New Measurements of the Deuteron to Proton F_2 Structure Function Ratio

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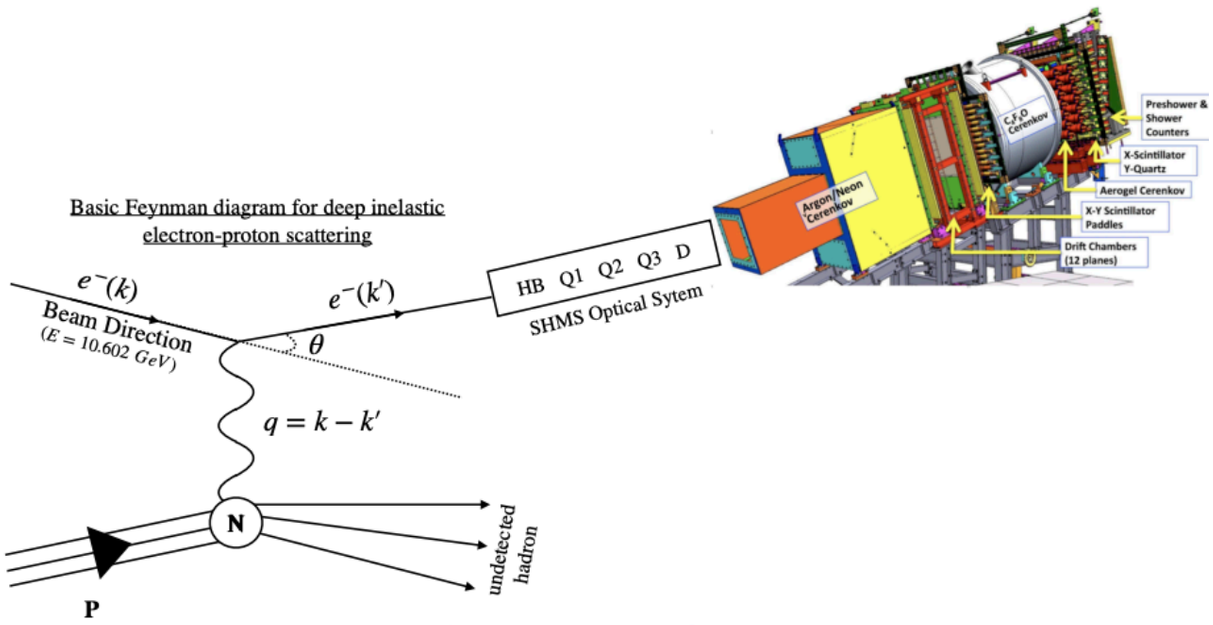
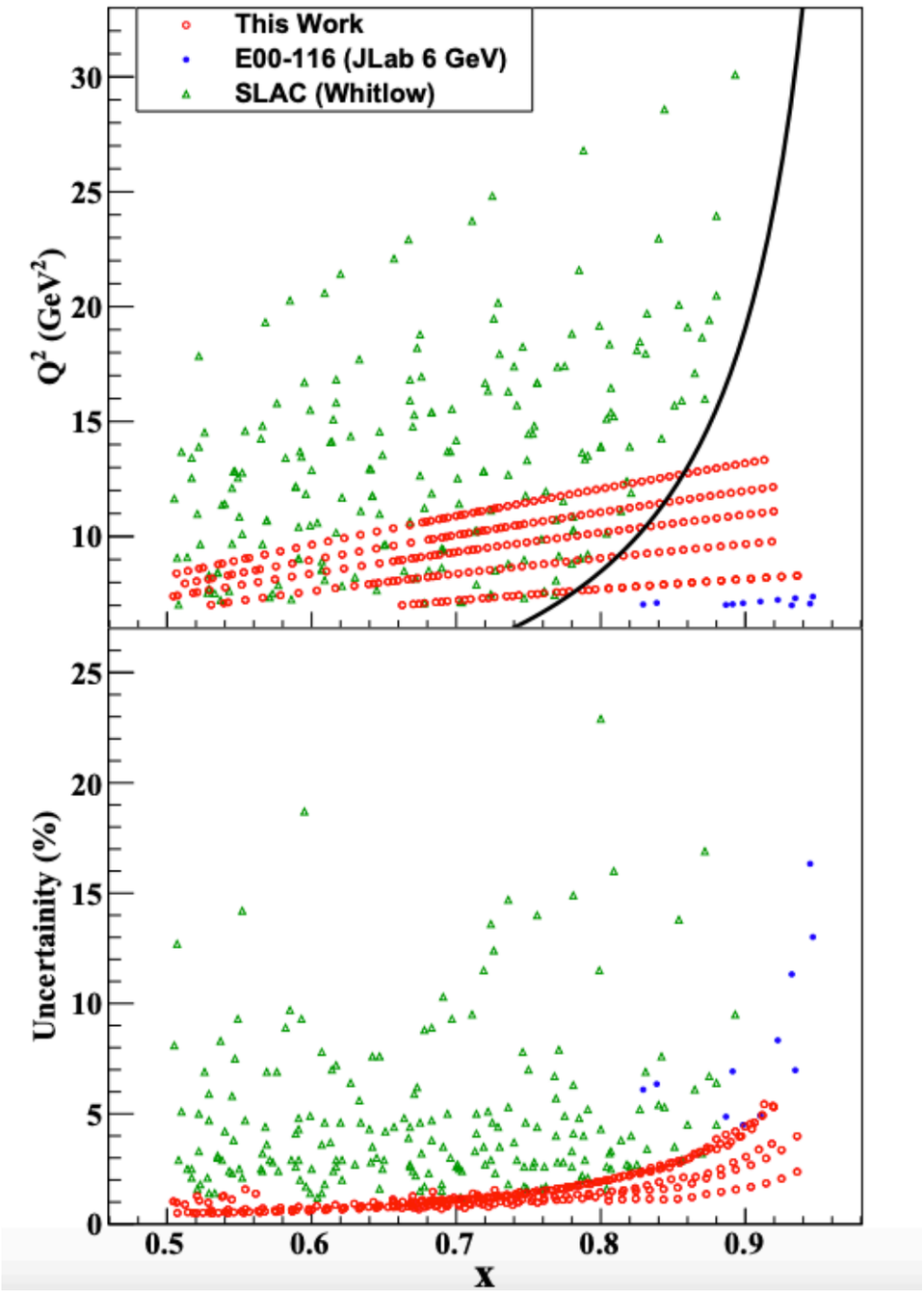
E12-10-002 Data

