Stochastic!

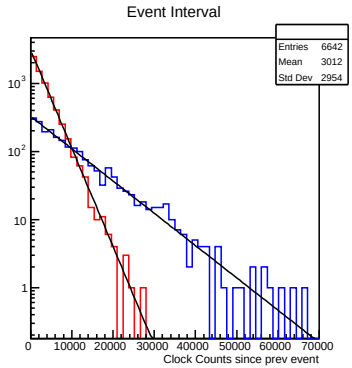


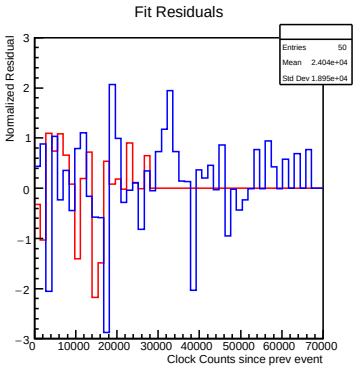




Scattered Electron Counting is Stochastic!

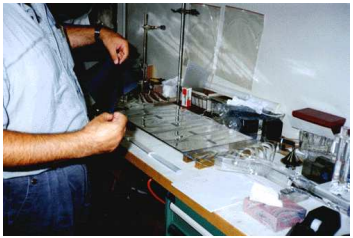


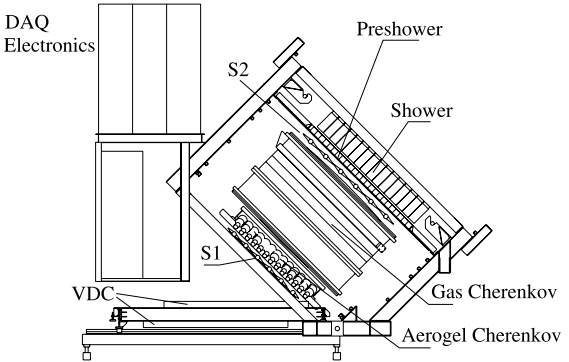




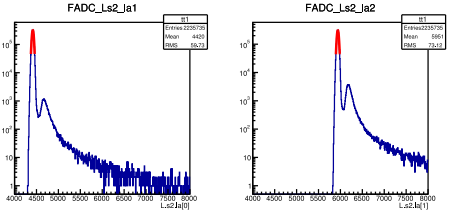
...for each choice of (E, E', θ)...

Scintillators (Triggering)

