Update on F2 in Hall C

E12-10-002

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

Bill Henry
July 16th, 2020

Outline

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

E12-10-002

Physics Motivation

- Constraint for PDF fits
- Quark Hadron Duality
- Benchmark for Lattice QCD
- Resonance/DIS modeling

Analysis

- Overview
- Preminary Results
- Outlook

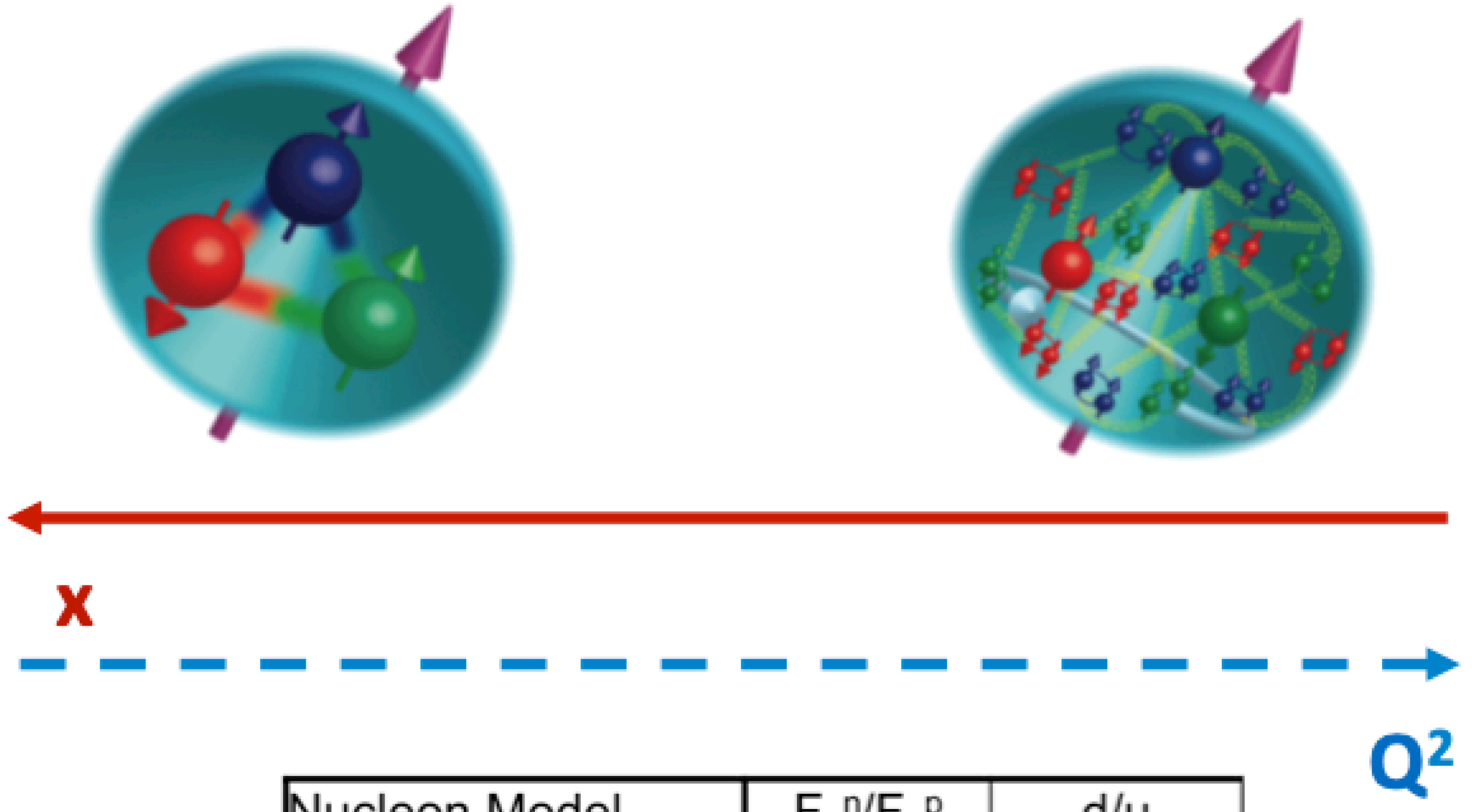
Why Is the Large-x Region Important?

- The partonic structure of the nucleon comes to the foreground in the valence region

- This partonic structure defines many of the nucleon's properties: charge, flavor content, baryon number, total spin…

- The valence region is a very good testing ground for various nucleon structure models

- Besides, all it's interconnected: uncertainties about the nucleon structure in the valence regime at low Q^2 and large x will sneak into the low x, large Q^2 region via evolution



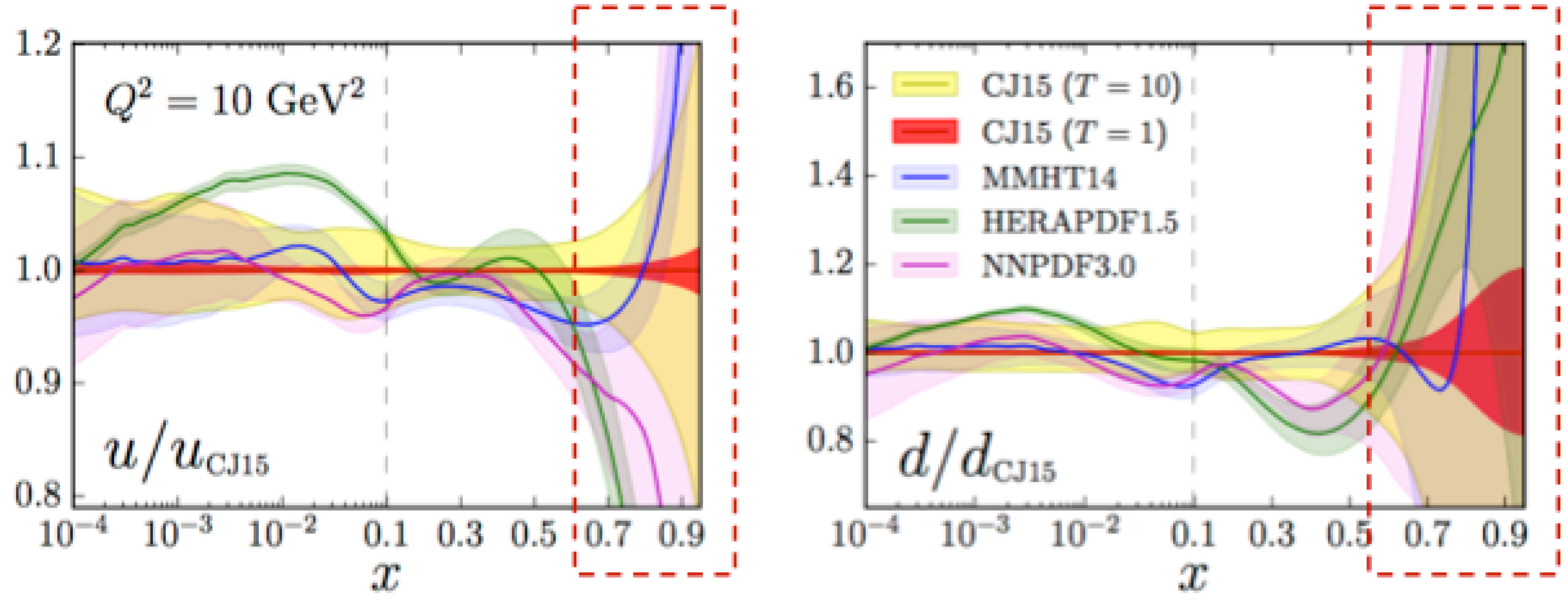
Nucleon Model	F_2^n/F_2^p	d/u
SU(6)	2/3	1/2
Valence Quark	1/4	0
DSE contact interaction	0.41	0.18
DSE realistic interaction	0.49	0.28
pQCD	3/7	1/5

Jefferson Lab has an unique experimental/theory program that explores the nucleon dynamics in the valence regime

Pushing PDFs Extraction into the Valence Region: CTEQ-JLab (CJ)

❑ CTEQ- based PDF fit **customized for the large x, lower Q^2 regime**

- Used a large body of data previously rejected via kinematic cuts
- Incorporated dynamical higher twist and target mass corrections
- Performed an extensive study of nuclear corrections in deuterium to better access the d-quark distribution

