F2 Update in Hall C

Precision measurements of the F_2 structure function at large x in the resonance region and beyond

William Henry

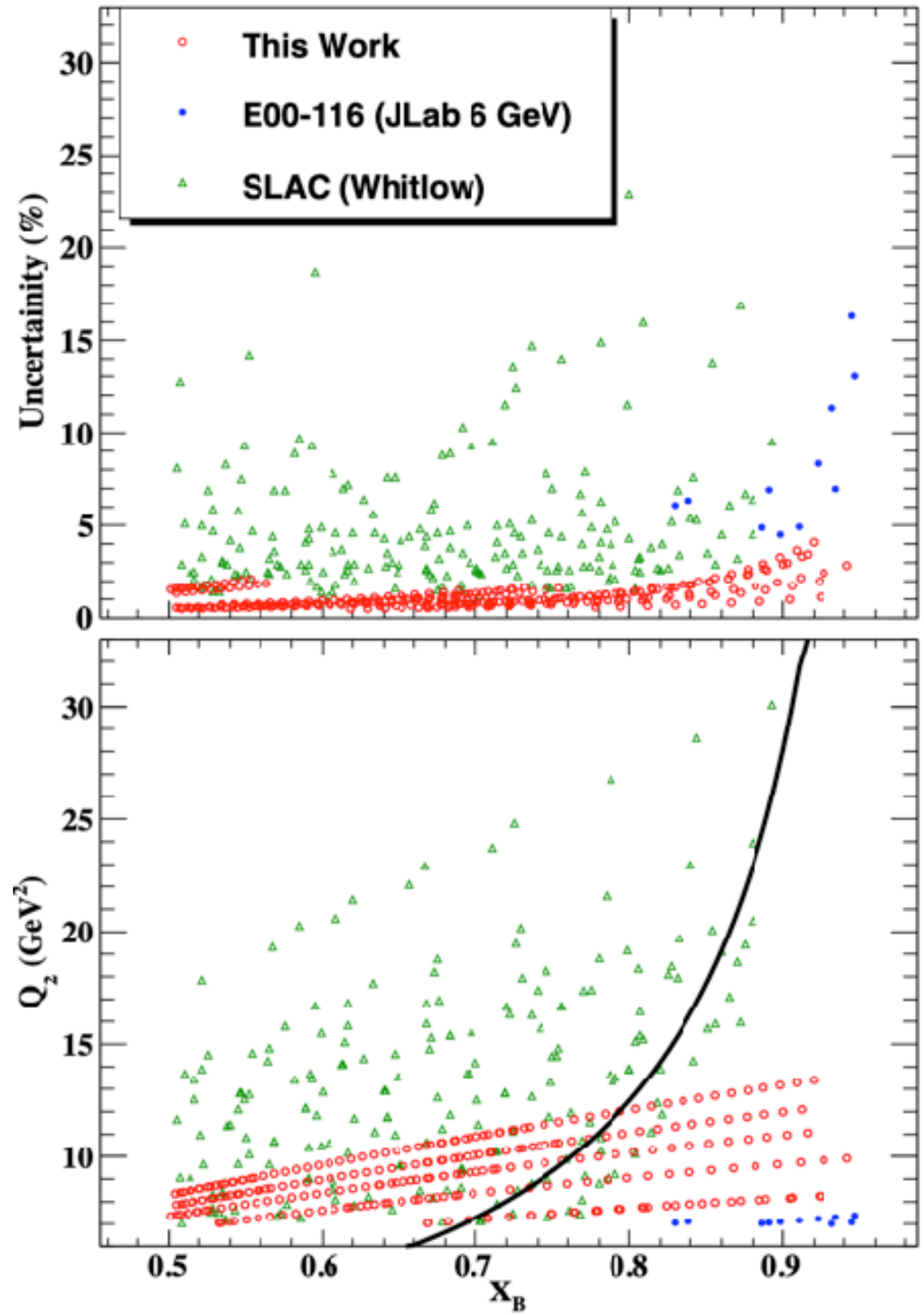
February 17th, 2022

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

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
$I_{BCM\ 4C} > 5.0$

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

Pion contamination + ~~Charge Symmetric background~~ + Cryo Cell Contribution

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

PS → Prescale

Total efficiency :

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

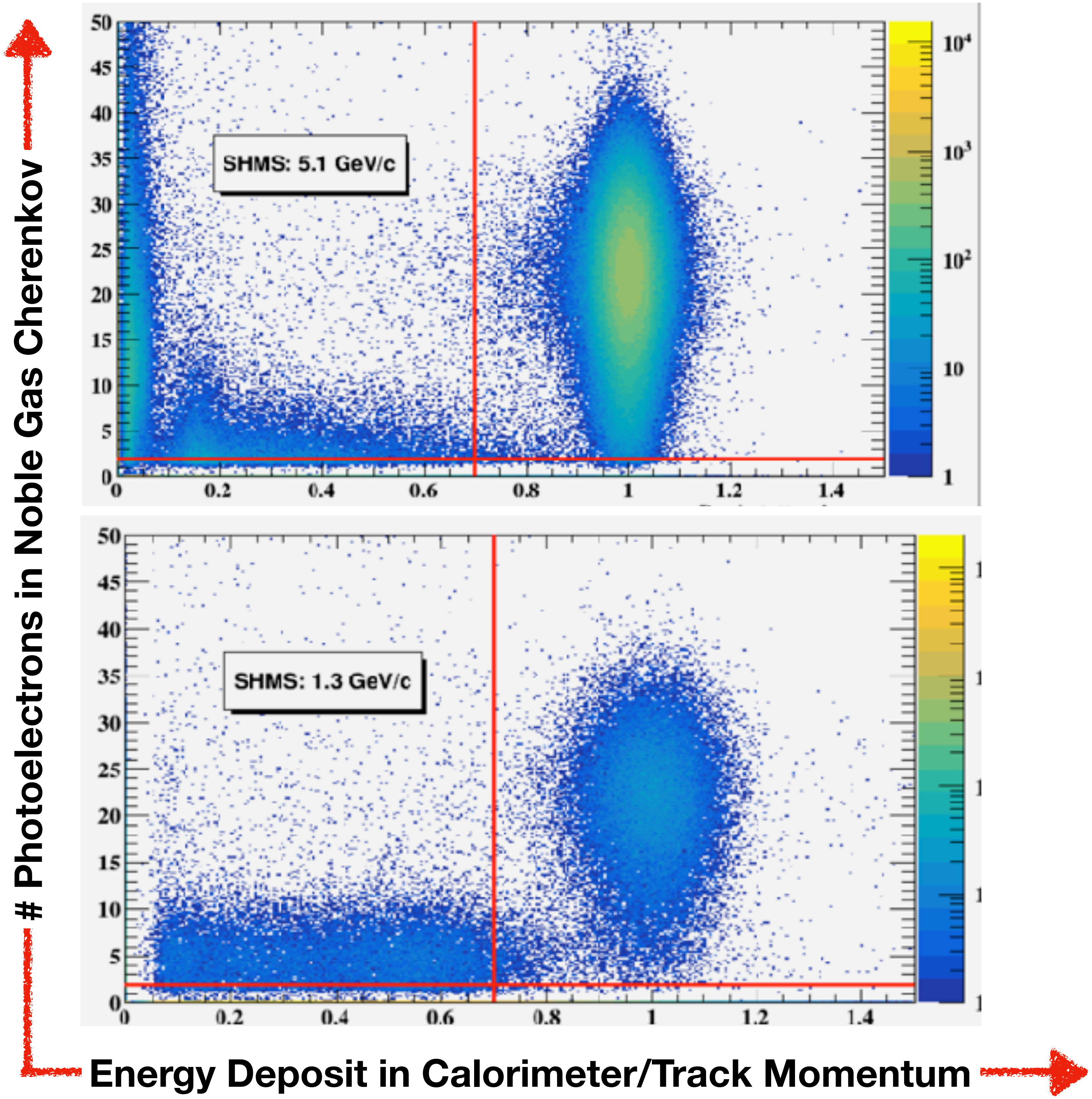
Electronic live time

Computer live time

F2 Cross Section Extraction

PID Cuts

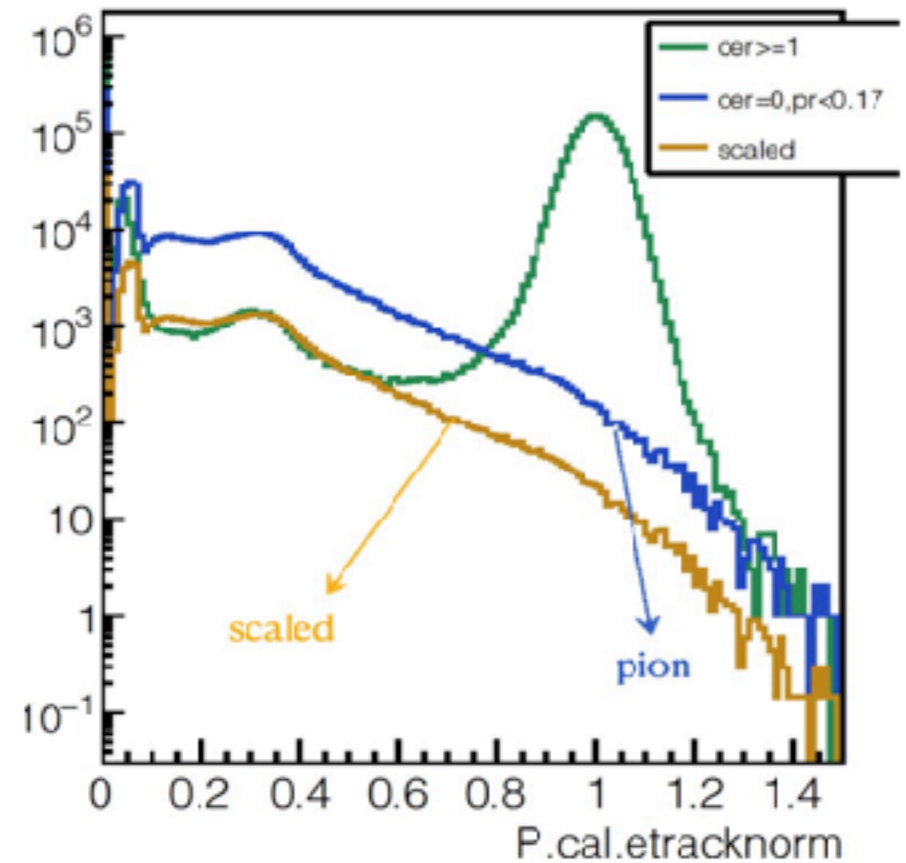
- E/p > 0.7
- NPE > 2.0

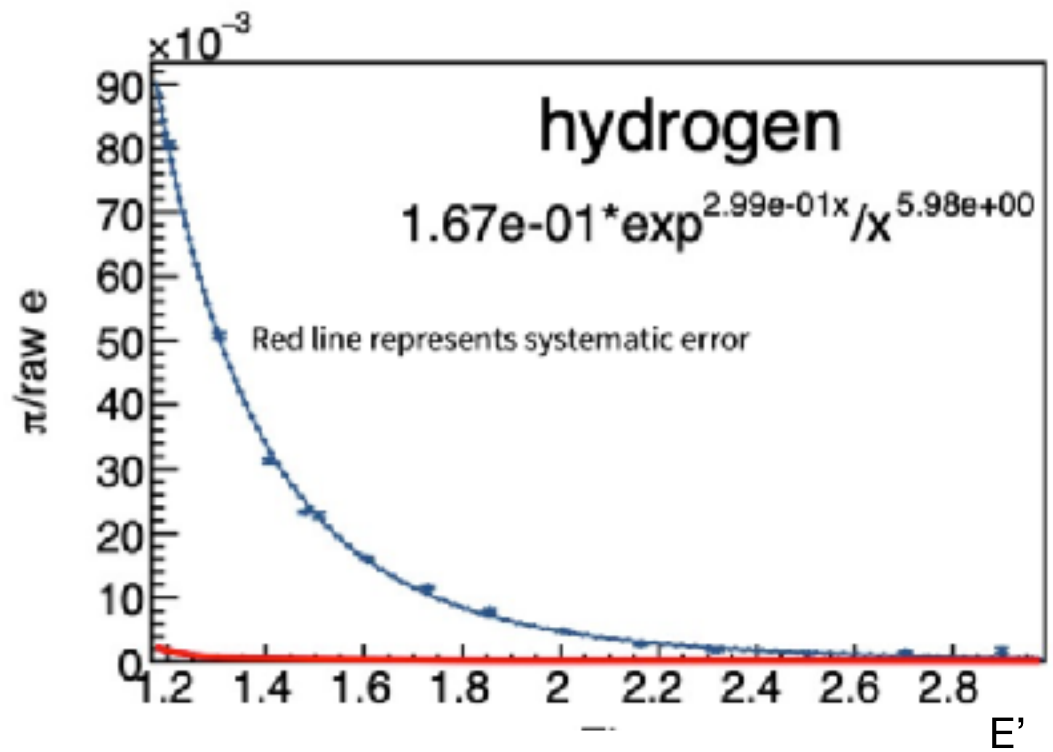


F2 Cross Section Extraction

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)