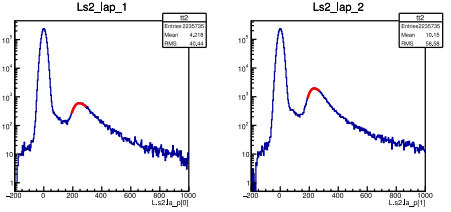




Scintillator Calibration

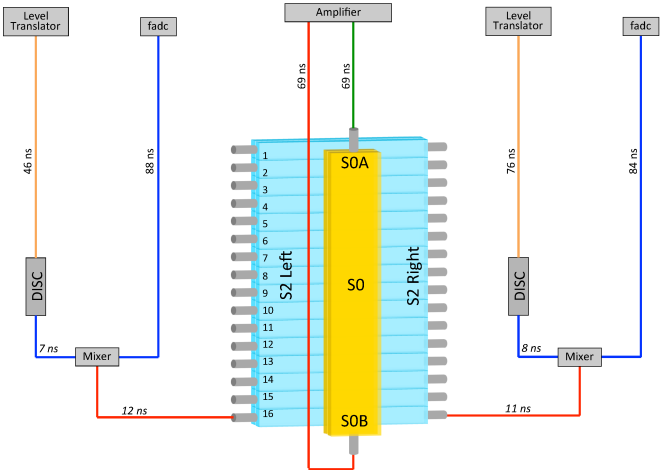


Pedestal Fitting

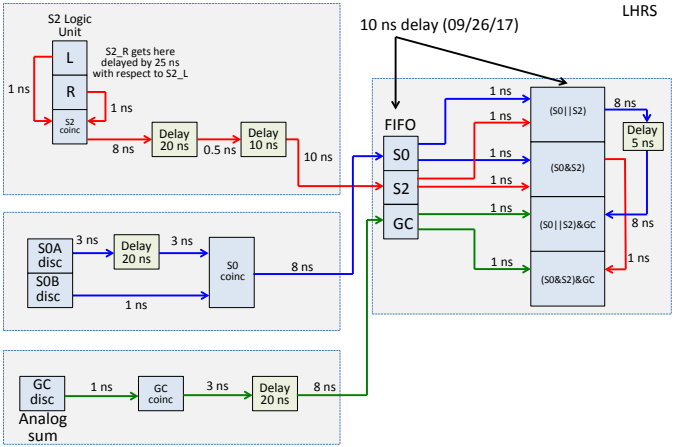


Single Photoelectron Peak Fitting

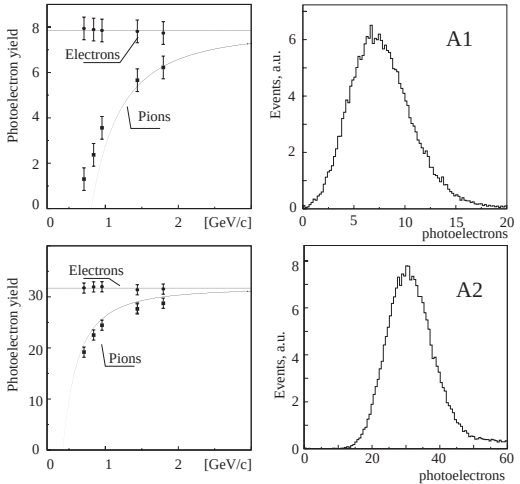
Trigger Setup and Commissioning

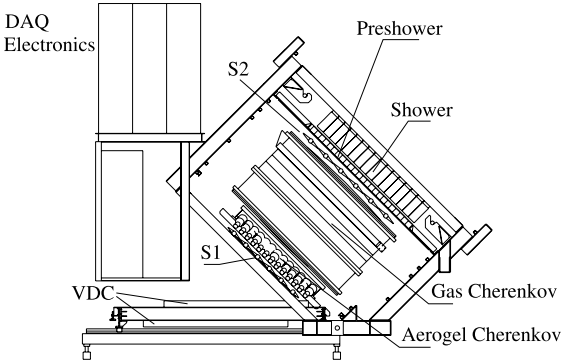


Trigger Setup and Commissioning

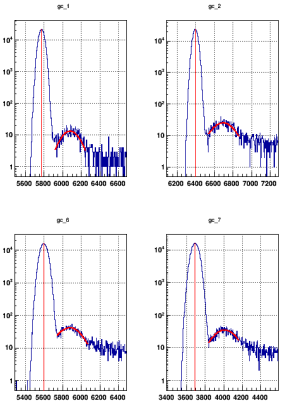


Cherenkovs (Particle Identification)

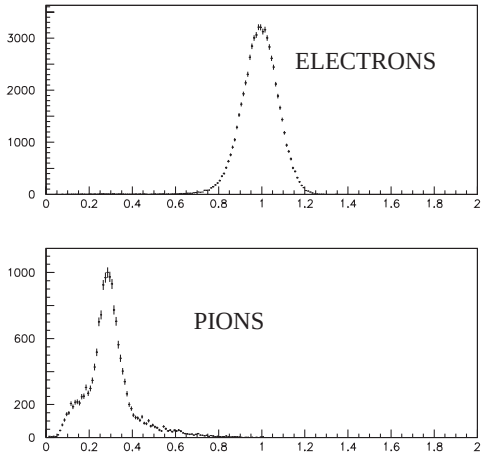


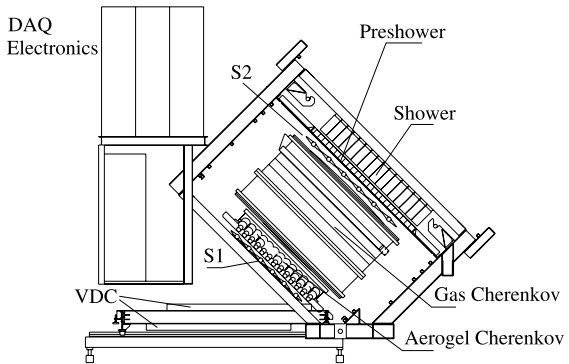


Cherenkov Calibration

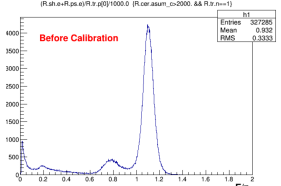


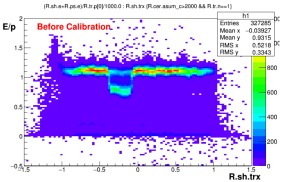
Calorimeters (Particle Identification)

