Cross section extraction from E12-10-002

New Measurements of the Deuteron to Proton F_2 Structure Function Ratio

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(for the Hall C Collaboration)

*Draft circulated to authors June 3rd

William Henry
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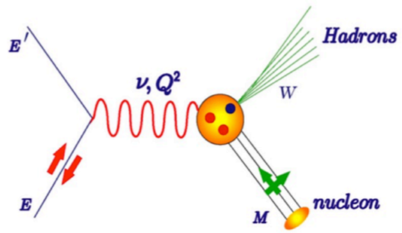
The F2 experiment in Hall C

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2\sin^4\left(\frac{\theta}{2}\right)}\left(\frac{2}{M}F_1(x,Q^2)\sin^2\left(\frac{\theta}{2}\right) + \frac{1}{\nu}F_2(x,Q^2)\cos^2\frac{\theta}{2}\right)$$

$Q^2 = 4EE'\sin^2(\theta/2)$	4-momentum transfer
$\nu = E - E'$	Energy transfer
$W = M^2 + 2M\nu - Q^2$	Final state hadronic mass
θ	Scattering angle
$x = Q^2/2M\nu$	Quark fractional momentum



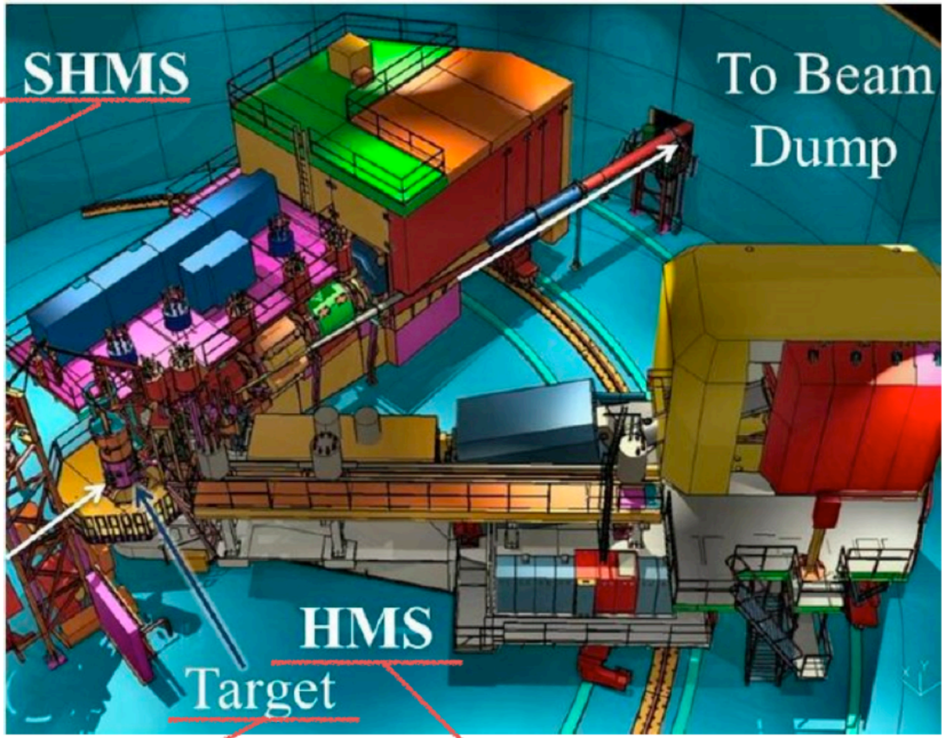
Physics motivation

- Constrain PDFs
- Quark hadron duality
- Non singlet moments
- Resonance /DIS modelling

The F2 experiment in Hall C

- JLab12 GeV Commissioning Experiment in Hall C
- Data taken in Spring 2018
- Single Arm (Inclusive) measurement
- Scattered e- detected in spectrometers
- Hydrogen and Deuterium Liquid Targets

Hall C Spectrometers



71% of total data were taken by SHMS

Push to high Q^2

LH_2, LD_2, Al

SHMS

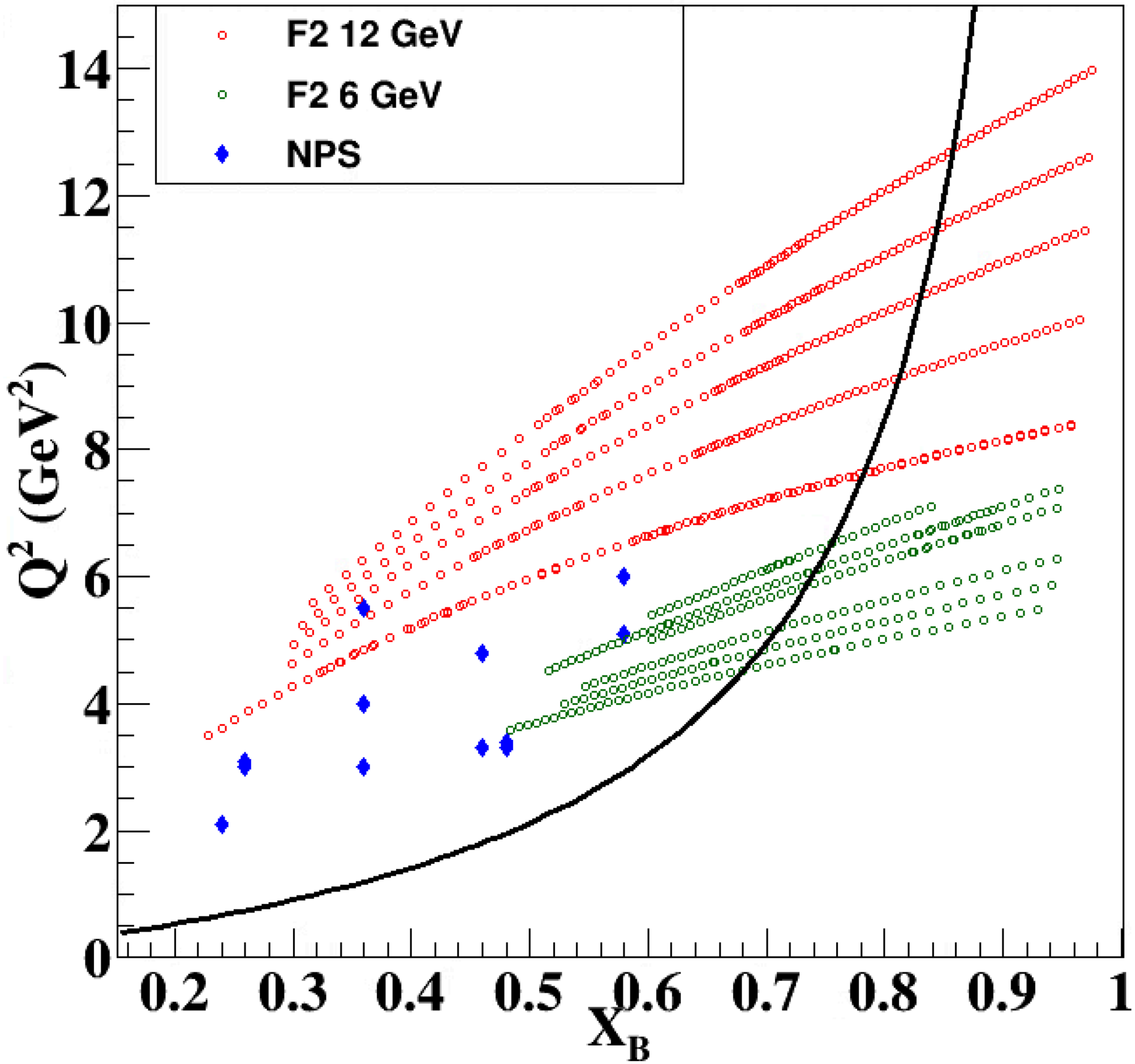
Angle	Momentum(GeV/c)
21	2.7, 3.3, 4.0, 5.1
25	2.5, 3.0, 3.5, 4.4
29	2.0, 2.4, 3.0, 3.7
33	1.7, 2.1, 2.6, 3.2
39	1.3, 1.6, 2.0, 2.5

We will extract H,D(e,e') cross sections.

positron data

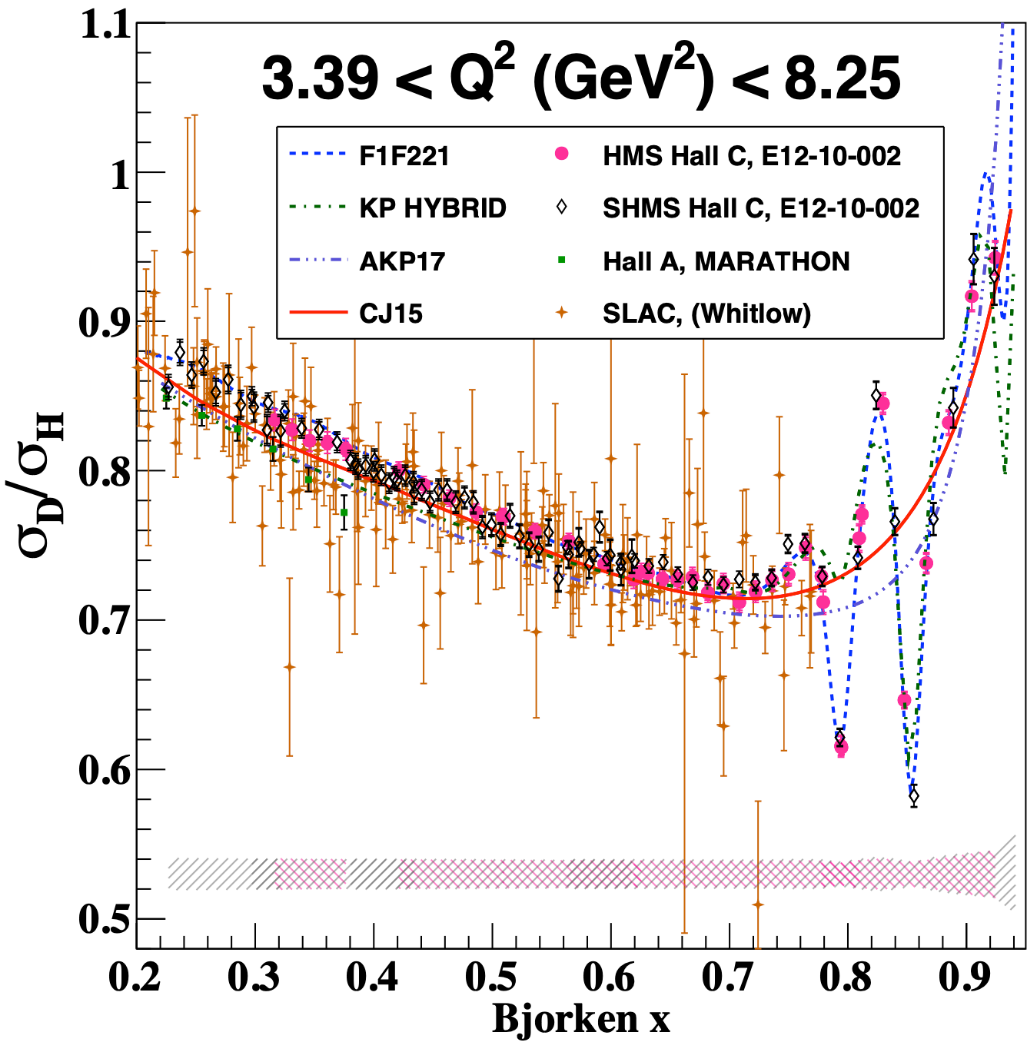
Angle	Momentum(GeV/c)
21	2.7
29	2.0, 2.7
39	1.3, 1.8