1. Top Panel
    1. Red circle : Kinematic coverage of E12-10-002 data
    2. Green triangle : Whitlow reanalysis of the SLAC data
    3. Blue dots : JLab 6 GeV data , Experiment E00-116
    4. Data are shown for the range $x > 0.5$ & $Q^2 > 6\ GeV^2$
    5. Solid curve corresponds to $W^2 = 3\ GeV^2$
2. Bottom Panel
    1. Statistical uncertainty of σ_D/σ_H
3. Take away
    1. Data was poorly populated prior to this experiment for $W^2 < 3\ GeV^2$ and $Q^2 > 6\ GeV^2$
    2. This work extends the data into the resonance region

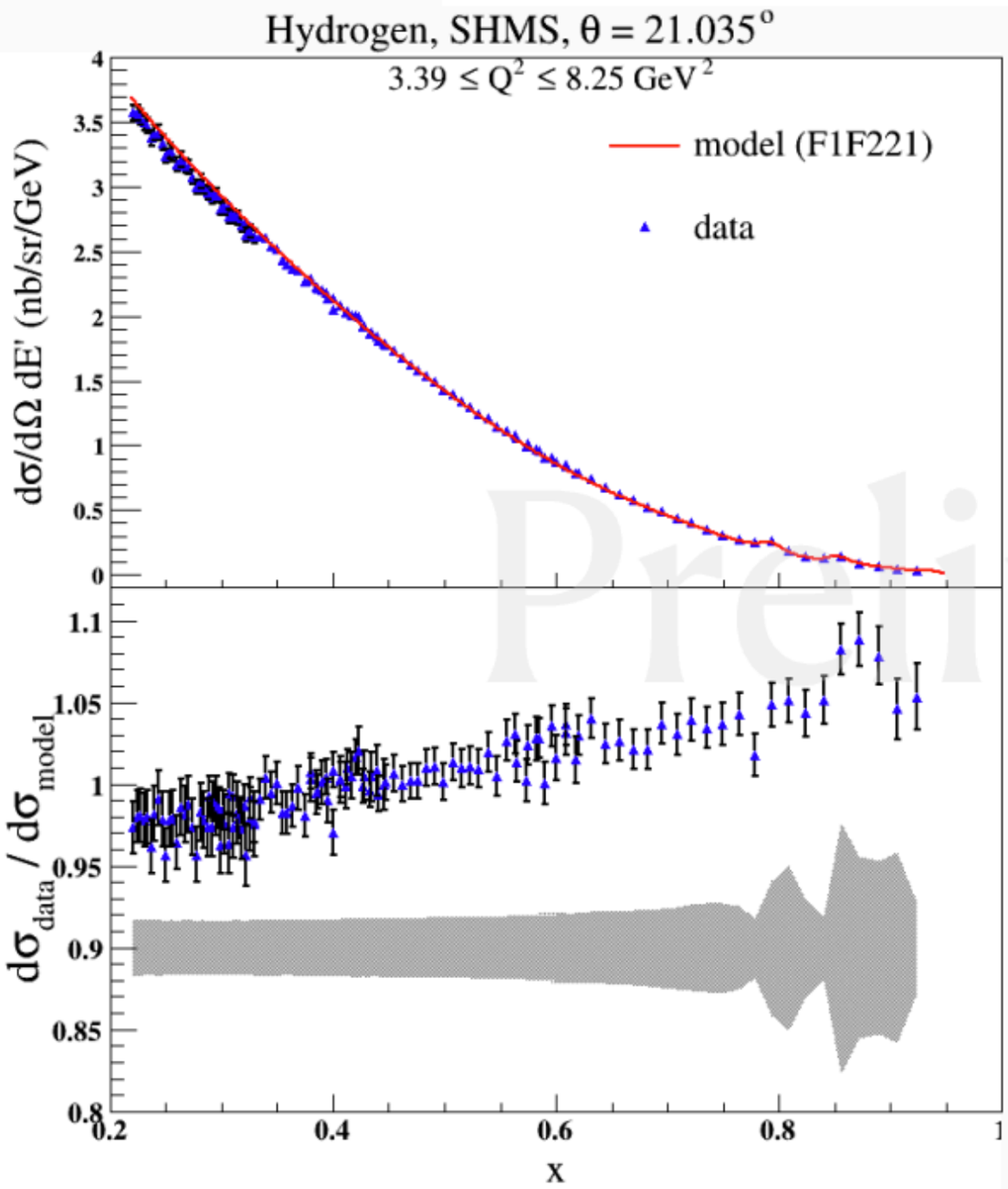
- Ran in the spring of 2018 in parallel with EMC experiment
- Targets used : liquid hydrogen and liquid deuterium
- Large Bjorken x coverage
- Large Q^2 coverage using both the HMS and SHMS spectrometers



$$Q^2 = 4EE'sin^2(\frac{\theta}{2}) \qquad X = \frac{Q^2}{2M\nu} \qquad W^2 = M^2 + 2M\nu - Q^2$$