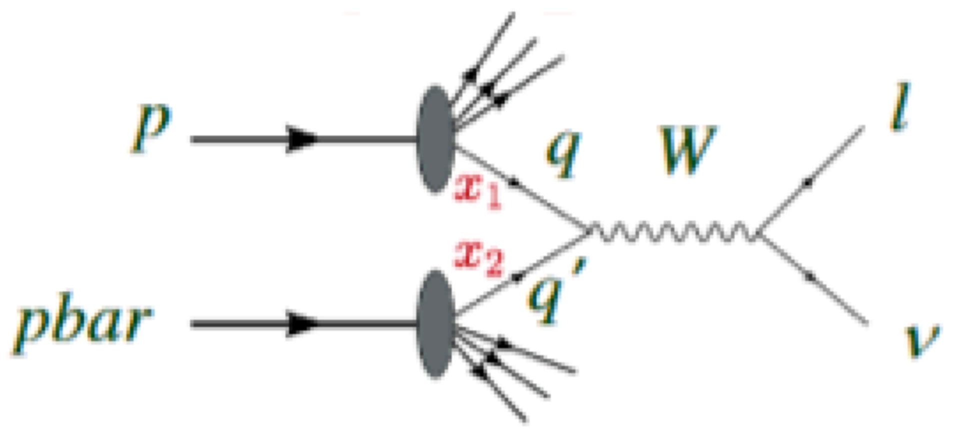


4 publications so far (first in 2010): 513 citations over all 4 papers

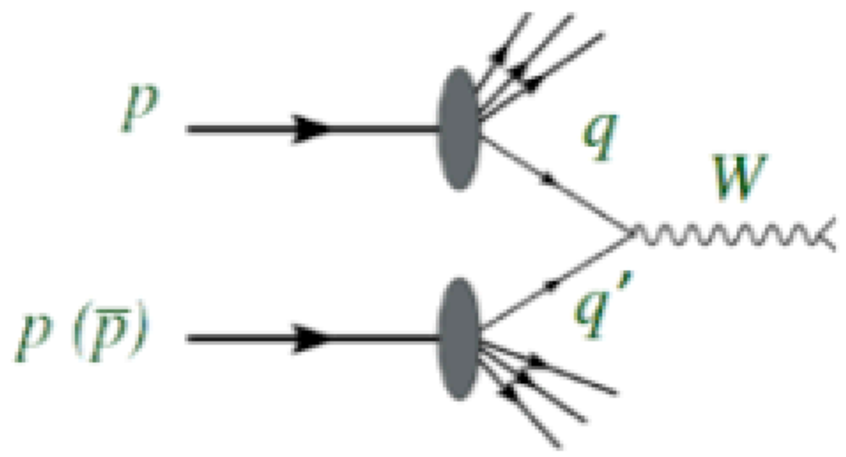
It clearly showed that PDFs don't lose their universality when higher twists are included thus giving rise to a new generation of PDF extractions

It demonstrated how the somewhat separated fields of high-energy particle physics and lower energy hadronic and nuclear physics can interact to the benefit of both

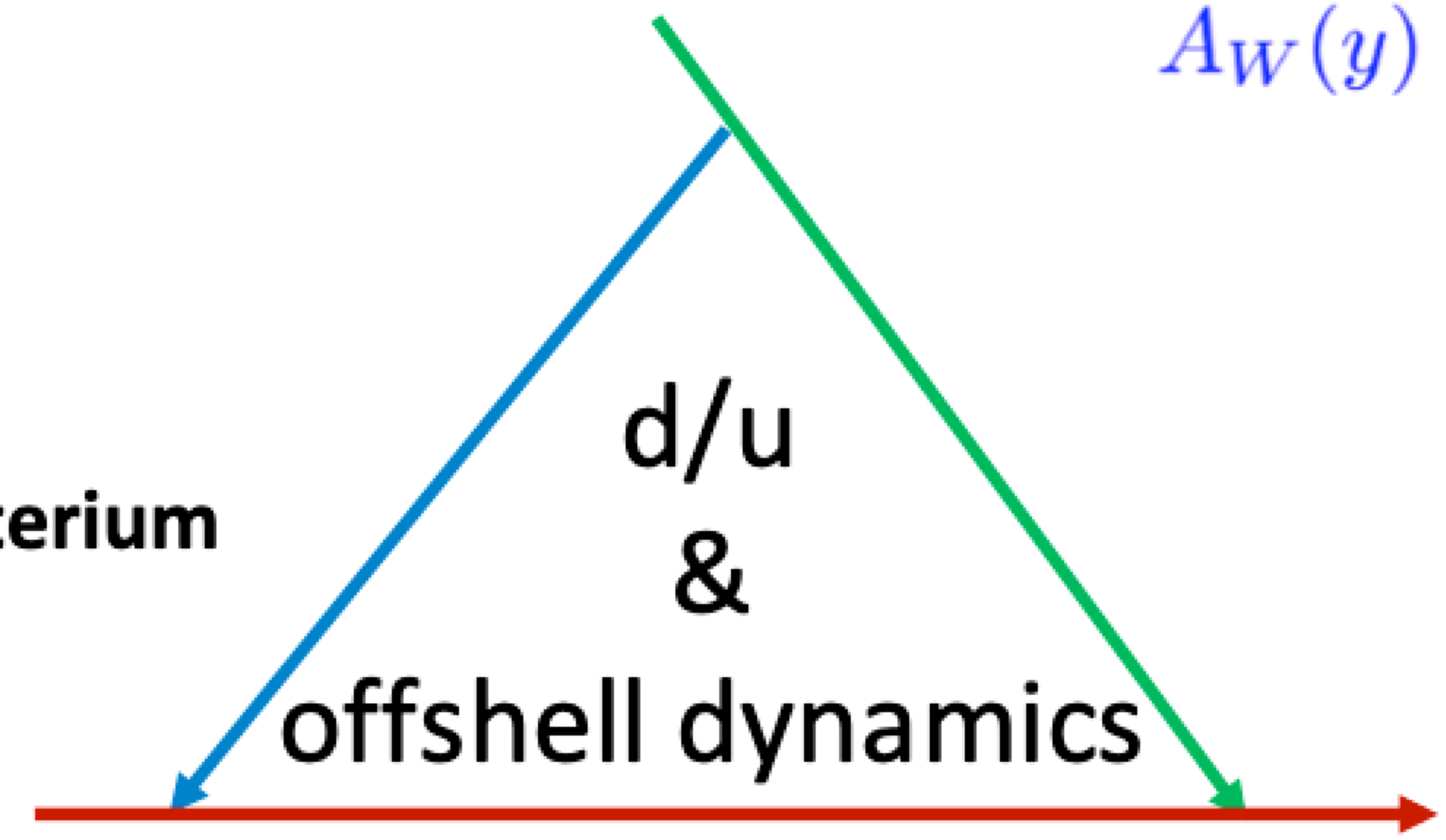
Pushing PDFs Extraction into the Valence Region: CTEQ-JLab (CJ)