The F2 experiment in Hall C



Results

- Excellent agreement between SHMS and HMS
- Vast improvement in statisical precision from SLAC data
- "F1F221" model does not include this work



Results

$\theta_C = 21^\circ$

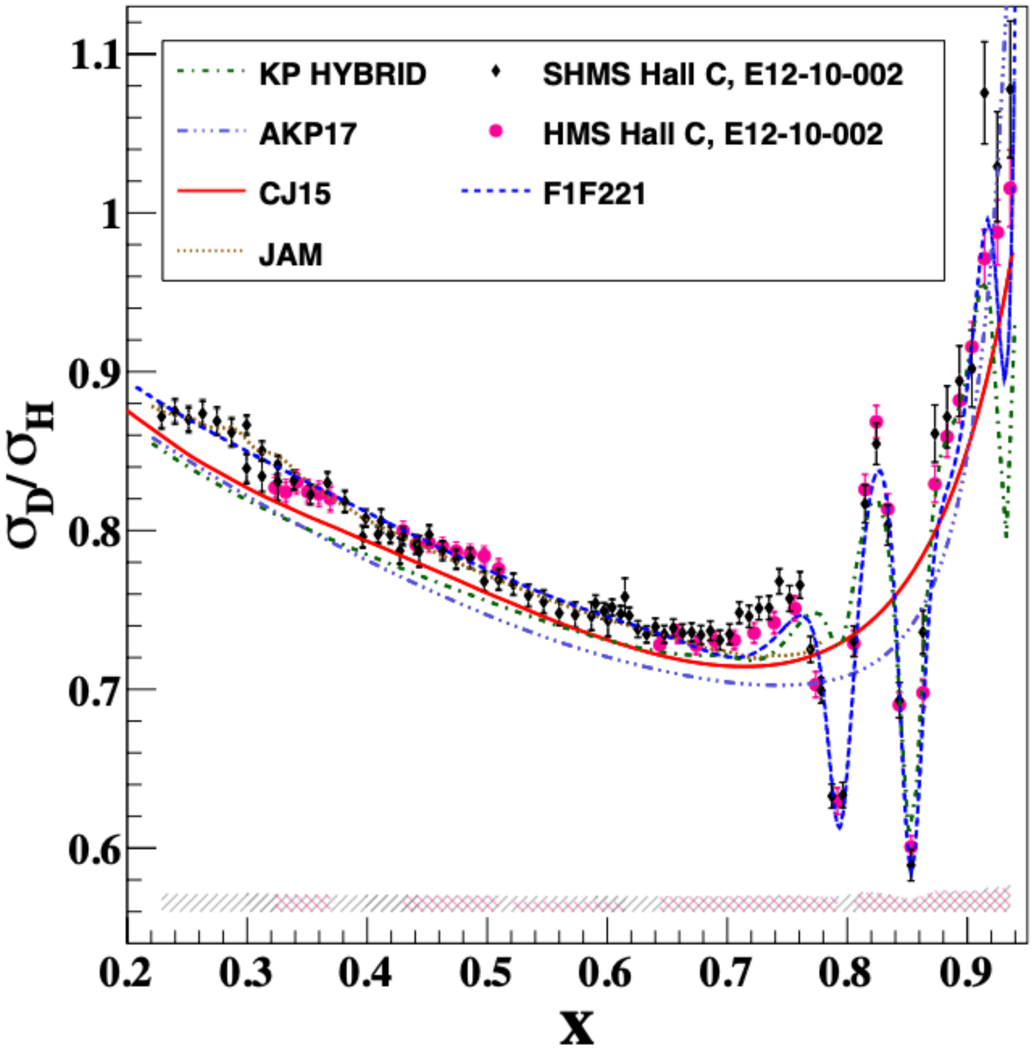


FIG. 2. The σ_D/σ_H ratio as a function of x for a spectrometer angle of 21 deg (Q^2 range from 3.39 to 8.25 GeV^2). The error bars include uncorrelated systematic and statistical errors. The error bands include correlated systematic errors and an overall normalization of 1.1%(see Table I.). F1F221 (blue dashed line) is the model used in this analysis, the other curves are from different PDF fits (see text). Good agreement is observed between the well-understood HMS and newly constructed SHMS spectrometers.

CJ15

Constraints on large-x parton distributions from new weak boson production and deep-inelastic scattering data

A. Accardi (Hampton U. and Jefferson Lab), L.T. Brady (Jefferson Lab and UC, Santa Barbara), W. Melnitchouk (Jefferson Lab), J.F. Owens (Florida State U.), N. Sato (Jefferson Lab)

Feb 9, 2016

KP Hybrid

Nuclear effects in the deuteron in the resonance and deep-inelastic scattering region

S.A. Kulagin (Moscow, INR)

Dec 31, 2018

AKP17

Nuclear Effects in the Deuteron and Constraints on the d/u Ratio

S.I. Alekhin (Serpukhov, IHEP), S.A. Kulagin (Moscow, INR), R. Petti (South Carolina U.)

Apr 1, 2017

Results

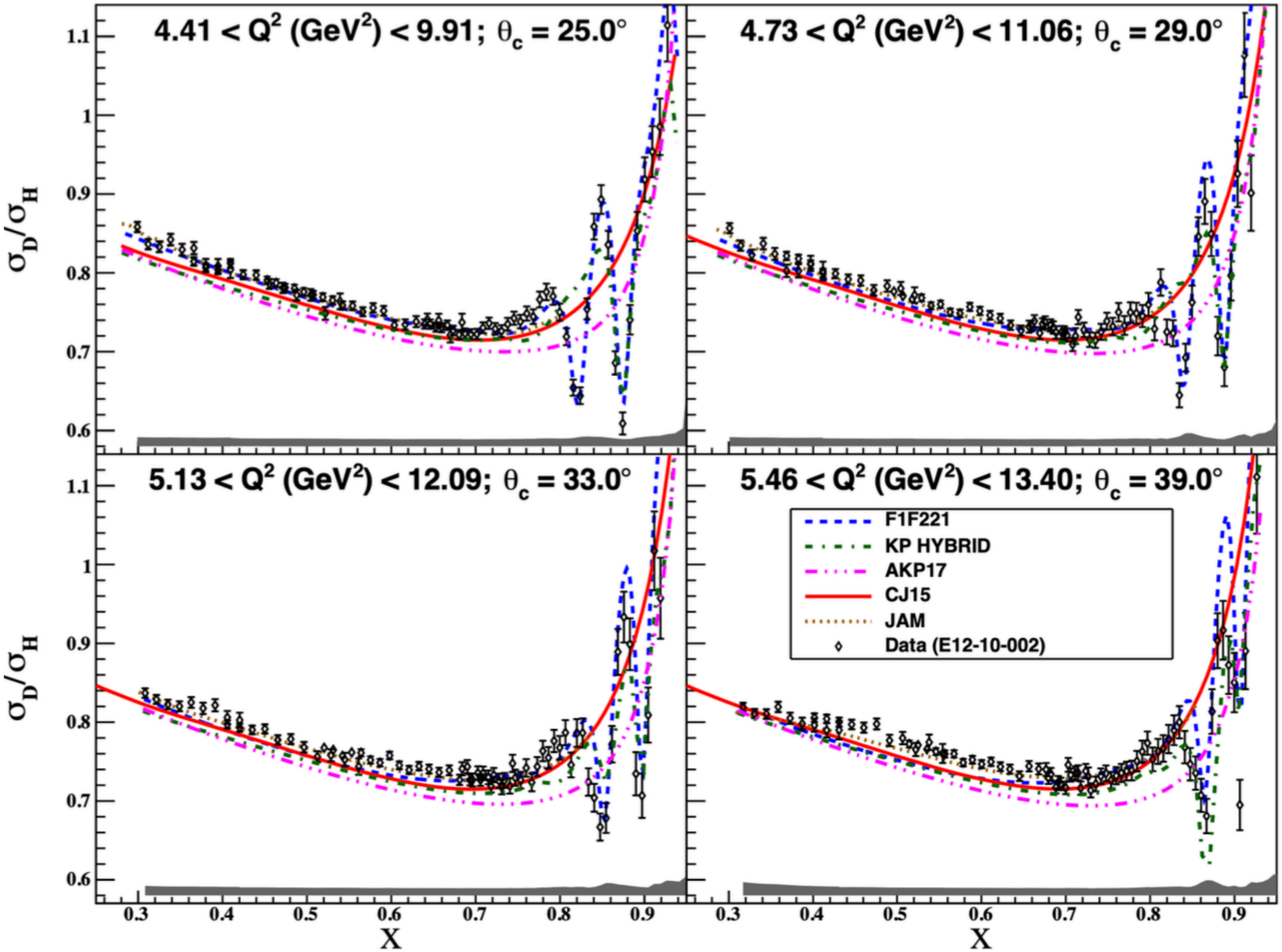
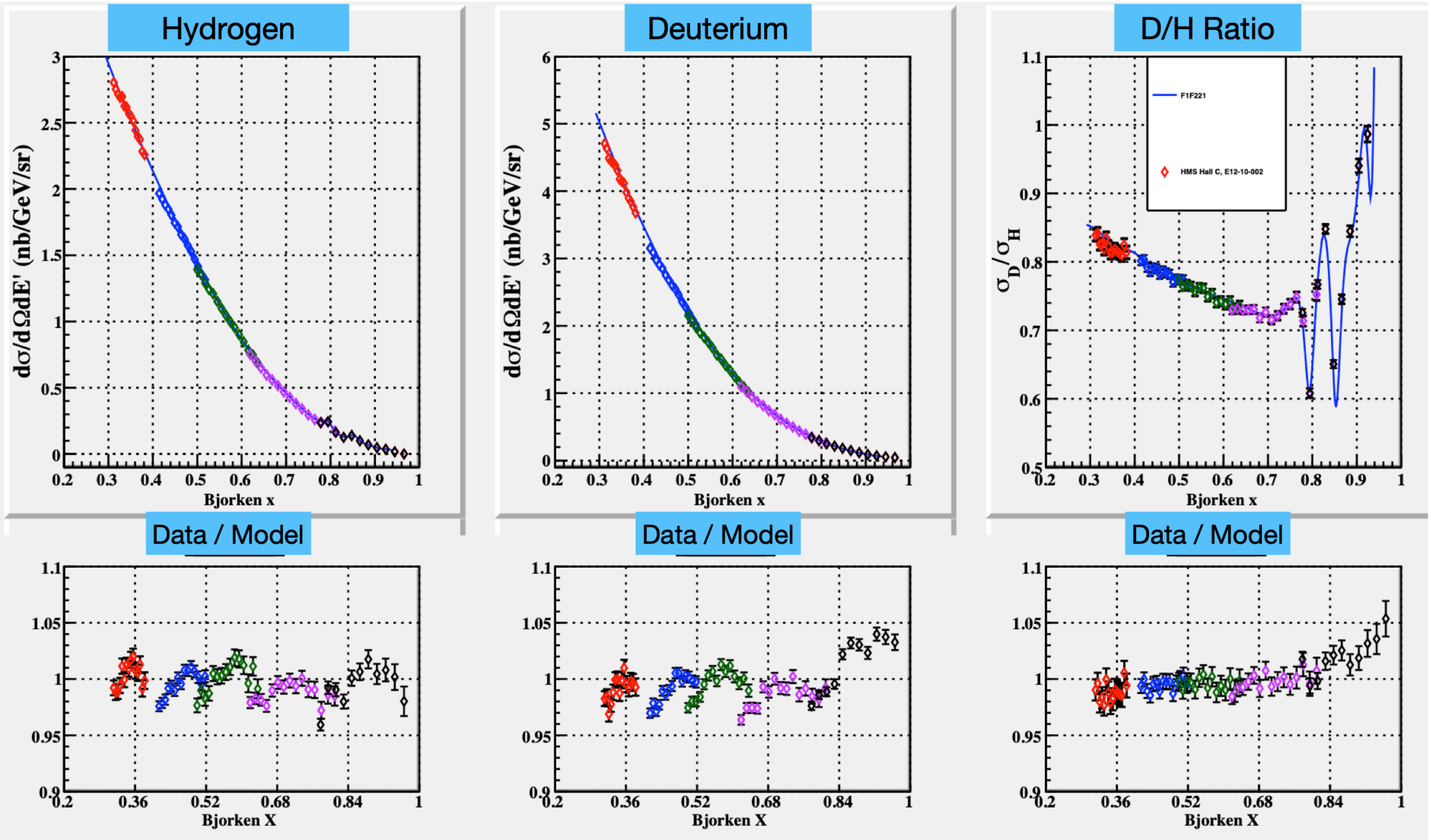