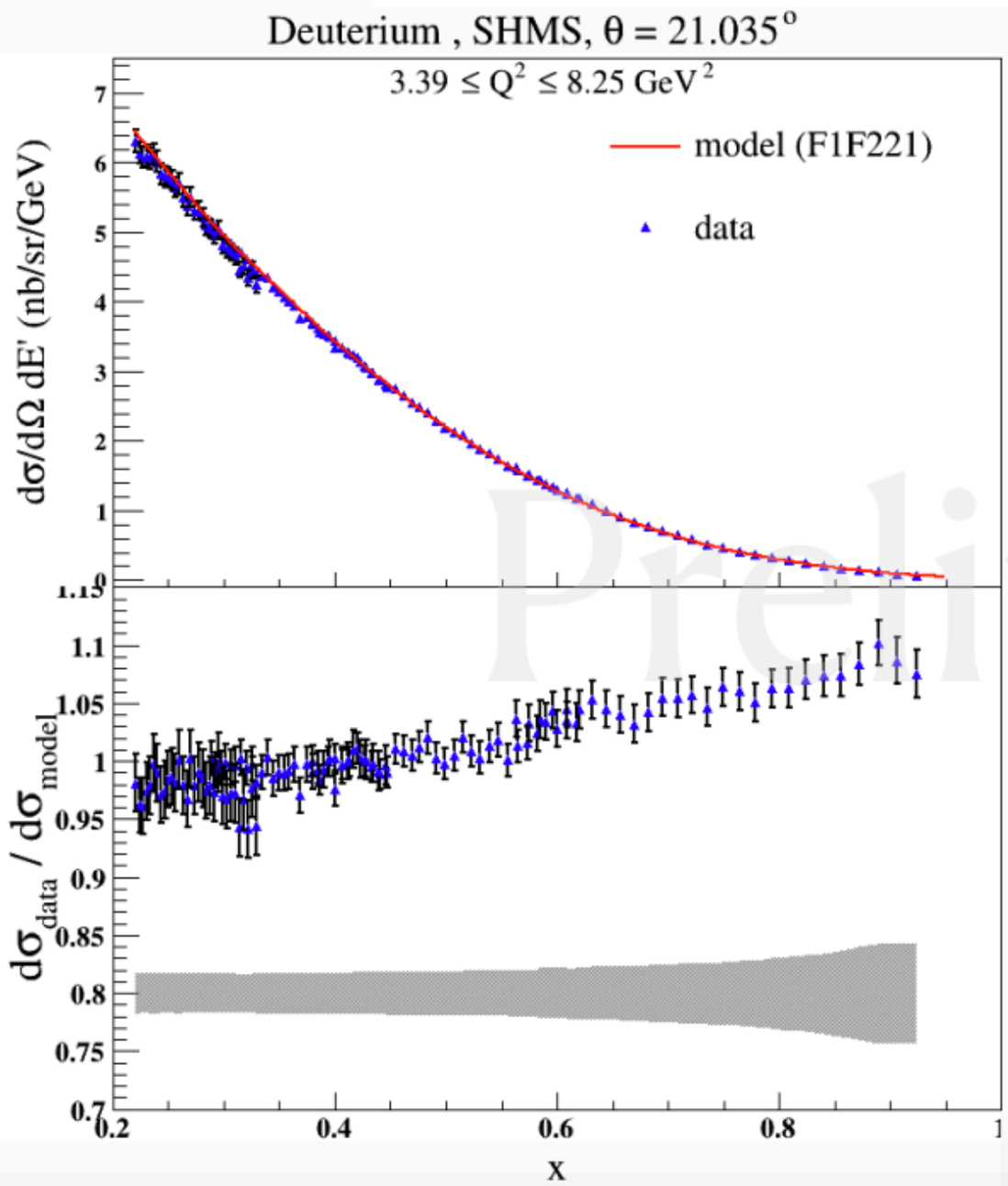
Extraction of Proton Cross-section



Monte Carlo Ratio Method : $\left(\frac{d^2\sigma}{d\Omega\, dE'}\right)_{\text{Exp}} = \frac{Y_{\text{Data}}}{Y_{\text{MC}}} \left(\frac{d^2\sigma}{d\Omega\, dE'}\right)_{\text{Model}}$

- Proton cross-section is extracted for SHMS at 21.035^o
- Proton cross-section is extracted also for four other SHMS angles 24.98^o, 28.99^o, 32.975^o, 38.975^o
- Compared with F1F221 (red solid line)
- F1F221 model is a fit to the world data of inclusive cross-sections
- In this plot model does not include the data from this experiment (E12-10-002)
- The model is valid for wide range for $W^2 < 30\ GeV^2$ and $Q^2 < 30\ GeV^2$
- For $x = 0.2$ to 0.7, the data matches with the model within better than 3%
- At large x the model is not well constrained, which is one of the biggest motivation for this experiment