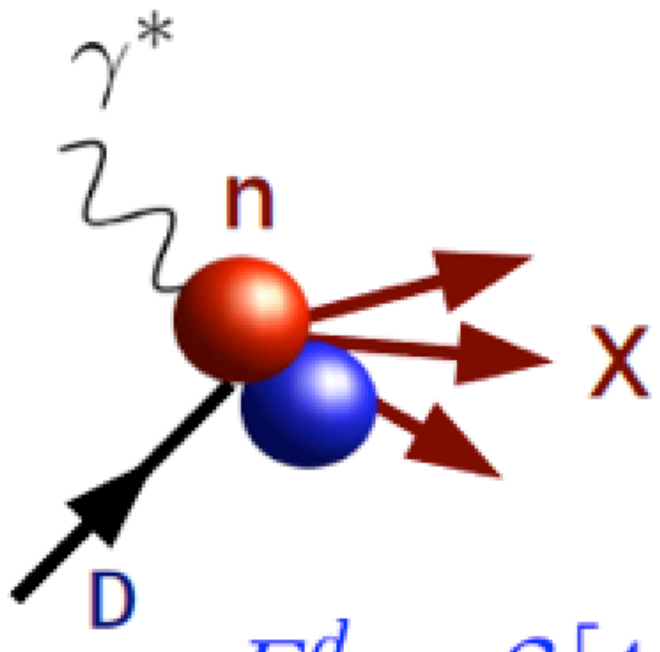
D0, CDF asymmetries



$$A_W(y) \xrightarrow{y \to y_{max}} \frac{1 - d/u(x_1)}{1 + d/u(x_1)}$$

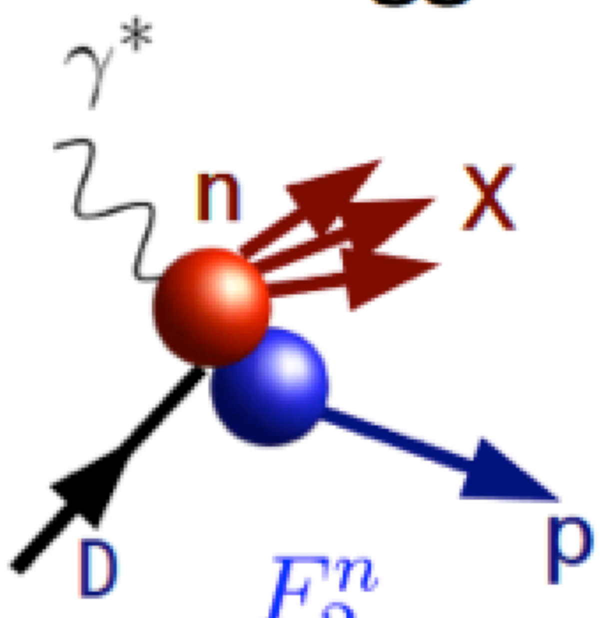


Deep inelastic scattering on deuterium



$$F_2^d \propto \mathcal{S}\left[4xu_{\rm off}(x) + xd_{\rm off}(x)\right]$$

"BONuS" tagged neutron target

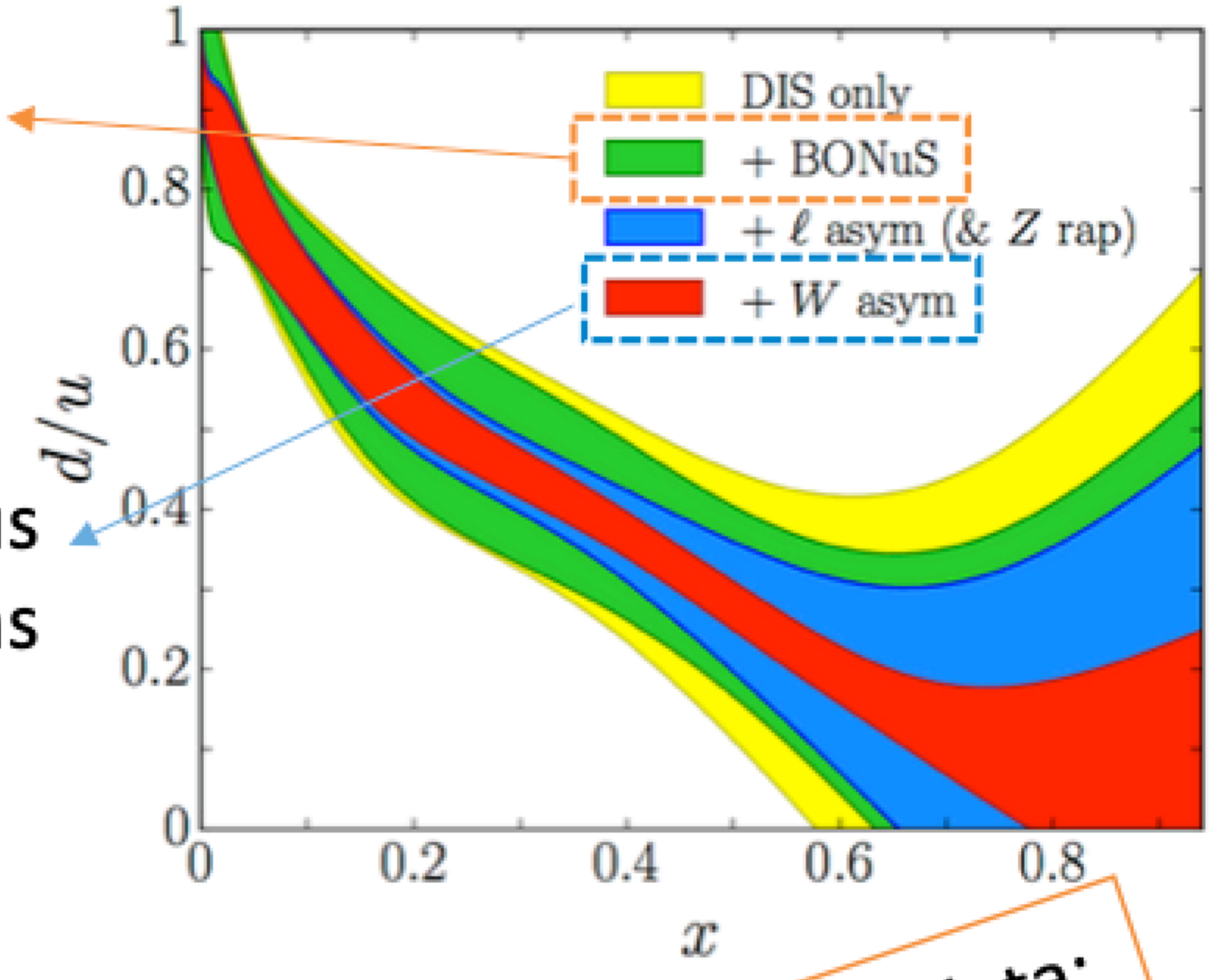


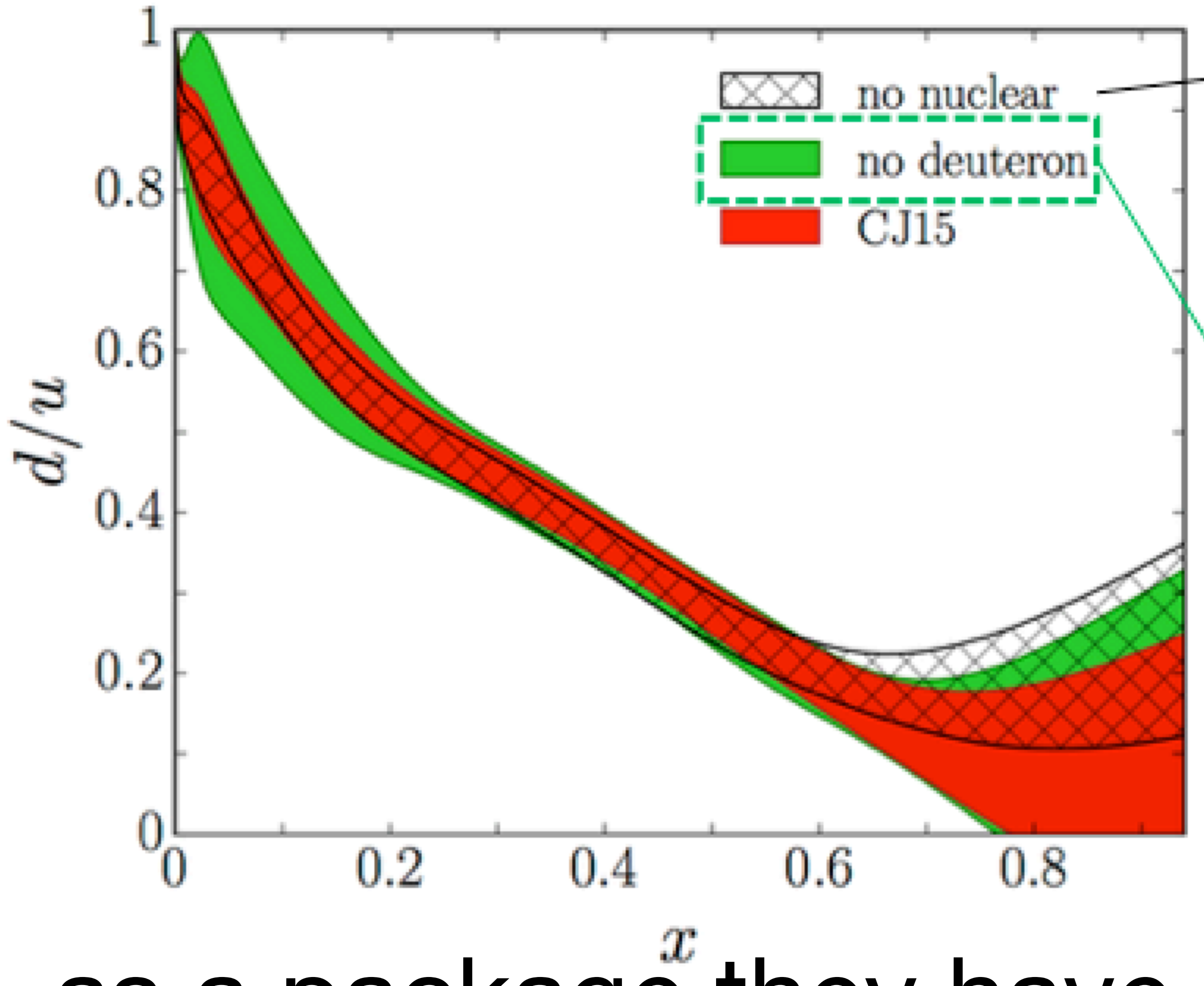
$$\frac{F_2^n}{F_2^d} \propto xu(x) + 4xd(x)$$

Pushing PDFs Extraction into the Valence Region: CTEQ-JLab (CJ)

