Precision Measurements of the Deuterium to Hydrogen F_2 Structure Function Ratio at Large x

William Henry
Jefferson Lab

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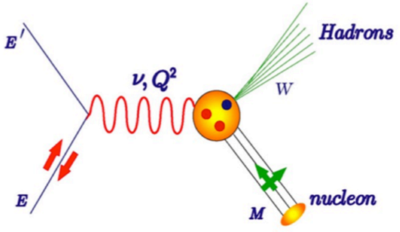
The F2 experiment in Hall C

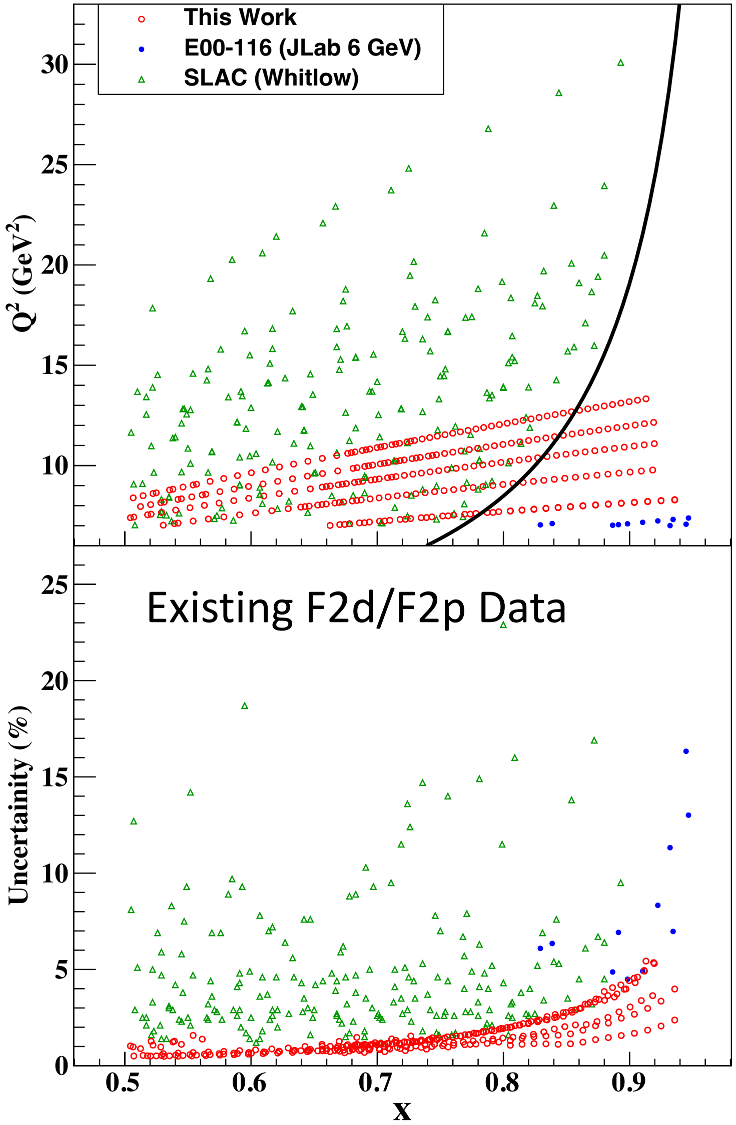
$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2 \sin^4\left(\frac{\theta}{2}\right)} \left(\frac{2}{M} F_1(x,Q^2) \sin^2\left(\frac{\theta}{2}\right) + \frac{1}{\nu} F_2(x,Q^2) \cos^2\frac{\theta}{2}\right)$$

$Q^2 = 4EE' \sin^2(\theta/2)$	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



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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

71% of total data were taken by SHMS

SHMS

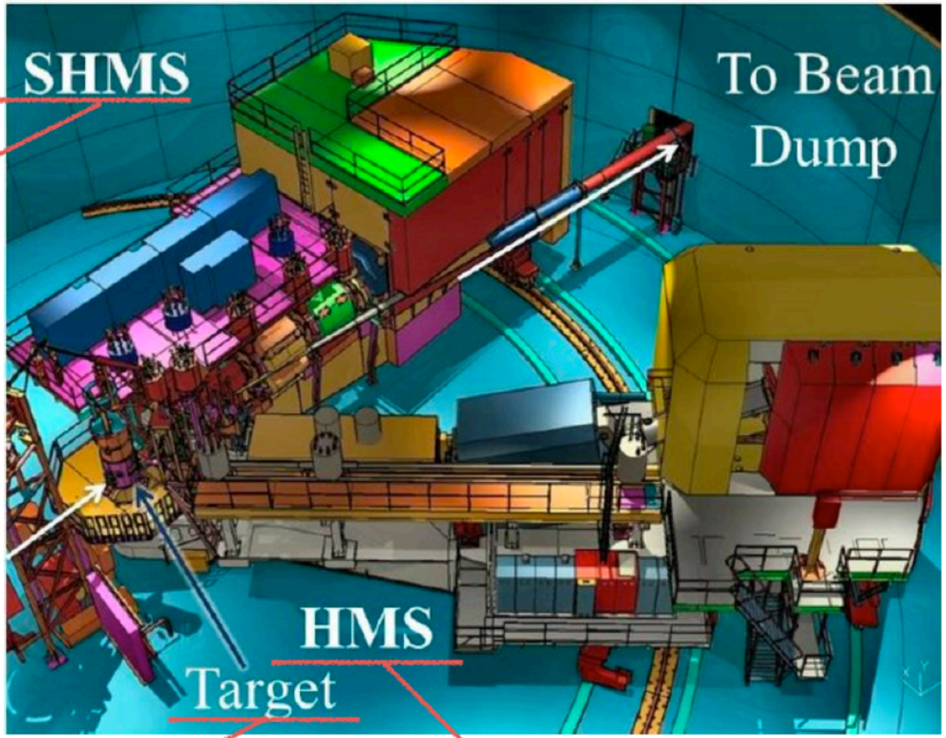
Angle	Momentum(GeV/c)
21	2.7, 3.3, 4.0, 5.1
25	2.5, 3.0, 3.5, 4.4
29	2.0, 2.4, 3.0, 3.7
33	1.7, 2.1, 2.6, 3.2
39	1.3, 1.6, 2.0, 2.5