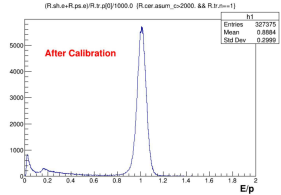


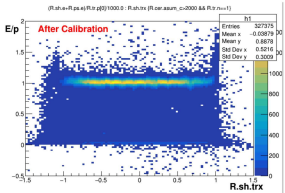


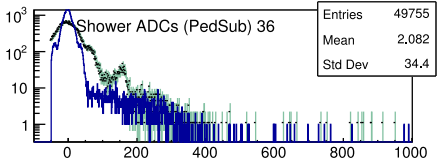
Calorimeter Calibration

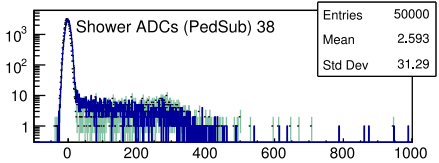




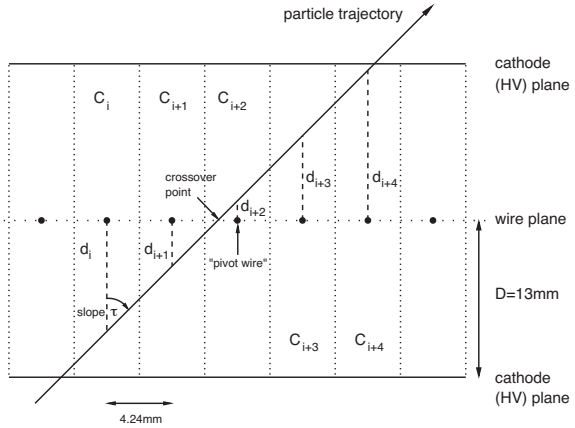


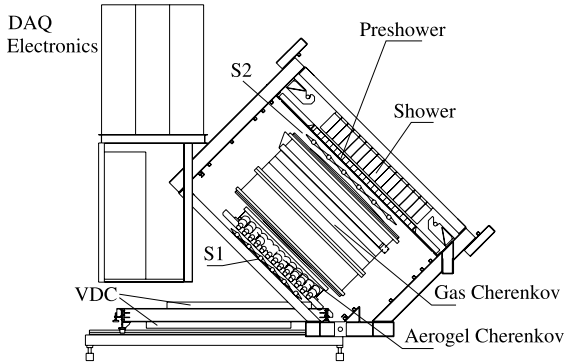




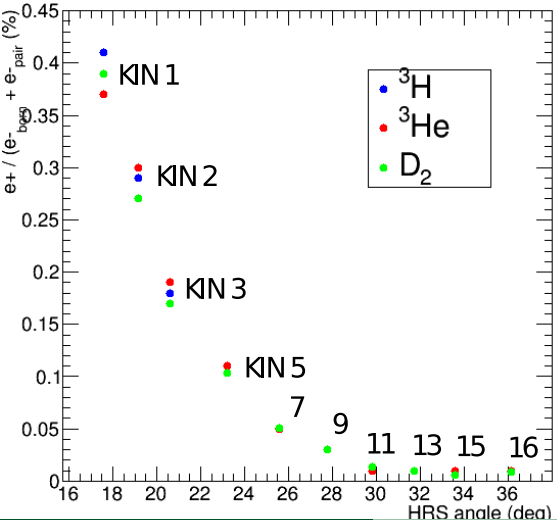


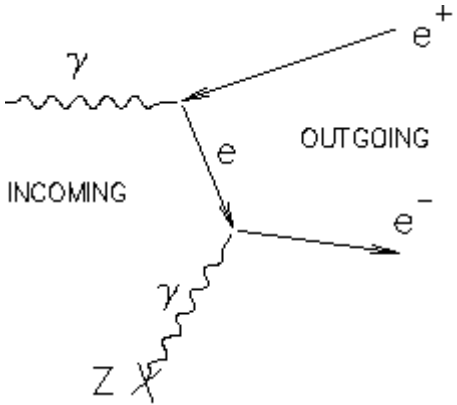
Wire Chambers (Track Reconstruction)



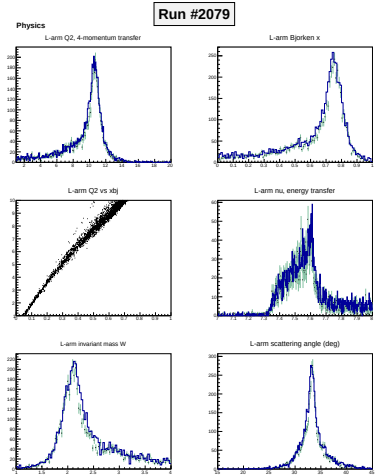


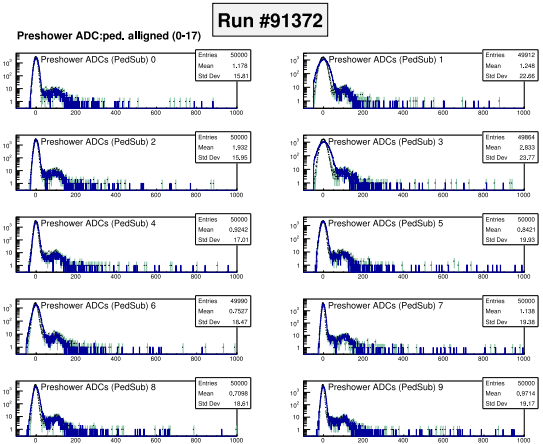
Pair-Produced Background (Check the positrons!)





Online Monitoring





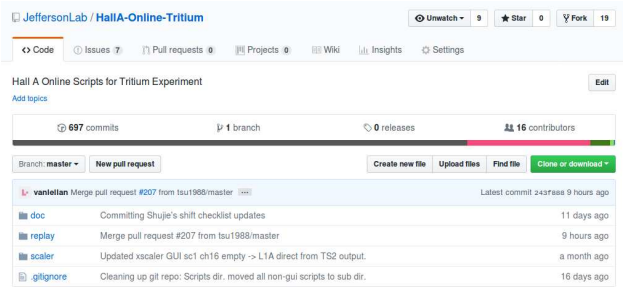
The Importance of Version Control in Collaborative Software Development

```
GIT(1)                                                          Git Manual

NAME
       git - the stupid content tracker

SYNOPSIS
       git [--version] [--help] [-C <path>] [-c <name>=<value>]
           [--exec-path[=<path>]] [--html-path] [--man-path] [--info-path]
           [-p|--paginate|--no-pager] [--no-replace-objects] [--bare]
           [--git-dir=<path>] [--work-tree=<path>] [--namespace=<name>]
           <command> [<args>]

DESCRIPTION
       Git is a fast, scalable, distributed revision control system with an unusually rich command set
```