F_2^n/F_2^p almost free of nuclear effects

Collider data can teach us about nuclear corrections in deuterium



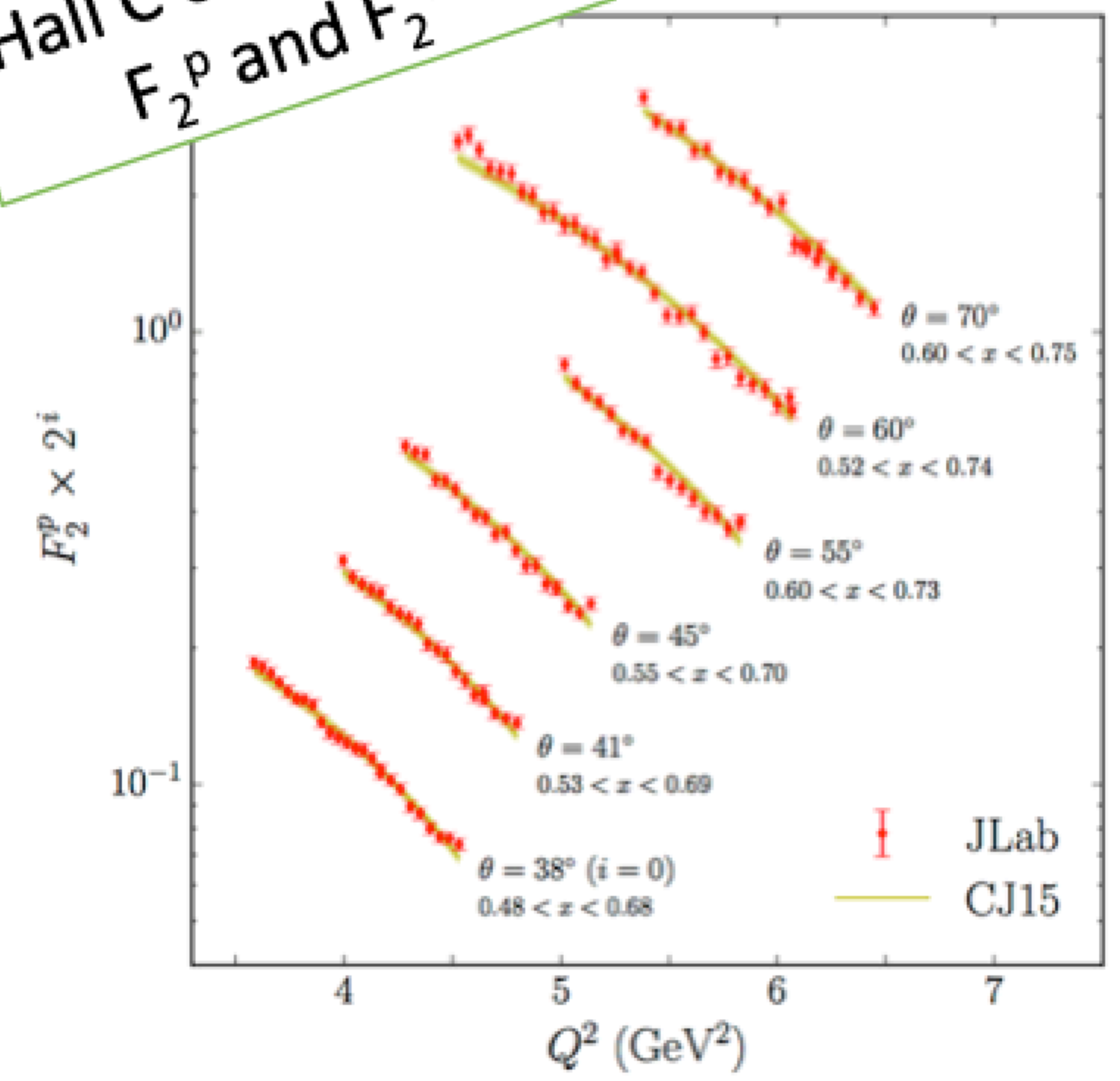


Without nuclear corrections we get the wrong answer especially at large x

Inclusion of deuterium data reduce the d/u uncertainty across the entire x range

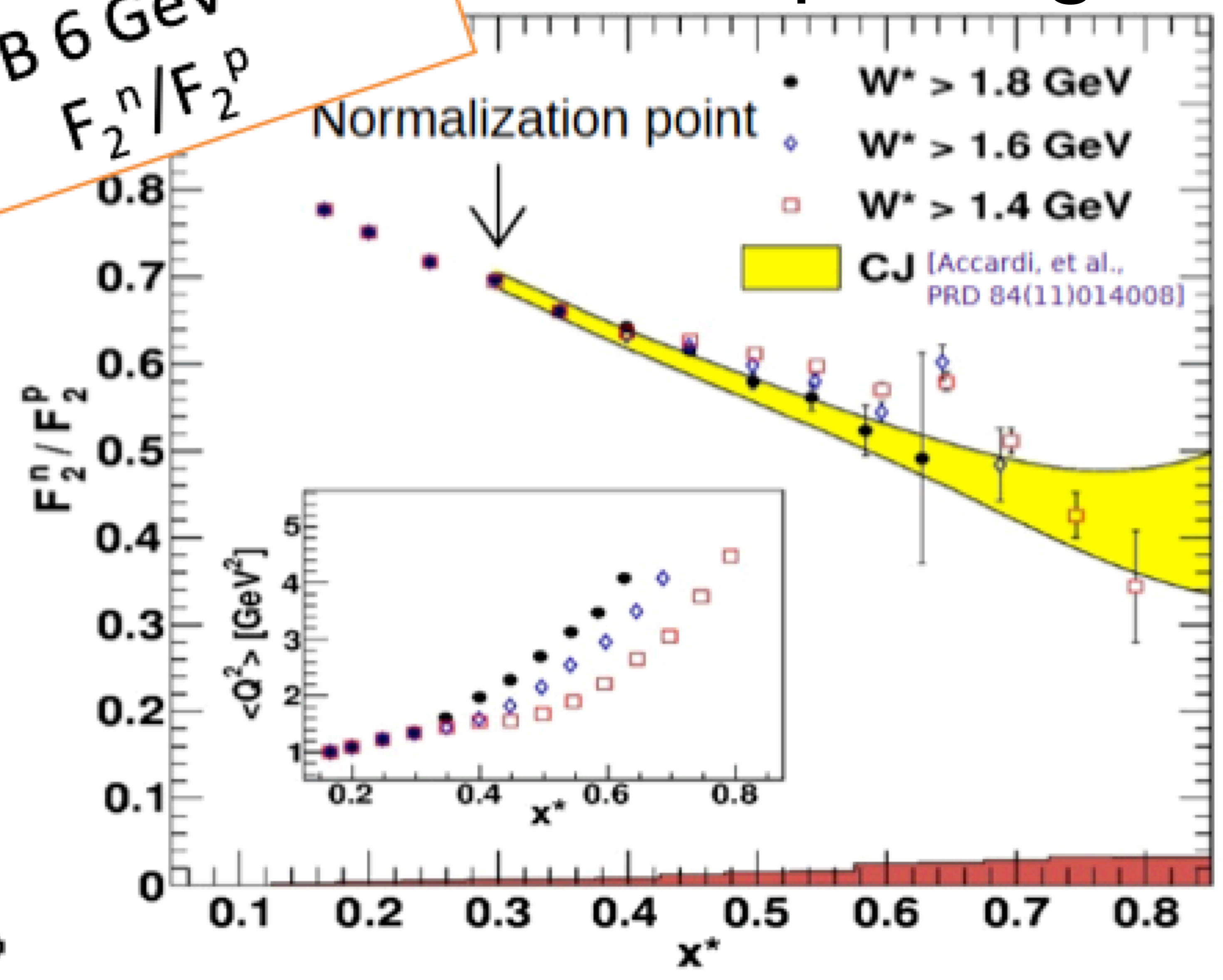
as a package they have a lot of power

Hall C 6 GeV data: F_2^p and F_2^d

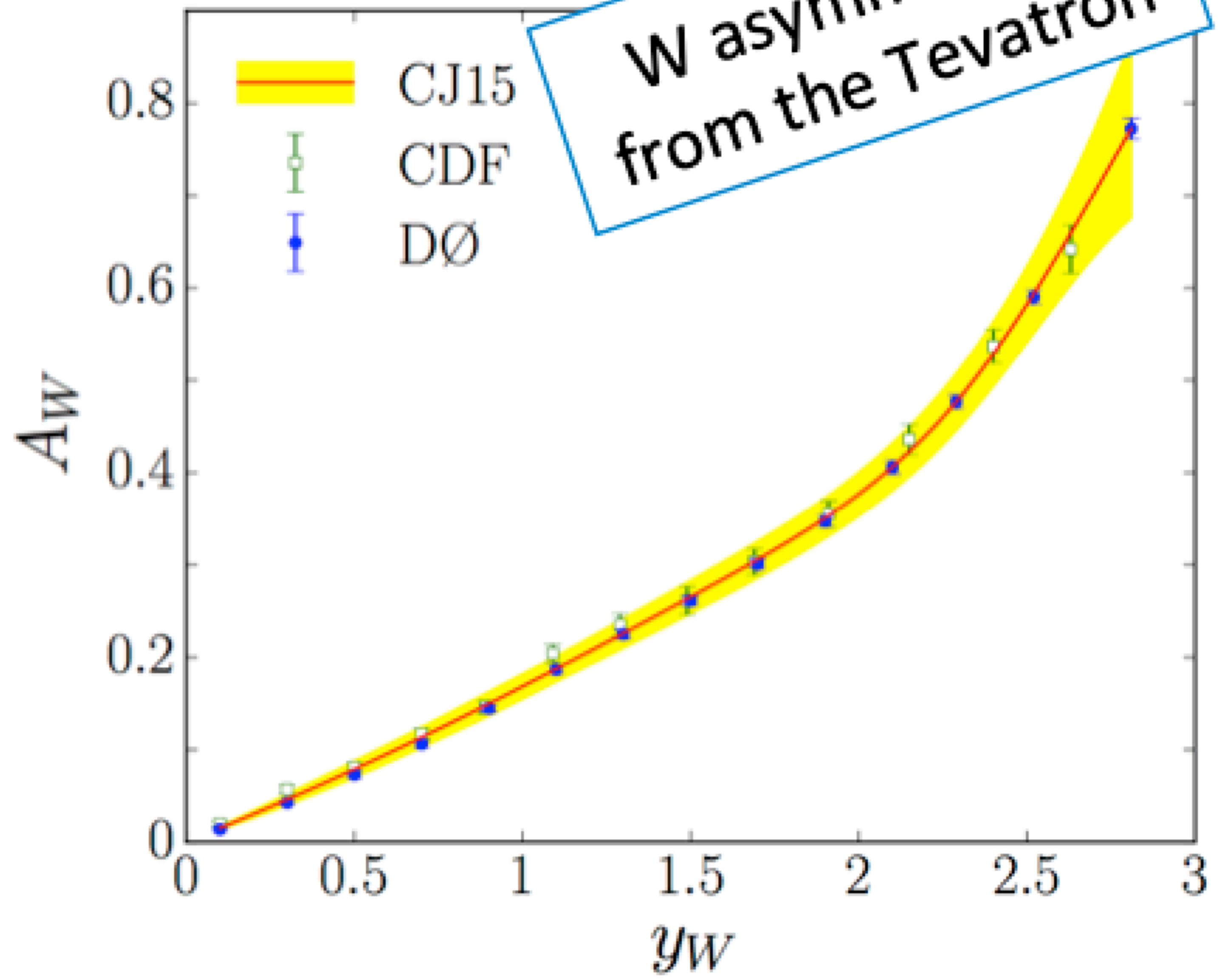


at large-x

Hall B 6 GeV data: F_2^n/F_2^p



W asymmetries from the Tevatron



The JLab @ 12 GeV Near Term Large-x **Experimental** Program*

Minimizes bias from nuclear effects by measuring $^3He/^3H$ ratios

<u>Hall A, 2018</u>

MARATHON took data on ^3H and ^3He to extract F_2^n/F_2^p