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

Hall C Spectrometers



LH_2, LD_2, Al

Push to high Q^2

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Cross Section Extraction: Data Yields

Number of scattered particles form the tracks in drift chambers and pass through all the PID (cerenkov and calorimeter) cuts

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
$I_{BCM\ 4C} > 5.0$

Pion contamination + Charge Symmetric background + Cryo Cell Contribution

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

Prescale

Total efficiency :

$$\epsilon_{tot} = \epsilon_{track} \times \epsilon_{cerenkov} \times \epsilon_{calorimeter}$$

Electronic live time

Computer live time

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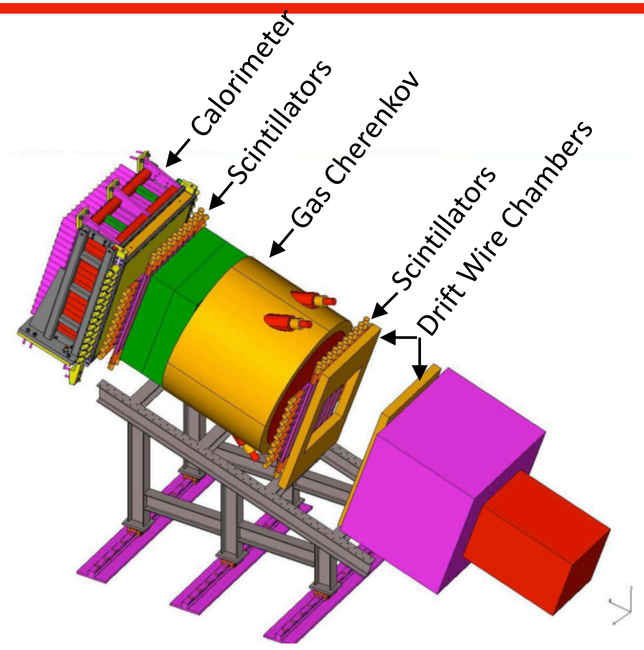
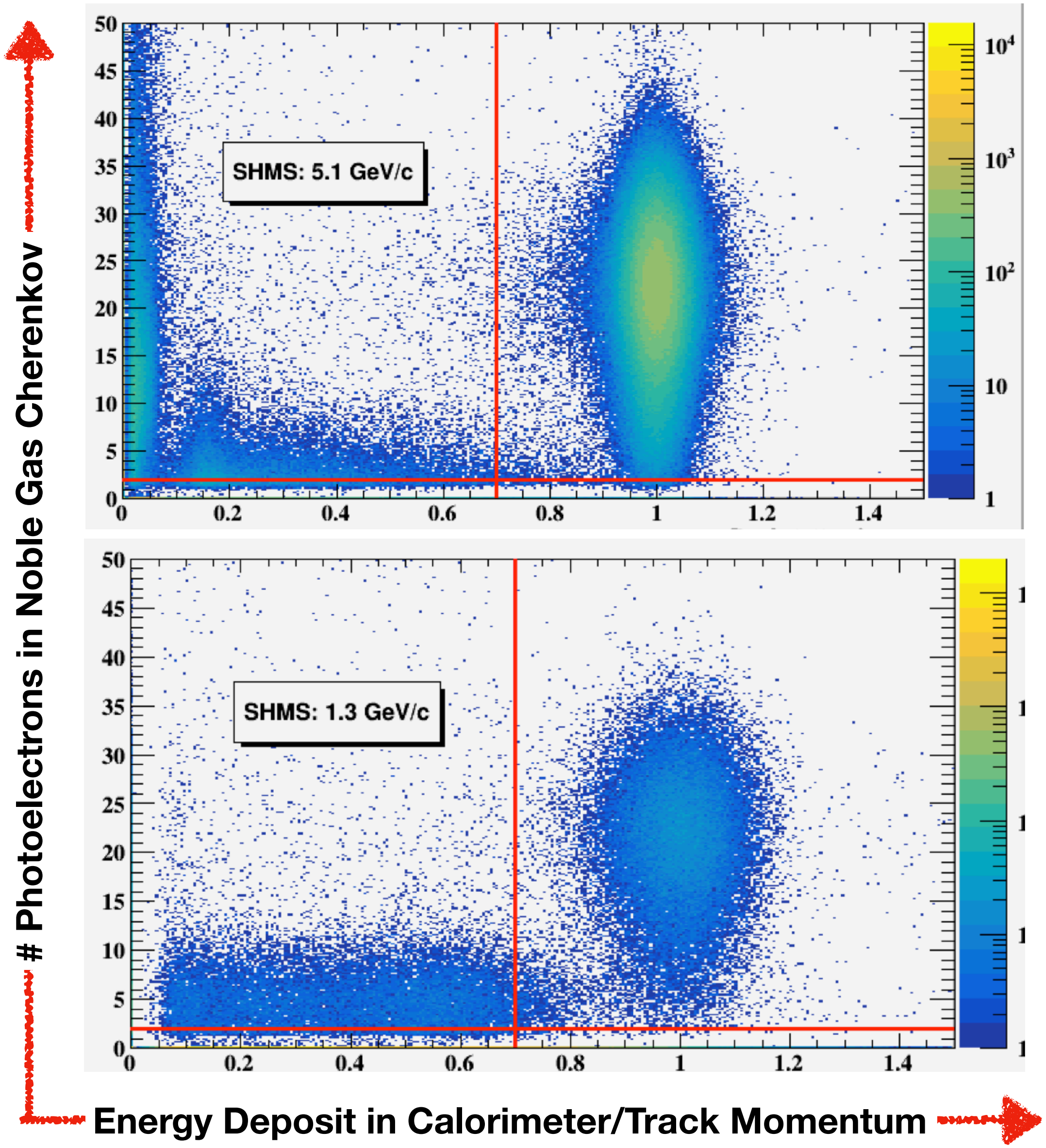
Cross Section Extraction: Particle identification