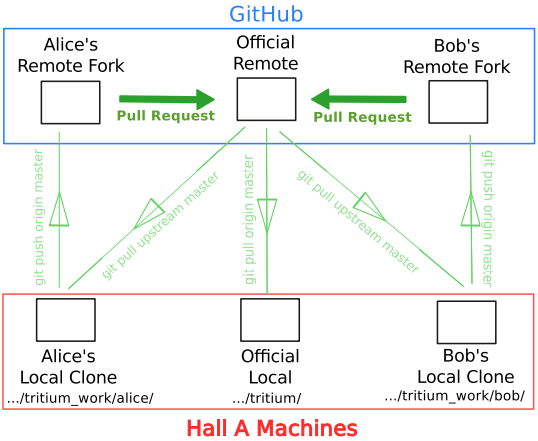
- Ar(e,e'p) inherited replay scripts from GMp.
- Little preparation time, last-minute development
- Many developers (tritium students), collisions and overwriting!

Hall A Online Tritium Repository!

- Track all online replay source code
  - Replay scripts
  - Tritium-specific libraries
  - DB files
  - many other online/offline scripts



Optimal Workflow



Success!

December 25, 2017 – January 25, 2018

Period: **1 month**

Overview

40 Active Pull Requests

10 Active Issues

40 Merged Pull Requests	**0** Proposed Pull Requests	**5** Closed Issues	**5** New Issues

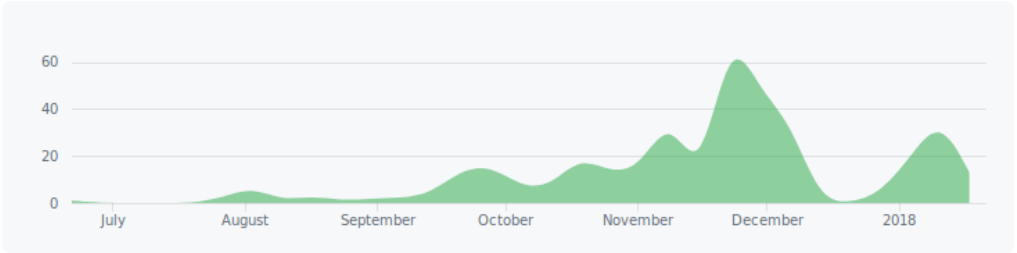
Excluding merges, **10 authors** have pushed **80 commits** to master and **80 commits** to all branches. On master, **115 files** have changed and there have been **4,752 additions** and **4,729 deletions**.

40 Pull requests merged by **10** people

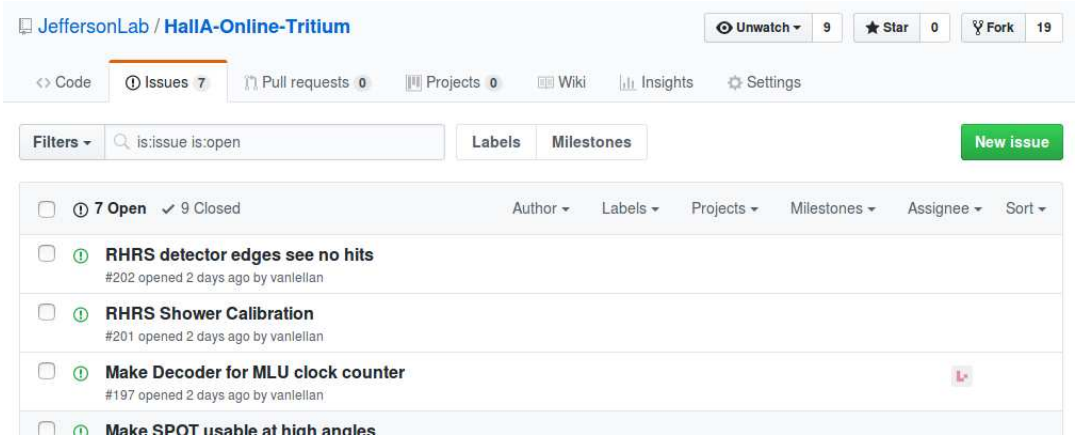
Merged #207 **modify the spot++ to get rid of cosmic rays** 9 hours ago

Merged #206 **little modifications** 9 hours ago

Commit History



Github Issue Tracker



Part II: From Counting Electrons to Relative Yields

Evan McClellan

June 13, 2018

Why Do We Care About Relative Yields?

Ratio Measurements!

$$R = \frac{d\sigma_1}{d\sigma_2} = \frac{Y_1}{Y_2}\frac{F_{\text{common}}}{F_{\text{common}}}$$

For example:

MARATHON: $\frac{F_2^{^3He}}{F_2^{^3H}}$

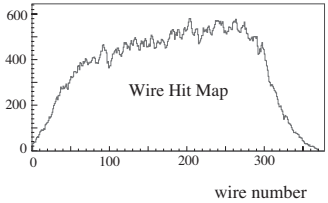
$^3H(e, e'p)$

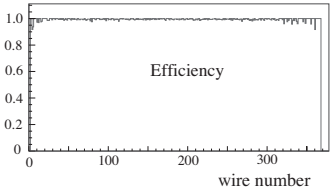
Asymmetry measurements...