Extraction of Deuterium Cross-section



- Deuterium cross-section is extracted for SHMS at 21.035^o
- Deuterium cross-section is extracted also for four other SHMS angles 24.98^o, 28.99^o, 32.975^o, 38.975^o
- Compared with F1F221 (red solid line)
- F1F221 model is a fit to the world data of inclusive cross-sections
- In this plot model does not include the data from this experiment (E12-10-002)
- The model is valid for wide range for $W^2 < 30\ GeV^2$ and $Q^2 < 30\ GeV^2$
- For $x = 0.2$ to 0.7, the data matches with the model within better than 3%
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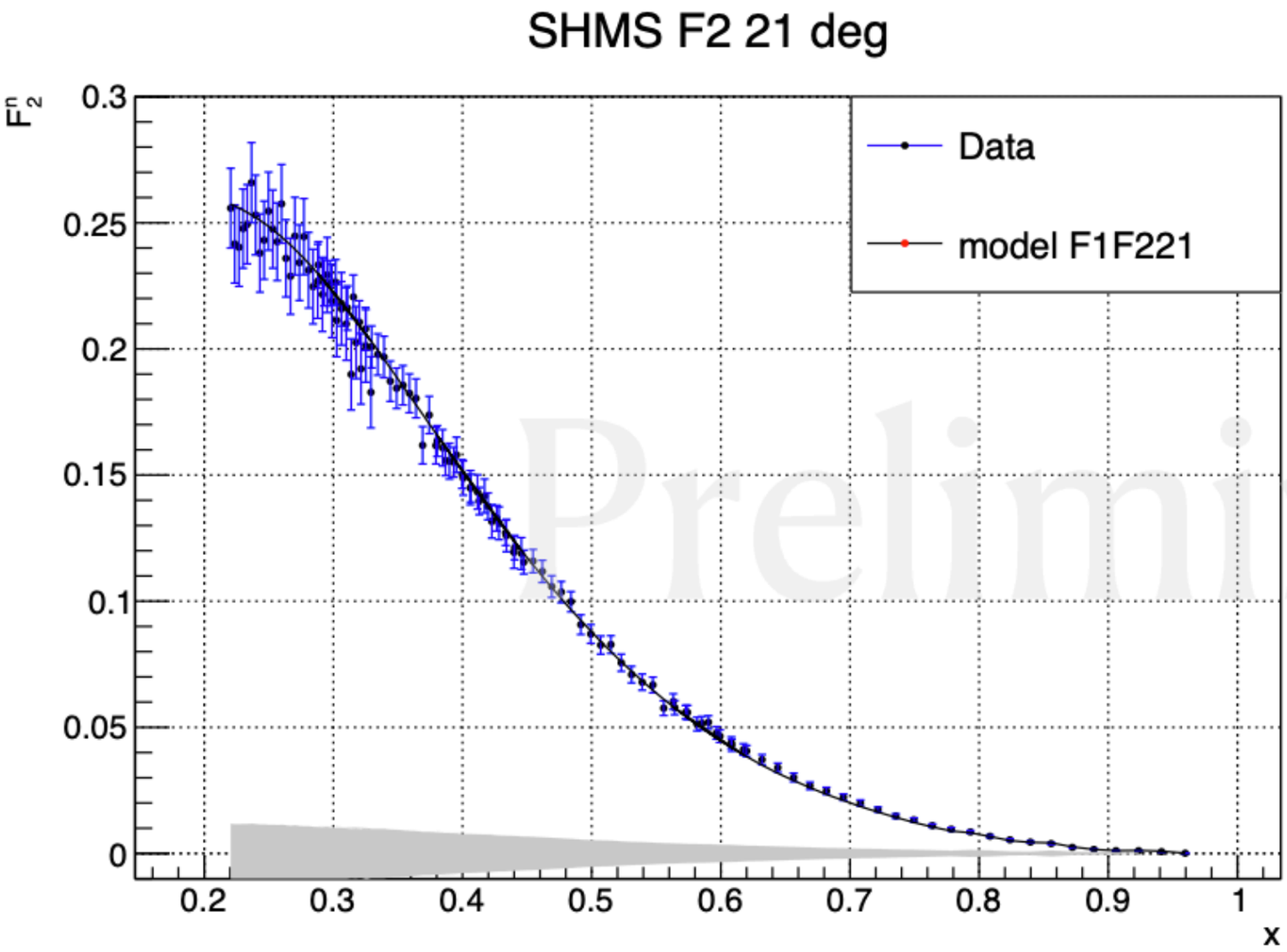
Extraction of Neutron Cross-section



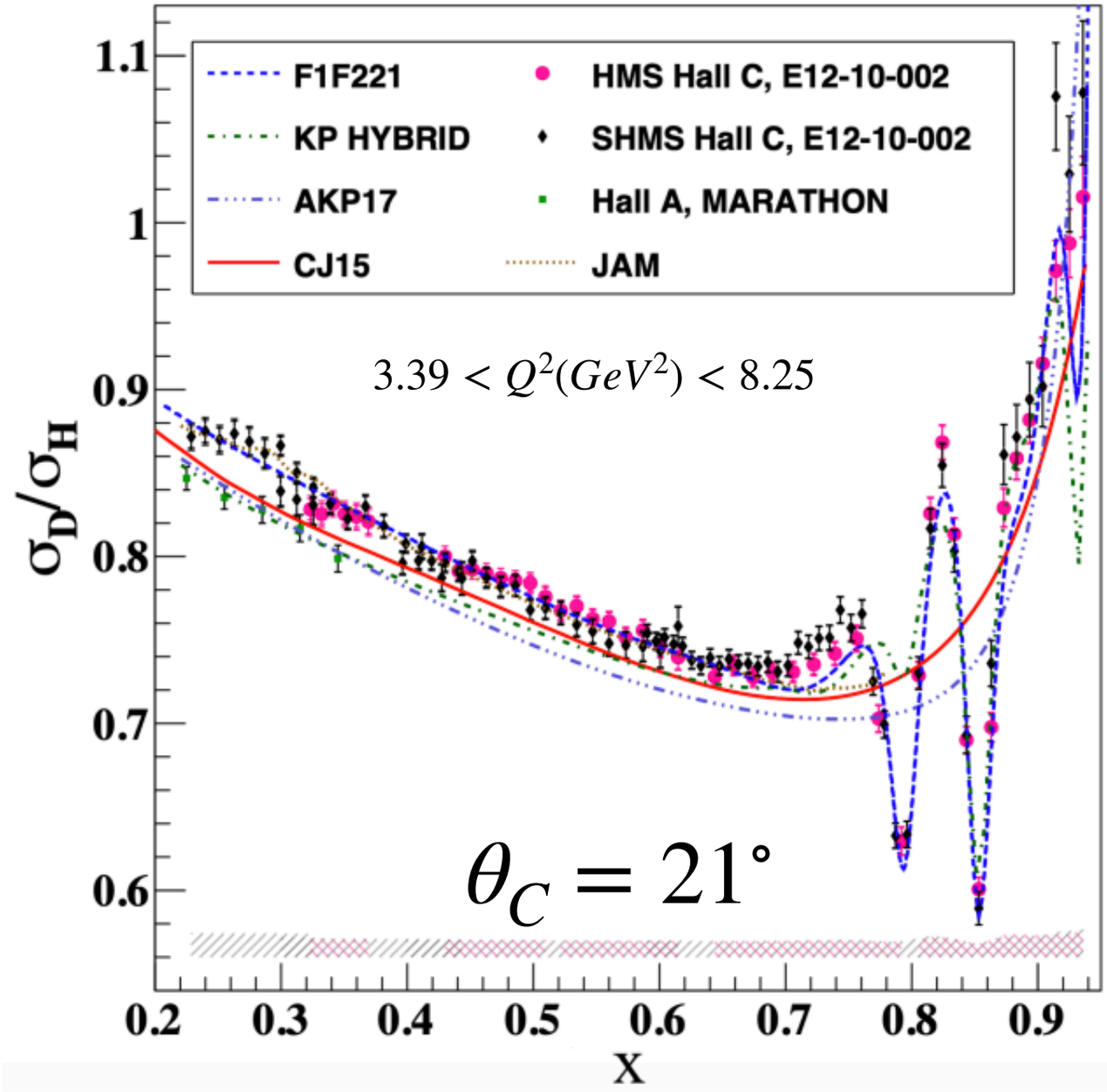
- In deuterium proton and neutron are in bound state
- Neutron cross-section can be calculated by subtracting the proton cross-section from the deuteron and nuclear effects removed
- To get the unbound p+n cross-section from the bound p+n state inside deuterium-