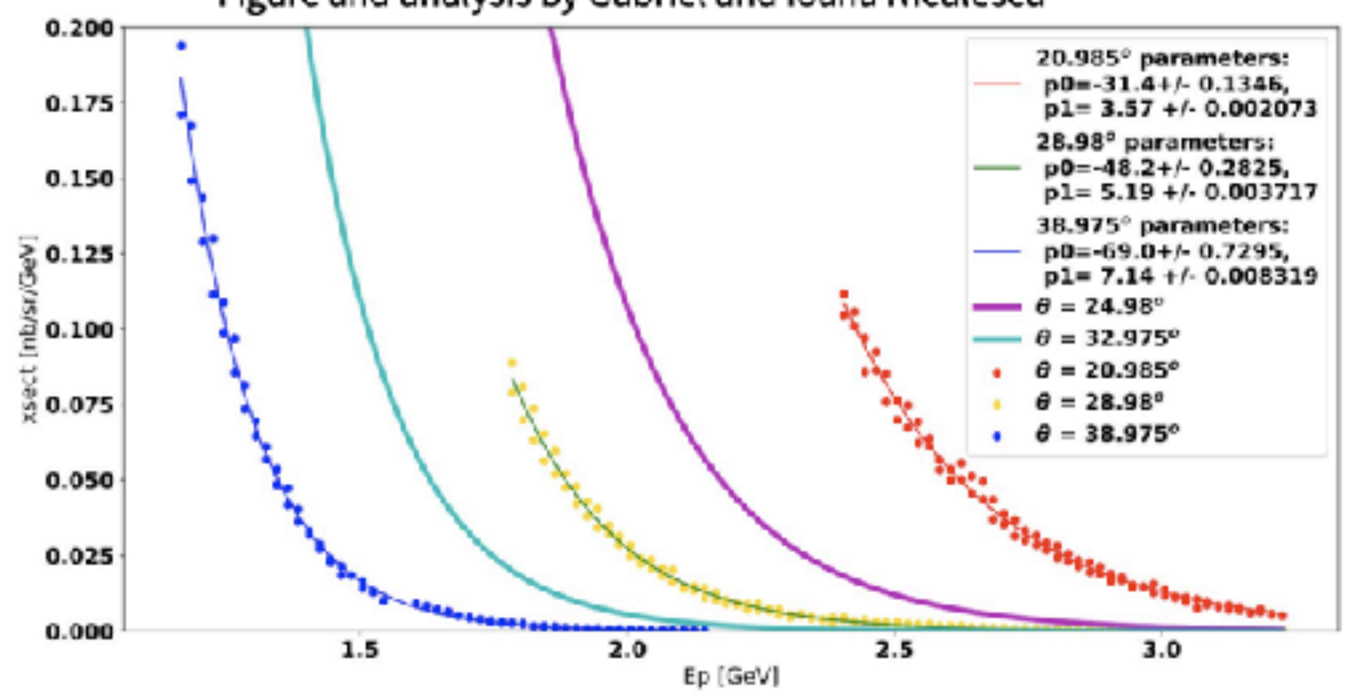


F2 Cross Section Extraction

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

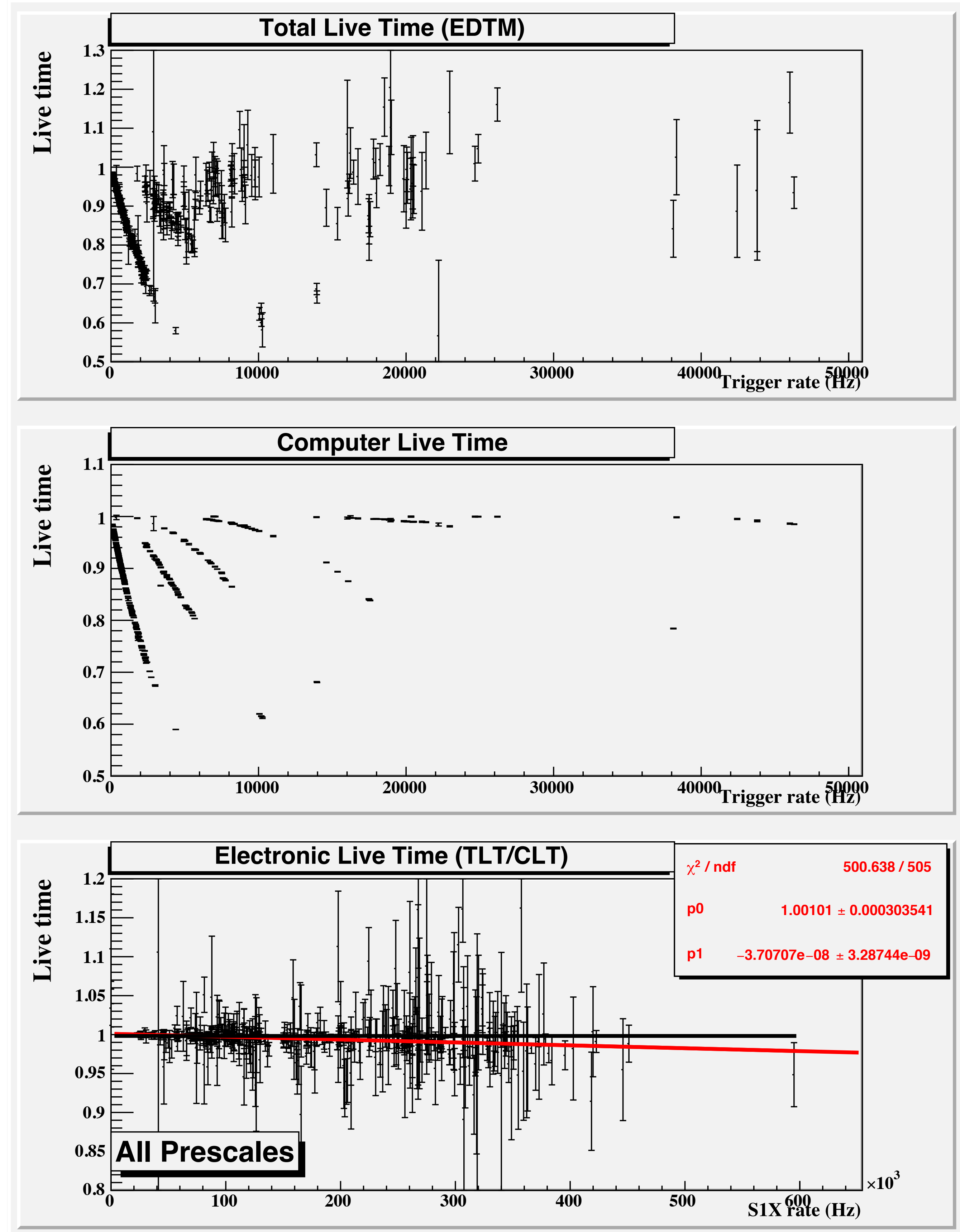
Figure and analysis by Gabriel and Ioana Niculescu



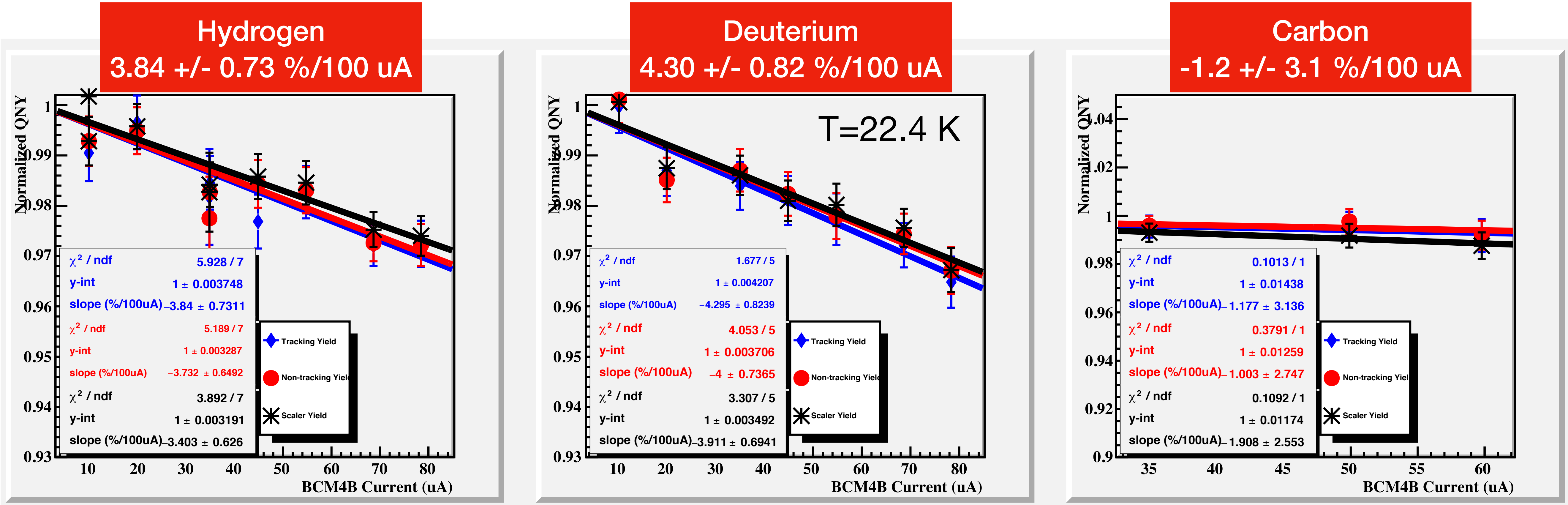
F2 Cross Section Extraction

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 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



F2 Cross Section Extraction



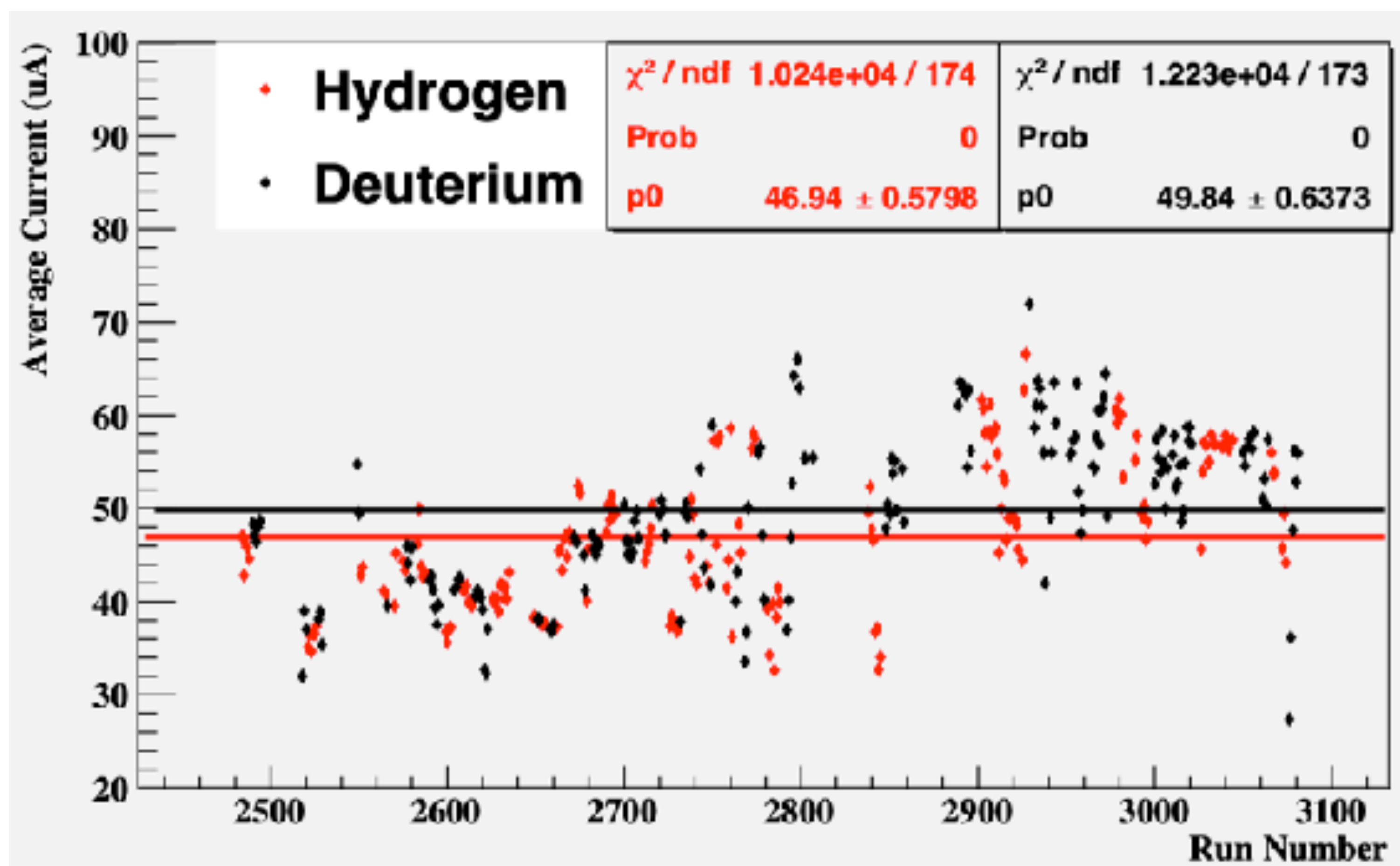
- Recently learned that the PID on LD2 was changed during the run.
- Deuterium boiling study taken at 22.4 K
- Use Dave Mack’s boiling result from Fall 2018 (same fan speed and temperature) 2.84 +/- 0.32 % / 100 uA
- Additional density correction applied to 22.4 K data (0.6%)

F2 Cross Section Extraction

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

Monte Carlo (MC) Ratio Method

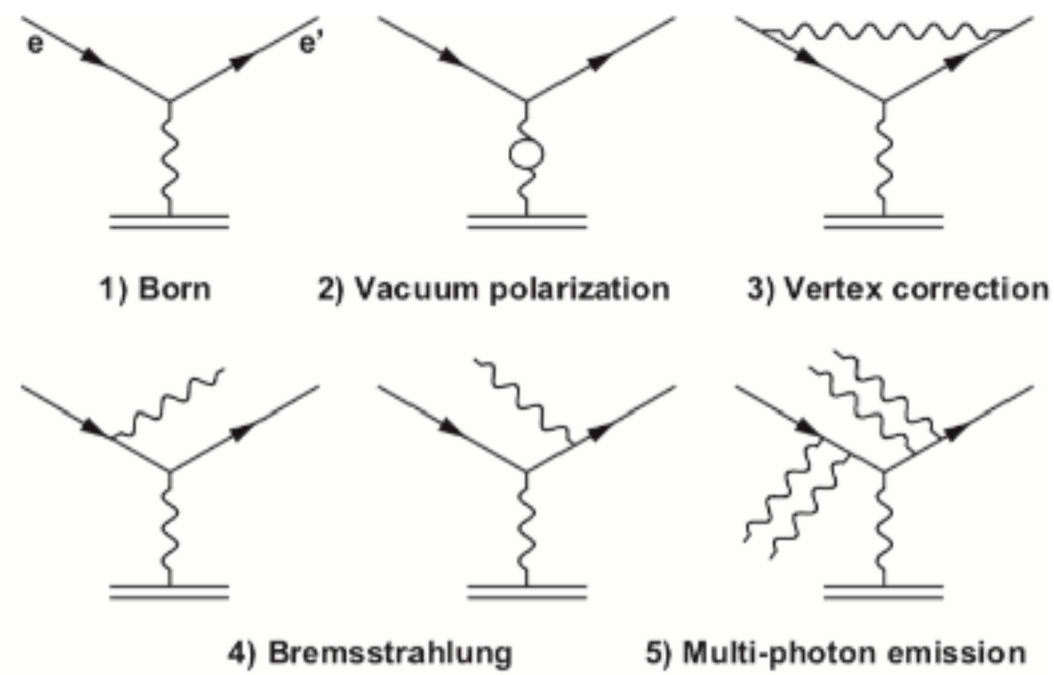
$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{exp} = \left(\frac{d\sigma}{d\Omega dE'}\right)_{model} \frac{Y_{data}}{Y_{MC}}$$

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

F2 Cross Section Extraction

Radiative Corrections

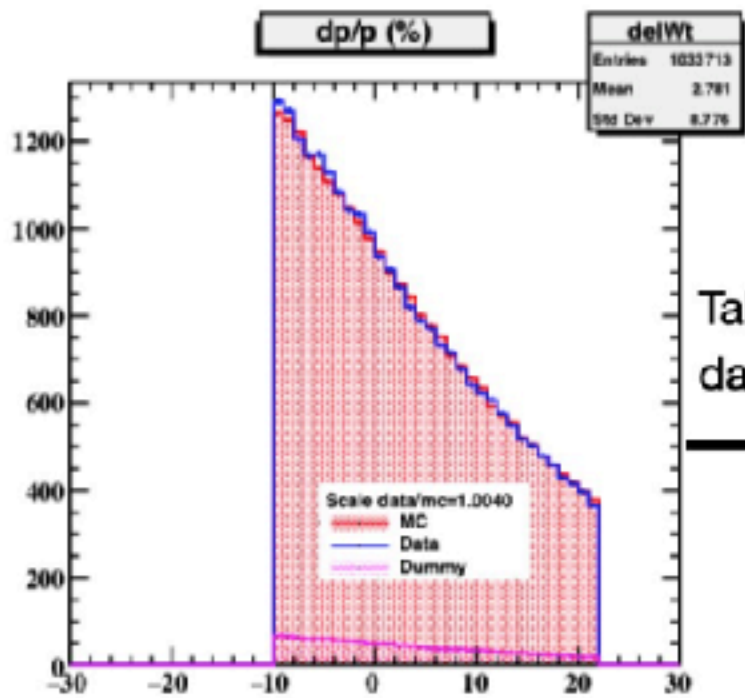
- Monte-Carlo events generated by the mc-single-arm does not consider the effect of the several radiative processes. Born approximation is just the first order approximation in α of electron-nucleon scattering by one photon exchange. To mimic the reality we $\boxed{\text{multiply the each events of MC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



- Cross section model is radiated using “rc_externals”.