FIG. 3. The σ_D/σ_H ratio as a function of x for SHMS spectrometer angles of 25, 29, 33, and 39 deg. The Q^2 range of each setting is indicated in each panel.

F2 Results

HMS @ 21 degrees



Cross Section Extraction: Data Yields

Acceptance Cuts for SHMS
$-10.0 < y_{tar} < 10.0$
$-0.1 < y'_{tar} < 0.1$
$-0.1 < x'_{tar} < 0.1$
$-10.0 < \delta < 22.0$
PID Cuts for SHMS
$N_{cer} > 2.0$
$E_{calo}/E' > 0.7$
Current Cut for SHMS
$I_{BCM\ 4C} > 5.0$

$$Y_{data} = \frac{N^{e-} - BG}{\epsilon_{tot} E_{LT} C_{LT}} \times PS$$

- N^{e-}: Number of scattered particles form the tracks in drift chambers and pass through all the PID (cerenkov and calorimeter) cuts
- BG: Pion contamination + Charge Symmetric background + Cryo Cell Contribution
- PS: Prescale
- ϵ_{tot}: Total efficiency : $\epsilon_{tot} = \epsilon_{track} \times \epsilon_{cerenkov} \times \epsilon_{calorimeter}$
- E_{LT}: Electronic live time
- C_{LT}: Computer live time

F2 Cross Section Extraction

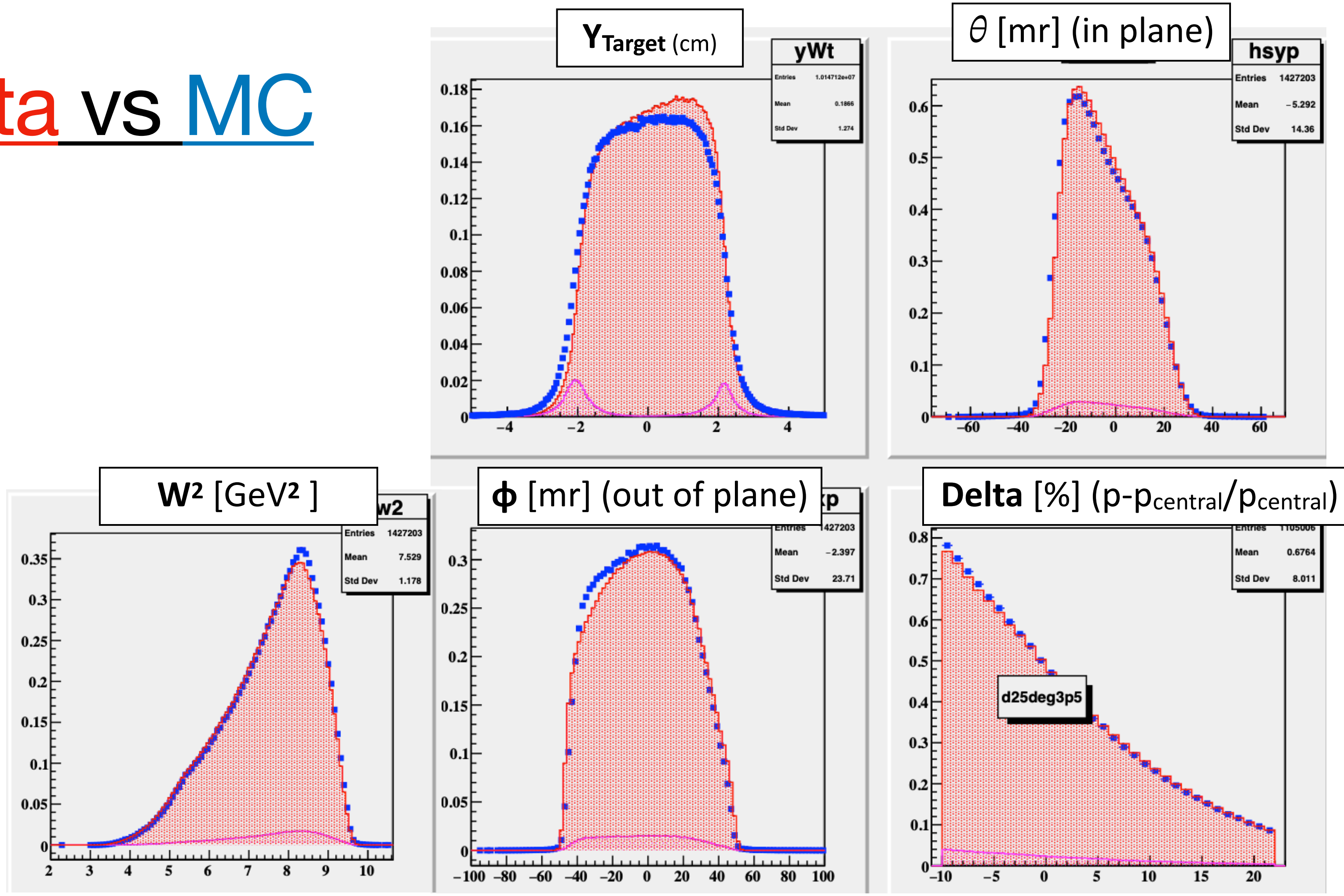
Monte Carlo (MC) Ratio Method

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{exp} = \left(\frac{d\sigma}{d\Omega dE'}\right)_{model} \frac{Y_{data}}{Y_{MC}}$$

- MC ran for 50M events mc-single-arm
- Events are weighted after using radiated using rc_externals and f1f221 model
- Charge Symmetric Background added to MC

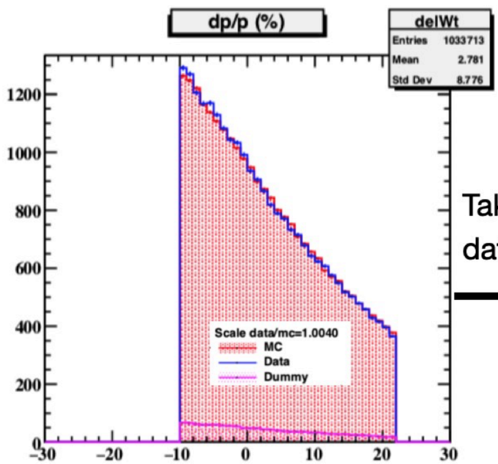
Cross Section Extraction: Monte Carlo Ratio Method

Data vs MC



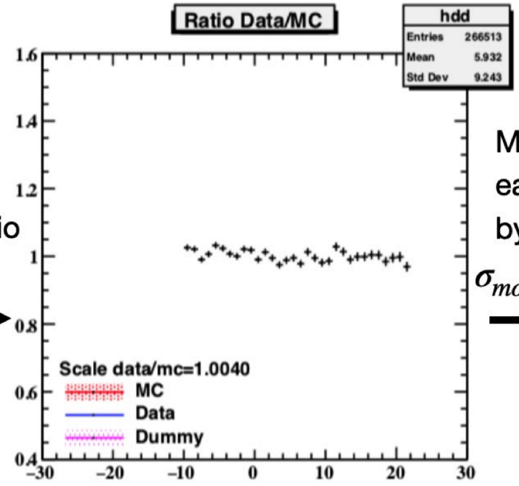
Cross Section Extraction: Monte Carlo Ratio Method