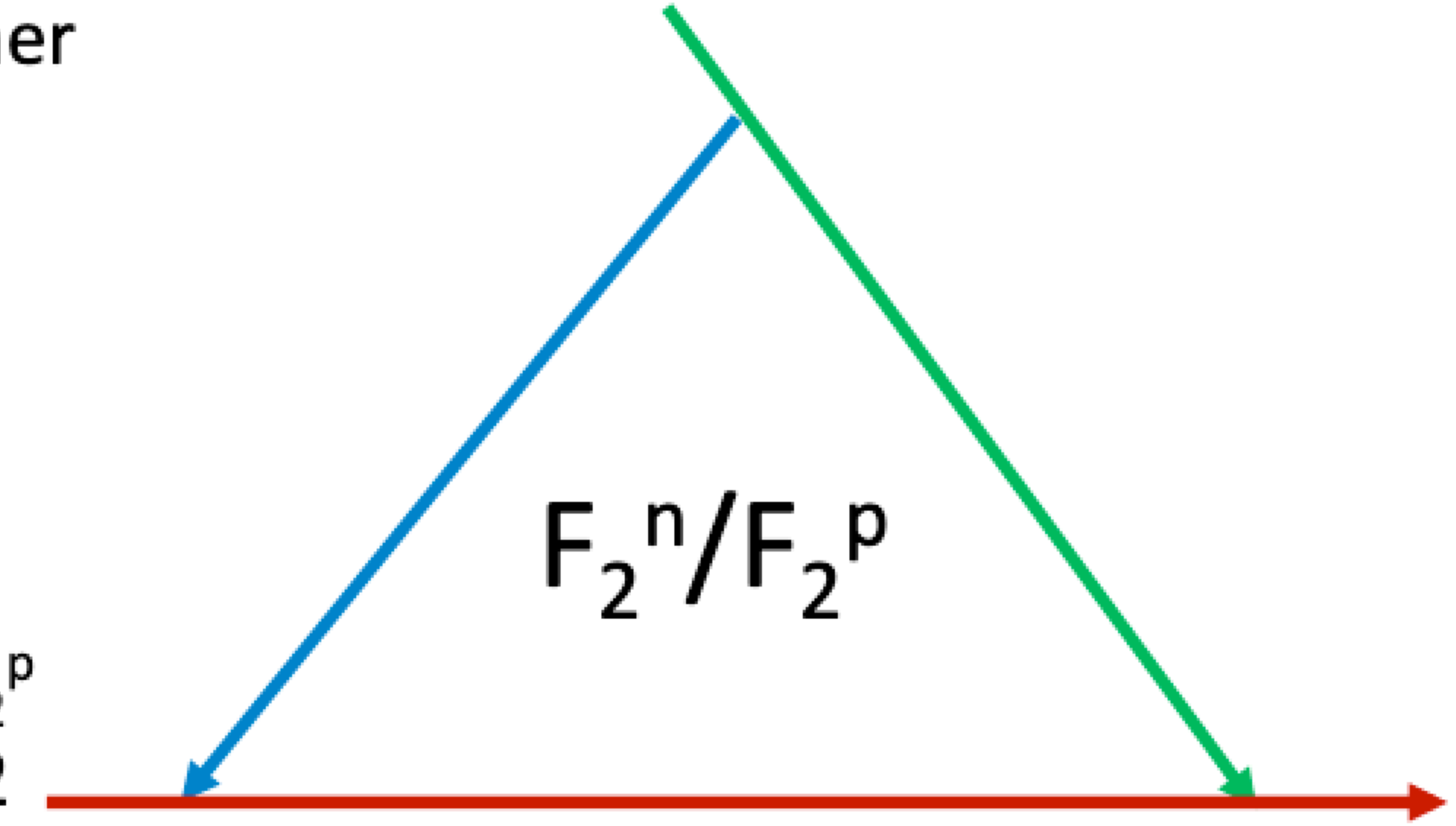
Submission for publication of the F_2^n/F_2^p ratio expected by the end of Summer

Full blown nuclear effects (deuterium)

<u>Hall C, 2018</u>

E12-10-002 took data to extract F_2^p and F_2^d in a wide x range (from 0.2 to 1) with small statistical and systematic uncertainties

Submission for publication of the F_2^n/F_2^p ratio expected this Fall



Minimizes bias from nuclear effects by using fixed target tagged DIS

<u>Hall B, 2019</u>

E12-06-113 (BoNus12) started taking data in Spring 2020; data taking will resume this Summer

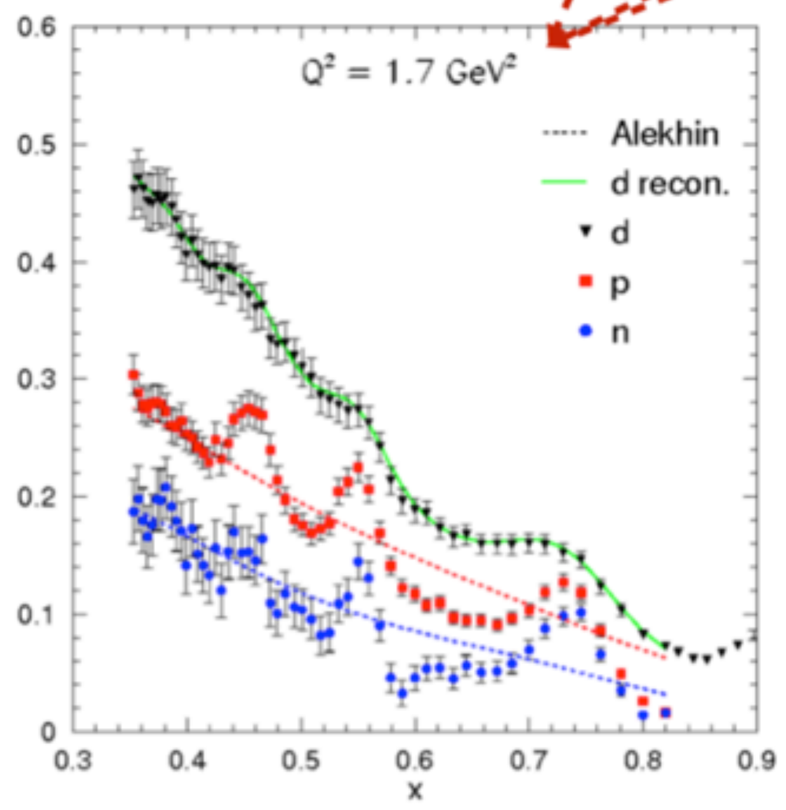
Will extend the F_2^n/F_2^p extraction almost free of nuclear corrections to larger x and Q^2