$$\sigma_{p+n} = \frac{\sigma_{p+n}^{model}}{\sigma_d^{model}} \times \sigma_d^{data}$$

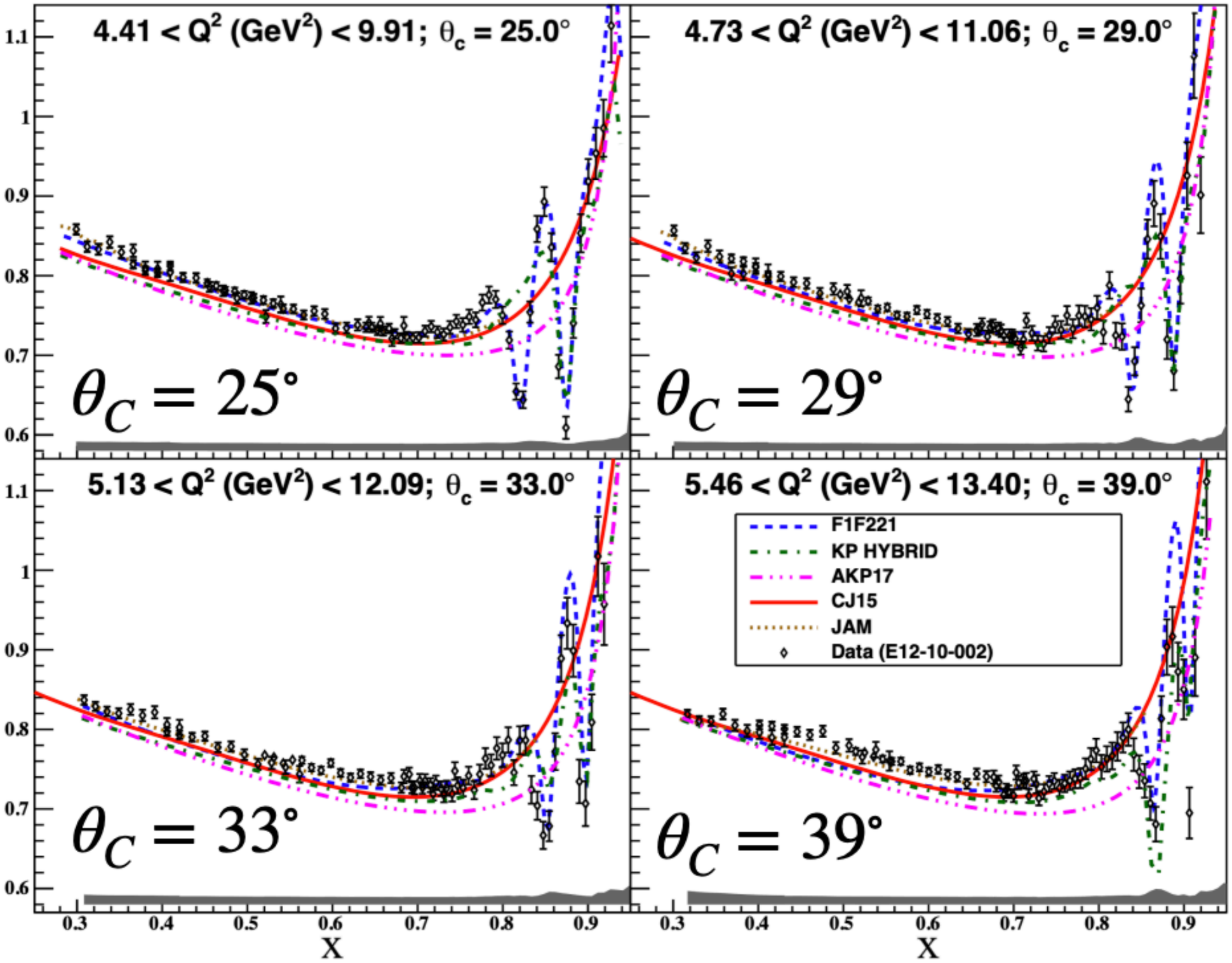
$$\sigma_{data}^{n} = \sigma^{p+n} - \sigma_{data}^{p}$$