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{exp} = \frac{Y_{Data}}{Y_{MC}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{model}$$

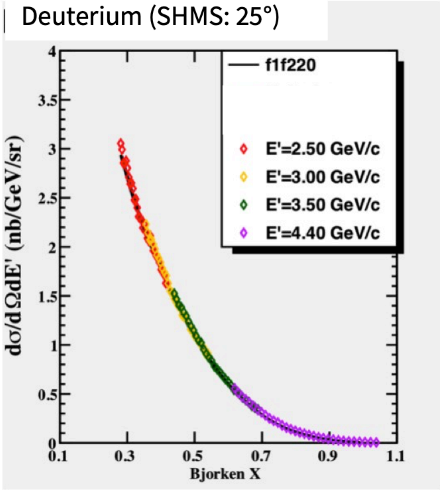


(Data is dummy subtracted)

Take Ratio data/MC



Multiply each bin by $\sigma_{model}(E',\theta)$

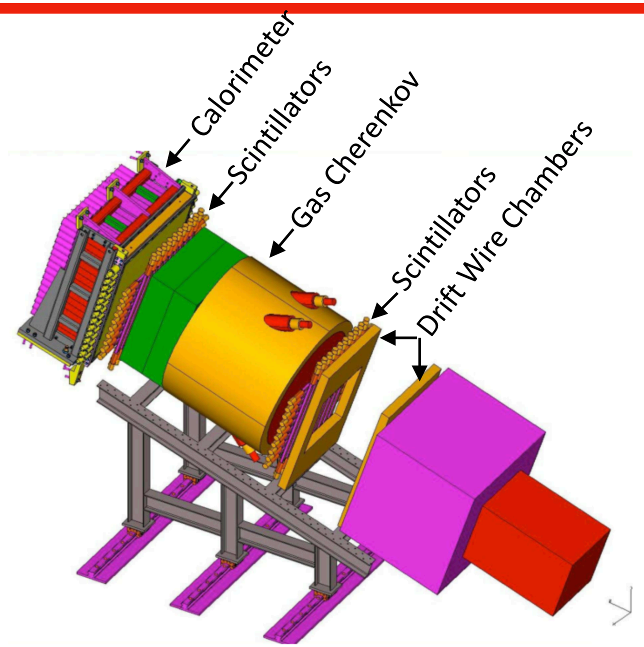


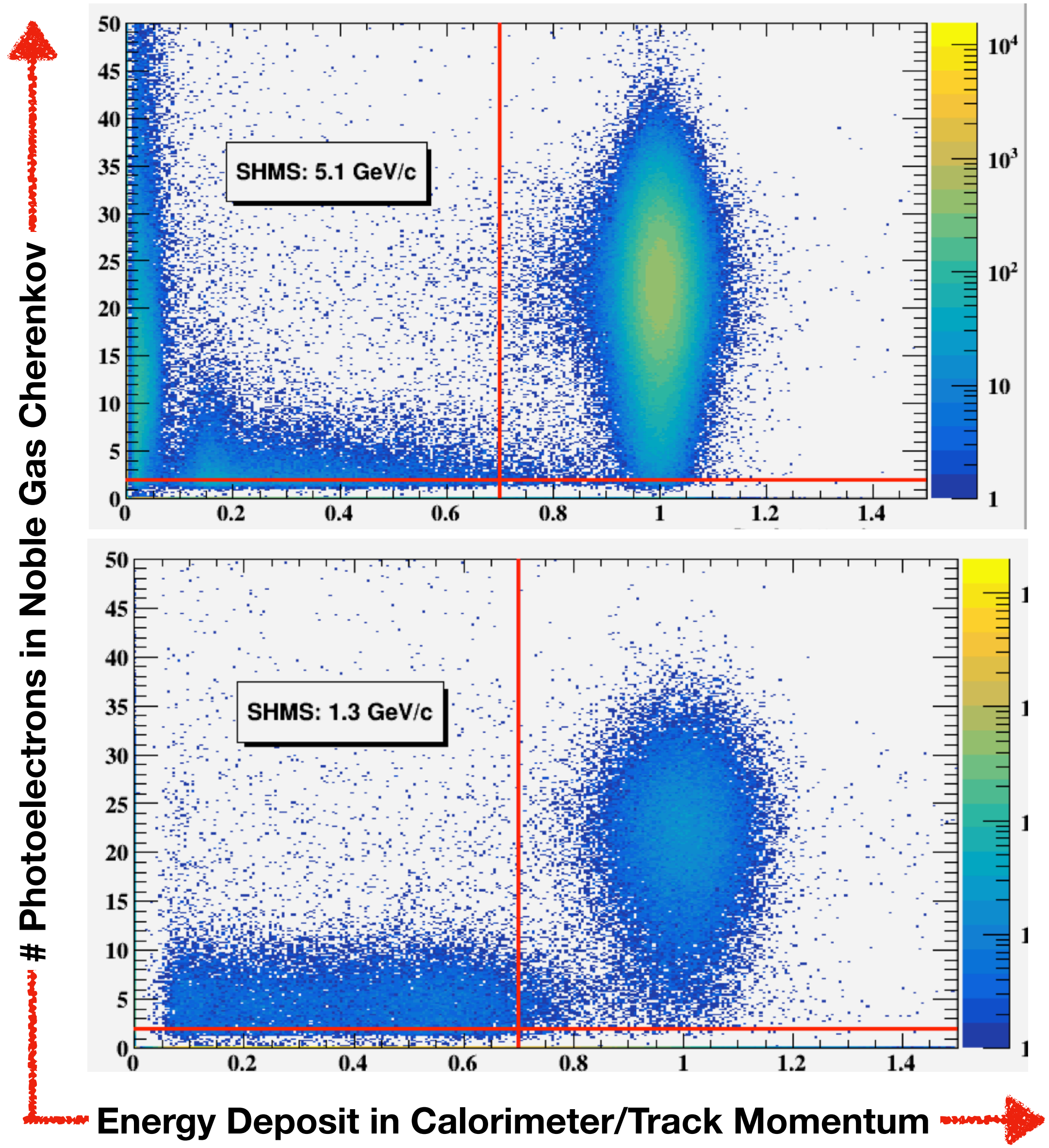
1) MC (weighted with radiative cxsec) and corrected data yields are binned in delta

2) Take ratio of data and MC

3) Multiply each bin by model (not radiated) to get cross section

Cross Section Extraction: Particle identification

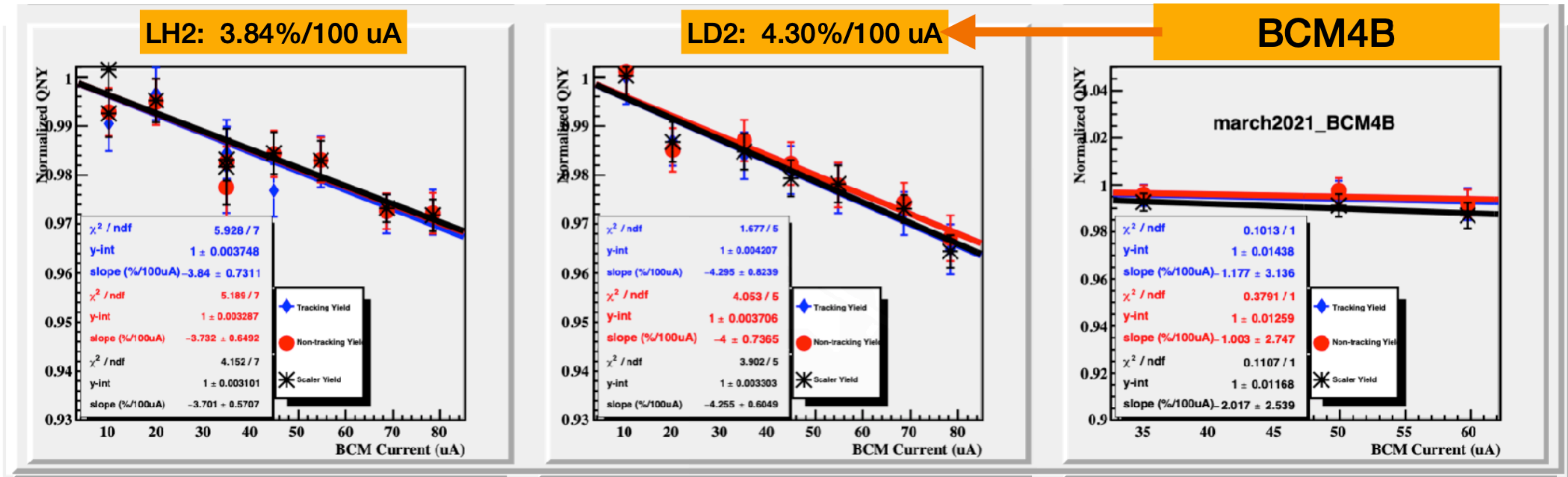




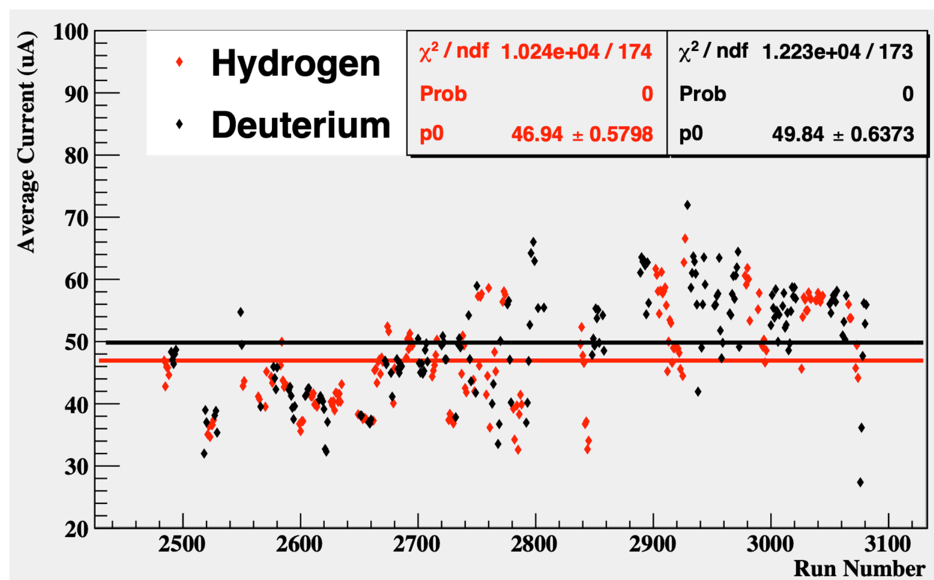
PID Cuts

- E/p > 0.7
- NPE > 2.0

Target Density Correction



- Luminosity Runs were used to determine the density correction
- Experiment ran at an average beam current of 50 uA
- Target density uncertainty in D/H ratio ~1.1%