F2 Cross Section Extraction

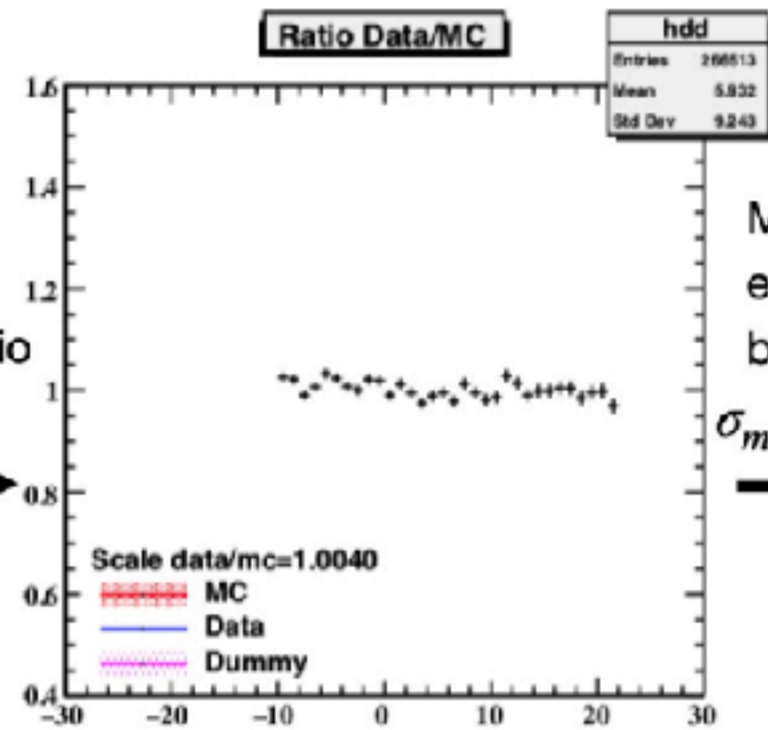
Cross Section Extraction (MC Ratio Method)



(Data is dummy subtracted)

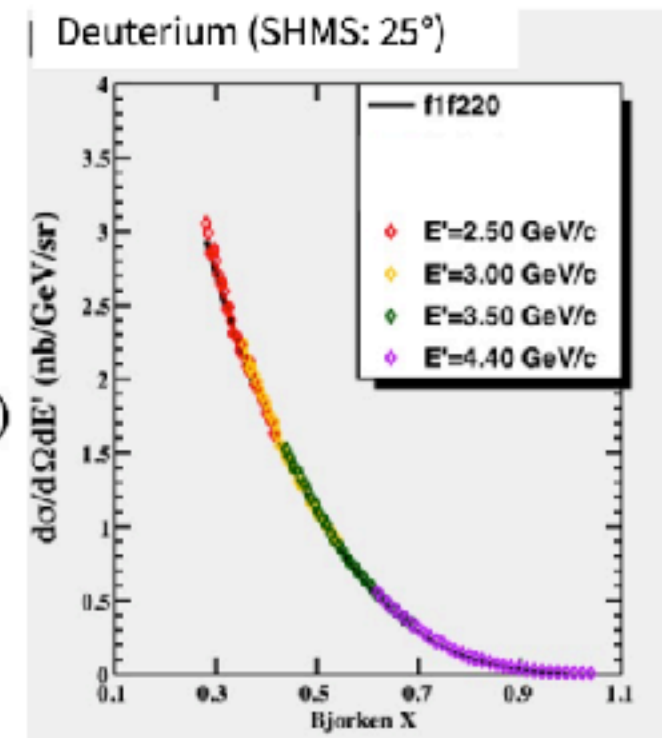
1) MC (weighted with radiative cxsec) and corrected data yields are binned in delta

Take Ratio data/MC



2) Take ratio of data and MC

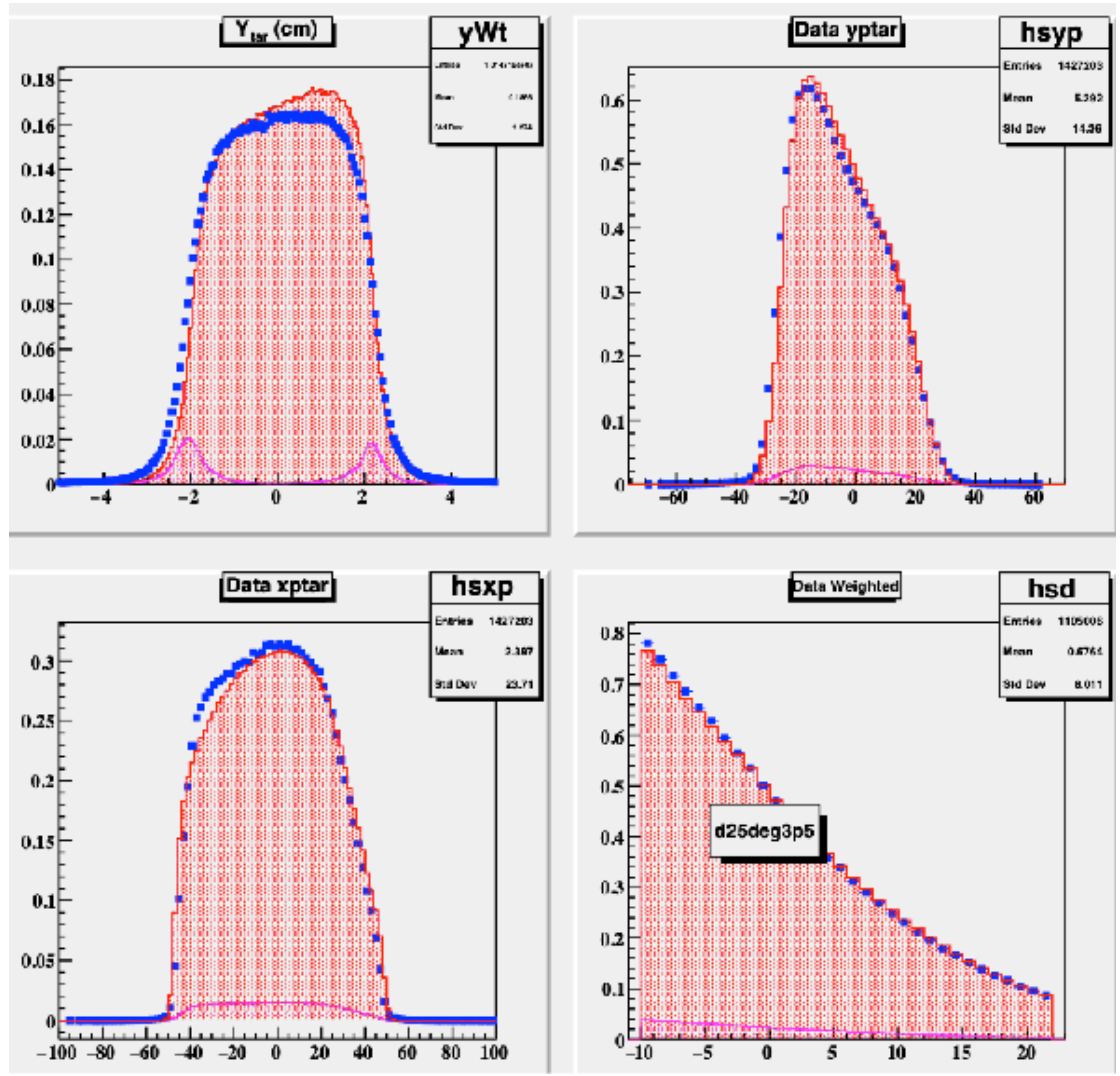
Multiply each bin by $\sigma_{model}(E', \theta)$