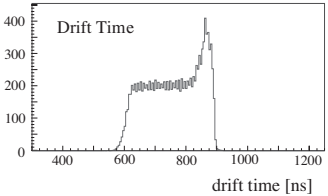
F_{common} typically includes:

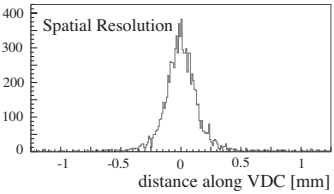
- Spectrometer Acceptance
- Detector efficiencies
- Reconstruction efficiencies
- Absolute Beam Charge
- Absolute Target Thickness

Relative Efficiencies

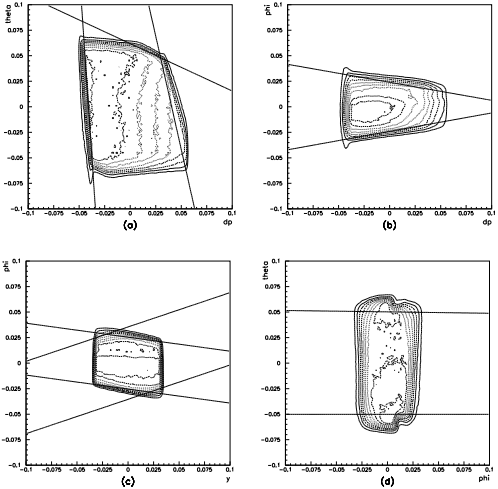




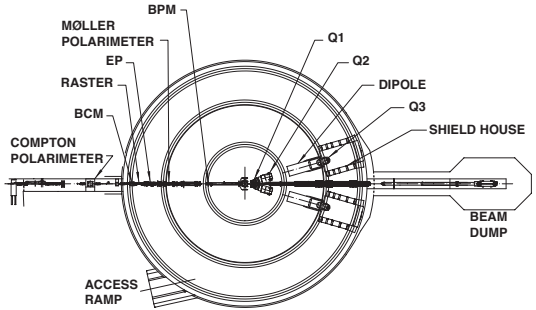




Relative Acceptances

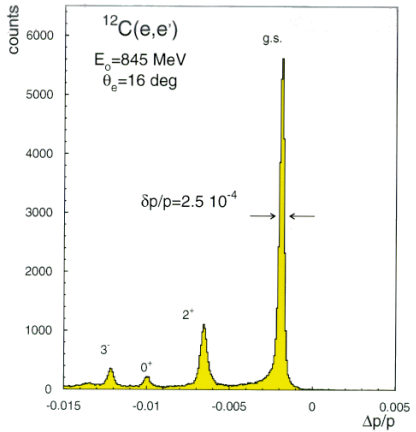


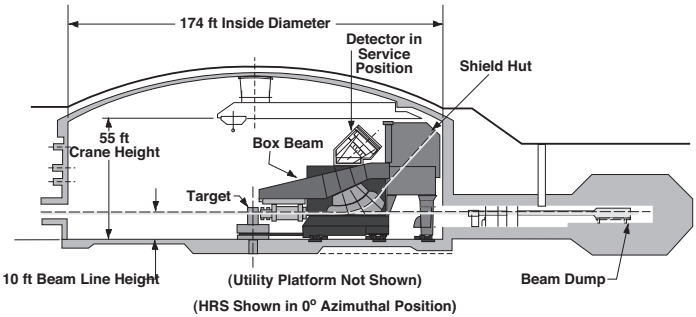
Spectrometer Angle



Video!