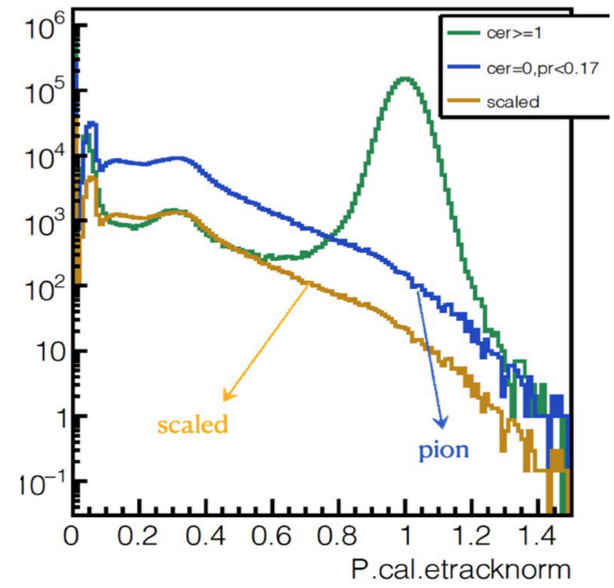


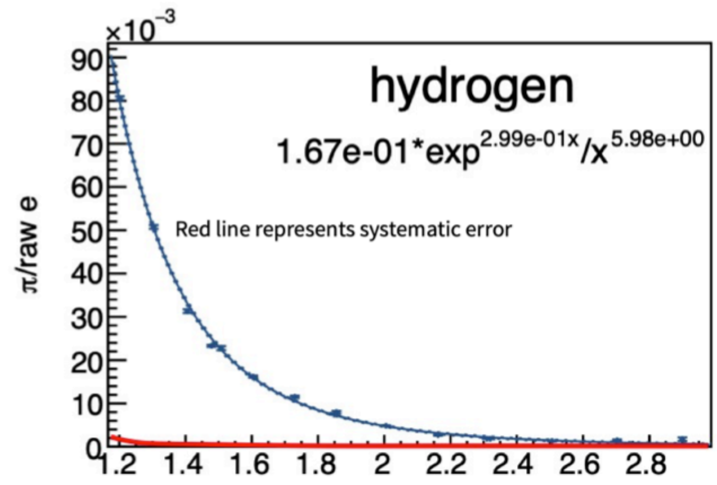
<u>PID Cuts</u>

- E/p > 0.7
- NPE > 2.0

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)





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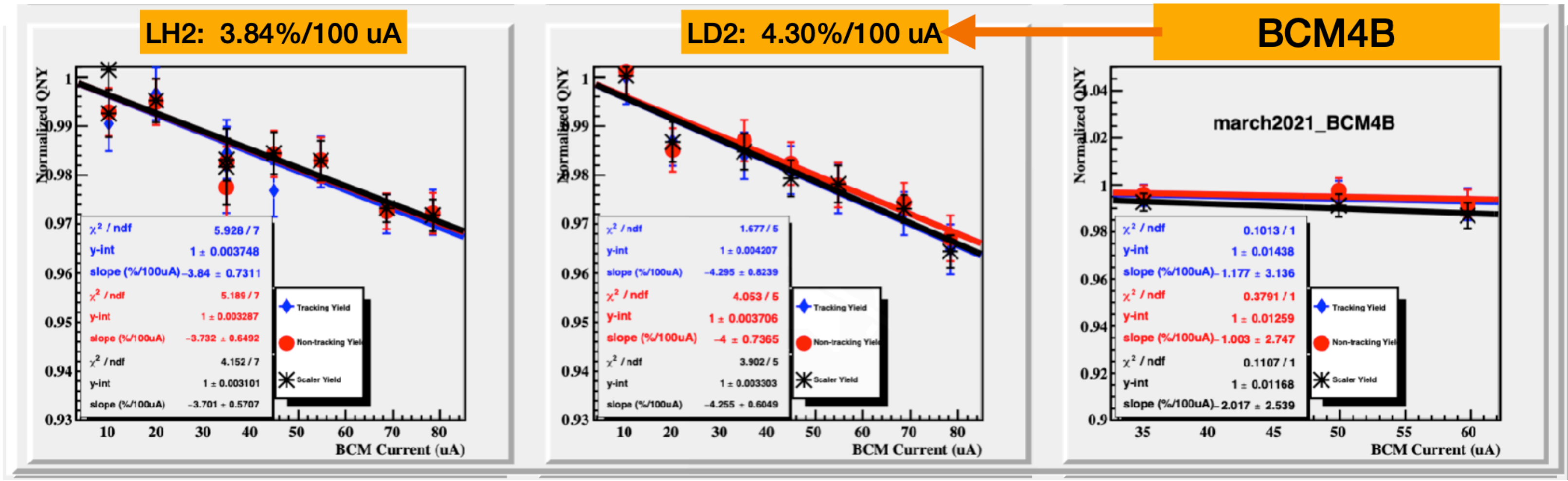
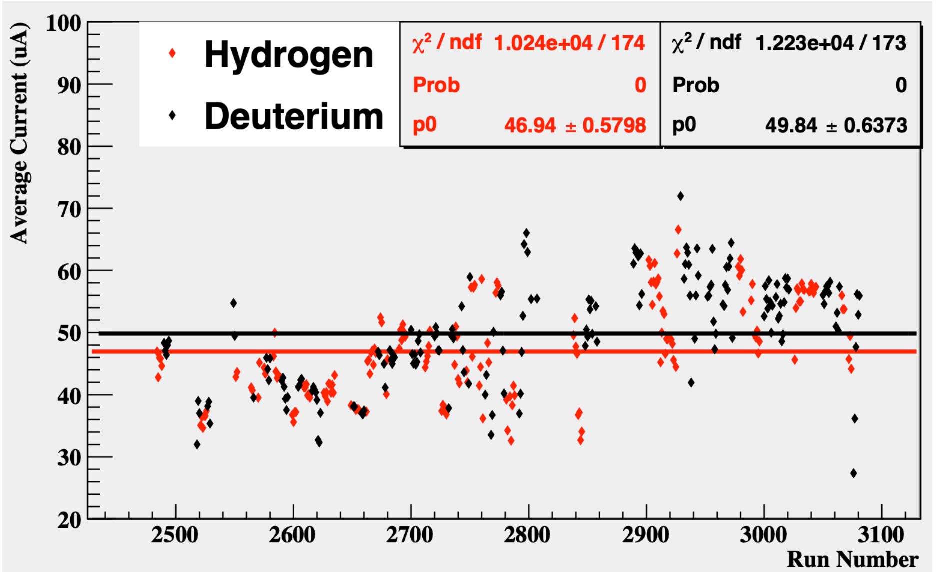
Target Density Correction

