F2 Update in Hall C

Precision measurements of the F2 structure function at large x in the resonance region and beyond
F2 Experiment in Hall C

- 12 GeV Commissioning Experiment
- Ran in Spring 2018
- Single Arm (Inclusive) measurement
- Scattered e- detected in spectrometers
- Hydrogen and Deuterium Liquid Targets

Physics motivation

- Constrain PDFs
- Quark hadron duality
- Non singlet moments
- Resonance /DIS modelling
F2 Cross Section Extraction

Data Yields

- Calculated in 1% delta bins

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

<table>
<thead>
<tr>
<th>Acceptance Cuts for SHMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-10.0 &lt; y_{tar} &lt; 10.0$</td>
</tr>
<tr>
<td>$-0.1 &lt; y'_{tar} &lt; 0.1$</td>
</tr>
<tr>
<td>$-0.1 &lt; x'_{tar} &lt; 0.1$</td>
</tr>
<tr>
<td>$-10.0 &lt; \delta &lt; 22.0$</td>
</tr>
</tbody>
</table>

PID Cuts for SHMS

$N_{\text{tot}} > 2.0$

$E_{\text{calo}}/E > 0.7$

Current Cut for SHMS

$I_{\text{BCM 4c}} > 5.0$

Total efficiency:

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

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

Pion contamination + Charge Symmetric background + Cryo Cell Contribution

Electronic live time

Computer live time
F2 Cross Section Extraction

PID Cuts

- $E/p > 0.7$
- $NPE > 2.0$
Pion Contamination

- Pions that pass the electron cuts need to be removed from yields
- The $\pi/e$ 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)
Charge Symmetric Background

- Electrons can be produced from charge symmetric processes
- e.g. \((\pi_0 \rightarrow 2\gamma \rightarrow 2(e^+e^-))\)
- 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
Livetime Correction

- Total livetime (TLT) was measured by the new EDTM system.
- Since the EDTM rate was small (10 Hz) there was insufficient 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 livetime (ELT) is not measured directly.
- However, since TLT = ELT * CLT, a fit of TLT/CLT over all runs was used to calculate the total livetime correction.
- e.g. ELT at 270 kHz plane rate = 99.0%
- A 100% uncertainty was applied to the ELT calculation.
• Recently learned that the PID on LD2 was changed during the run.

• Deuterium boiling study taken at 22.4 K

• Use Dave Mack’s boiling result from Fall 2018 (same fan speed and temperature) 2.84 +/- 0.32 % / 100 uA

• Additional density correction applied to 22.4 K data (0.6%)
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.
Monte Carlo (MC) Ratio Method

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

- MC ran for 50M events mc-single-arm
- Events are weighted after using radiated model
- Charge Symmetric Background added to MC
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 $\alpha$ of electron-nucleon scattering by one photon exchange. To mimic the reality we multiply the each events of MC by $\frac{\sigma_{\text{rad}}}{\sigma_{\text{model}}}$. Where,

$$\sigma_{\text{model}} = \text{model Born cross-section}, \sigma_{\text{Rad}} = \text{total radiative model cross-section}$$

- Cross section model is radiated using “rcExternals”.

[Diagram showing various processes: 1) Born, 2) Vacuum polarization, 3) Vertex correction, 4) Bremsstrahlung, 5) Multi-photon emission]
F2 Cross Section Extraction

Cross Section Extraction (MC Ratio Method)

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
F2 Cross Section Extraction

Data vs MC
F2 Cross Section Extraction

Focal Plane Comparisons: Data Vs Monte Carlo

Monte Carlo vs Data - Focal Plane Comparisons

- x_fp vs y_fp
- x_p_fp vs y_p_fp

Monte Carlo

Data - Dummy
F2 Cross Section Extraction

Focal Plane Comparisons: Data Vs Monte Carlo

Monte Carlo  \( x_{fp} \) vs \( x_{fp} \)

Data - Dummy  \( x_{fp} \) vs \( x_{fp} \)

Monte Carlo  \( y_{fp} \) vs \( y_{fp} \)

Data - Dummy  \( y_{fp} \) vs \( y_{fp} \)
The upstream and down stream thickness ratios are considered separately instead of an average thickness.

- The ratio $r_{c_{\text{dummy}}} / r_{c_{\text{cryo cell}}}$ is maximum $\pm 3\%$ (for either upstream or downstream).
- The maximum value of $CNY_{\text{dummy}} / CNY_{\text{total}}$ for hydrogen is $\sim 10.33\%$ and for deuterium for deuterium is $\sim 5.11\%$.
- For hydrogen the maximum effect is $(3\% \text{ of } 10.33\%) = 0.3\%$.
- For deuterium the maximum effect is $(3\% \text{ of } 5.11\%) = 0.15\%$.
F2 Results

HMS @ 21 degrees
F2 Results

HMS and SHMS @ 21 degrees

CJ15
Constraints on large-$\alpha$ 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. Kulesh (Moscow, INR)
Dec 51, 2018

AKP17
Nuclear Effects in the Deuteron and Constraints on the d/u Ratio
S.J. Aidekh (JINP, INR), S.A. Kulesh (Moscow, INR), R. Petri (South Carolina U.)
Apr 1, 2017

3.39 < $Q^2$ (GeV$^2$) < 8.25

$\frac{\sigma_D}{\sigma_H}$ vs Bjorken x

- F1F221
- KP HYBRID
- AKP17
- CJ15

HMS Hall C, E12-10-002
SHMS Hall C, E12-10-002
Hall A, MARATHON

F2 Update for Winter Hall C Collaboration Meeting

Jefferson Lab
February 17th, 2022
HMS and SHMS @ 21 degrees

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Apr 1, 2017

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\[\frac{\sigma_D}{\sigma_H}\]

Bjorken \(x\)

F2 Update for Winter Hall C Collaboration Meeting  February 17th, 2022
F2 Cross Section Extraction

Kinematic Uncertainties

How well do we know E, E', and \( \theta \)?