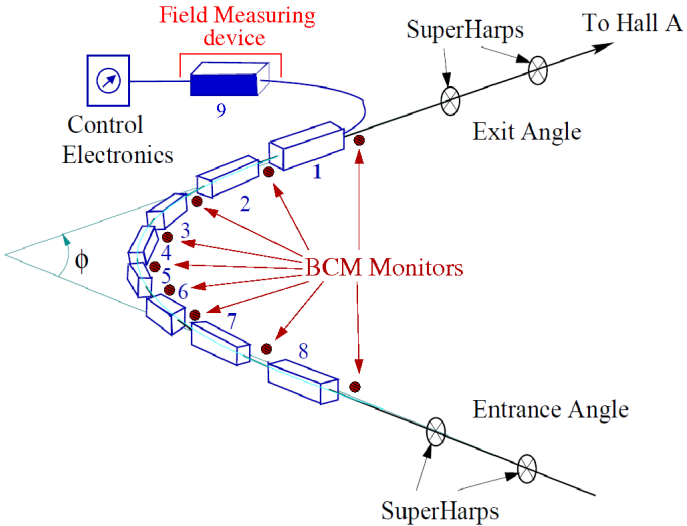
Spectrometer Momentum





High **R**esolution **S**pectrometer

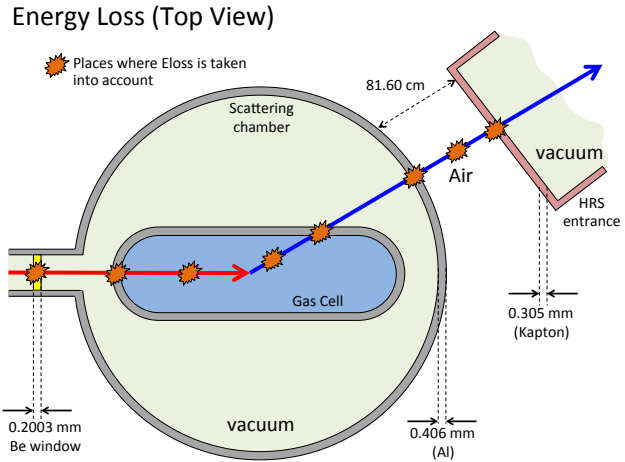
Beam Energy



$$p = k\frac{\int \vec{B}\cdot\vec{dl}}{\phi}$$

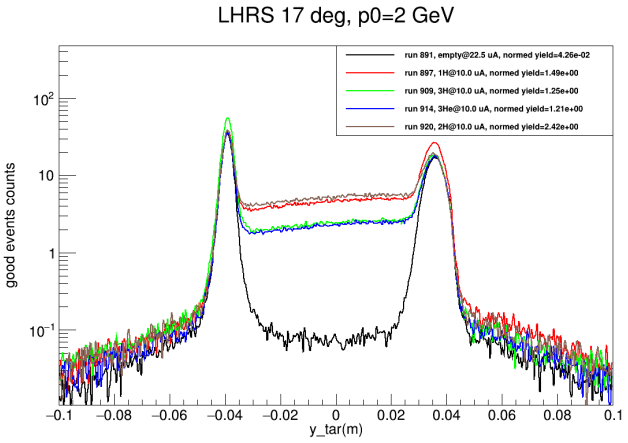
- (+ sync rad correction)
- Dispersive Optics
- No quad-steering!

Energy Loss



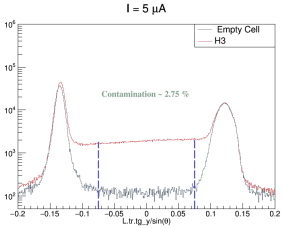
Credit: Rey Torres

Target 'Length' and Fill Density

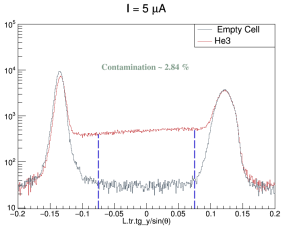


- Gas densities are not identical
- Count scales with gas density
- Need independent measure

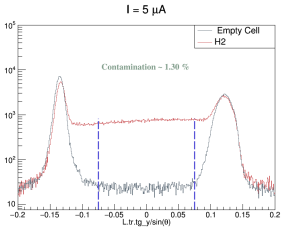
Target Window Subtraction



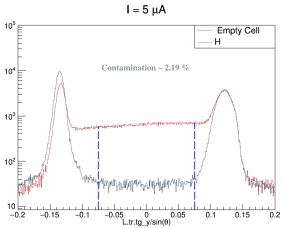
(a) H3



(b) He3

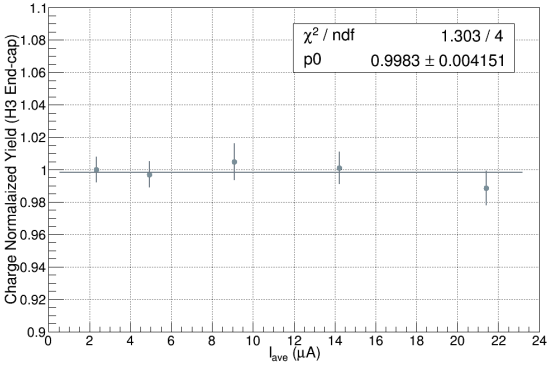


(c) H2



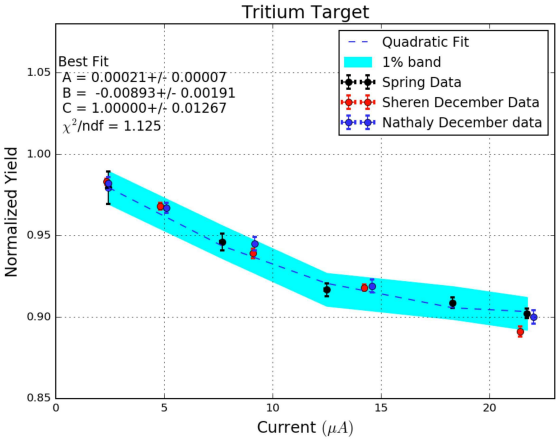
(d) H

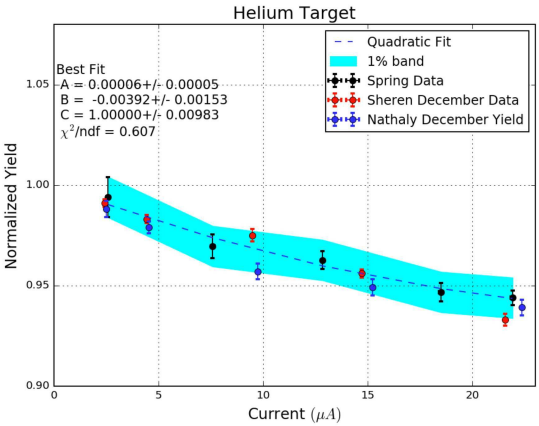
Target Density Current Dependence ('boiling')