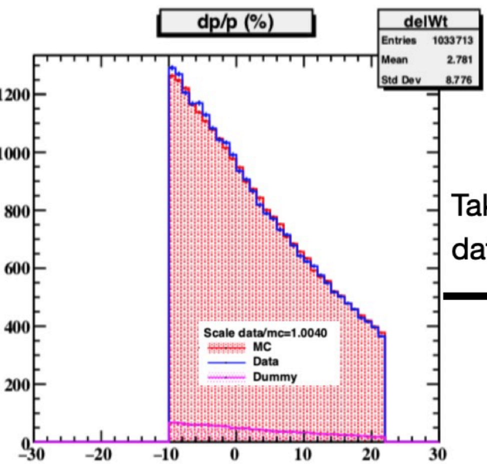


- Luminosity Runs were used to determine the density correction
- Experiment ran at an average beam current of 50 uA
- Target density uncertainty in D/H ratio ~1.1%



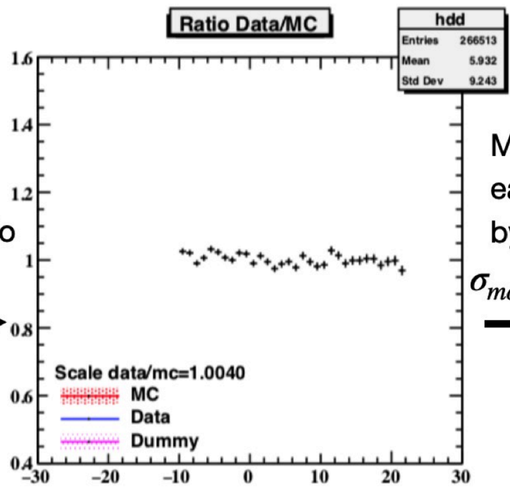
Cross Section Extraction: Monte Carlo Ratio Method

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

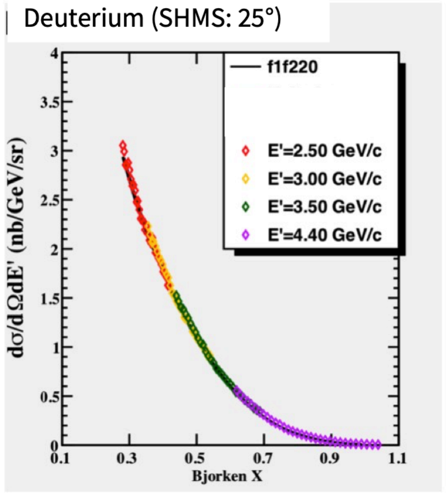


(Data is dummy subtracted)

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

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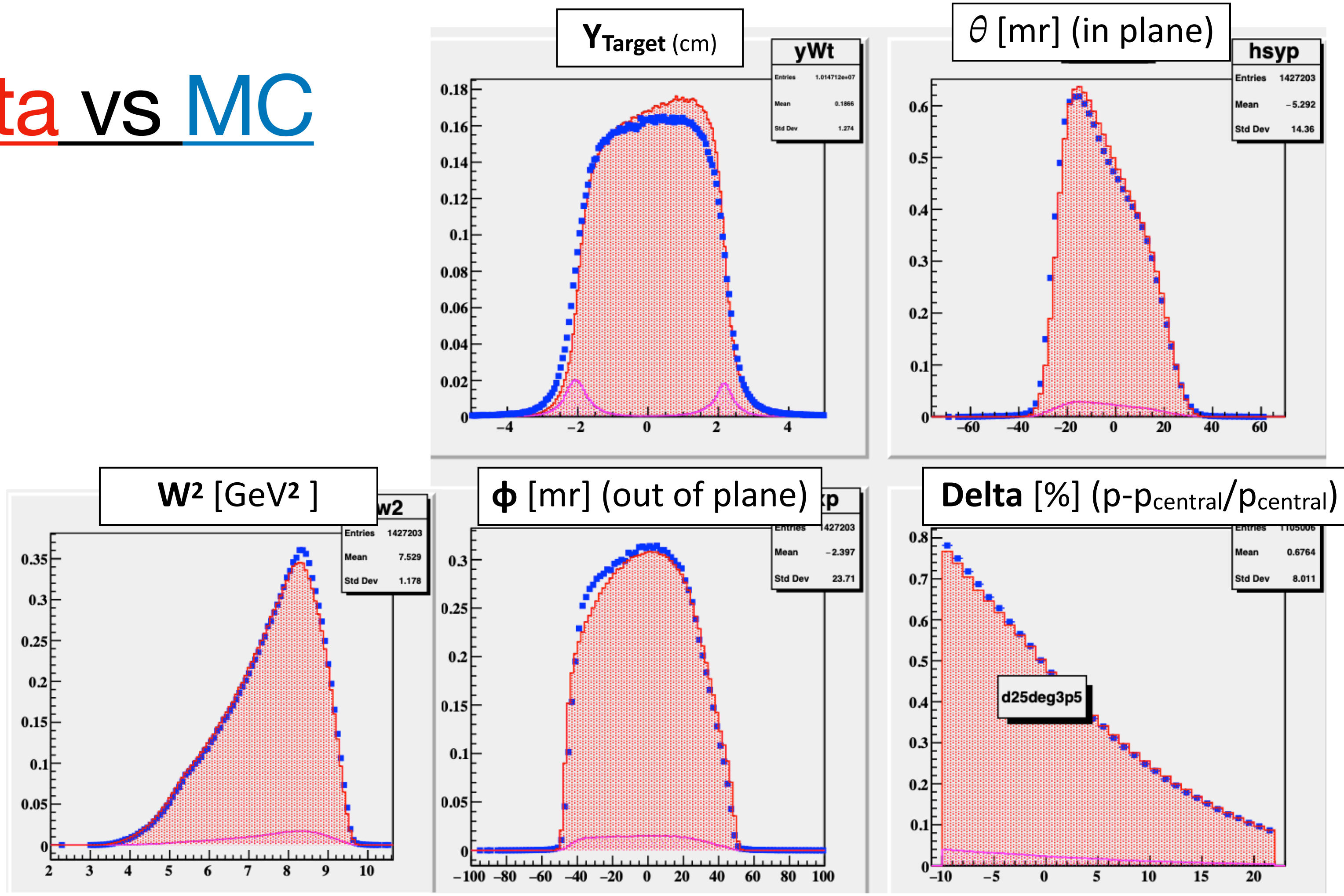
Cross Section Extraction: Monte Carlo Ratio Method