Hydrogen

- Entries: 2130730
- Mean: 5.92
- Std Dev: 9.215

Deuterium

- Entries: 3032434
- Mean: 5.96
- Std Dev: 9.23

D/H Ratio

- Entries: 1225430
- Mean: 6.04
- Std Dev: 9.248

21deg 5p1GeV shms

- \( \theta_c + 0.25 \) mr
- \( \theta_c - 0.25 \) 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.
CJ Impact Study

1. Data set from Bill: Normalization=1.1%, correlated/uncorrelated pt p errcrs are provided.

2. Perform a new fit with this new dataset together with the CJ15 original datasets. The fit will shift data points within given normalization and correlated errors.

3. Compare the modified data with calculation from new fit. The residual = (data - fit) / data_err should be a gaussian with width close to 1

Courtesy of Alberto Accardi and Shujie Li
F2 Results

CJ15 Impact Study

- No tension with original CJ15 data set
  - Data compatible with global data set (not always the case…)
  - Otherwise, one can bring to light neglected systematic uncertainties

![Graphs showing u/u_{CJ15} and (d/u)/(d/u)_{CJ15}](image)

Courtesy of Alberto Accardi and Shujie Li
F2 Results

CJ15 Impact Study

- No tension with original CJ15 data set
  → Data compatible with global data set (not always the case…)
  → Otherwise, one can bring to light neglected systematic uncertainties

- Uncertainty reduction comparable to full JLab 6 data set

![Graphs](image)

Courtesy of Alberto Accardi and Shujie Li
F2 Results

JAM Impact Study

Without E12-10-002

- 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

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

With E12-10-002

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

- Similar efforts are underway to see the impact the data will have on the JAM fits
- Working with CJ and JAM to understand the data’s impact on d, u, as well as nuclear effects
Summary and Acknowledgments

- D/H ratios complete and impact studies are being finalized. Paper being drafted (PRL)
- High Q2 setting in the HMS (59°) needs to be analyzed
- Absolute Cross Section Tasks
  - Revisit Calorimeter Efficiency
  - Revisit forward and reconstruction matrices
  - F2d and F2n extraction
  - MC Ratio method vs Acceptance Method
- Quark-Hadron duality Averaging
- Compute non single moments
- Improve resonance/DIS modeling

Experiment Spokespeoples
- Eric Christy
- Thia Keppel
- Simona Malace
- Ioana Niculescu
- Gabriel Niculescu
- Dave Gaskell (EMC)

Graduate Students
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- Aruni Nadeeshani
- Abel Sun
- Abishek Karki (EMC)
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Post Doc
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- Carlos Yero
- Greg Smith
Acknowledgments

- F2/EMC

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Back-Ups
Isovector EMC effect from global QCD analysis with MARATHON data

C. Cocuzza,1 C. E. Keppel,2 H. Liu,3 W. Melnitchouk,2 A. Metz,1 N. Sato,2 and A. W. Thomas4

1Department of Physics, SERC, Temple University, Philadelphia, Pennsylvania 19122, USA
2Jefferson Lab, Newport News, Virginia 23606, USA
3Department of Physics, University of Massachusetts, Amherst, Massachusetts 01003, USA
4CSSM and CoEPP, Department of Physics, University of Adelaide SA 5005, Australia

Jefferson Lab Angular Momentum (JAM) Collaboration

(Dated: April 15, 2021)

<table>
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<th>process</th>
<th>$N_{\text{dat}}$</th>
<th>$\chi^2/N_{\text{dat}}$</th>
<th>fitted norm.</th>
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<tbody>
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<td>DIS</td>
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<td></td>
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<tr>
<td>MARATHON $^3\text{He}/^3\text{H}$</td>
<td>22</td>
<td>0.63</td>
<td>1.007(6)</td>
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<tr>
<td>MARATHON $D/p$</td>
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<tr>
<td>JLab E03-103 $^3\text{He}/D$</td>
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<td>1.006(10)</td>
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<td>jet</td>
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<tr>
<td>total</td>
<td>4466</td>
<td>1.11</td>
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</tr>
</tbody>
</table>

arXiv:2104.06946
Impact on PDF uncertainties

Reference: CJ15.0 (the original CJ15 which already included BoNUS6 and E00116)
Set 1: CJ15 + this data
Set 2: CJ15 + more JLab 6GeV data (Ioana, E91118, E94110, E06009, E03103)
Set 3: CJ15 + this data + JLab 6GeV data
- Additional density correction applied to 22.4 K data (0.6%)