σ_D/σ_H : SHMS & HMS

1. σ_D/σ_H ratio were compared for :
    1. SHMS data
    2. HMS data
    3. F1F221 model (used to extract the cross sections in this work)
    4. KP HYBRID
    5. AKP17
    6. CJ15
    7. MARATHON, HALL A
    8. JAM
2. Excellent agreement between SHMS and HMS for $\theta_C = 21^\circ$
3. The error bars include uncorrelated statistical and systematic errors
4. The error band include correlated systematic error and an overall normalization uncertainty of 1.1% (due to the uncertainty in the target density)
5. F1F221 or any other model does not include this data
6. As much as 4.3% discrepancy exists between MARATHON (Hall A) and E12-10-002 (Hall C) data
7. Total point to point error 0.6 - 5.4 (with $W^2 > 3\ GeV^2$ 2.9) %
8. Total correlated error 1.2 - 2.9 (with $W^2 > 3\ GeV^2$ 2.1) %

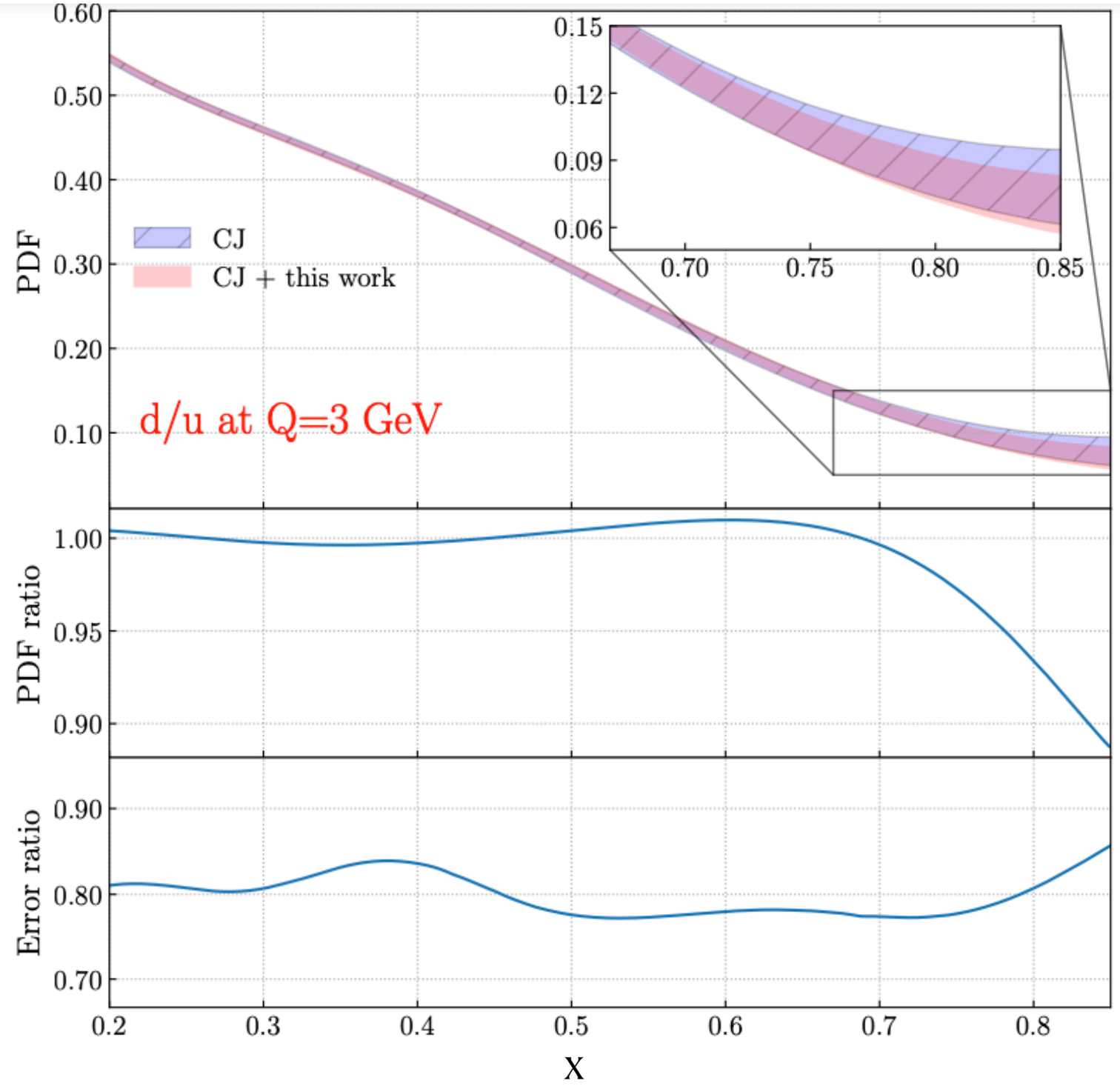


σ_D/σ_H : SHMS

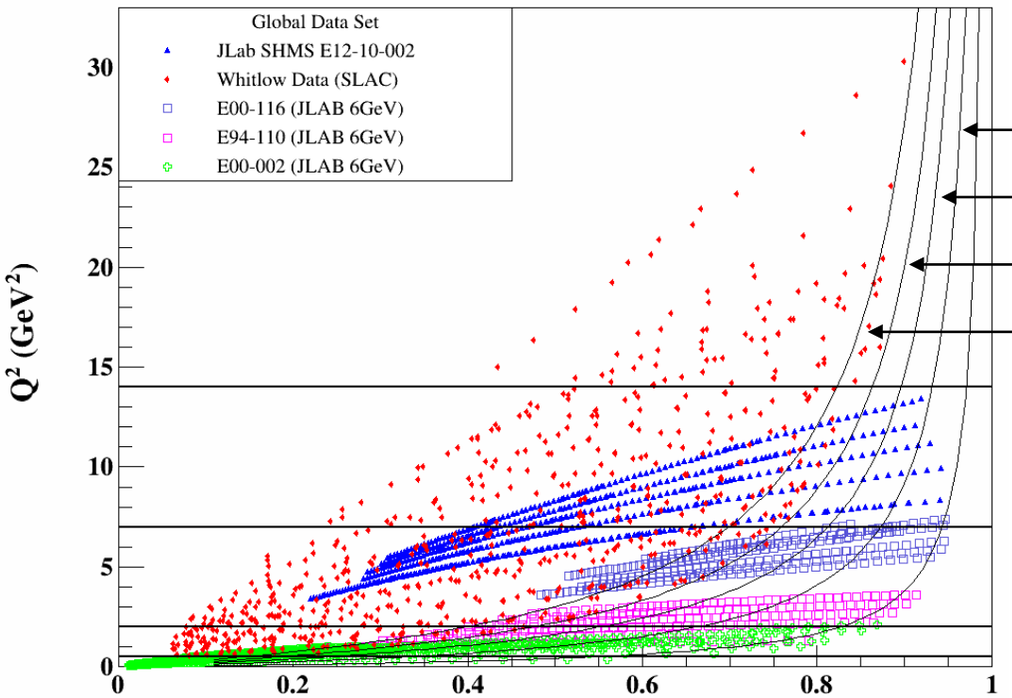


Impact Study : PDF Fitting

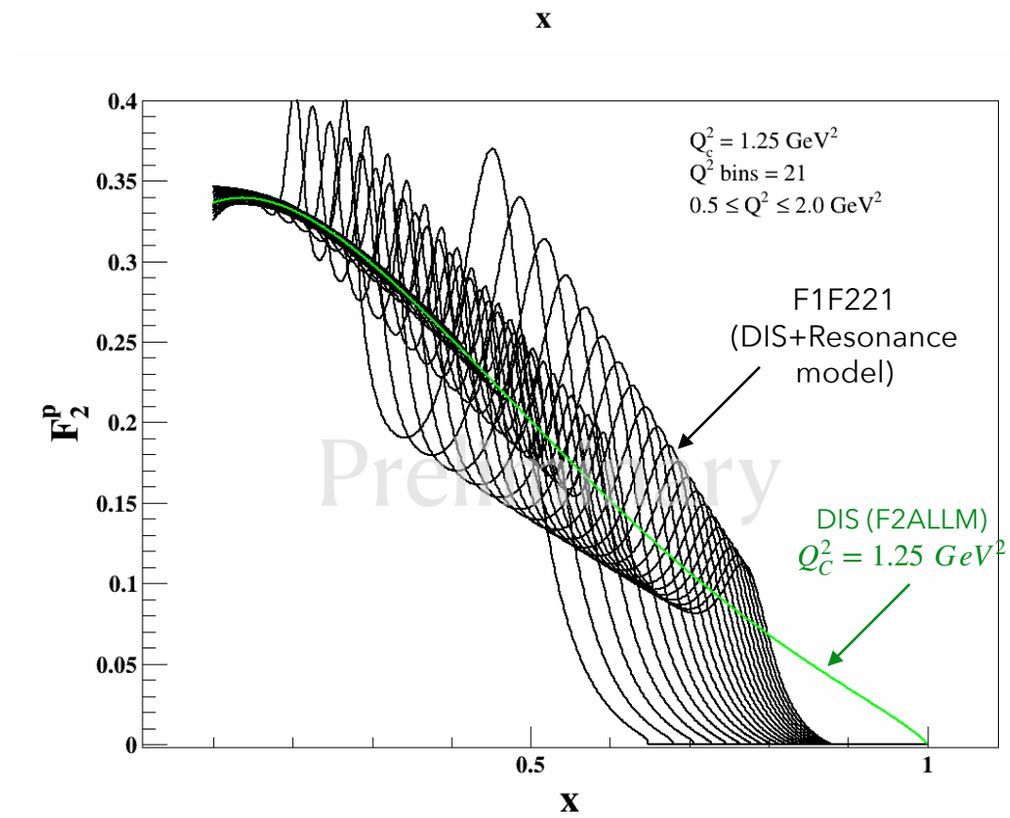
1. Impact of the new data were studied with CJ15 framework
2. d/u ratio for proton were plotted for $Q = 3\ GeV$ and for wide range of x
3. $W^2 > 3.5\ GeV^2$ cut on data to eliminate the resonance region
4. Magenta : CJ15 fit ONLY
5. Pink : CJ15 fit + data from this work
6. The central value of the d/u changes as much as 10% for x>0.7
    1. Previous absence of the deuterium data at high x is responsible for this change
7. The relative error in d/u ratio decreases by approximately 20% across the entire range range of x
8. To fit the data with the model, a normalization factor of -2.1% was applied to the data
    1. The x dependent correlated error for the data is 1.3-2.1%
    2. Another experiment (E12-10-007, EMC effect) ran along with this experiment observe the 2% normalization shift in result compared to the previous data , and the direction of the shift is consistent with this work



Impact Study : Quark-Hadron Duality



1. This experiment also populate the resonance region data at higher Q^2 : Expands the testing ground for quark-hadron duality