Data vs MC



Cross Section Extraction: Error Budget

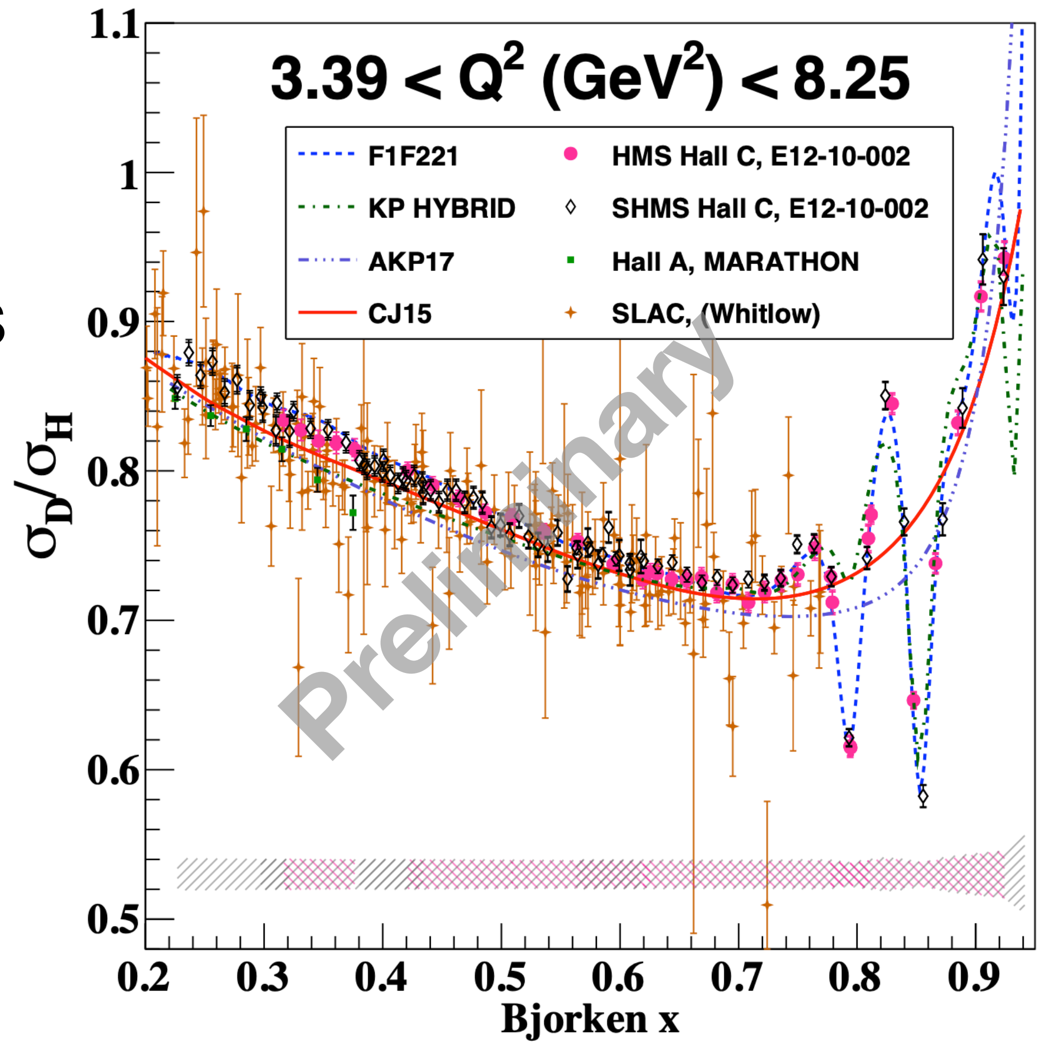
- In the ratio, F_2^D/F_2^p, many of the systematic errors are reduced
- Target density error: 1.1%
- Livetime errors approach 1% at the highest rate kinematics
- “Kinematic” error includes contributions from the $\delta E_{scat.}'$, δE_{beam}, and $\delta\theta_{central}$

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.