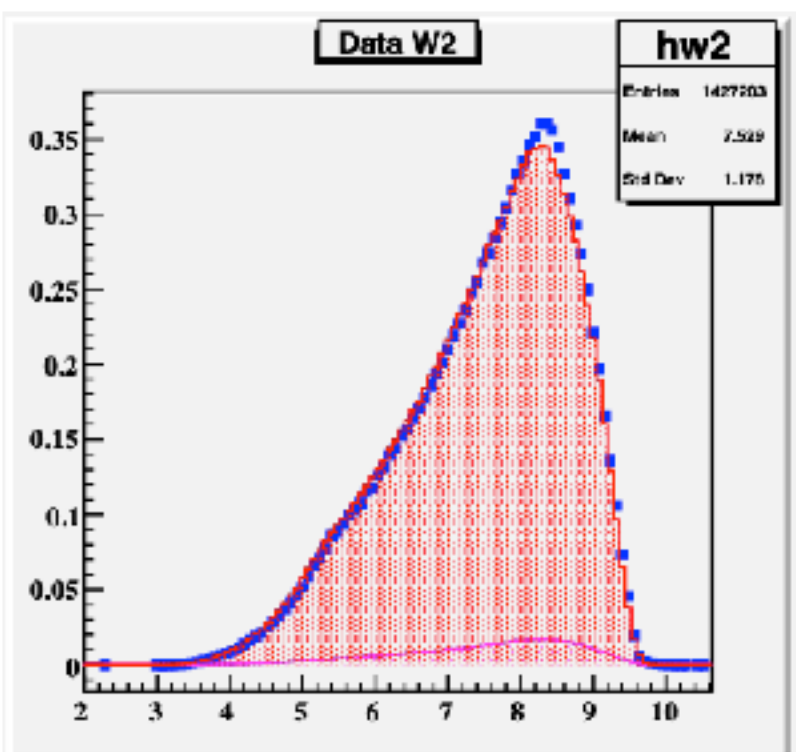


3) Multiply each bin by model (not radiated) to get cross section

F2 Cross Section Extraction

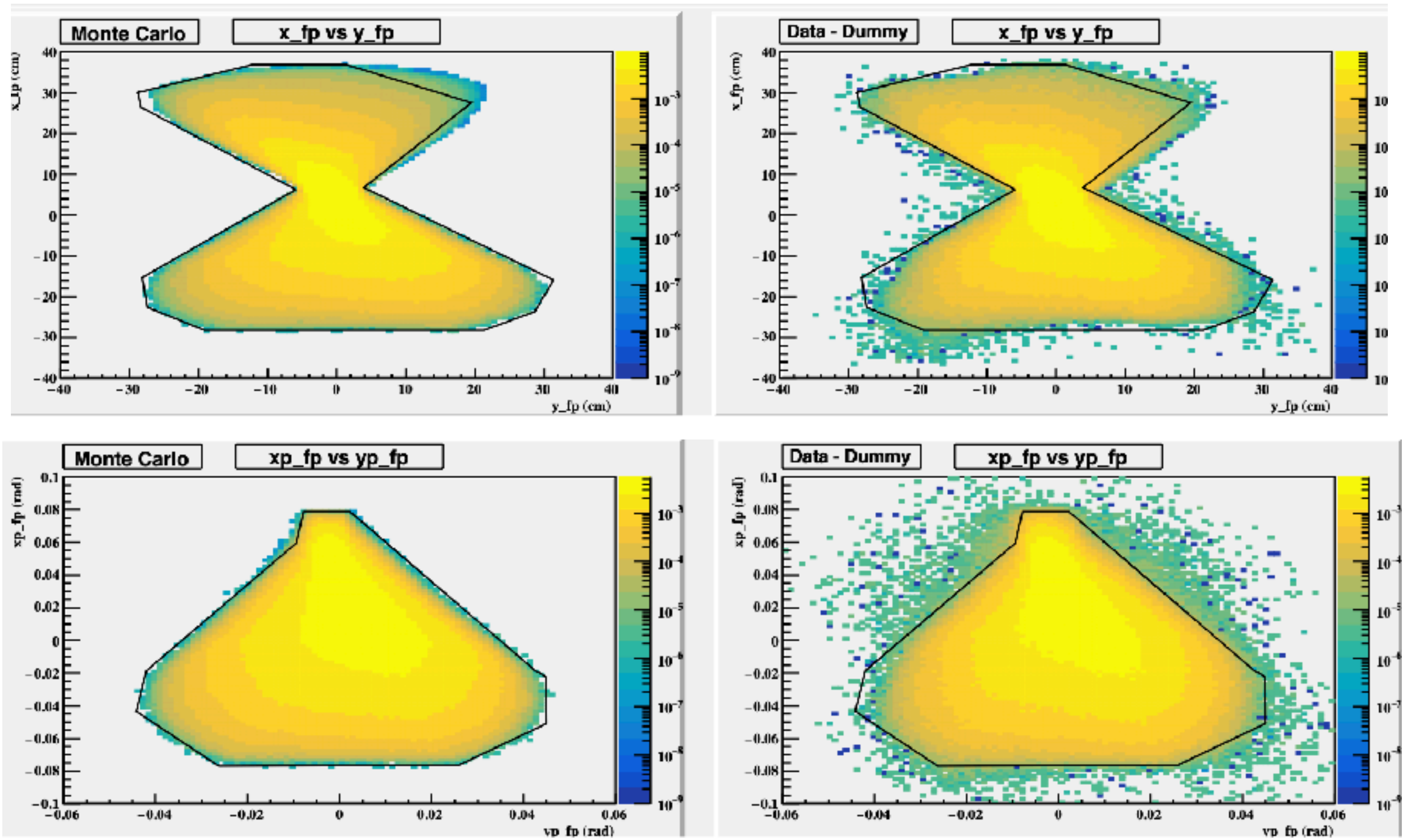
Data vs MC





F2 Cross Section Extraction

Focal Plane Comparisons: Data Vs Monte Carlo



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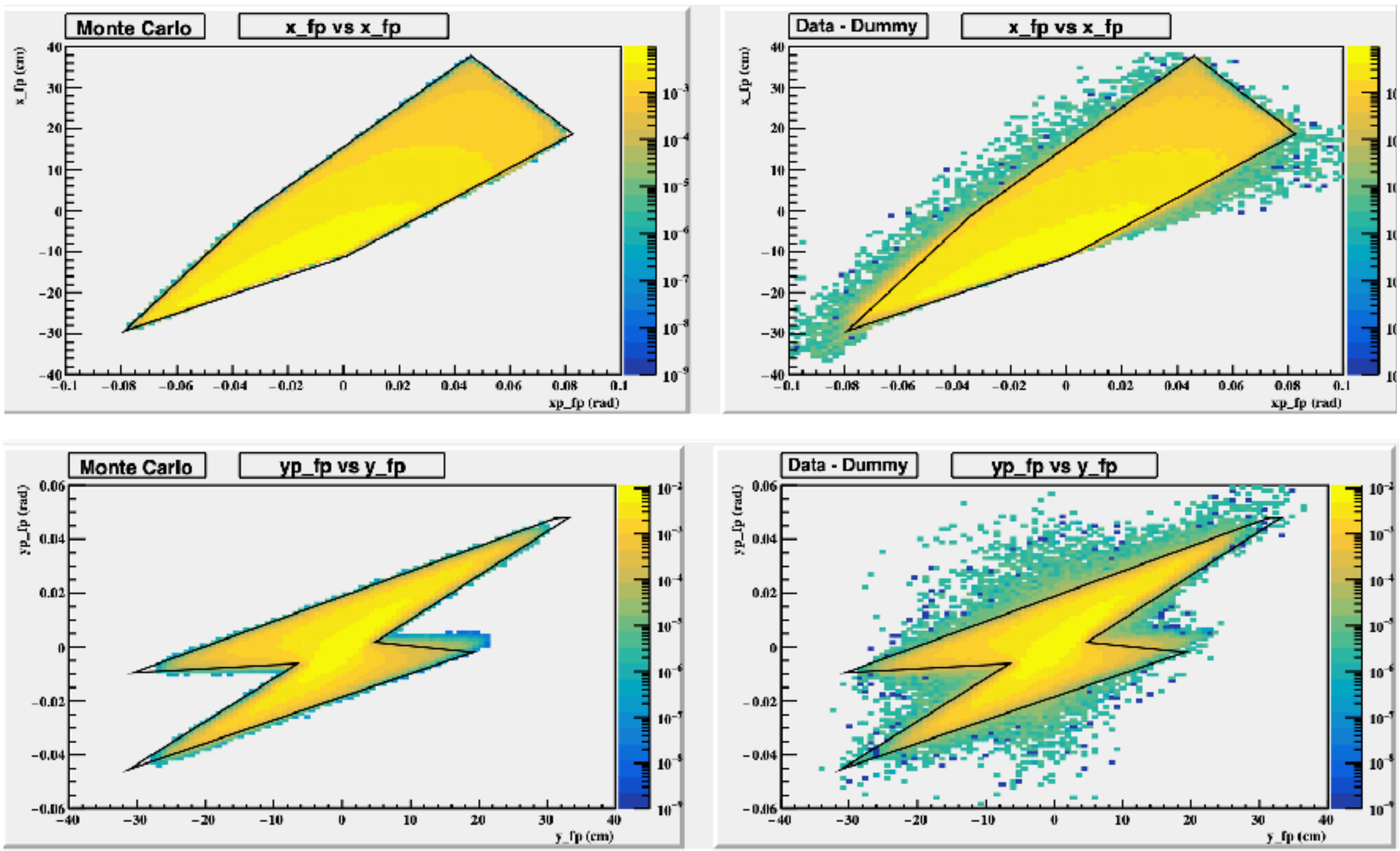
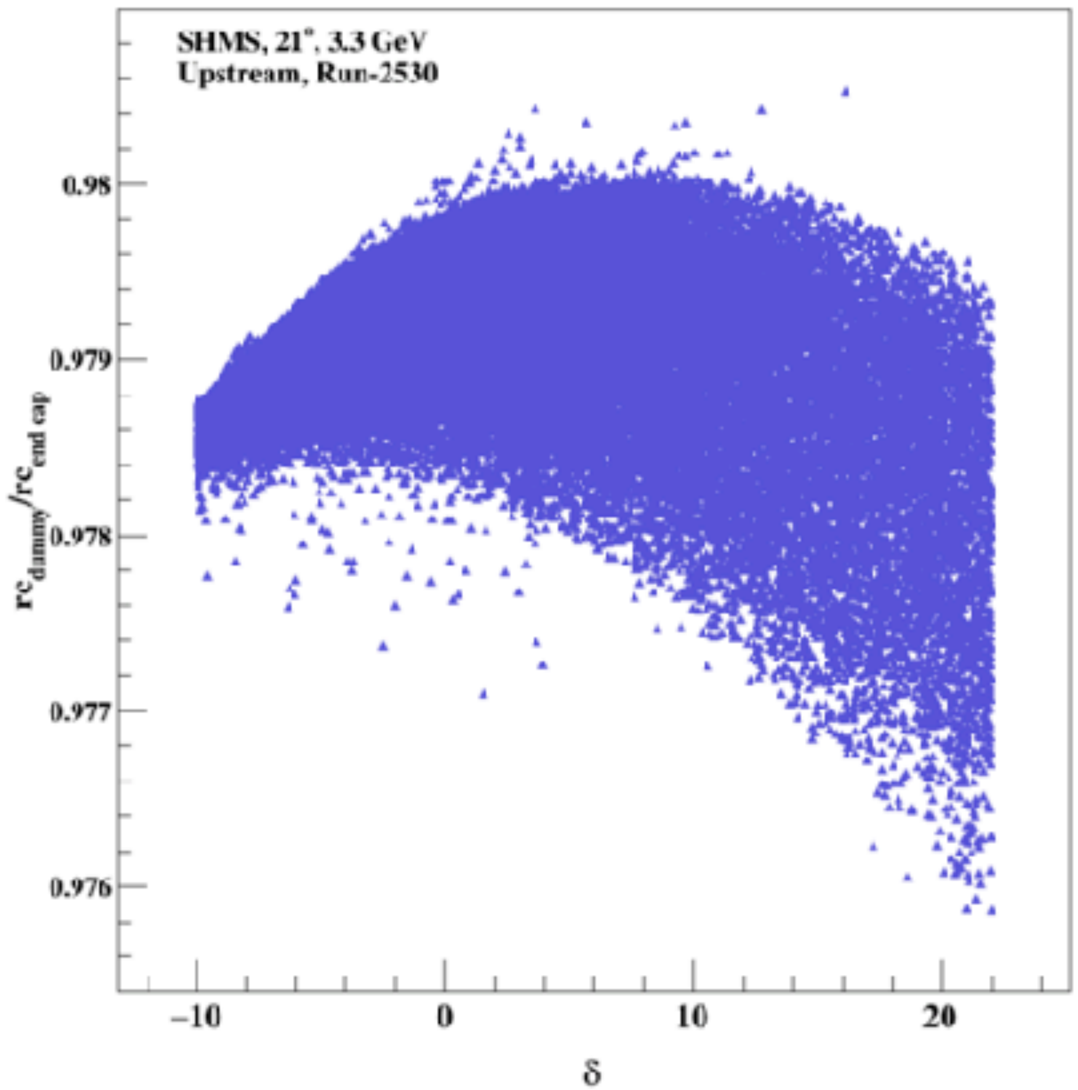
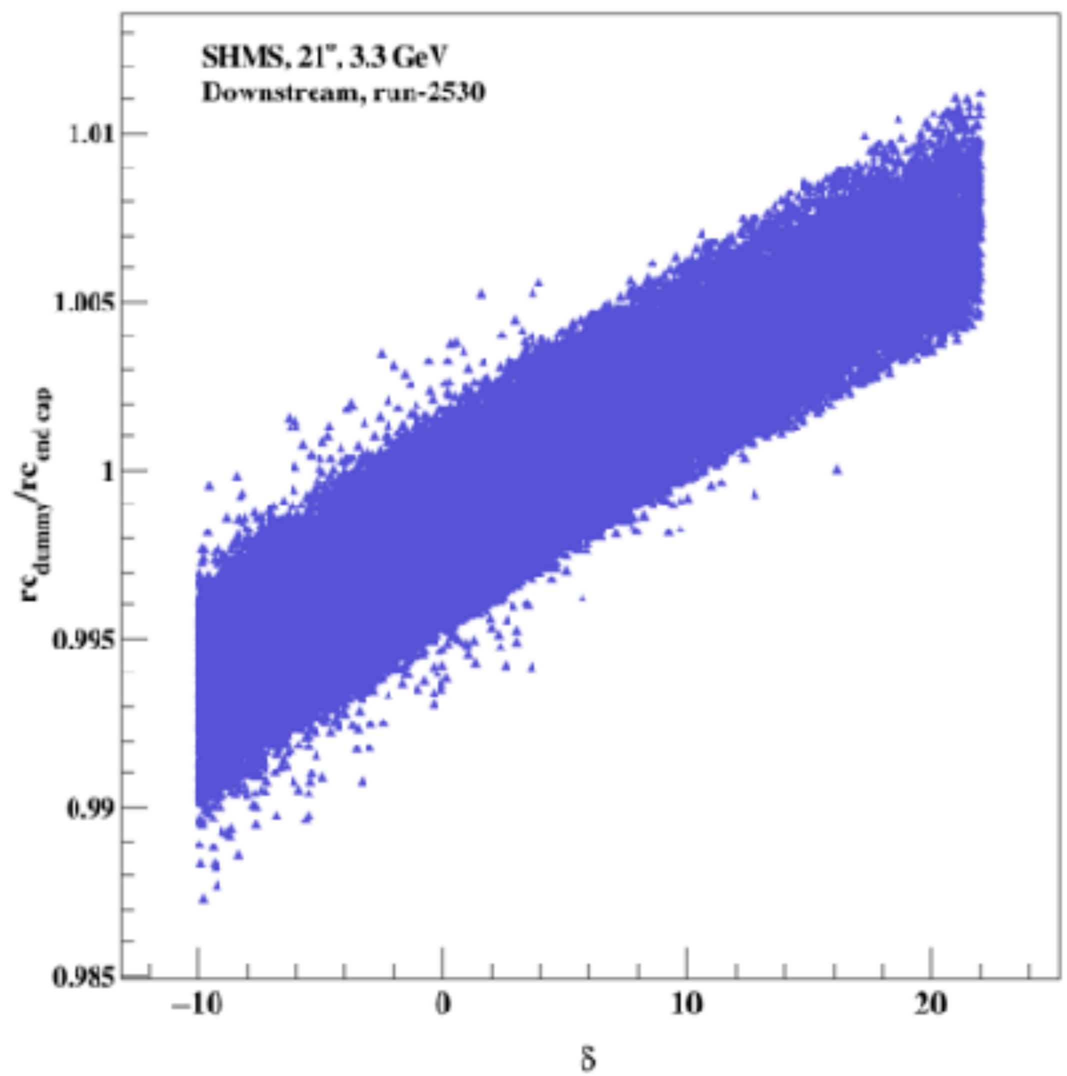


F2 Cross Section Extraction

Radiative Corrections for dummy subtraction

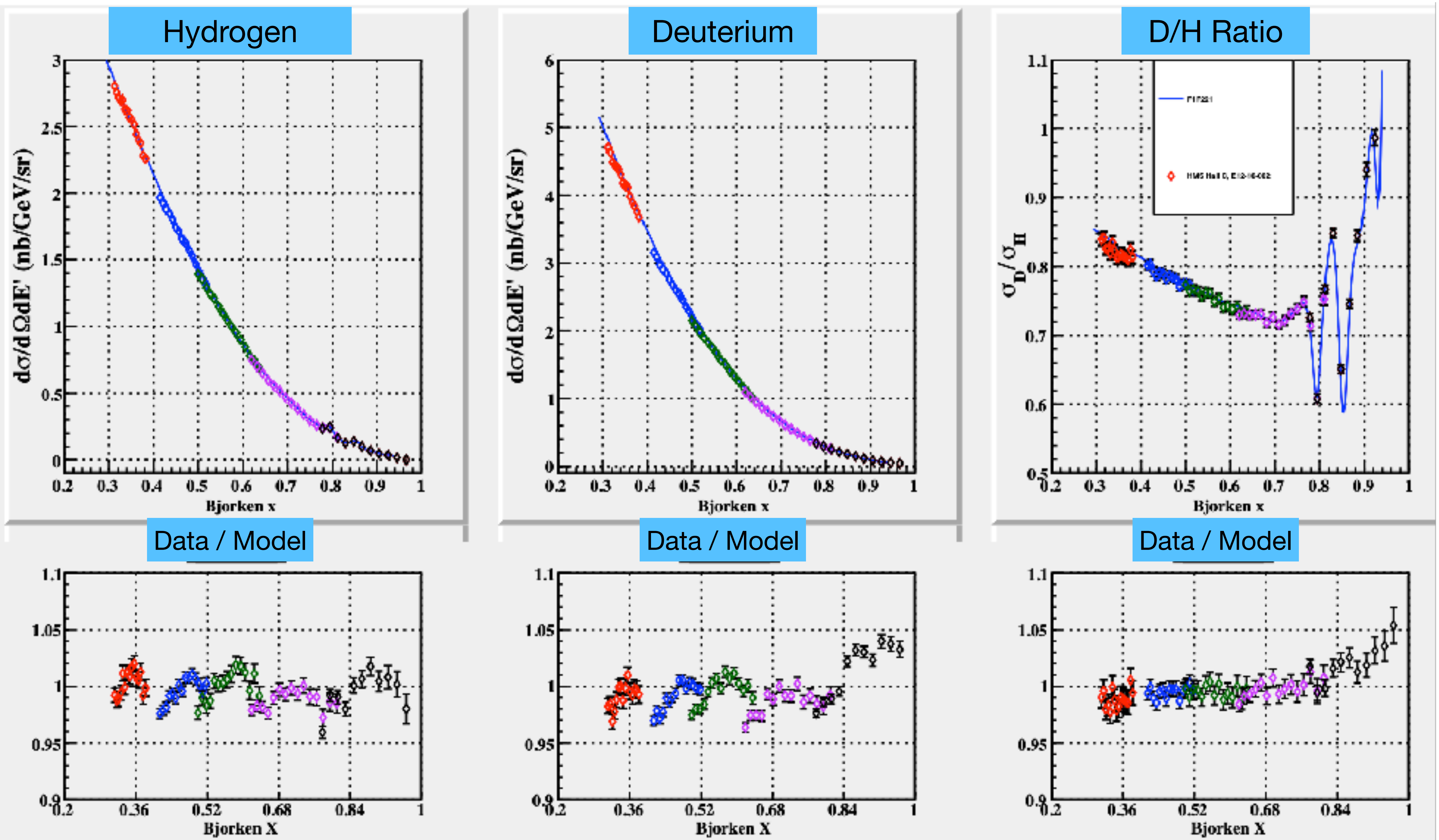
- The upstream and down stream thickness ratios are considered separately instead of a average thickness
- The ratio $rc_{dummy}/rc_{cryo\ cell}$ is maximum $\sim\pm 3\ \%$ (for either upstream or downstream)
- The maximum value of CNY_{dummy}/CNY_{total} for hydrogen is ~10.33% and for deuterium for deuterium is ~5.11%
- For hydrogen the maximum effect is (3% of 10.33%) = 0.3%
- For deuterium the maximum effect is (3% of 5.11%) = 0.15%