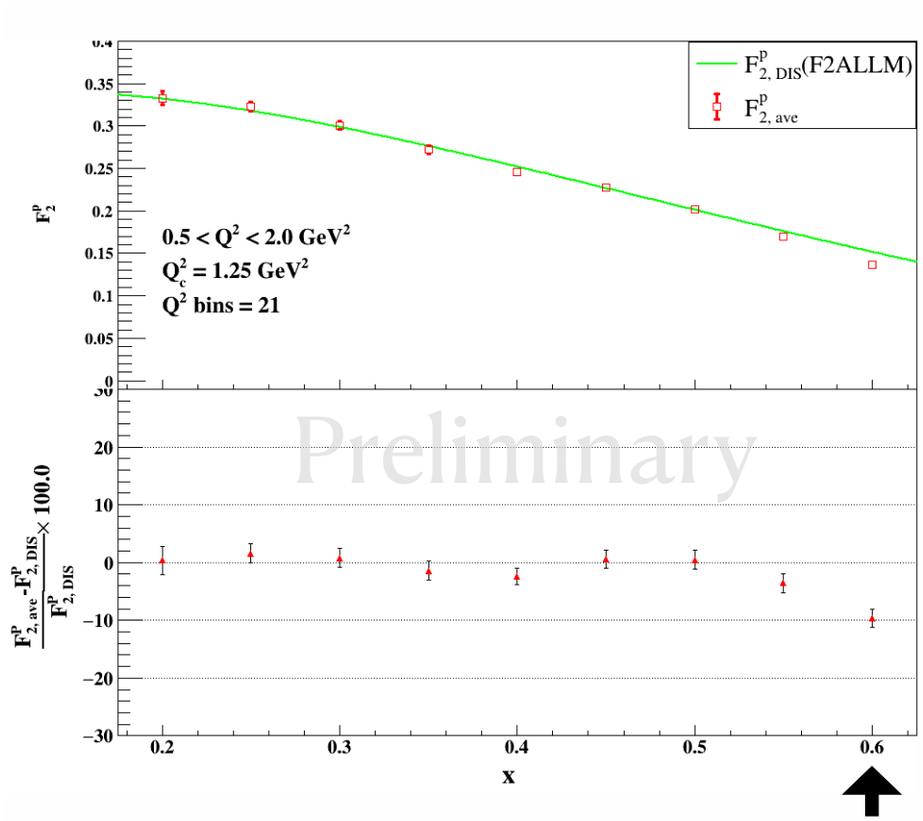


2. From the pioneering work of Bloom and Gilman at SLAC : F_2 Structure function data at DIS region also describe the average resonance region F_2 data at same Q^2

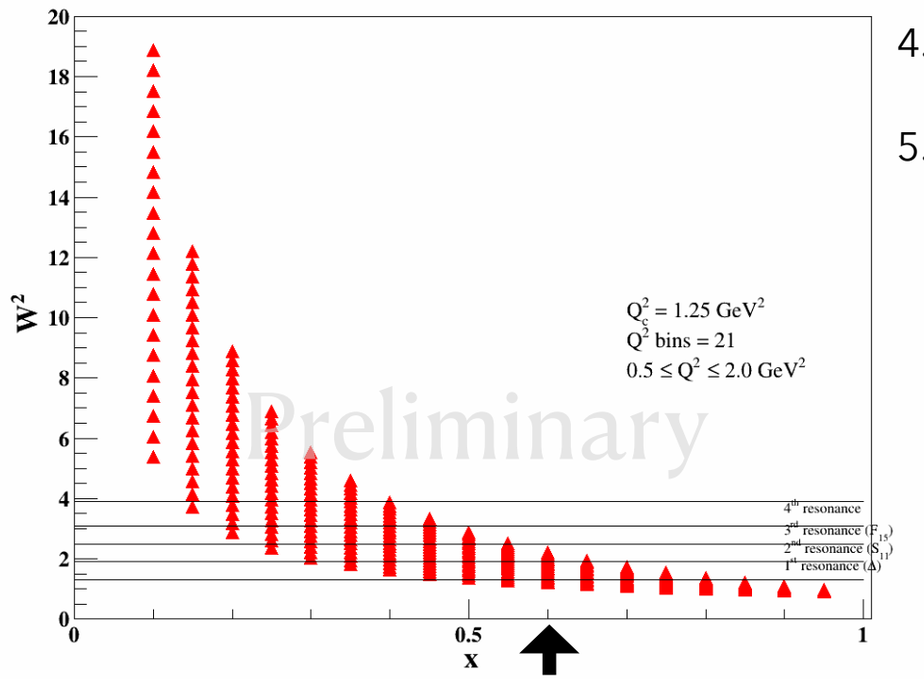
3. For a broad range of $Q^2$the dips and peaks (defined by W^2) of different resonances passes through a particular x

4. So, averaging over a large enough Q^2 region should recover the DIS curve, provided quark-hadron duality works

Impact Study : Quark-Hadron Duality



1. The red square points are average F_2 for a particular x bin
2. For $0.2 \leq x \leq 0.5$ The DIS curve is recovered better than ~3%
3. For $x = 0.55$ and $x = 0.6$ DIS curve is not fully recovered



4. W^2 coverage is shown for each x bin
5. Note that for $x = 0.55$ and $x = 0.6$, not enough resonances are covered and the data crosses the pion threshold limit

Summary

New Measurements of the Deuteron to Proton F_2 Structure Function Ratio

D. Biswas,[1] F. A. 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,[10,11] R. Ambrose,[8] W. Armstrong,[12] A. Asaturyan,[3] K. Assumin-Gyimah,[4] C. Ayerbe Gayoso,[13,4] A. Bandari,[13] S. Basnet,[8] V. Berdnikov,[14,3] 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] M. Cardona,[12] S. Covrig Dusa,[3] K. Craycraft,[5] S. Danagoulian,[9] D. Day,[7] M. Diefenthaler,[3] M. Dlamini,[18] J. Dunne,[4] B. Duran,[12] 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] J. O. Hansen,[3] F. Hauenstein,[20,3] 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,[24] H. Mkrtchyan,[24] Z. Moore,[25] S.J. Nazeer,[1] S. Nanda,[4] G. Niculescu,[25] I. Niculescu,[25] D. Nguyen,[7] Nuruzzaman,[26] B. Pandey,[1,27] S. Park,[2] E. Pooser,[3] A. J. R. Puckett,[19] J. Reinhold,[15] B. Sawatzky,[3] G. R. Smith,[3] H. Szumila-Vance,[3,15] A. S. Tadepalli,[26] V. Tadevosyan,[24] R. Trotta,[14] S. A. Wood,[3] C. Yero,[15,14] and J. Zhang[2]

1. The structure function ratio paper is on arxiv (https://arxiv.org/pdf/2409.15236)
2. Ratio paper is submitted to PRL
3. Data set is available for inclusion in PDF fits, model …

4. Future Work
    1. Cross-section ratio from HMS 59 degree data : ongoing
    2. Absolute proton and deuteron cross sections
        1. Quark-Hadron Duality study
        2. Non-Singlet Moments
        3. Improve resonance / DIS modeling