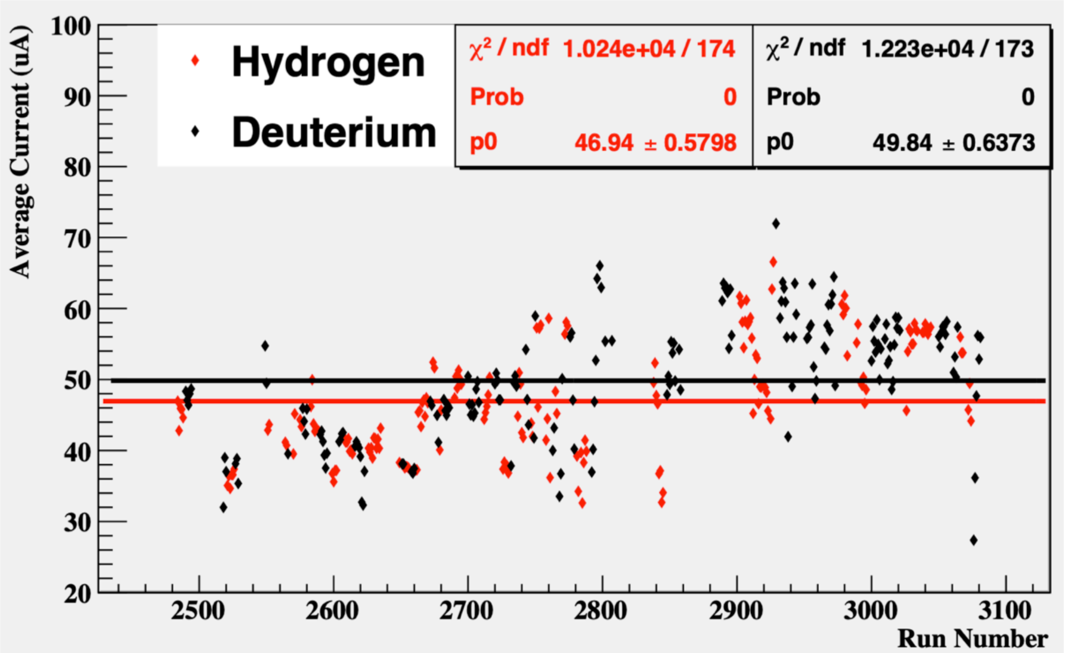


Target Density Correction

Target Density Uncertainty

- The overall normalization uncertainty used is slightly larger than the table; 0.75% in cross sections and 1.1% in D/H ratio.
- Global error reflects our lack of knowledge to the target boiling, temperature, density, length and beam position.
- An additional point to point uncertainty is calculated by taking the difference with the average current

Error	Value	Uncertainty	$\frac{\delta\rho t}{\rho t}$
Temperature	19 K	$\pm 182 mK$	0.27%
Pressure	25 psia	$\pm 2 psia$	0.02%
Equation of State			0.1%
Length Measurement Precision	100 mm	$\pm 0.26 mm$	0.26%
Length (Inner or Outer?)	100 mm	$\pm 0.26 mm$	0.26%
Target Contraction	99.6%	$\pm 0.1\%$	0.1%
Beam Position	0	$\pm 3 mm$	0.2%
Avg Boiling Correction LH2(LD2)			0.30% (0.36%)
Total LH2 (LD2)			0.60% (0.63%)

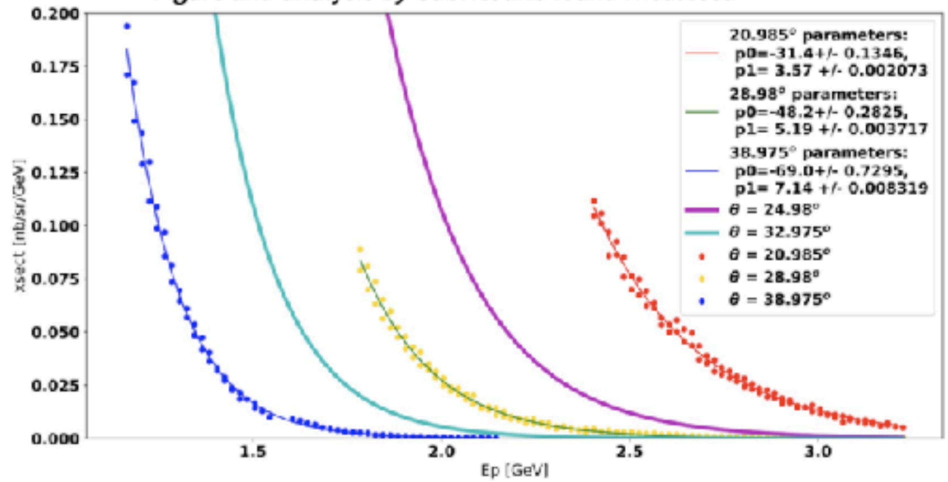


F2 Cross Section Extraction

Charge Symmetric Background

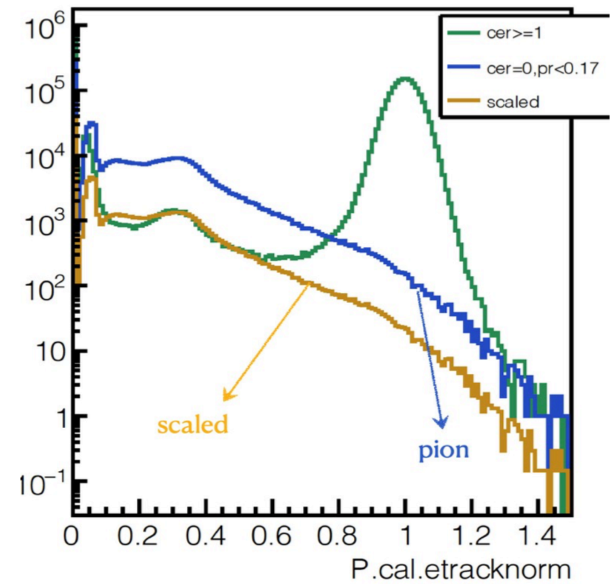
- Electrons can be produced from charge symmetric processes
- e.g. ($\pi_0 \rightarrow 2\,\Upsilon \rightarrow 2\,(e+e-)$)
- These events can look like inclusive scatterers
- Positron runs were taken at several kinematics in order to measure the CSB
- The results were parametrized and extrapolated to all kinematics were positron runs was not taken
- The background was added into the MC weighting

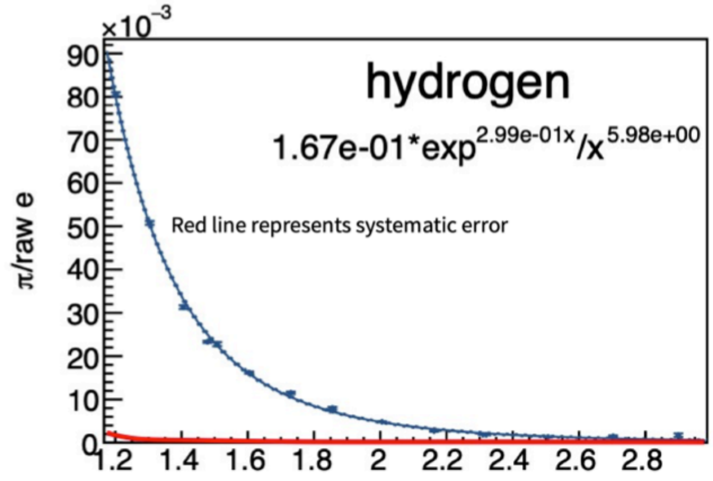
Figure and analysis by Gabriel and Ioana Niculescu



Cross Section Extraction: Pion Contamination

- Pions that pass the electron cuts need to be removed from yields
- The π/e ratio was calculated for each spectrometer angle and parameterized as a function of E'
- Analysis was done for each target (LH2, LD2, C12, AL)
- For large angle/ small E' this can be very large (~10 % effect)