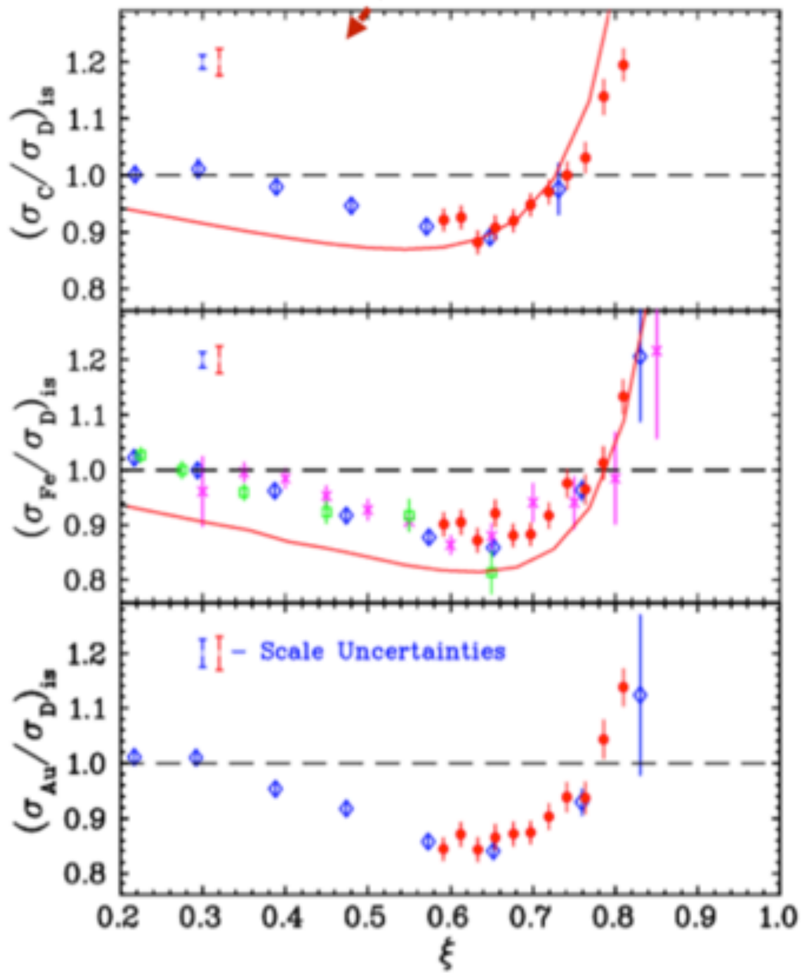
*unpolarized

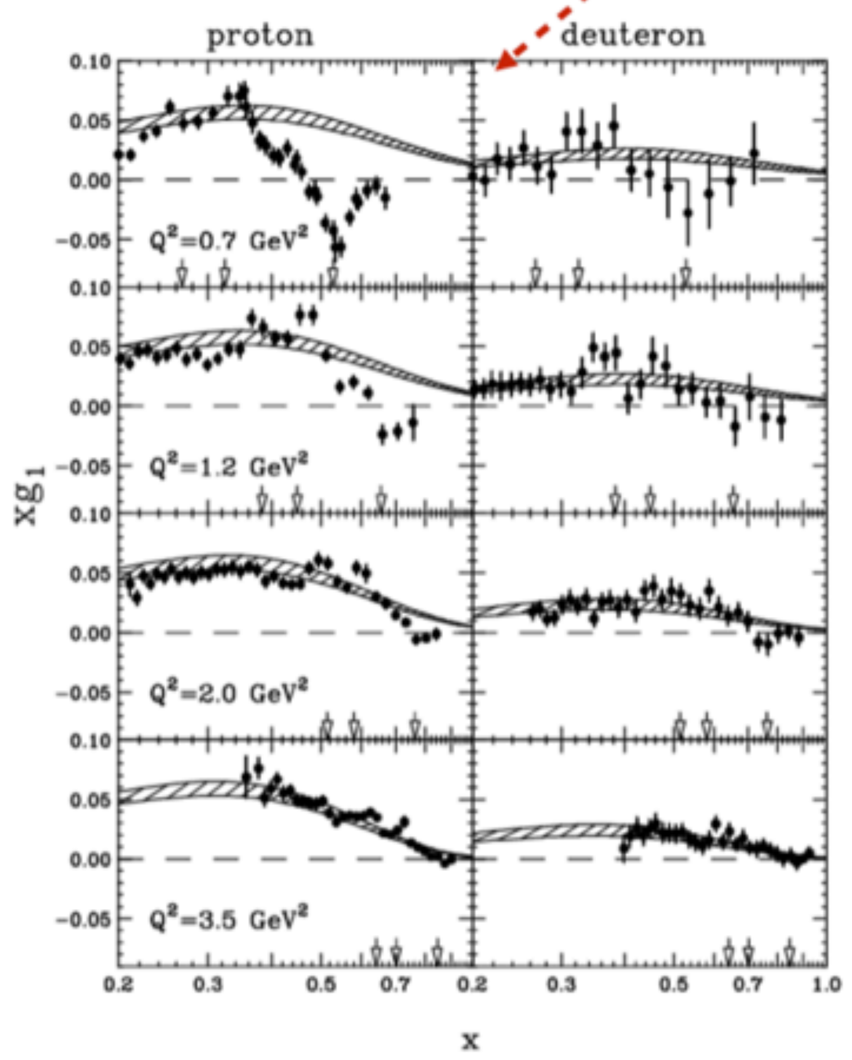
Physics Motivation: Quark Hadron Duality

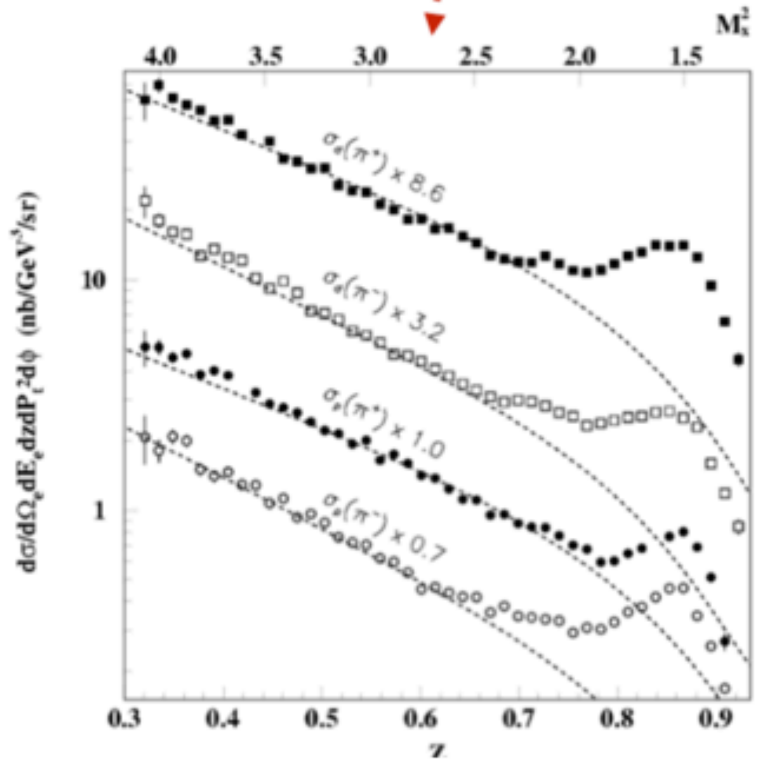
- Structure functions in resonance region on average behave like structure functions in DIS regime.

- It's a fundamental property of nucleon structure - Observed in: F_2^p, F_1^p, F_L^p, F_2^n, F_2^d, F_2^C, F_2^{Fe}, F_2^{Au}, A_1^p, g_1^p, g_1^d, g_1^n, g_1^{3He}, SIDIS









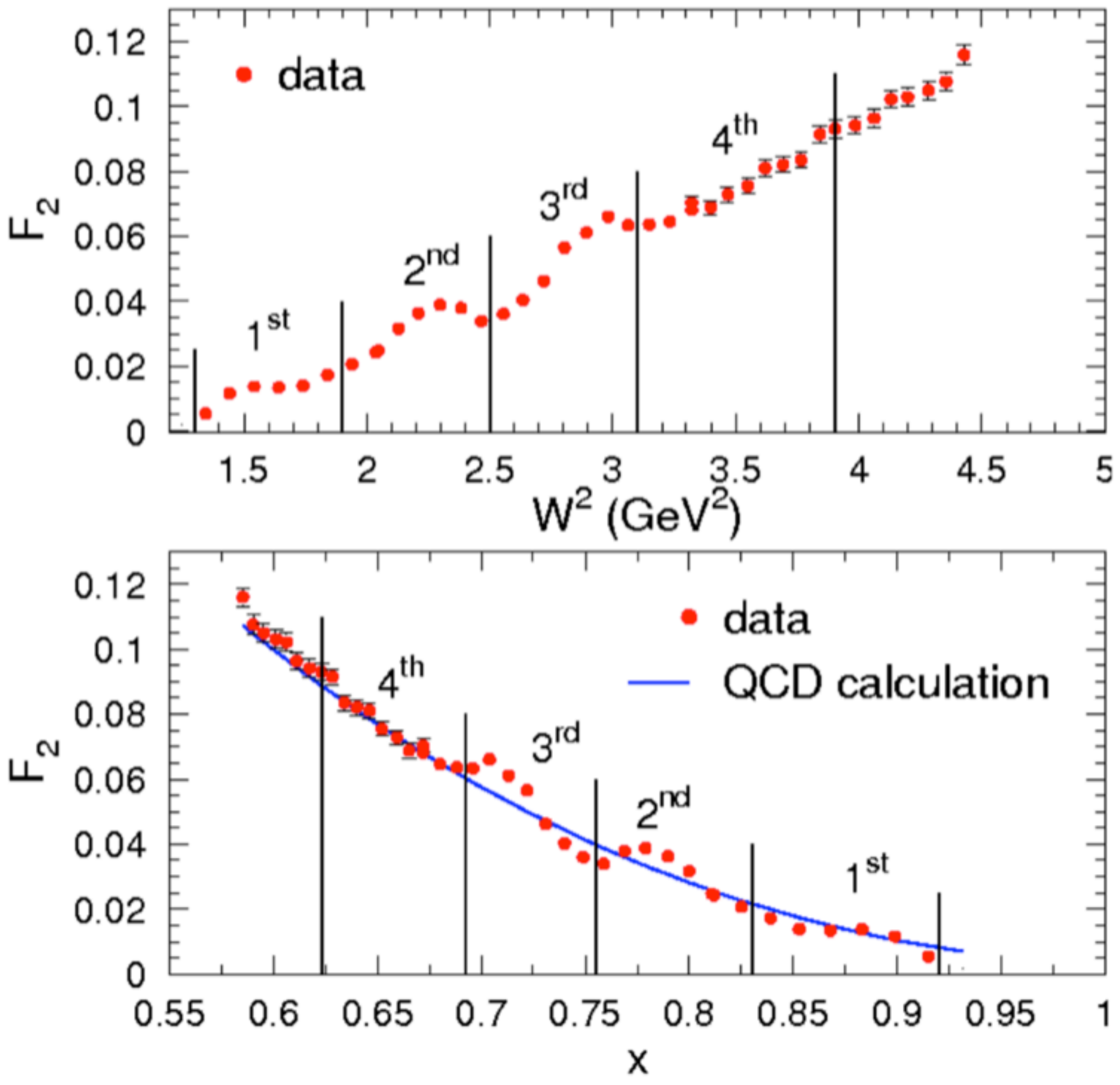
- Resonance region measurements allow us to explore this phenomenon