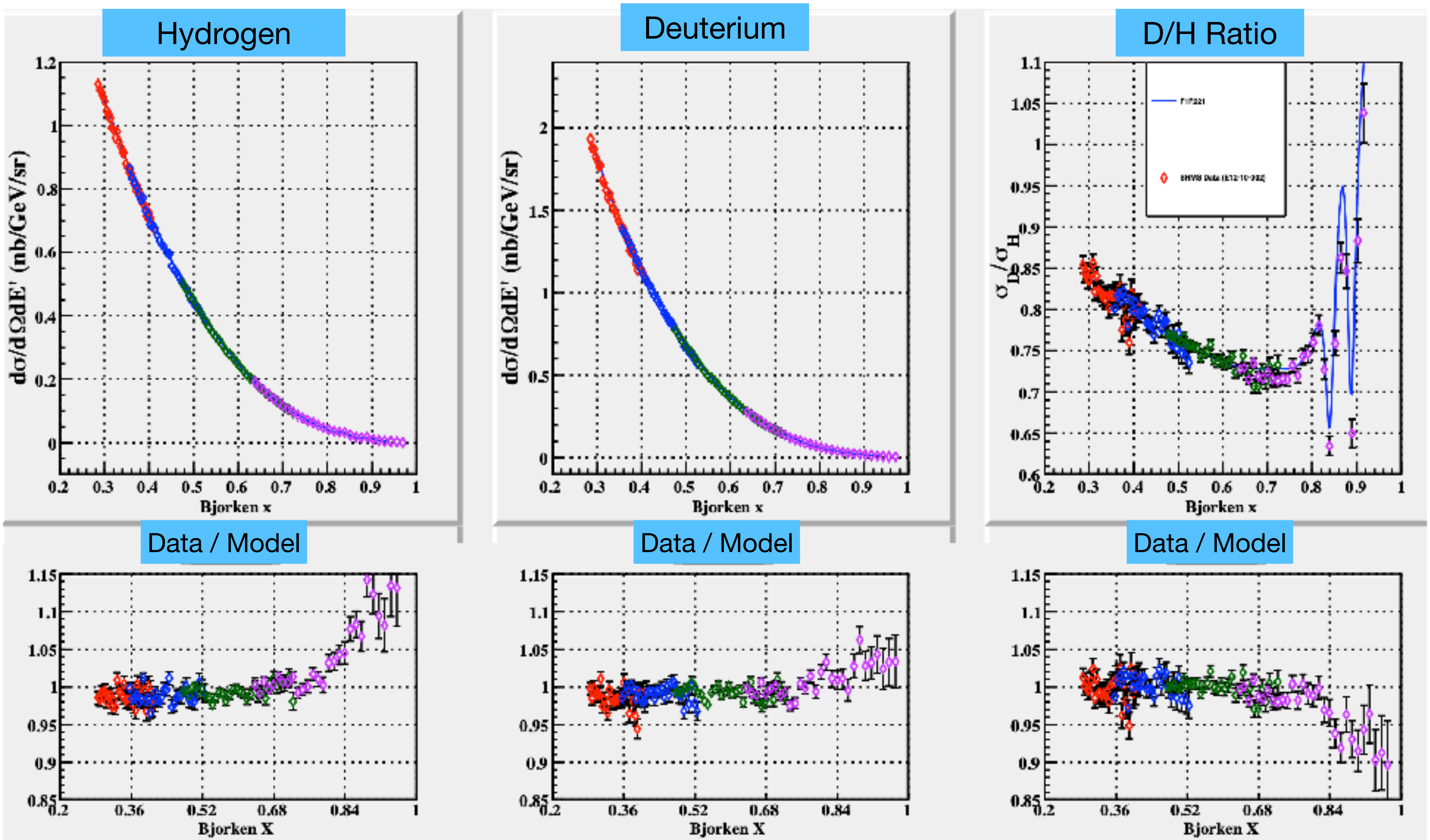
F2 Results

HMS @ 21 degrees



F2 Results

SHMS @ 29 degrees



F2 Results

HMS and SHMS @ 21 degrees

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

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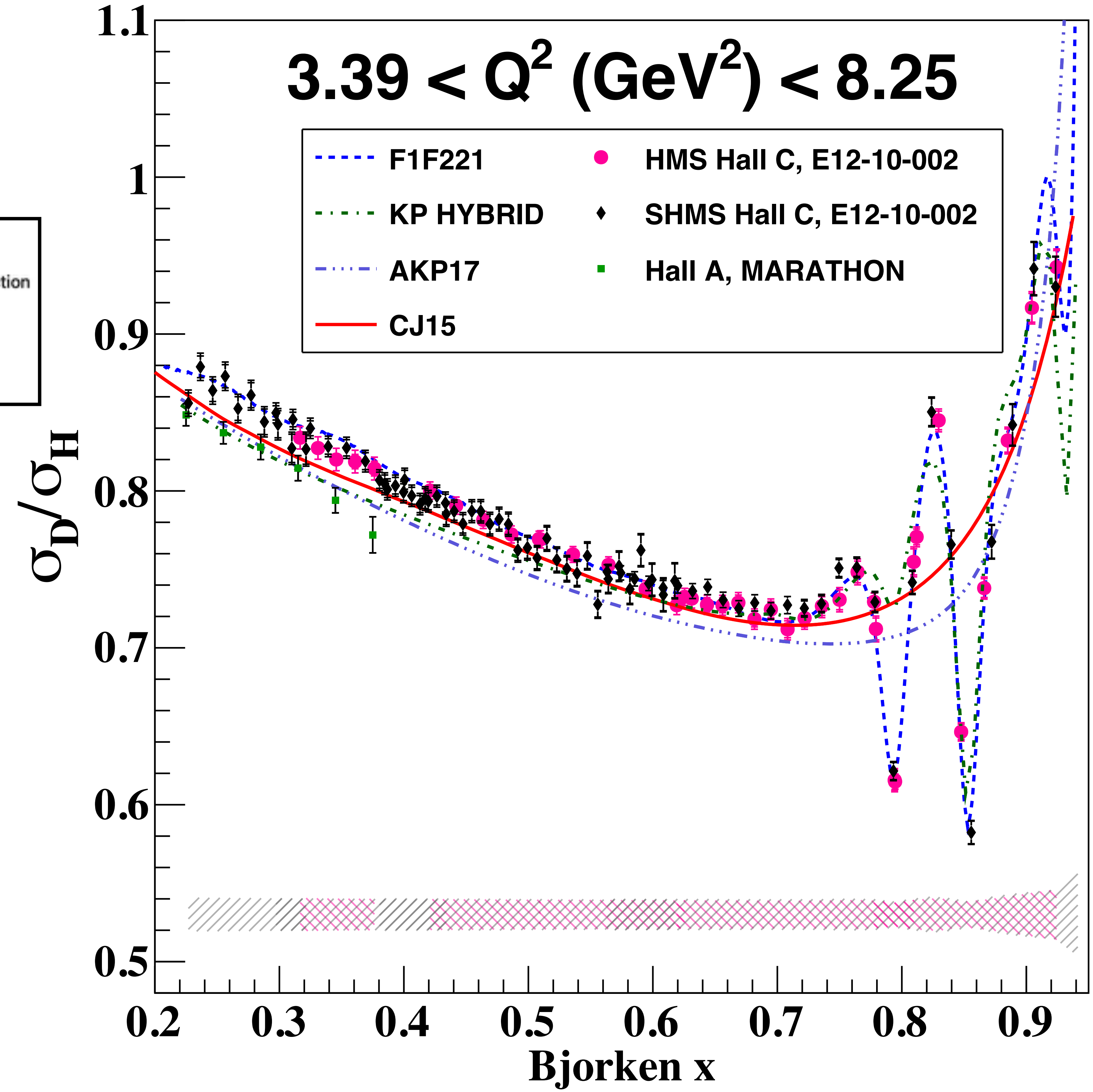
Apr 1, 2017



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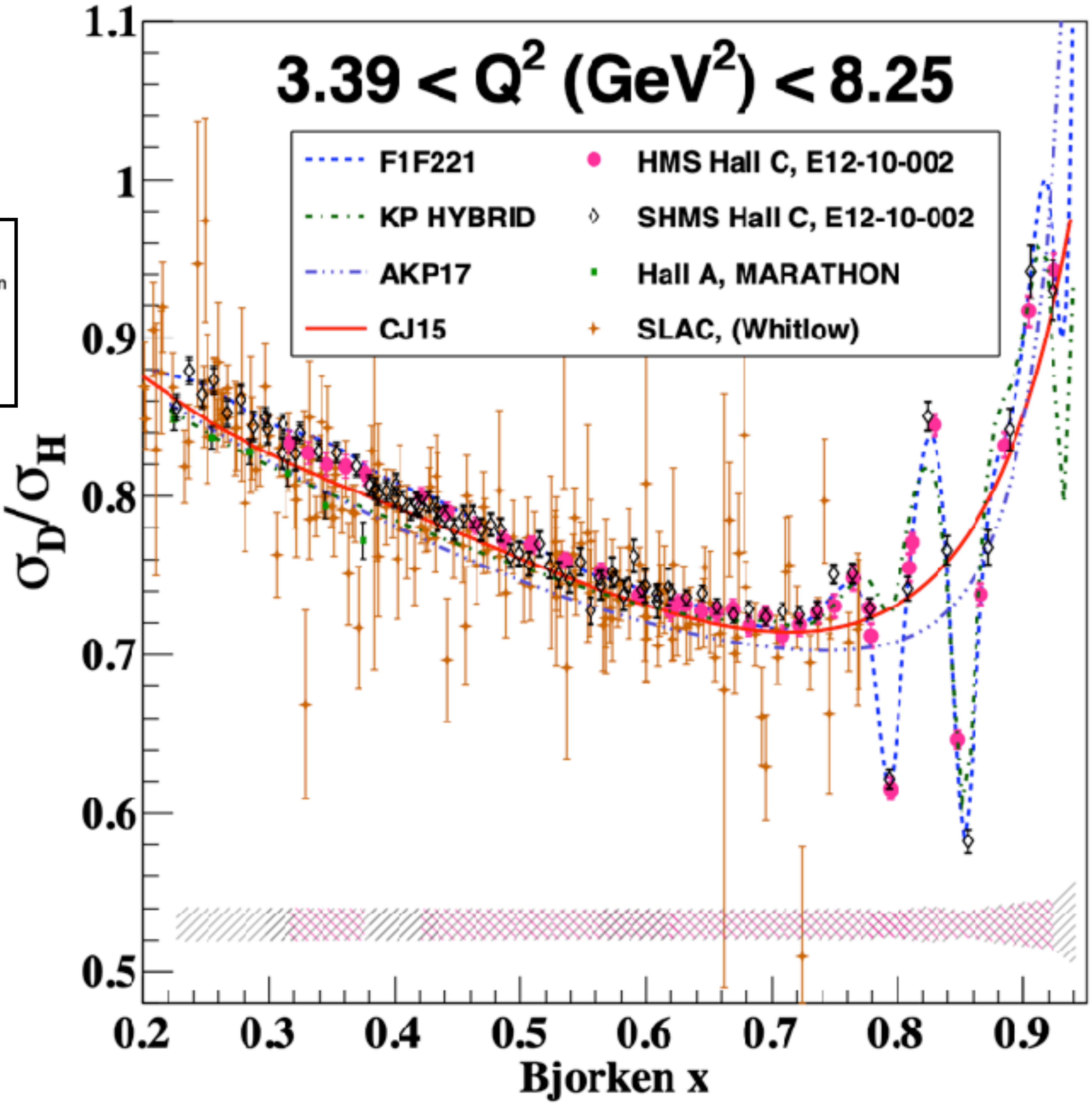
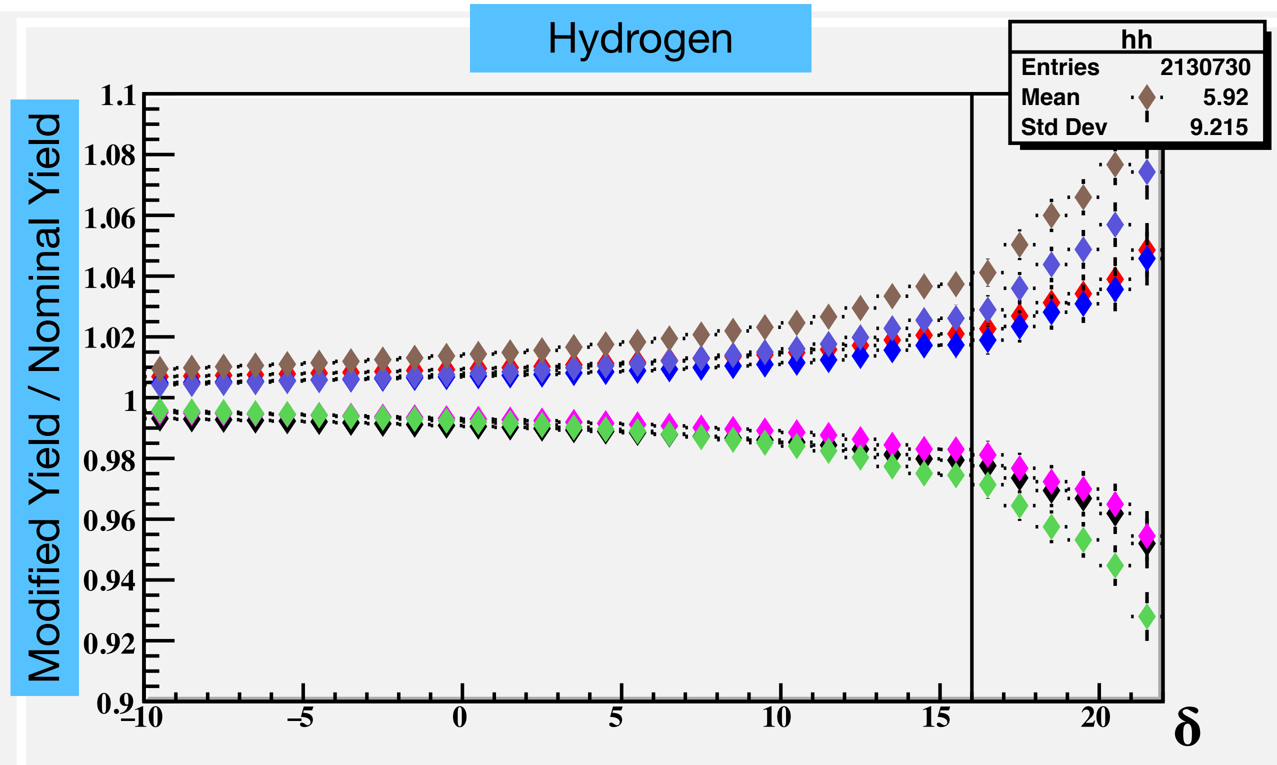
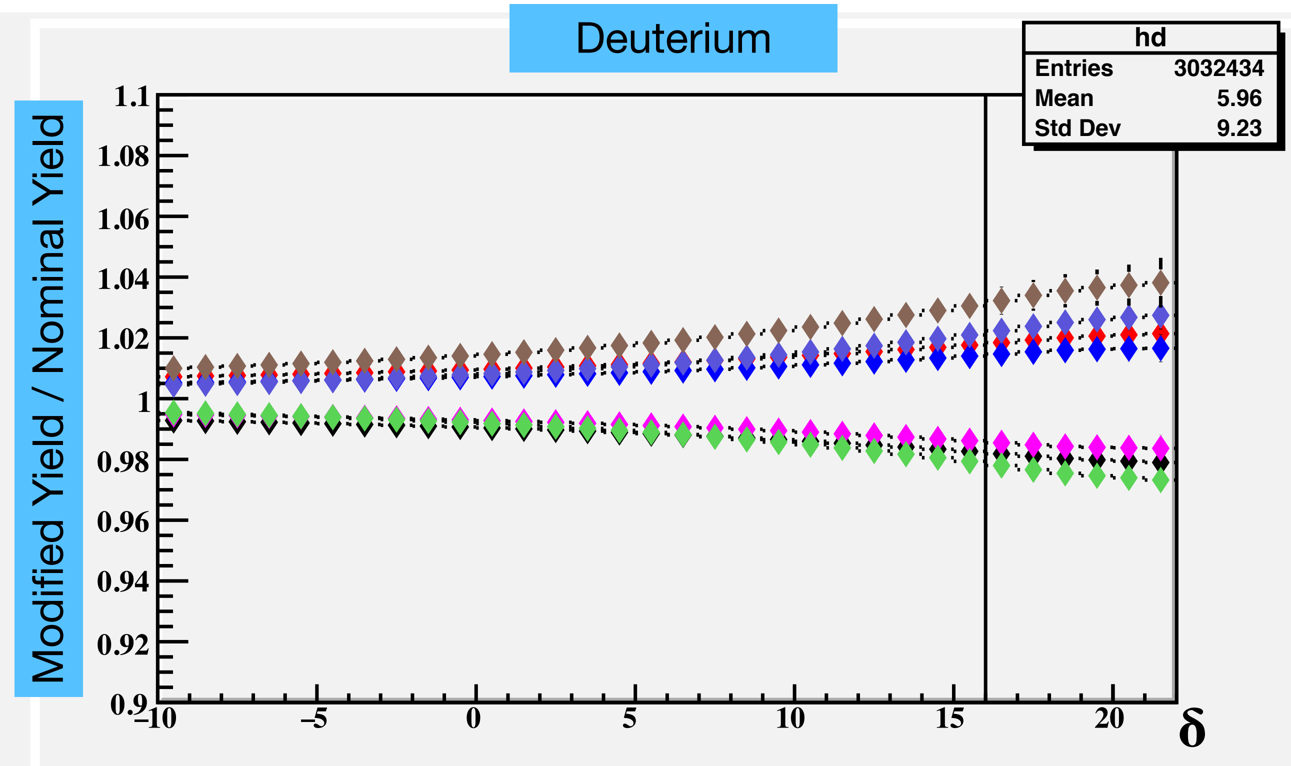