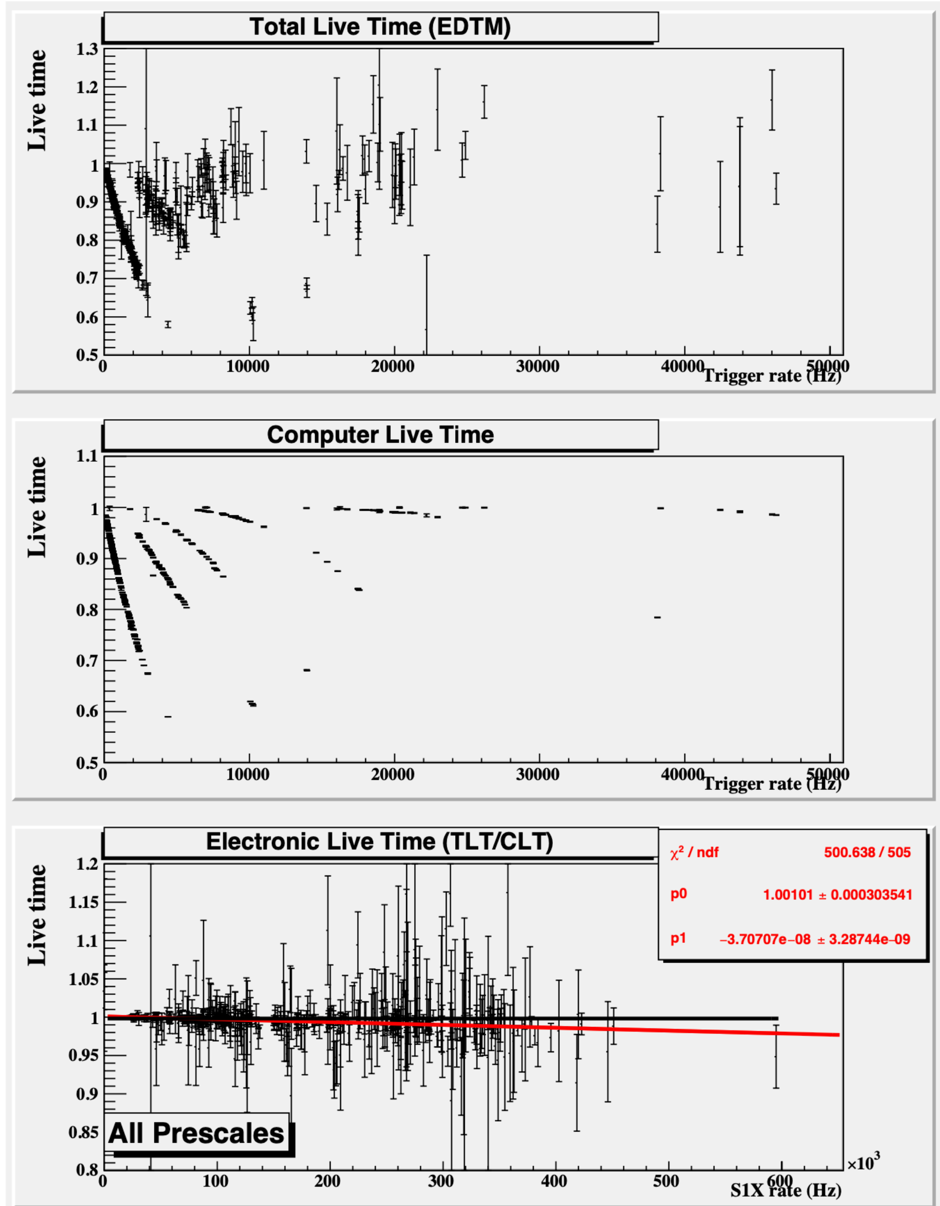




F2 Cross Section Extraction

Livetime Correction

- Total livetime (TLT) was measured by the new EDTM system.
- Since the EDTM rate was small (10 Hz) there was insuffienct statistics to provide an accurate measure of the TLT
- The computer livetime (CLT) can be calculated by looking at the scalers trigger counts vs recorded triggers.
- The electronic live time (ELT) is not measured directly.
- However, since TLT = ELT * CLT, a fit was of TLT/CLT over all runs was used to calculate the total live time correction.
- e.g.   ELT at 270 kHz plane rate = 99.0%
- A 100% uncertainty was applied to the ELT calculation



HMS delta correction

Measurements of F_2 and $R = \sigma_L/\sigma_T$

on Nuclear Targets in the Nucleon Resonance Region

Vahe Mamyan
Yerevan, Armenia

B.S. Yerevan State University, 1999
M.S. Yerevan State University, 2001

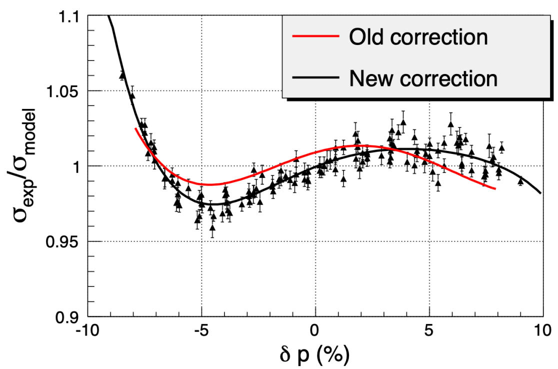
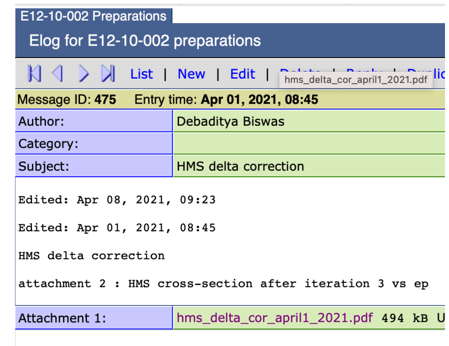
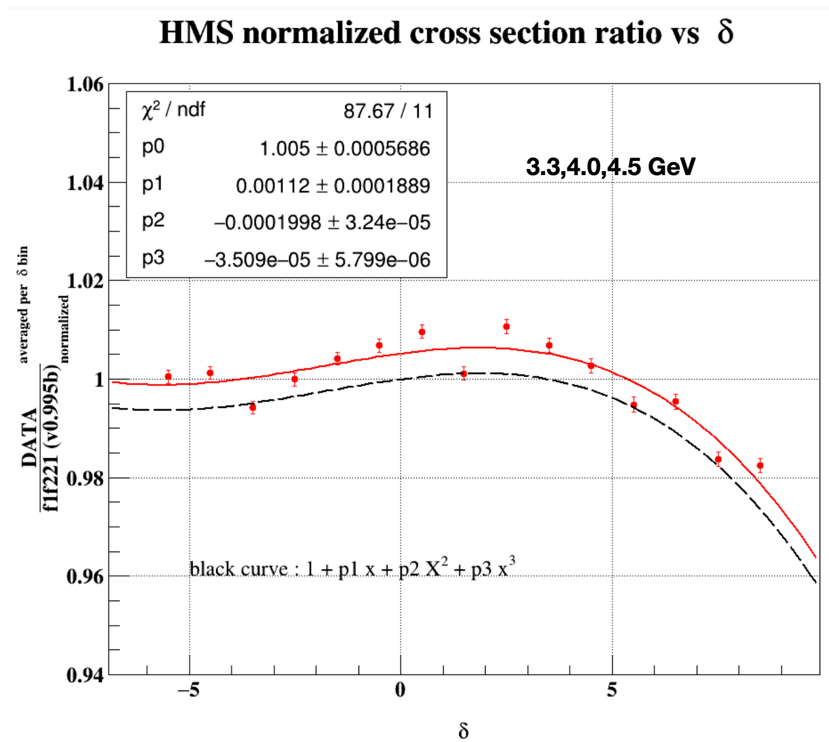


Figure 44: Ratio of experimental to model cross sections versus δp. The red line is the same ratio obtained in a previous experiment, E99-118. This effect is caused by optic mis-calibration.





SHMS acceptance correction

E12-10-002 Preparations

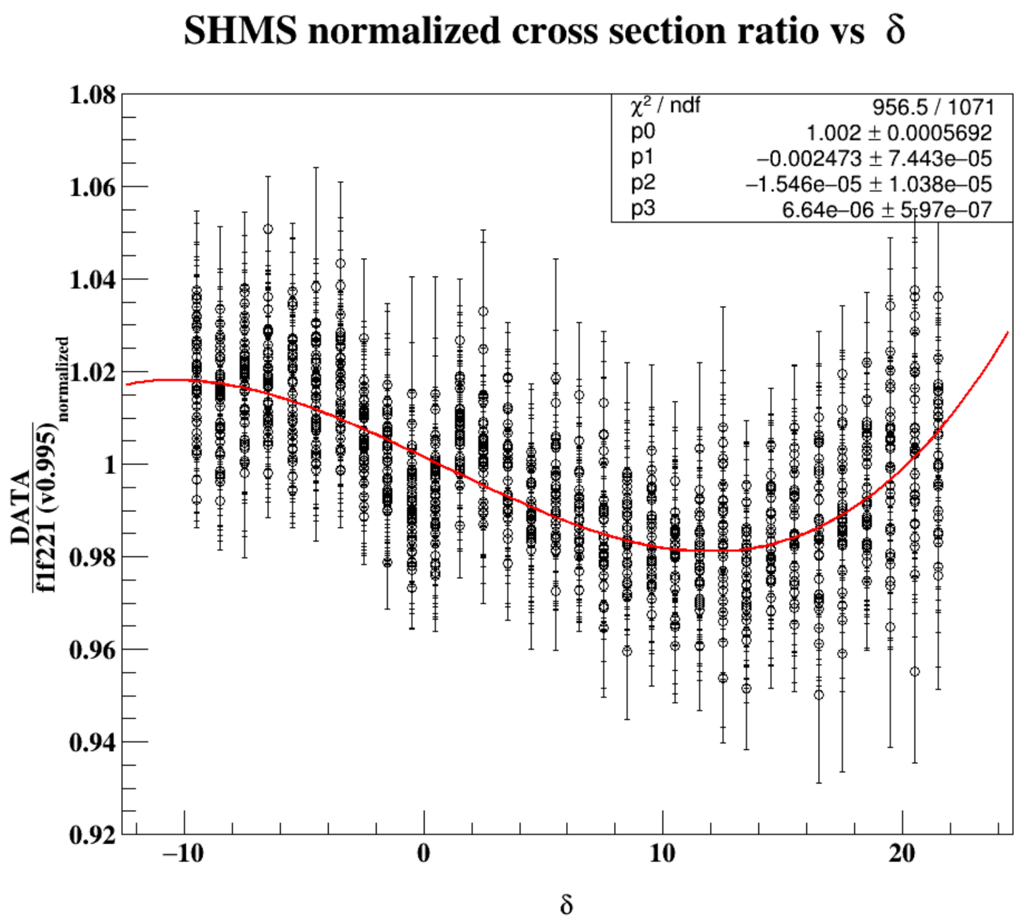
Elog for E12-10-002 preparations

List | New | Edit | Delete | Reply | Duplicate | Find

Message ID: **520** Entry time: **Sep 22, 2021, 18:02**

Author:	Debaditya Biswas
Category:	
Subject:	SHMS acceptance correction and error estimation