Results

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



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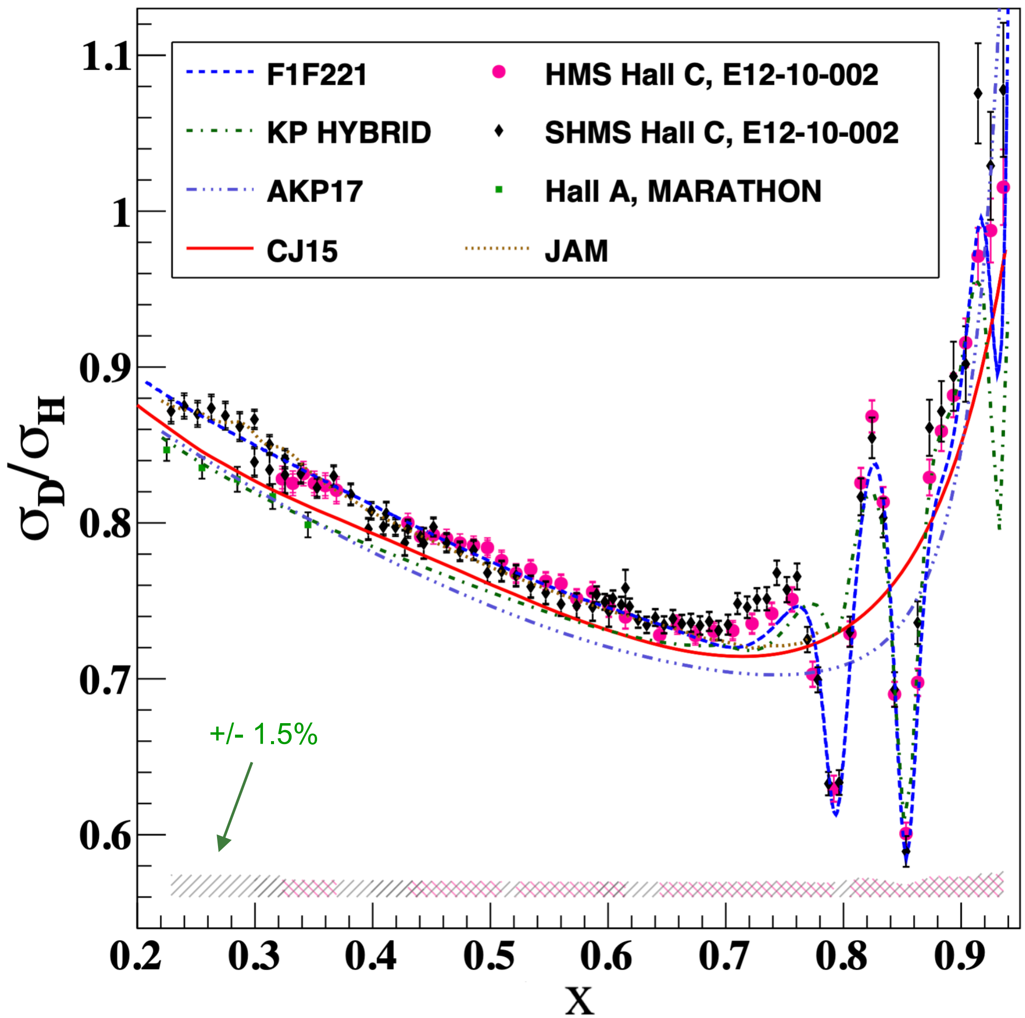
Results

- Excellent agreement between SHMS and HMS
- "F1F221" model does not include this work
- 2-3% discrepency exists between the Hall A and Hall C results

$$\theta_C = 21°$$



Results

- Other models/fits shown are:

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)