Physics Motivation: Quark Hadron Duality

- Define duality intervals

Region	1st	2nd	3rd	4th	DIS	global
W_{min}	1.3	1.9	2.5	3.1	3.9	1.9
W_{max}	1.9	2.5	3.1	3.9	4.5	4.5

→ There is arbitrariness in defining the local W intervals; typically try to catch peaks and valleys within one interval

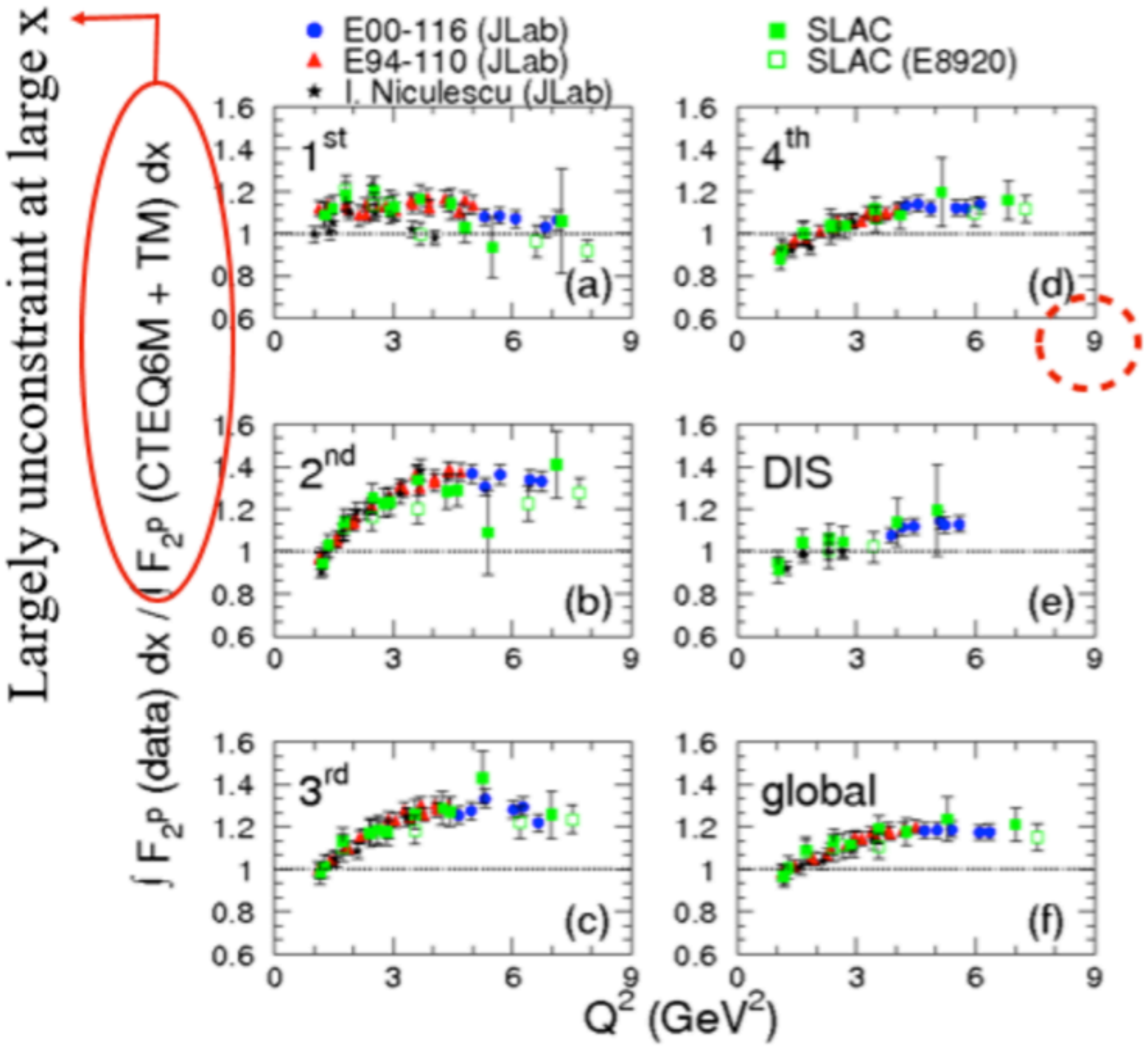


How well resonance data average to the scaling curve?

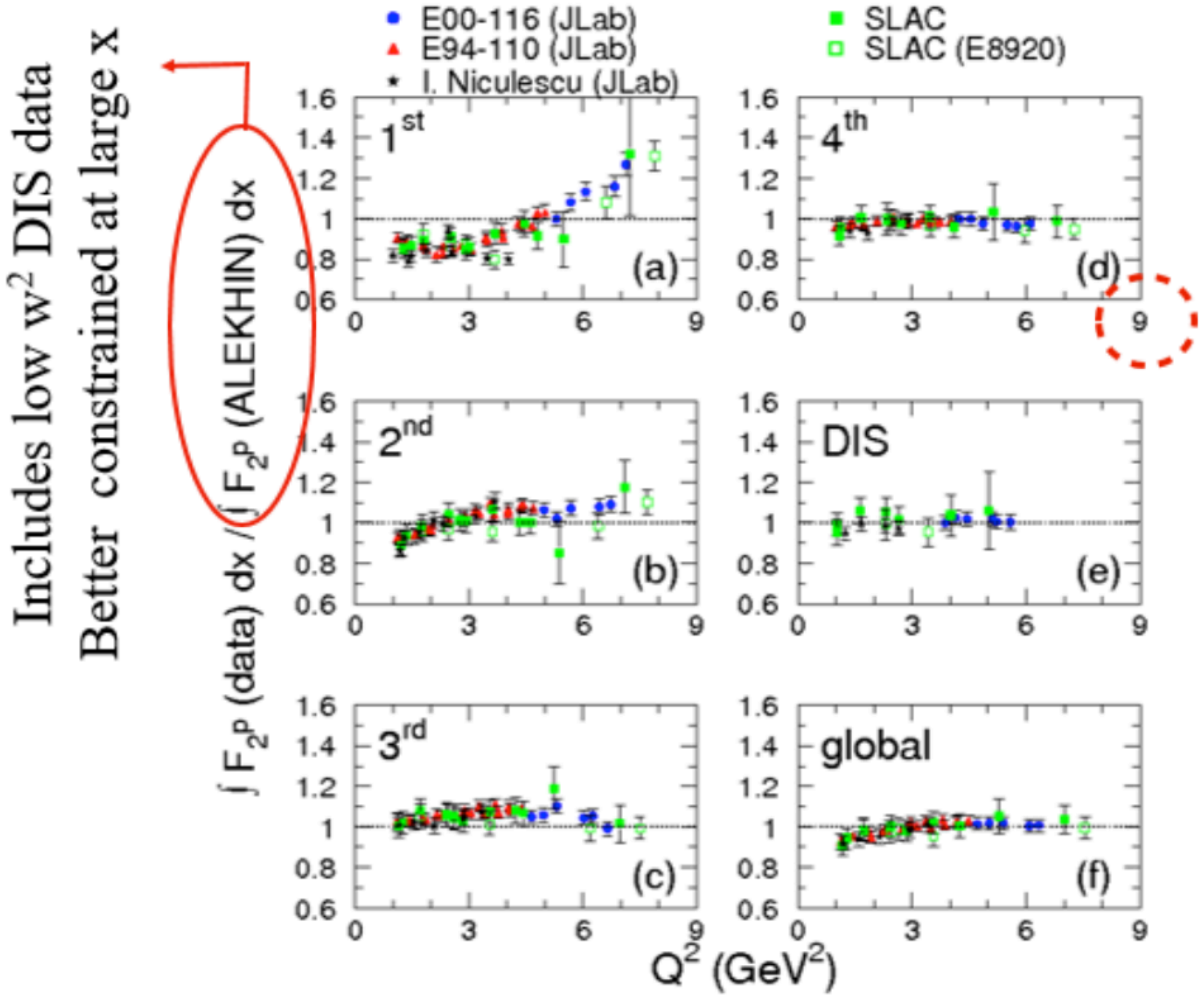
- Calculate ratio:

$$\int_{x_{min}}^{x_{max}} F^{data}(x,Q^2)\,dx \Big/ \int_{x_{min}}^{x_{max}} F^{param.}(x,Q^2)dx$$