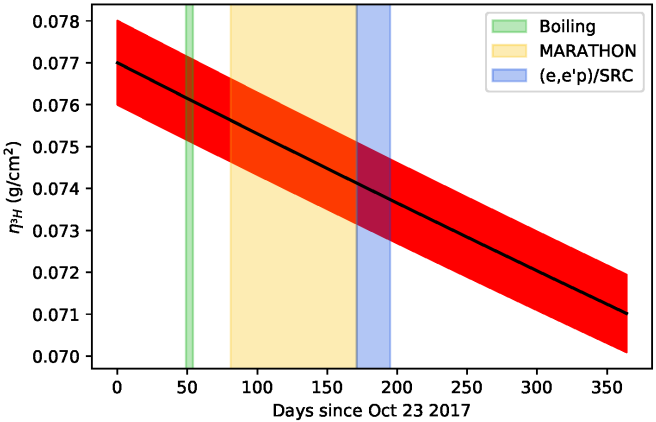
- Liquid targets boil along the beam
- Local density changes for gas too
- Varies with beam current

Target Density Current Dependence ('boiling')

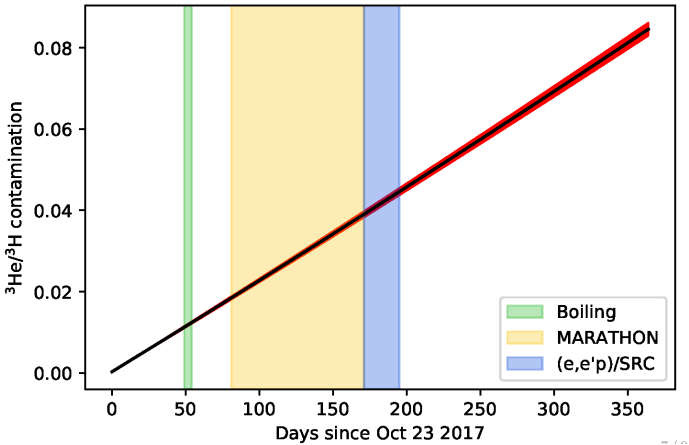




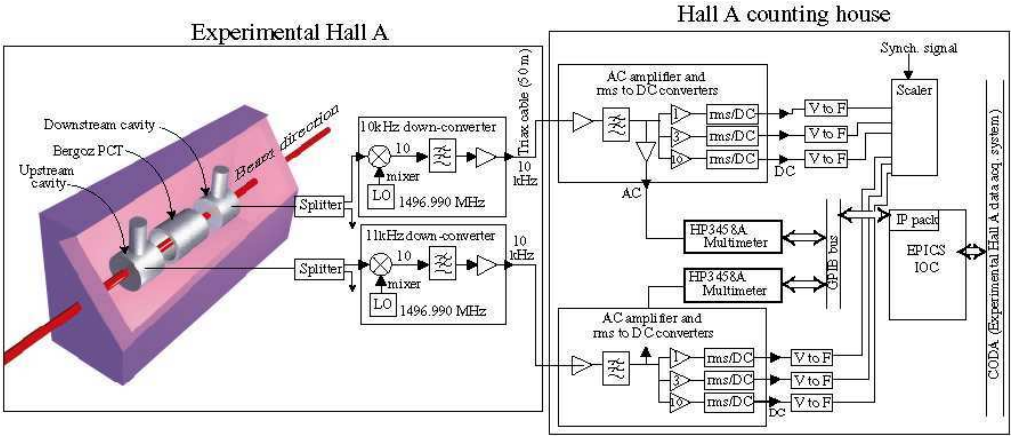
Target Gas Contamination



Target Gas Contamination



Relative Integrated Beam Charge



Part III: Onward to Absolute Cross Sections!

Absolute Efficiencies

- Detectors
- Trigger Logic
- Tracking Algorithm

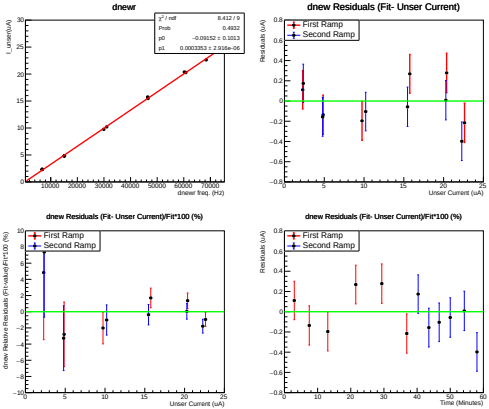
Absolute Acceptances

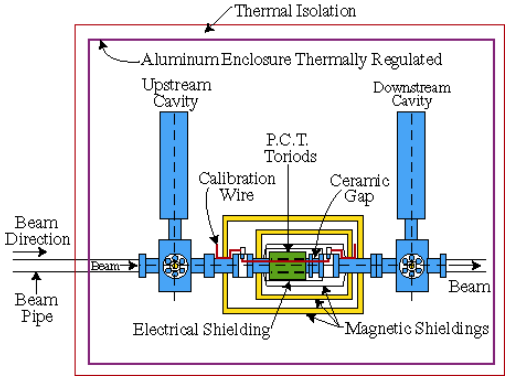
- $d\theta$ shape
- dp shape
- Trade stats for systematics?