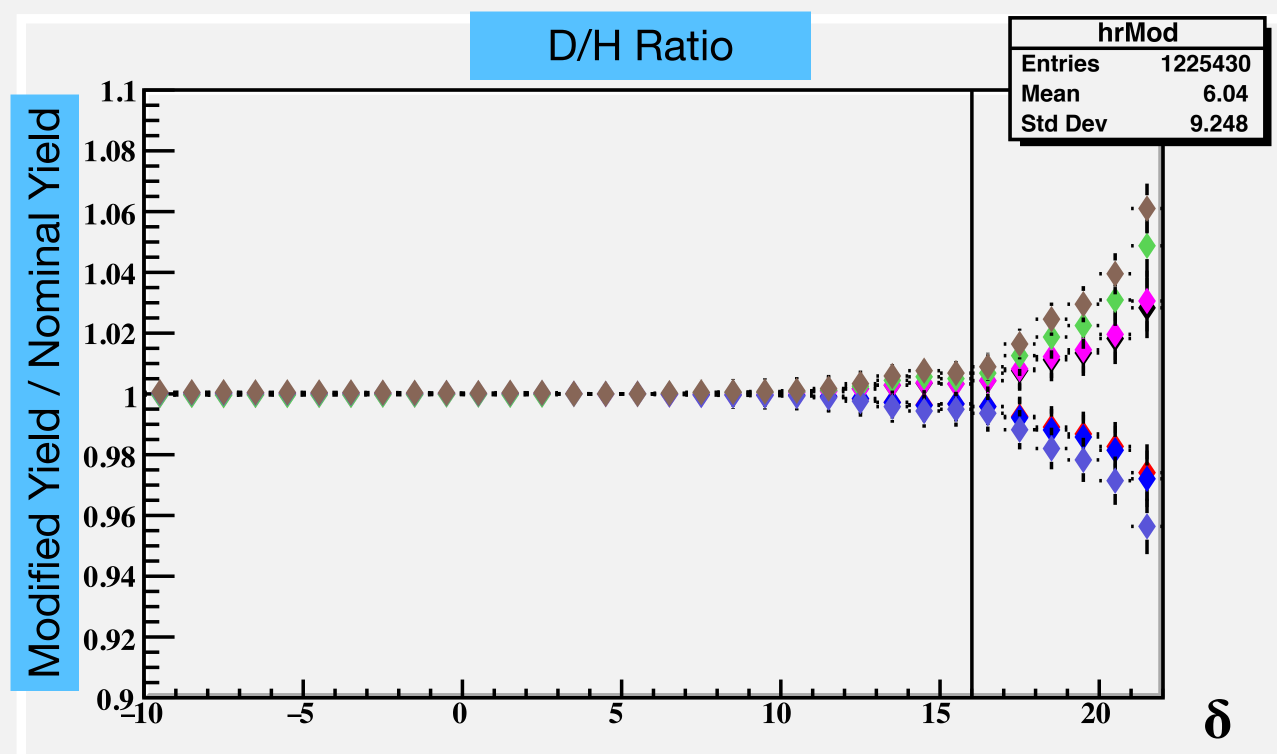
F2 Cross Section Extraction

Kinematic Uncertainties

How well do we know E, E’, and θ ?





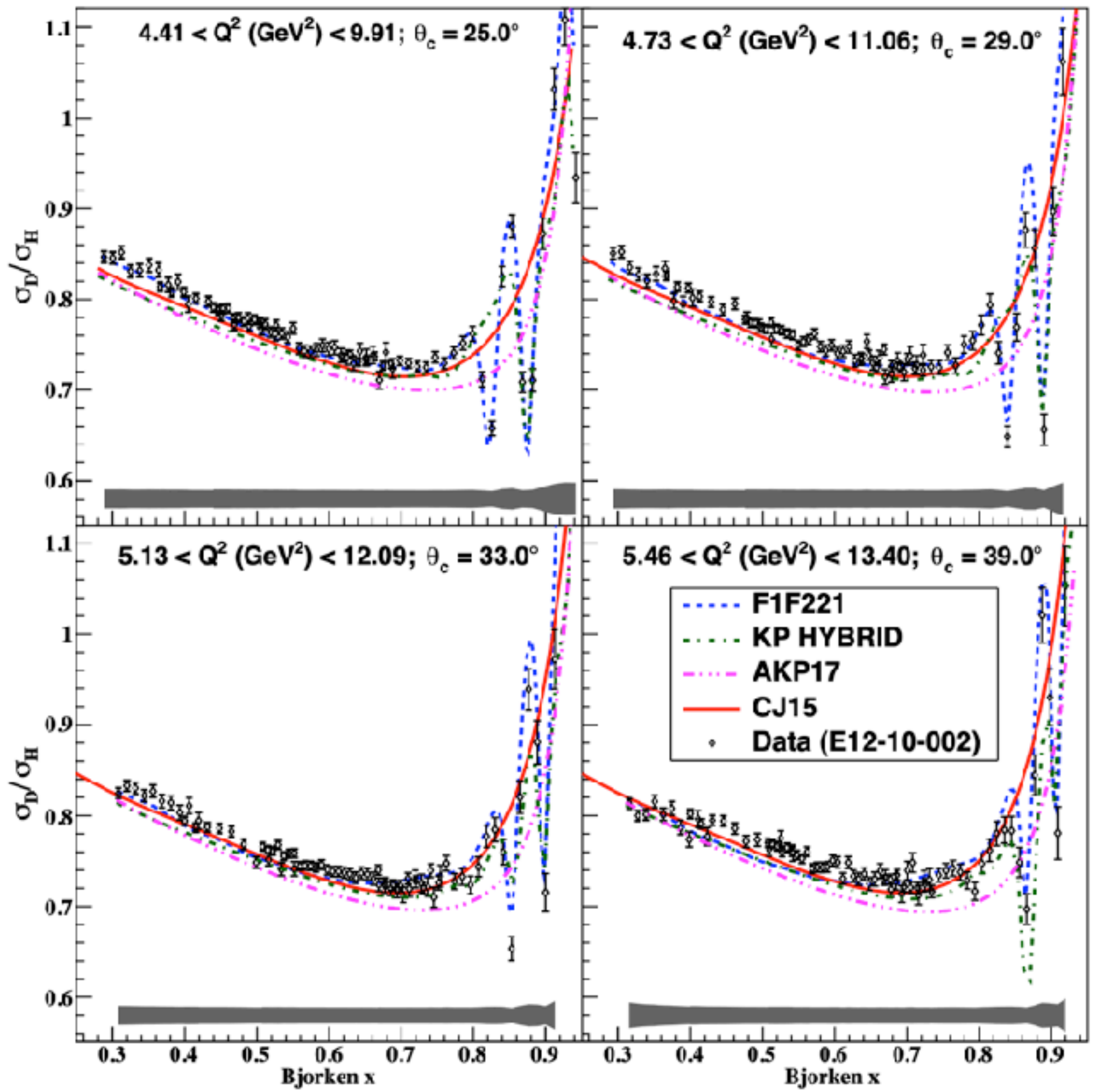


21deg 5p1GeV shms

- 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 Results

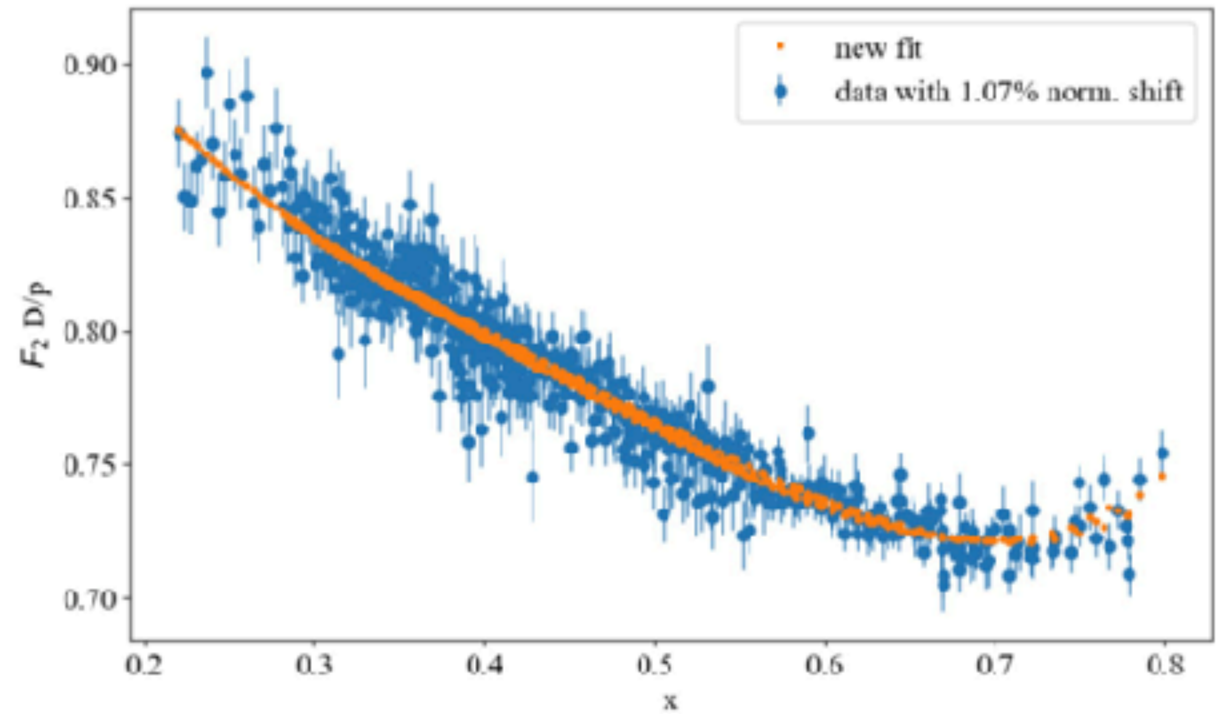


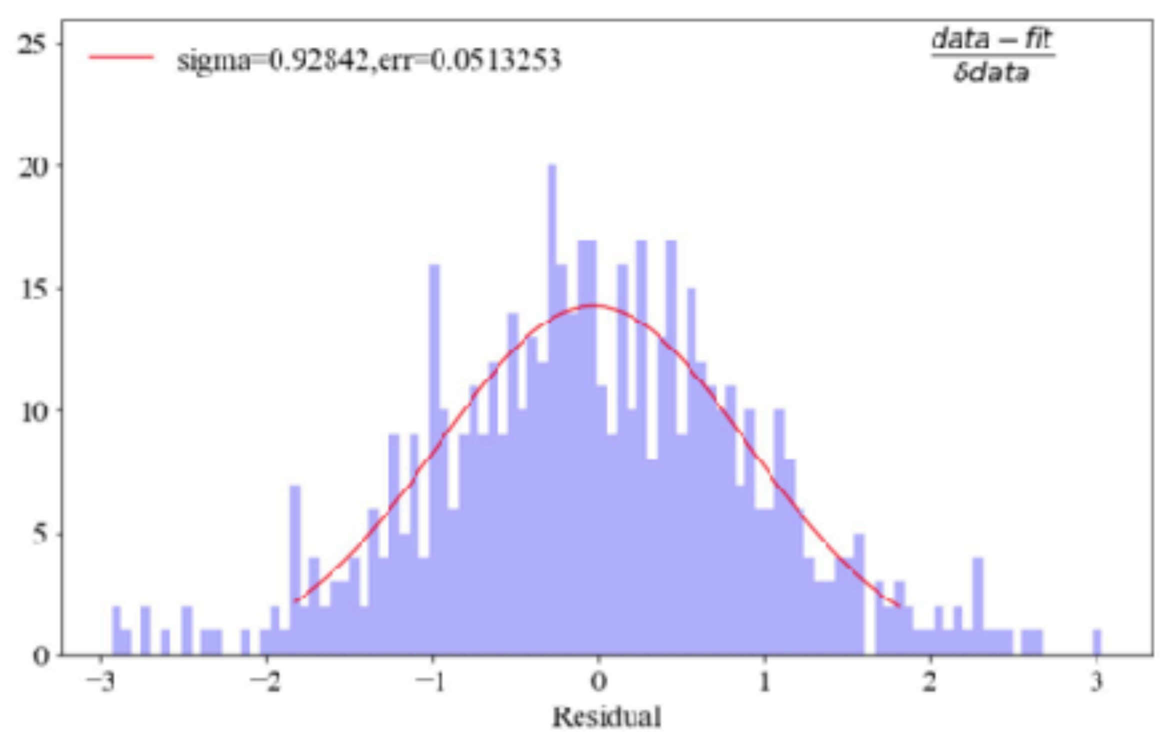
4.41 < Q² (GeV²) < 9.91; θc = 25.0°
4.73 < Q² (GeV²) < 11.06; θc = 29.0°
5.13 < Q² (GeV²) < 12.09; θc = 33.0°
5.46 < Q² (GeV²) < 13.40; θc = 39.0°
F1F221
KP HYBRID
AKP17
CJ15
Data (E12-10-002)
σD/σH
Bjorken x

F2 Results

CJ Impact Study

1. Data set from Bill: Normalization=1.1%, correlated/uncorrelated ptp errors 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