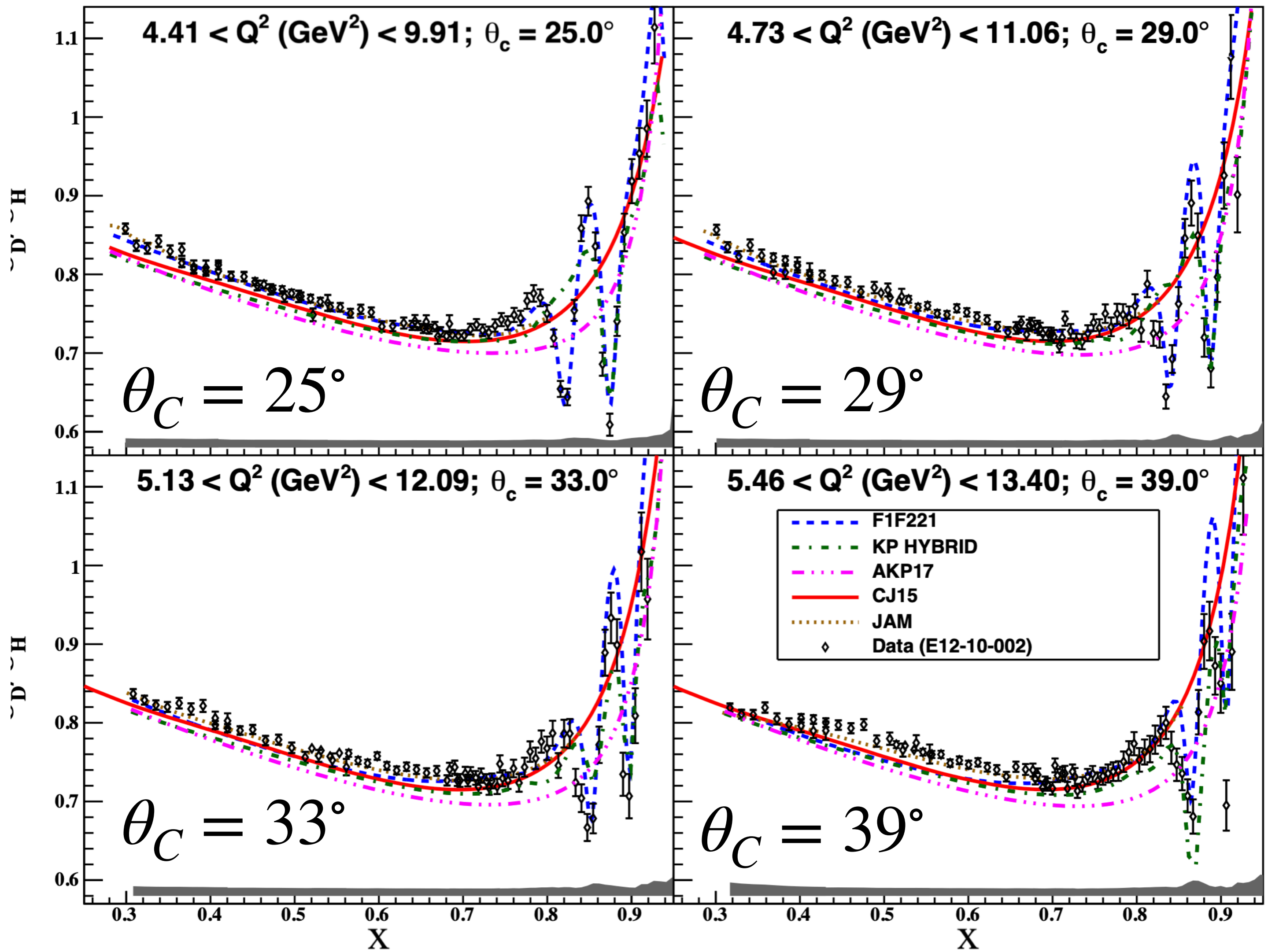
Dec 31, 2018

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



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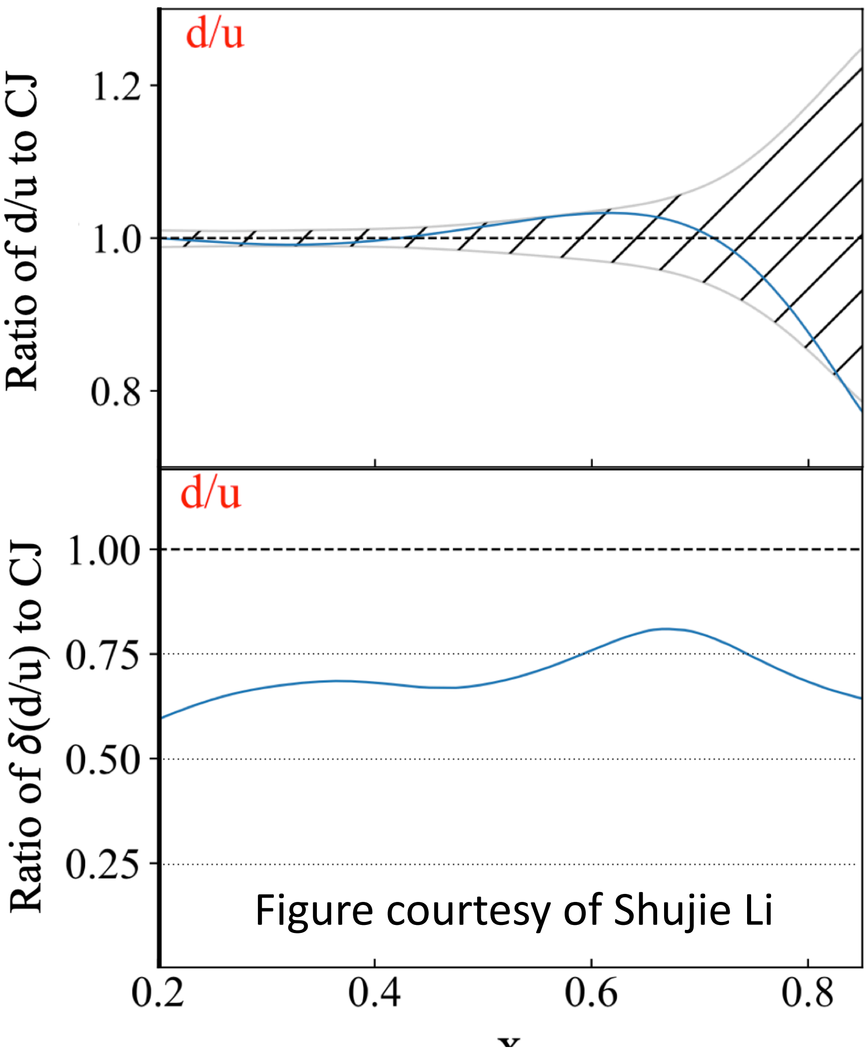
Impact Studies

- Impact studies from the CJ collaboration demonstrate the constraining power of this data on PDF fits
- The central value of the largly unconstrained d/u PDFs at large x shifted (top)
- The relative errors in the d/u PDF was reduced significantly across a wide range in x