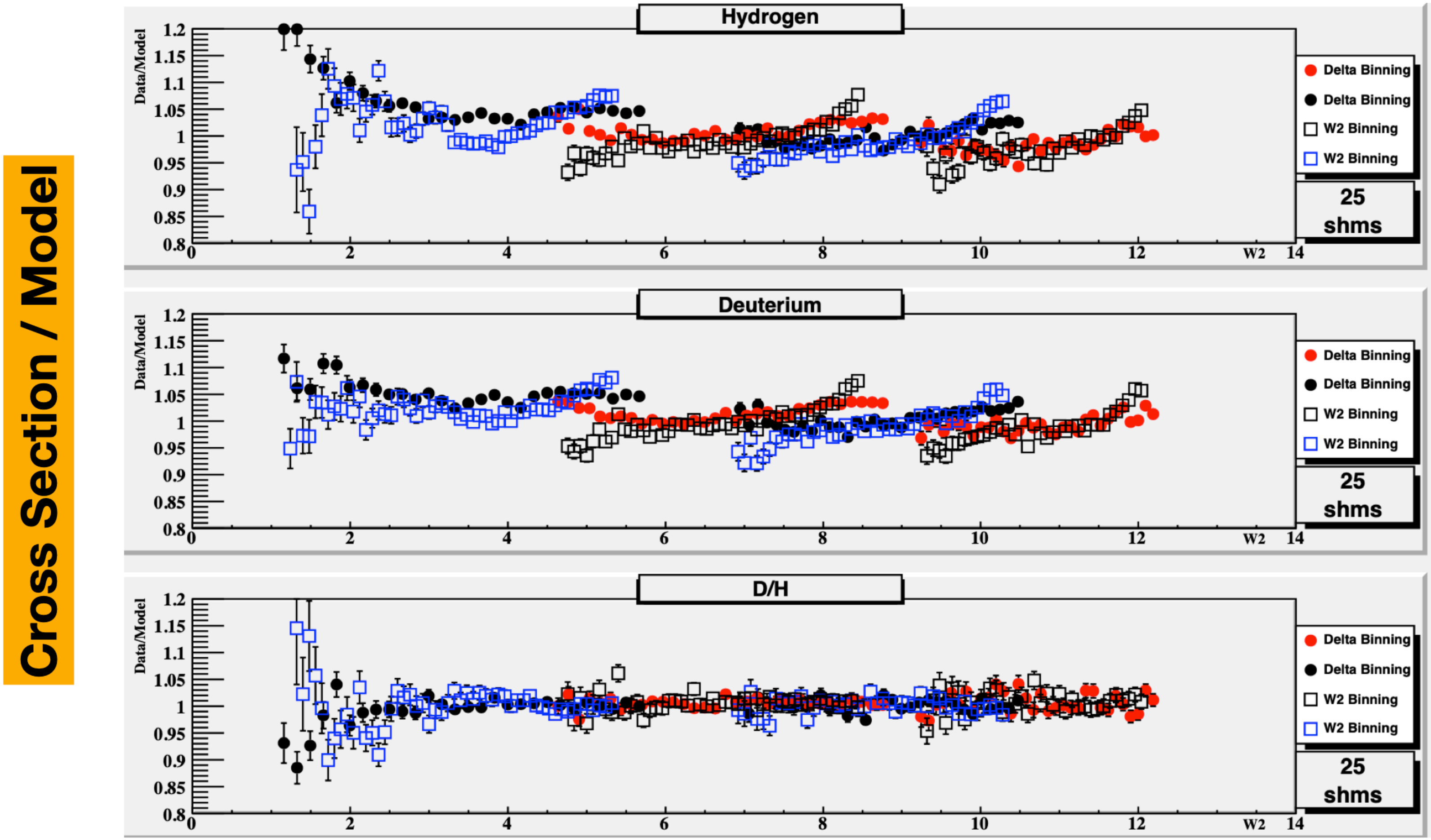
```
Edited: Oct 08, 2021, 00:44

Edited: Sep 22, 2021, 18:01
SHMS acceptance correction

p0 = 1.00156
p1 = -0.002473
p2 = -1.54588e-05
p3 = 6.63986e-06

correction factor : p0 + p1*(delta) + p2*(delta^2) + p3*(delta^3)

new cross-section = cross-section * (1/correction factor)

error budget : 0.439% random point to point
```



Jefferson Lab

Recent Changes to Analysis

Cross section extraction: W2 vs Delta binning



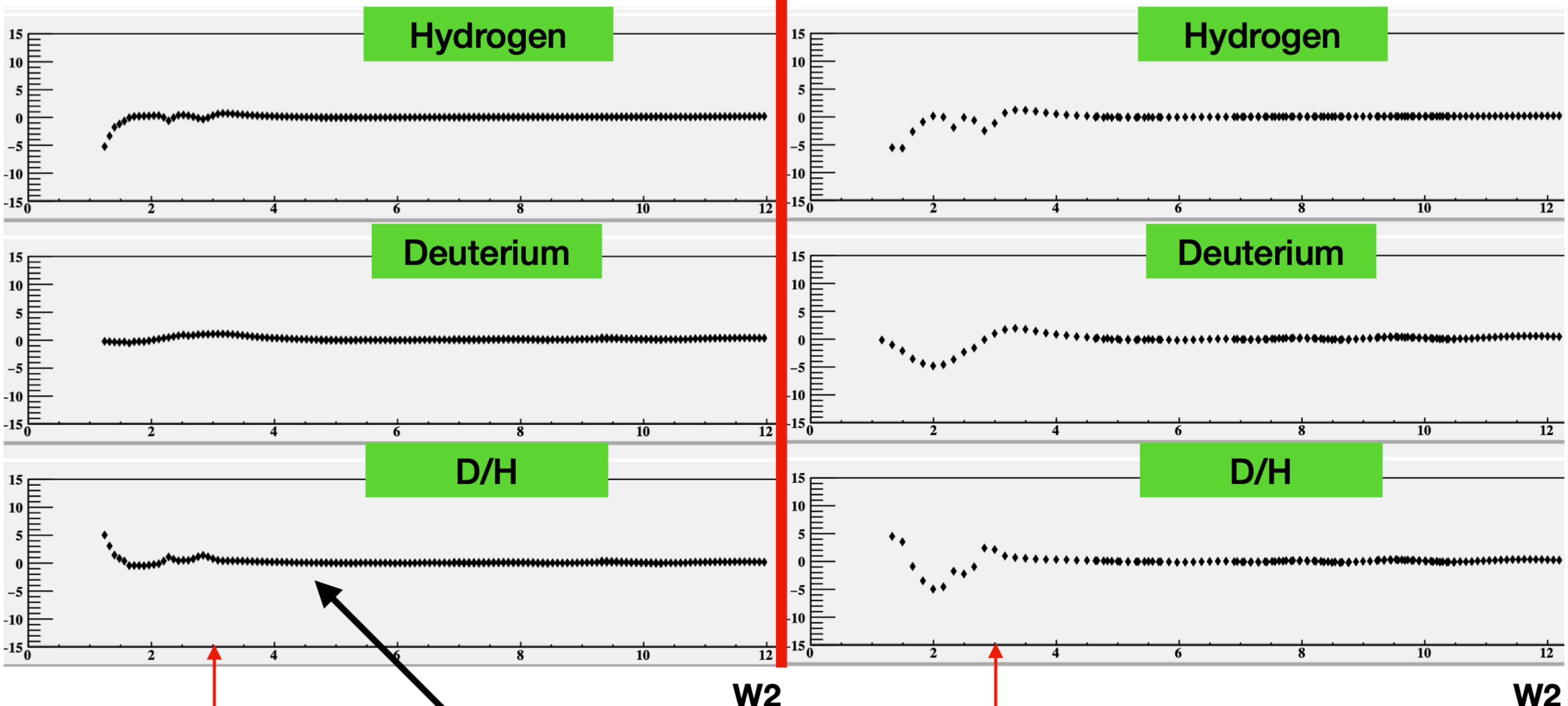
- **Overlap region in cross section is worst with W2 binning but vanishes in D/H ratio**
- **Needs to be addressed for absolute cross sections**

Recent Changes to Analysis

Change in extracted cross section when using different input models

W2 Binning | **Delta Binning**

Percent Difference



W2 | W2

- **Apply as additional systematic error**

- **W2 Binning is less sensitive to model dependence, especially in the resonance region!**

Cross Section Extraction: Error Budget

- In the ratio, F_2^D/F_2^p, many of the systematic errors are reduced
- Target density error: 1.1%
- Livetime errors approach 1% at the highest rate kinematics
- “Kinematic” error includes contributions from the $\delta E_{scat.}$’, δE_{beam}, and $\delta \theta_{central}$

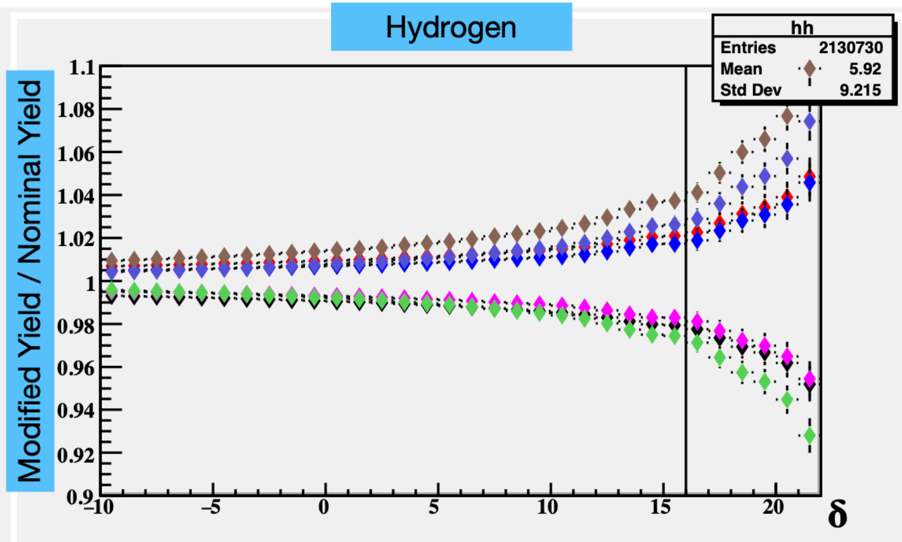
Error	Pt. to Pt (%)	Correlated (%)
Statistical	0.6 – 5.6(2.9)	
Charge	0.1 – 0.6	
Target Density	0.0 – 0.2	1.1
Livetime		0.0 – 1.0
Model Dependence		0.0 – 2.6(1.2)
Charge Sym. Background		0.0 – 1.4
Acceptance		0.0 – 0.6(0.3)
Kinematic		0.0 – 0.4
Radiative Corrections		0.5 – 0.7(0.6)
Pion Contamination		0.1 – 0.3
Cerenkov Efficiency		0.1
Total	0.6 – 5.7(2.9)	1.3 – 2.9(2.1)