Absolute Beam/Target

- Beam Charge
- Target Density ('boiling')
- Target Windows
- Target purity

BCM Calibration





Part IV: Preliminary Look at Spring 2018 Tritium Data

MeAsurement of the F_2^n/F_2^p, d/u **RA**tios and A=3 EMC Effect in Deep Inelastic Electron Scattering Off the **T**ritium and **H**elium Mirr**Or** **N**uclei.

Jefferson Lab PAC37 Proposal, December 2010

The JLab **MARATHON** Collaboration

J. Arrington, D. F. Geesaman, K. Hafidi, R. J. Holt, D. Potterveld, P. Reimer, J. Rubin, J. Singh, X. Zhan
Argonne National Laboratory, Argonne, Illinois, USA

K. A. Aniol, D. J. Margaziotis, M. B. Epstein
California State University, Los Angeles, California, USA

G. Fanourakis
Demokritos National Center for Scientific Research, Athens, Greece

J. Annand, D. Ireland, R. Kaiser, G. Rosner
University of Glasgow, Scotland, UK

E. Cisbani, F. Cussano, S. Frullani, F. Garibaldi, M. Iodice, L. Lagamba, R. De Leo, E. Pace, G. Salmè, G. M. Urciuoli
Istituto Nazionale di Fisica Nucleare, Rome and Bari, Italy

J.-P. Chen, E. Chudakov, J. Gomez, J.-O. Hansen, D. W. Higinbotham, C. W. de Jager, J. LeRose, D. Meekins, W. Melnitchouk, R. Michaels, S. K. Nanda, B. Sawatsky, P. Solvignon, A. Saha, B. Wojtsekhowski
Jefferson Lab, Newport News, Virginia, USA

B. D. Anderson, A. T. Katramatou, D. M. Manley, S. Margetis, G. G. Petratos, W.-M. Zhang
Kent State University, Kent, Ohio, USA

Proton and Neutron Momentum Distributions in $A = 3$ Asymmetric Nuclei

A Hall A Collaboration Experiment

Proposal PR12-13-012 to Jefferson Lab PAC 42, July 2014

C. Hyde, S.E. Kuhn and L.B. Weinstein (co-spokesperson)
Old Dominion University, Norfolk VA

M. Braverman, E. Cohen, O. Hen (co-spokesperson), I. Korover, J. Lichtenstadt, E. Piasetzky, and I. Yaron
Tel-Aviv University, Tel Aviv, Israel

W. Boeglin (co-spokesperson), P. Markowitz and M. Sargsian
Florida International University, Miami, FL

W. Bertozzi, S. Gilad (co-spokesperson), and V. Sulkosky
Massachusetts Institute of Technology, Cambridge, MA

D.W. Higinbotham, C. Keppel, P. Solvignon and S.A. Wood
Thomas Jefferson National Accelerator Facility, Newport News, VA

Guy Ron
Hebrew University, Jerusalem, Israel

R. Gilman
Rutgers University, New Brunswick, NJ

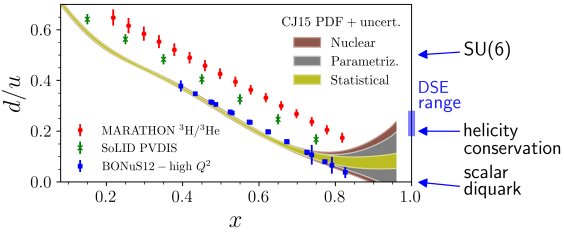
J.W. Watson
Kent State University, Kent, OH

A. Beck and S. Maytal-Beck
Nuclear Research Center Negev, Beer-Sheva, Israel

J. Beričič, M. Mihovilovič, S. Širca, and S. Štajner
Jožef Stefan Institute, Ljubljana, Slovenia

D. Keller

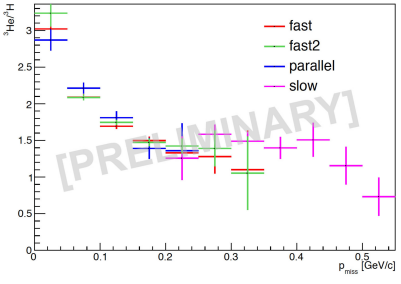
MARATHON (proposal)

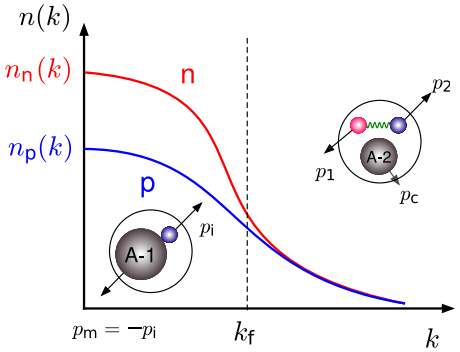


- No data plots released yet...
- d/u at high-x
- Refines valence quark description of the proton!

- Data is on tape
- Analysis is ongoing

(e,e'p)


^{3}He/^{2}H
fast
fast2
parallel
slow
[PRELIMINARY]
p_{miss} [GeV/c]


$n(k)$
$n_n(k)$
$n_p(k)$
n
p
A-1
A-2
p_i
p_2
p_1
p_c
$p_m = -p_i$
k_f
k

That's All, Folks

Thanks!