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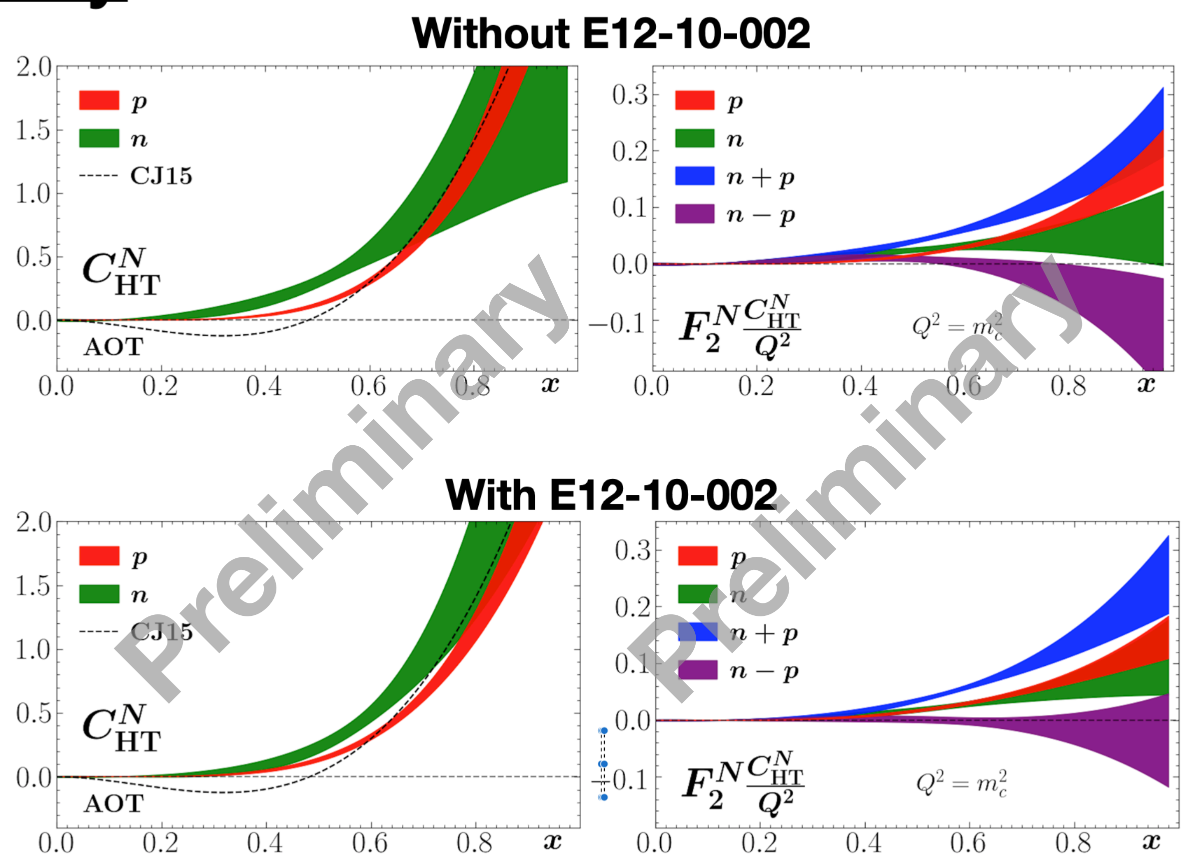
JAM Impact Study

https://www.jlab.org/theory/jam

- D/H ratio was provided to Jefferson Lab Angular Momentum Collaboration (JAM) to incorporate into their global QCD analysis of PDFs
- New F2 data significantly improves the uncertainty of higher twist corrections to F2

$$F_2(x,Q^2) = F_2^{\rm LT}(x,Q^2)\left(1+\frac{C_{\rm HT}(x)}{Q^2}\right)$$



Courtesy of Chris Cocuzza, W. Melnitchouk, and N. Gonzalez

William Henry

wmhenry@jlab.org

Summary/Outlook

- Deuteron to proton ratios complete
  - Dataset is available for inclusion in PDF fits, models, etc
  - First publication ready for PRL submission
- 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

Experiment Spokespeople	Graduate Students	JLab Staff
Eric Christy	Deb Biswas	Bill Henry **(Contact)**
Thia Keppel	Aruni Nadeeshani	
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Gabriel Niculescu	Casey Morean (EMC)	Carlos Yero
Dave Gaskell (EMC)		Greg Smith

New Measurements of the Deuteron to Proton F_2 Structure Function Ratio

D. Biswas,[1] F. Gonzalez,[2] W. Henry,[3] A. Karki,[4] C. Morean,[5] A. Nadeeshani,[1] A. Sun,[6] D. Abrams,[7] Z. Ahmed,[8] B. Aljawrneh,[9] S. Alsalmi,[10] R. Ambrose,[8] W. Armstrong,[11] A. Asaturyan,[12] K. Assumin-Gyimah,[4] C. Ayerbe Gayoso,[13,4] A. Bandari,[13] S. Basnet,[8] V. Berdnikov,[14] H. Bhatt,[4] D. Bhetuwal,[4] W. U. Boeglin,[15] P. Bosted,[13] E. Brash,[16] M. H. S. Bukhari,[17] H. Chen,[7] J. P. Chen,[3] M. Chen,[7] M. E. Christy,[1,3] S. Covrig,[3] K. Craycraft,[5] S. Danagoulian,[9] D. Day,[7] M. Diefenthaler,[3] M. Dlamini,[18] J. Dunne,[4] B. Duran,[11] D. Dutta,[4] R. Ent,[3] R. Evans,[8] H. Fenker,[3] N. Fomin,[5] E. Fuchey,[19] D. Gaskell,[3] T. N. Gautam,[1] F. A. Gonzalez,[2] J. O. Hansen,[3] F. Hauenstein,[20] A. V. Hernandez,[14] T. Horn,[14] G. M. Huber,[8] M. K. Jones,[3] S. Joosten,[21] M. L. Kabir,[4] C. Keppel,[3] A. Khanal,[15] P. M. King,[18] E. Kinney,[22] M. Kohl,[1] N. Lashley-Colthirst,[1] S. Li,[23] W. B. Li,[13] A. H. Liyanage,[1] D. Mack,[3] S. Malace,[3] P. Markowitz,[15] J. Matter,[7] D. Meekins,[3] R. Michaels,[3] A. Mkrtchyan,[12] H. Mkrtchyan,[12] Z. Moore,[24] S.J. Nazeer,[1] S. Nanda,[4] G. Niculescu,[24] I. Niculescu,[24] D. Nguyen,[7] Nuruzzaman,[25] B. Pandey,[1] S. Park,[2] E. Pooser,[3] A. Puckett,[19] M. Rehfuss,[11] J. Reinhold,[15] B. Sawatzky,[3] G. R. Smith,[3] H. Szumila-Vance,[3] A. Tadepalli,[25] V. Tadevosyan,[12] R. Trotta,[14] S. A. Wood,[3] C. Yero,[15] and J. Zhang[2]
(for the Hall C Collaboration)