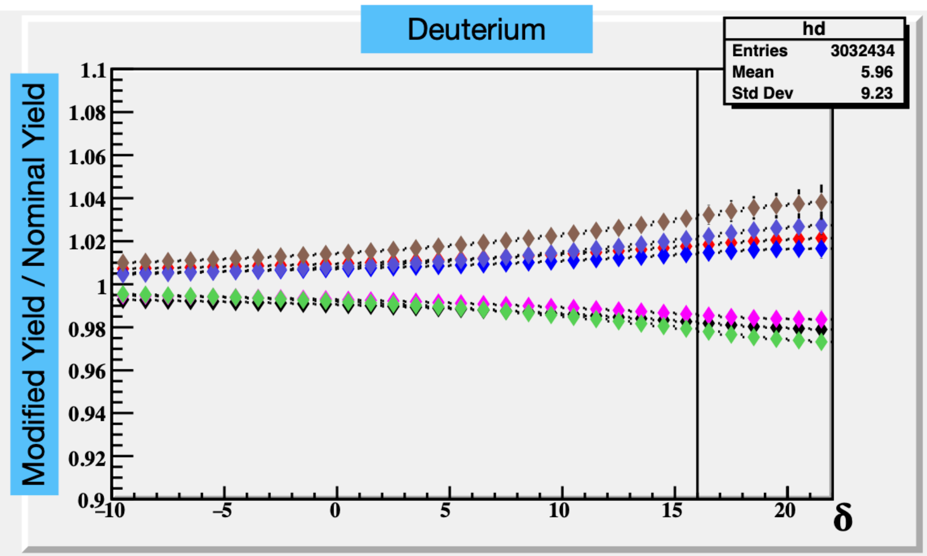
TABLE I. Error budget for the cross section ratio σ_D/σ_H. The error after a cut of $W^2 > 3$ GeV^2 is shown in parenthesis, this is a typical cut applied to eliminate the resonance region while performing PDF fits.

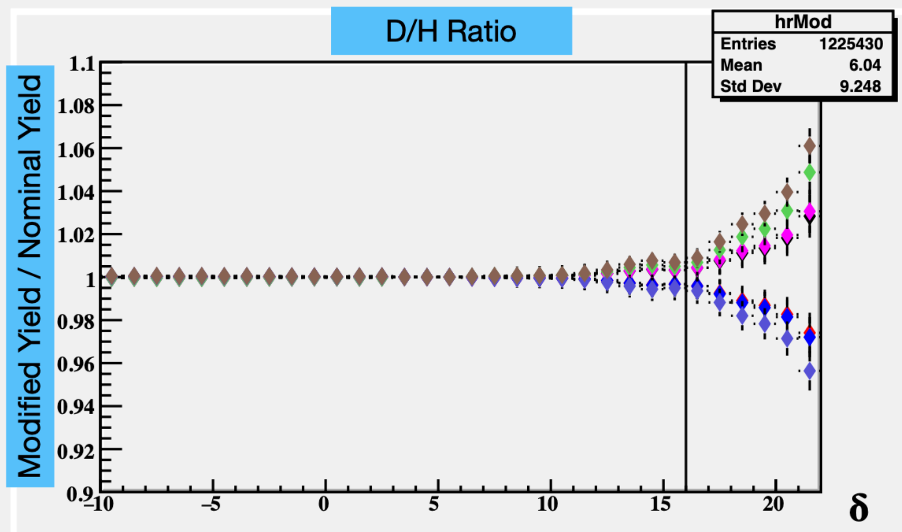
F2 Cross Section Extraction

Kinematic Uncertainities

How well do we know E, E', and θ ?







21deg 5p1GeV shms

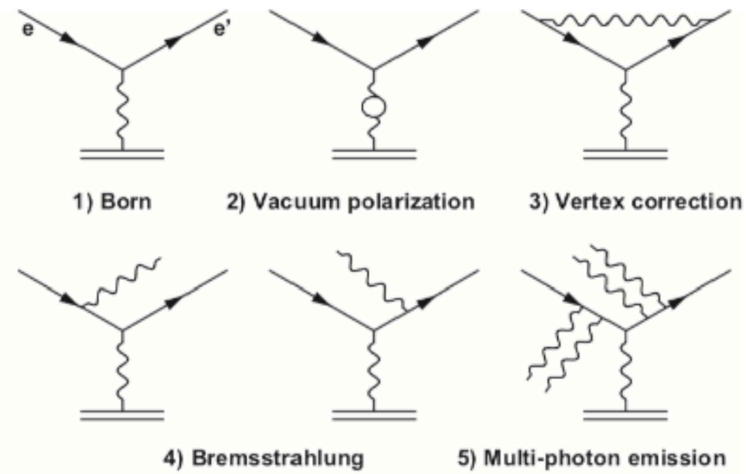
- θ_C + 0.25 mr
- θ_C - 0.25 mr
- Ebeam +0.1%
- Ebeam -0.1%
- E' +0.1%
- E' +0.1%
- Total Error

Vary these in monte carlo and compare to nominal yields

F2 Cross Section Extraction

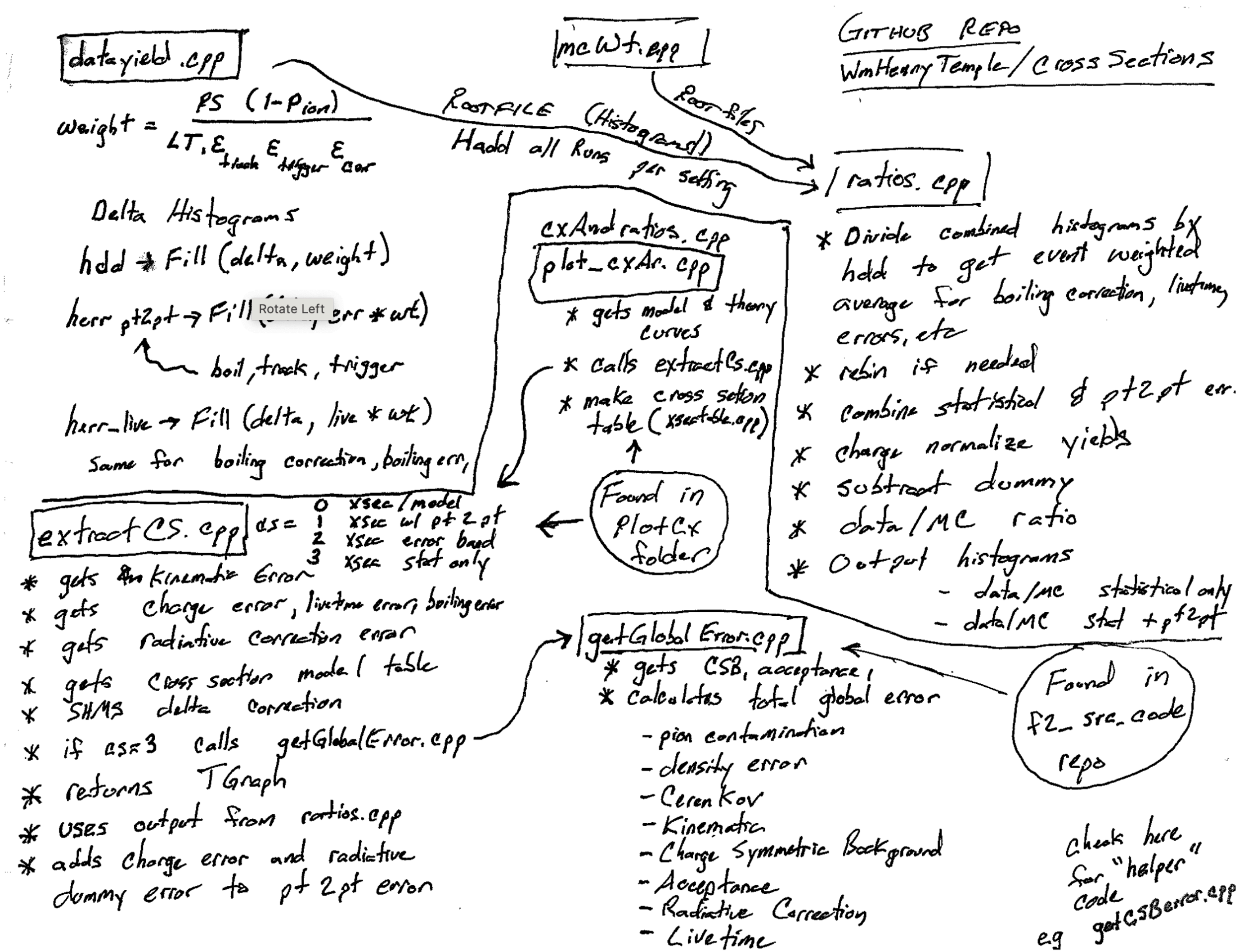
Radiative Corrections

- Monte-Carlo events generated by the mc-single-arm does not consider the effect of the several radiative processes. Born approximation is just the first order approximation in α of electron-nucleon scattering by one photon exchange. To mimic the reality we multiply the each events of MC by $\frac{\sigma_{rad}^{model}}{\sigma_{Born}^{model}}$ where, σ_{born}^{model} = model Born cross-section, σ_{Rad}^{model}= total radiative model cross-section



- Cross section model is radiated using “rc_externals”.

Analysis Flow



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Summary/Outlook

- Deuteron to proton ratios complete
  - Dataset is available for inclusion in PDF fits, models, etc
  - 2nd draft of PRL publication to be submitted this month
- Future work
  - $\theta_C = 59^{\circ}$ ratios from HMS. Analysis ongoing
  - Absolute deuteron and proton cross section.
    - Quark-Hadron duality Averaging
    - Compute non single moments
    - Improve resonance/DIS modeling

<u>Experiment Spokespeople</u>
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Thia Keppel
Simona Malace
Ioana Niculescu
Gabriel Niculescu
Dave Gaskell (EMC)

<u>Graduate Students</u>
Deb Biswas
Aruni Nadeeshani
Abel Sun
Abishek Karki (EMC)
Casey Morean (EMC)

<u>JLab Staff</u>
Bill Henry **(Contact)**

<u>Special Thanks to</u>
Mark Jones
Carlos Yero
Greg Smith

New Measurements of the Deuteron to Proton F_2 Structure Function Ratio

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(for the Hall C Collaboration)

https://github.com/WmHenryTemple/crossSections

https://github.com/WmHenryTemple/f2_src_code

https://hallcweb.jlab.org/DocDB/0008/000867/002/inclusive_analysis-2017-1.pdf

https://hallcweb.jlab.org/elogs/E12-10-002+Preparations/

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