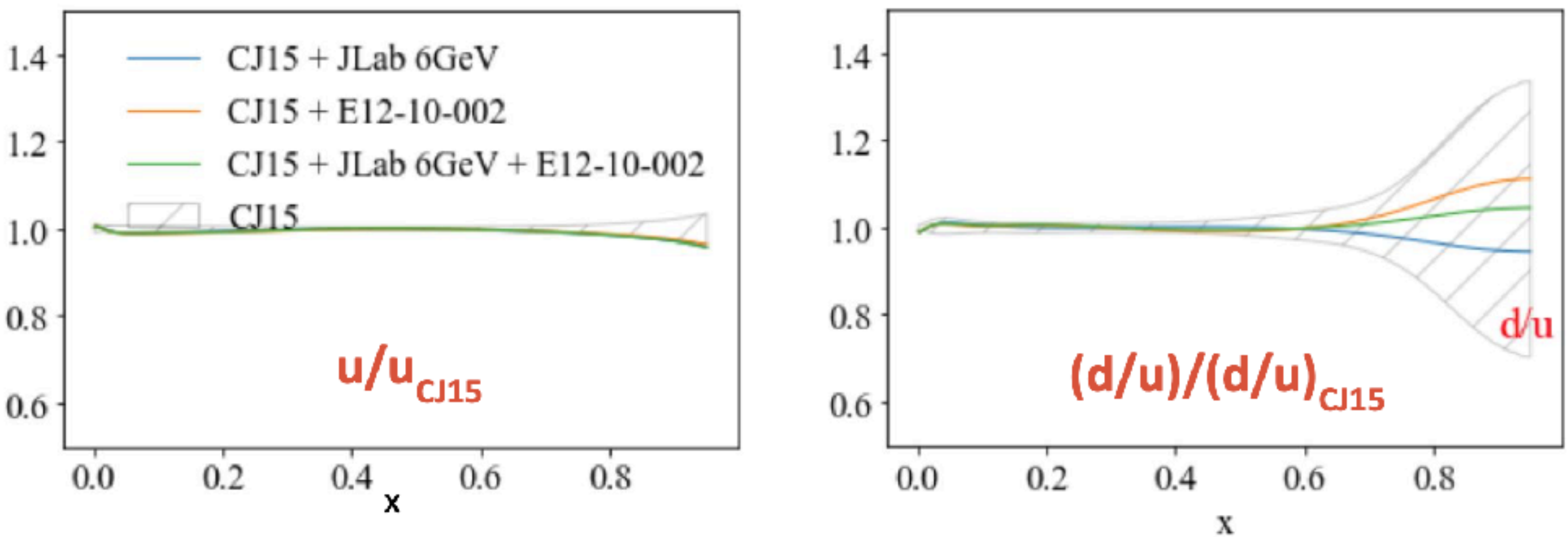


Courtesy of Alberto Accardi and Shujie Li

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

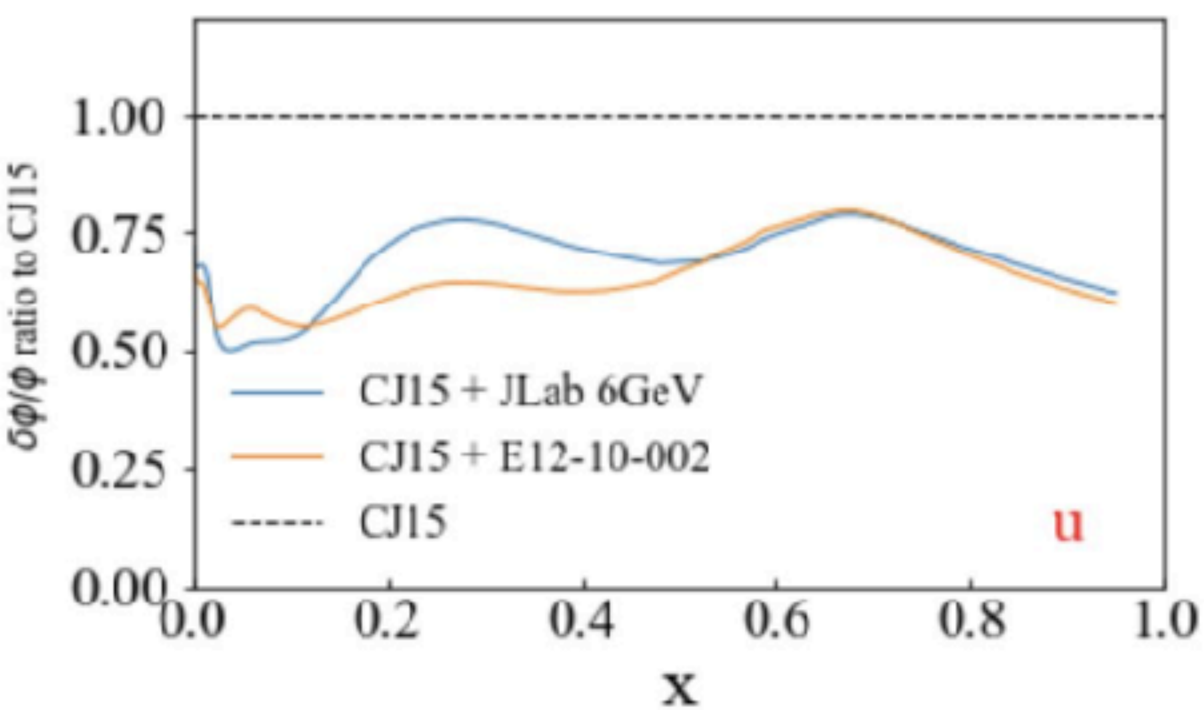


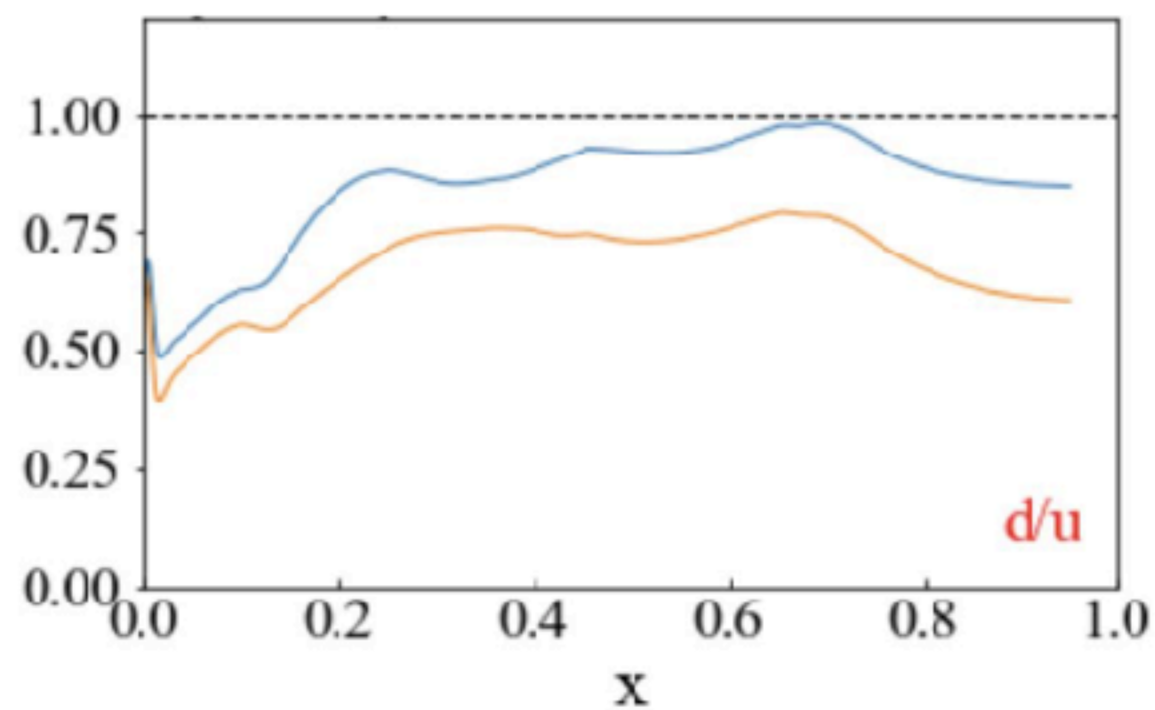
Courtesy of Alberto Accardi and Shujie Li

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**





Courtesy of Alberto Accardi and Shujie Li

F2 Results

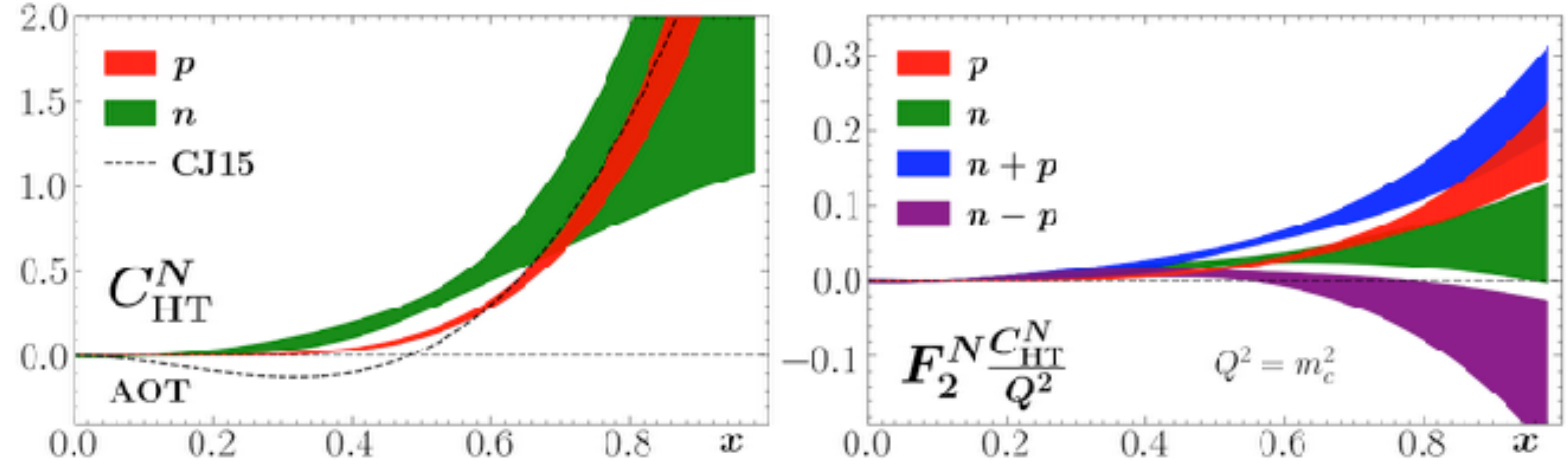
JAM Impact Study

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

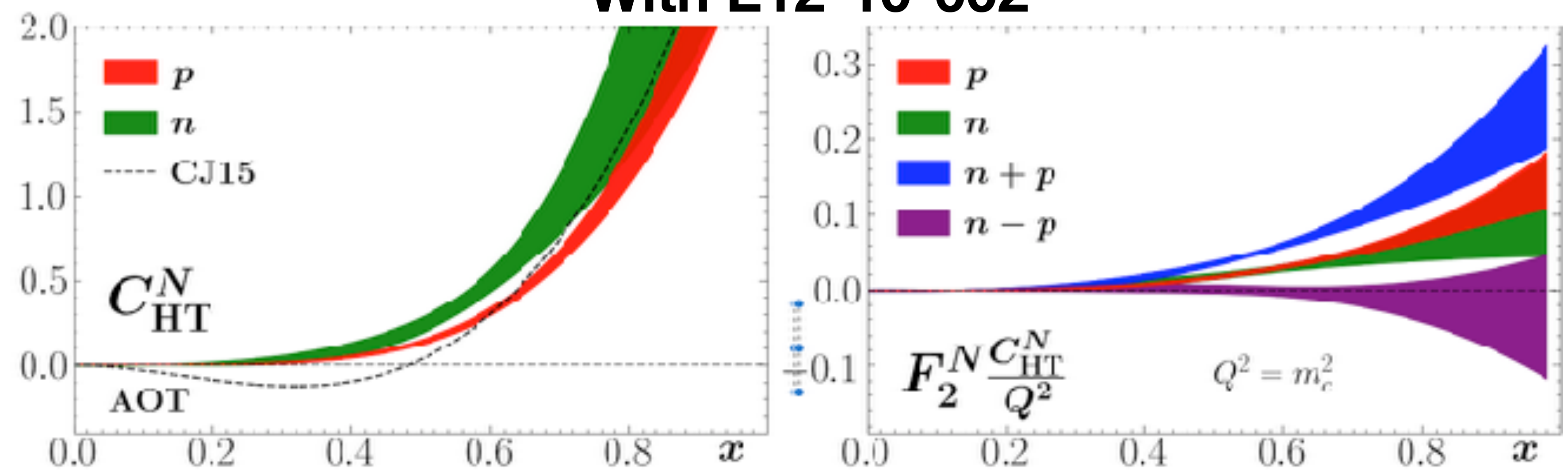
- D/H ratio was provided to Jefferson Lab Angular Momentum Collaboration (JAM) to incorporate into their global QCD analysis of PDFs
- New F2 data significantly improves the uncertainty of higher twist corrections to F2

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

Without E12-10-002



With E12-10-002

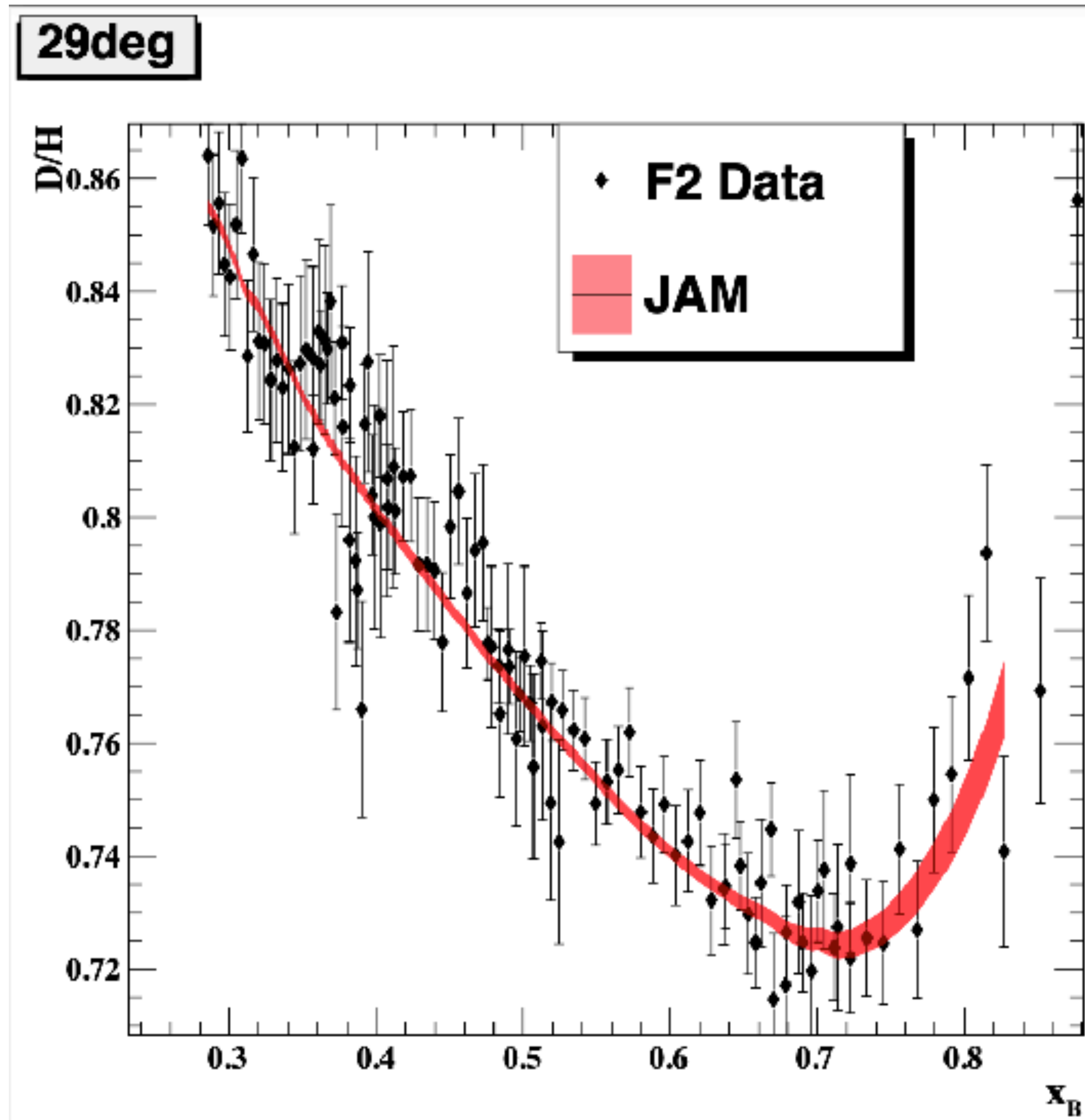


Courtesy of Chris Cocuzza, W. Melnitchouk, and N. Gonzalez

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

JAM Prediction NOT constrained by new data



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

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] 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] 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)

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

Graduate Students
Deb Biswas
Aruni Nadeeshani
Abel Sun
Abishek Karki (EMC)
Casey Morean (EMC)

Post Doc
Bill Henry (Contact)

Special Thanks to
Mark Jones
Carlos Yero
Greg Smith

Acknowledgments

- F2/EMC

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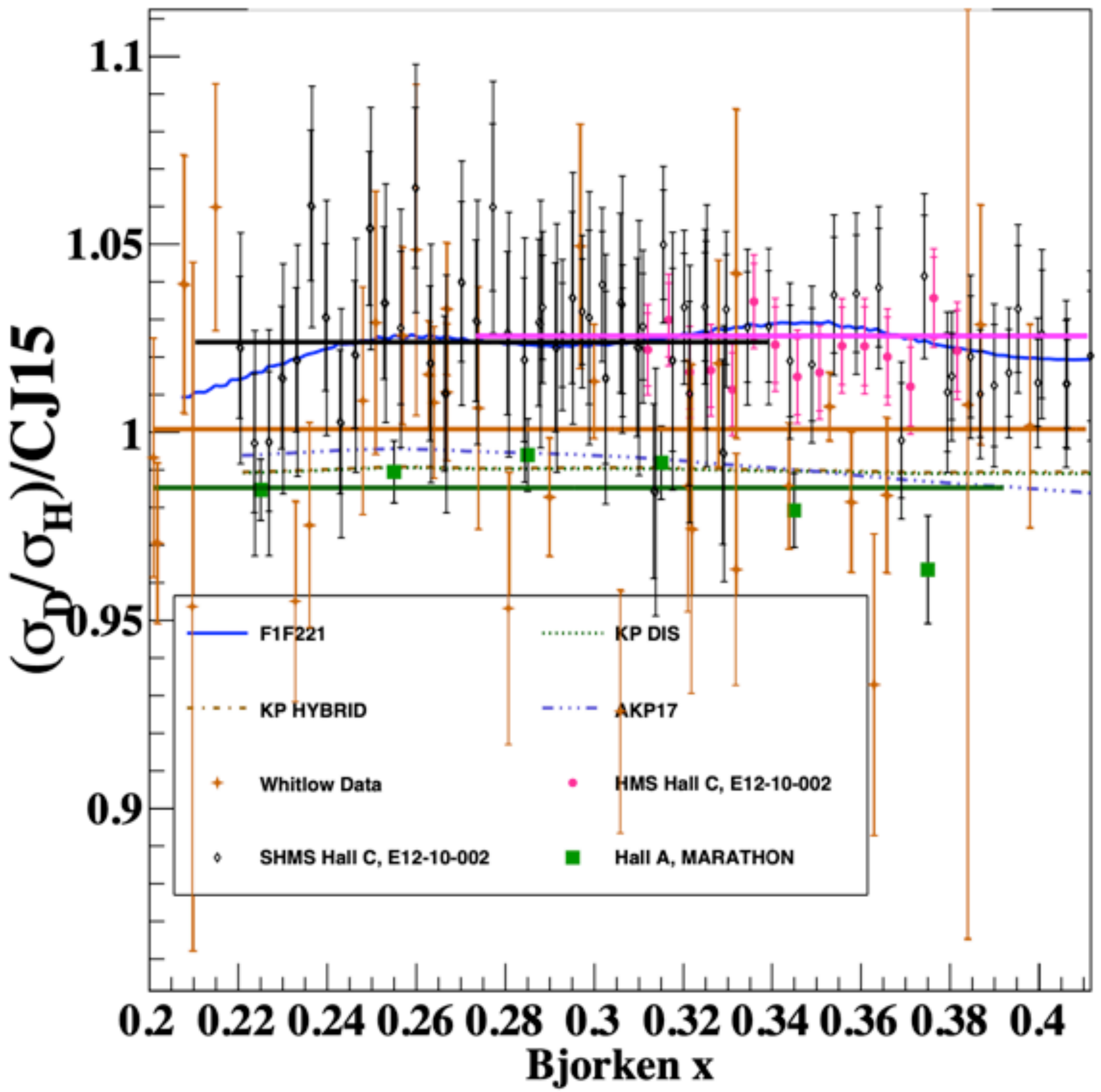
Back-Ups



1.1
1.05
1
0.95
0.9
0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 0.36 0.38 0.4
Bjorken x
(σ_D/σ_H)/CJ15
F1F221
KP DIS
KP HYBRID
AKP17
Whitlow Data
HMS Hall C, E12-10-002
SHMS Hall C, E12-10-002
Hall A, MARATHON
1.023 +/- 0.004
1.026 +/- 0.003
1.001 +/- 0.004
0.985 +/- 0.004

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. Thomas[4]
[1] Department of Physics, SERC, Temple University, Philadelphia, Pennsylvania 19122, USA
[2] Jefferson Lab, Newport News, Virginia 23606, USA
[3] Department of Physics, University of Massachusetts, Amherst, Massachusetts 01003, USA
[4] CSSM and CoEPP, Department of Physics, University of Adelaide SA 5005, Australia
Jefferson Lab Angular Momentum (JAM) Collaboration

(Dated: April 15, 2021)

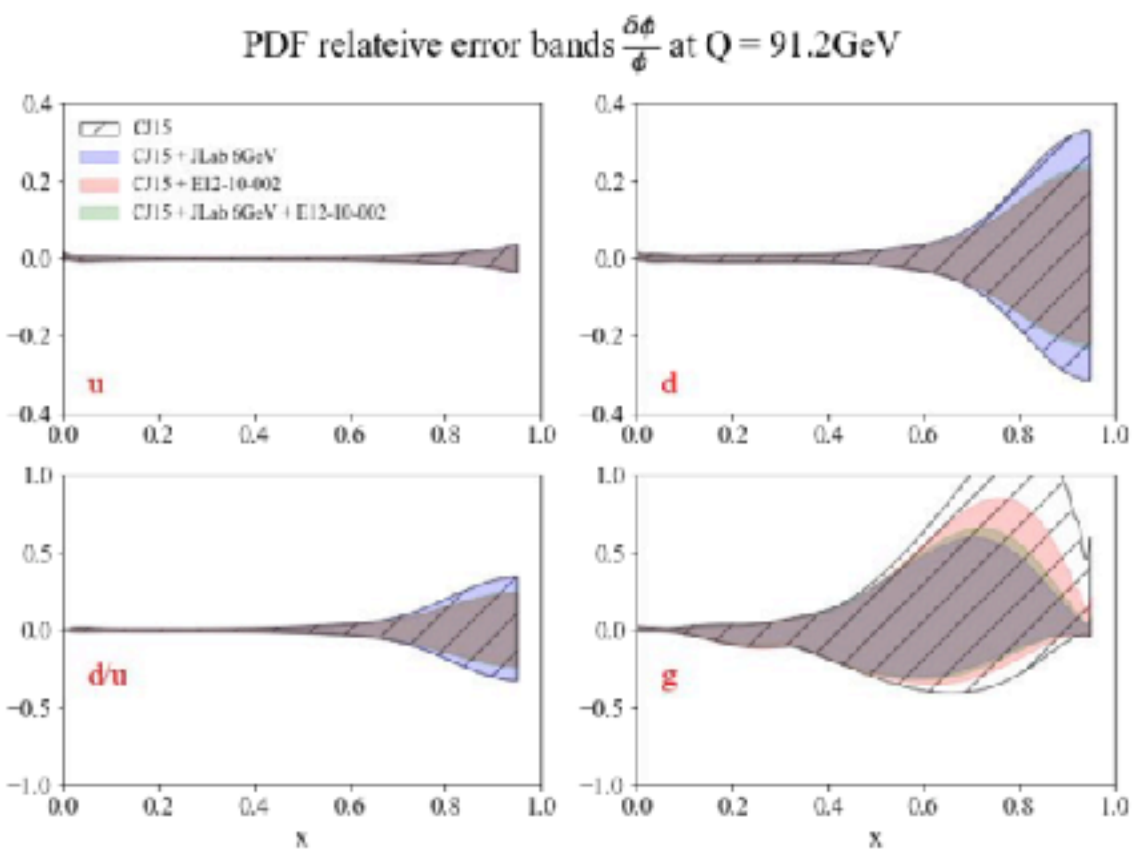
TABLE I. Summary of the χ^2 values per number of points $N_{\rm dat}$ for the data used in this analysis. The MARATHON and JLab E03-103 ^{3}He/D are separated from the rest of the fixed target data, and their fitted normalizations are shown.

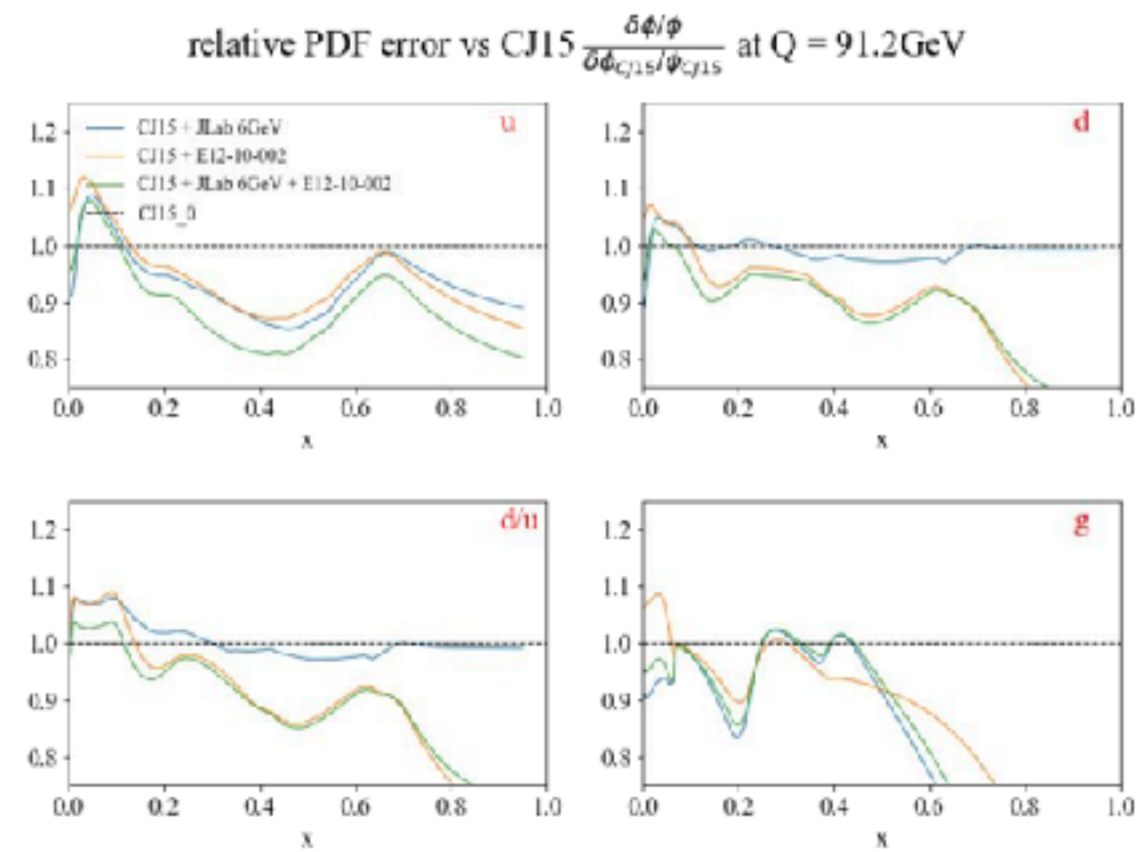
process	$N_{\rm dat}$	$\chi^2/N_{\rm dat}$	fitted norm.
DIS			
MARATHON ^{3}He/^{3}H	22	0.63	1.007(6)
MARATHON D/p	7	0.95	1.019(4)
JLab E03-103 ^{3}He/D	16	0.25	1.006(10)
other fixed target	2678	1.05	
HERA	1185	1.27	
Drell-Yan	205	1.20	
W-lepton asym.	70	0.81	
W charge asym.	27	1.14	
Z rapidity	56	1.04	
jet	200	1.11	
total	**4466**	**1.11**	

arXiv:2104.06946

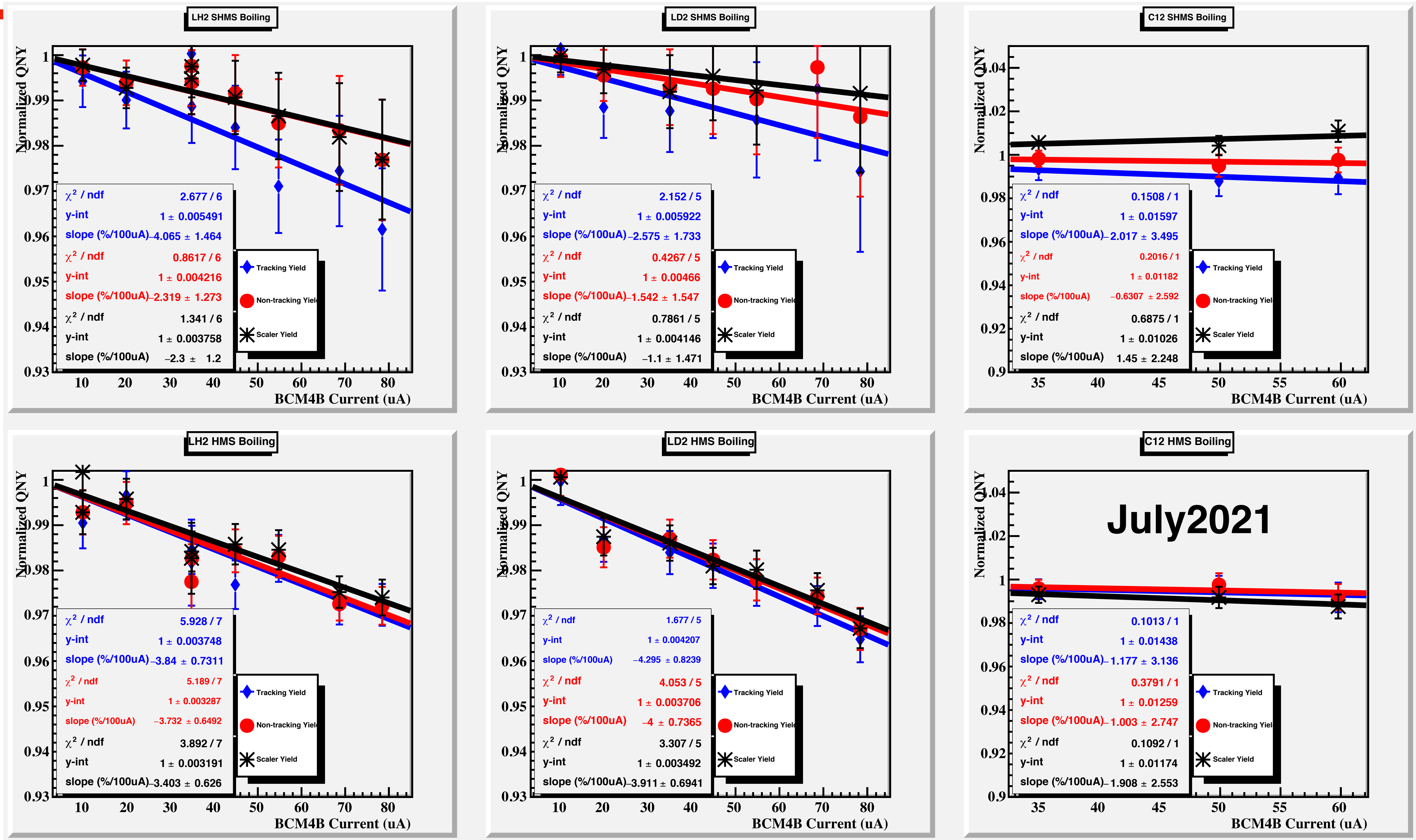
Impact on PDF uncertainties

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, E99118, E94110, E06009, E03103)
Set 3: CJ15 + this data + JLab 6GeV data





F2 Cross Section Extraction



- Additional density correction applied to 22.4 K data (0.6%)