Physics Motivation: Quark Hadron Duality



- Ratio is independent of Q^2 starting at Q^2= 4



- Average resonance region data are comparable at the level of 5% or less to the scaling curve
- Discrepancy observed only at the lowest w^2 / 1st region

Physics Motivation: Benchmark for LQCD

Measurements of Non-Singlet Moments of the Nucleon Structure Functions and Comparison to Predictions from Lattice QCD for $Q^2 = 4$ GeV^2

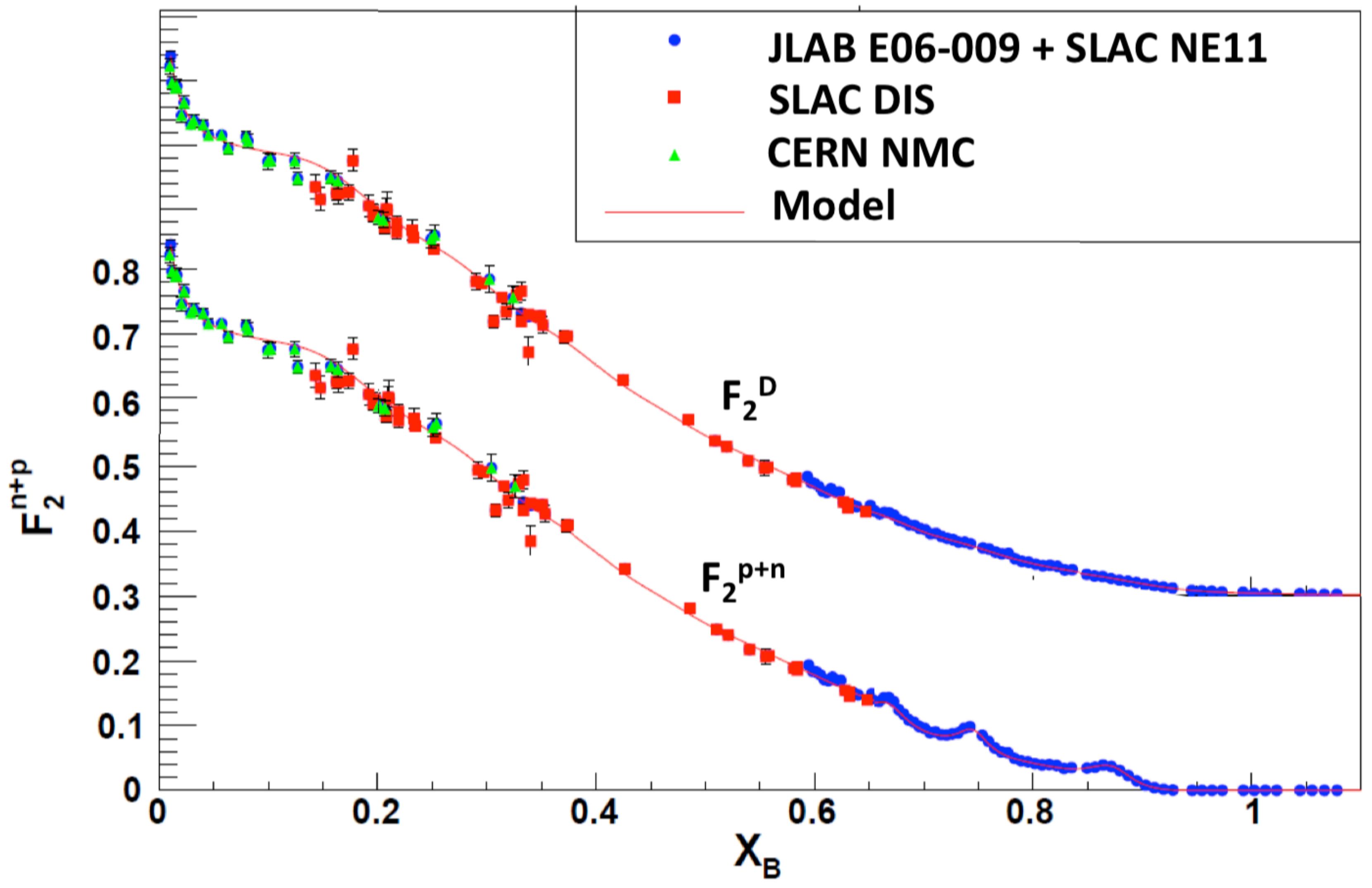
(The E06-009 Collaboration)

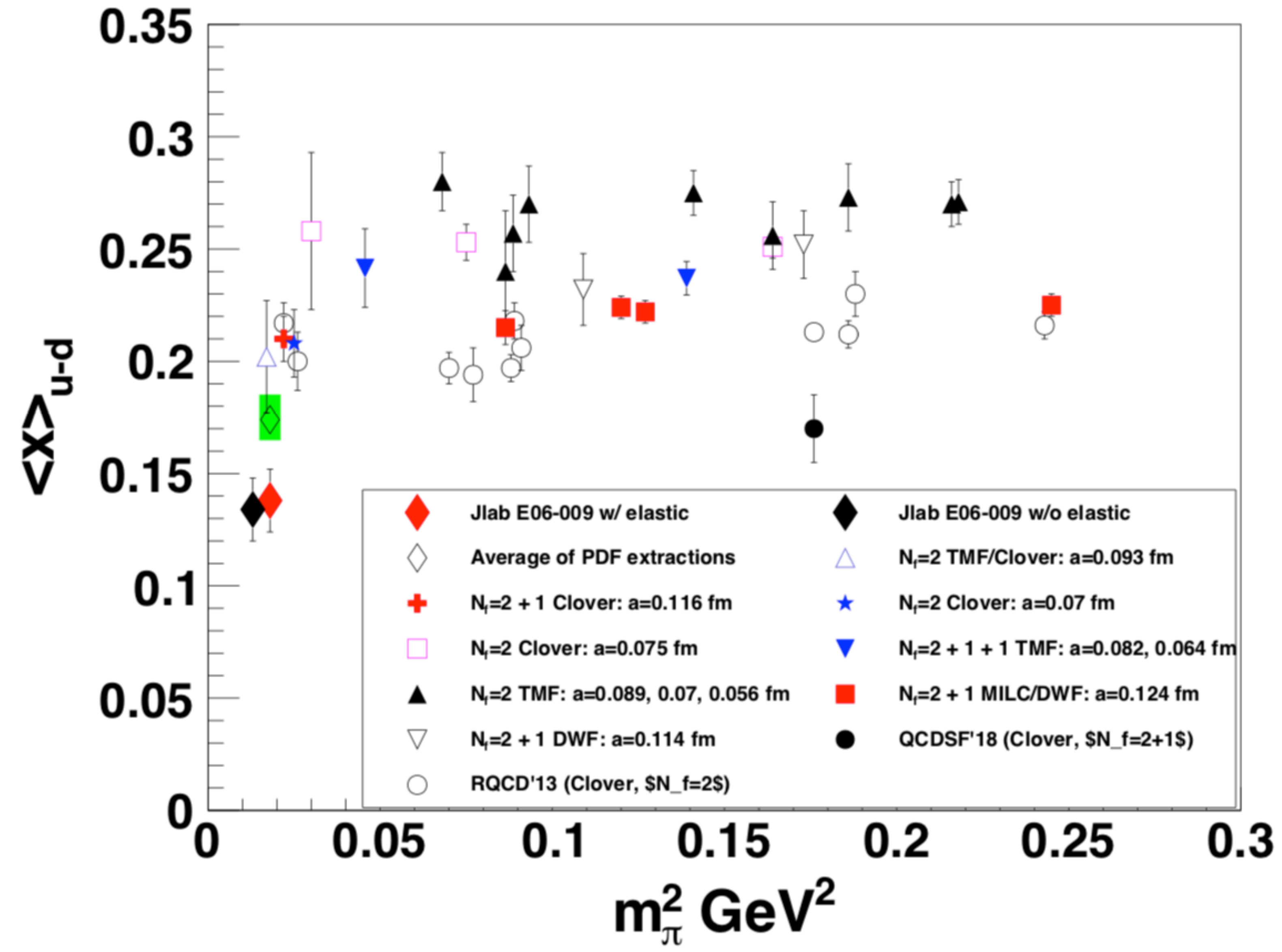
In the framework of Quantum Chromodynamics (QCD), the partonic structure of hadrons may be studied through *moments* (or Bjorken x weighted integrals) of the hadron structure functions. The difference of the u and d quark distributions is a flavor non-singlet quantity with the N even (considered in this work) non-singlet moments of these parton distribution functions (PDF) defined as,

$$\langle x^{N-1} \rangle_{u-d} = \int dx x^{N-1} [u(x) - d(x) + \bar{u}(x) - \bar{d}(x)]. \quad (1)$$

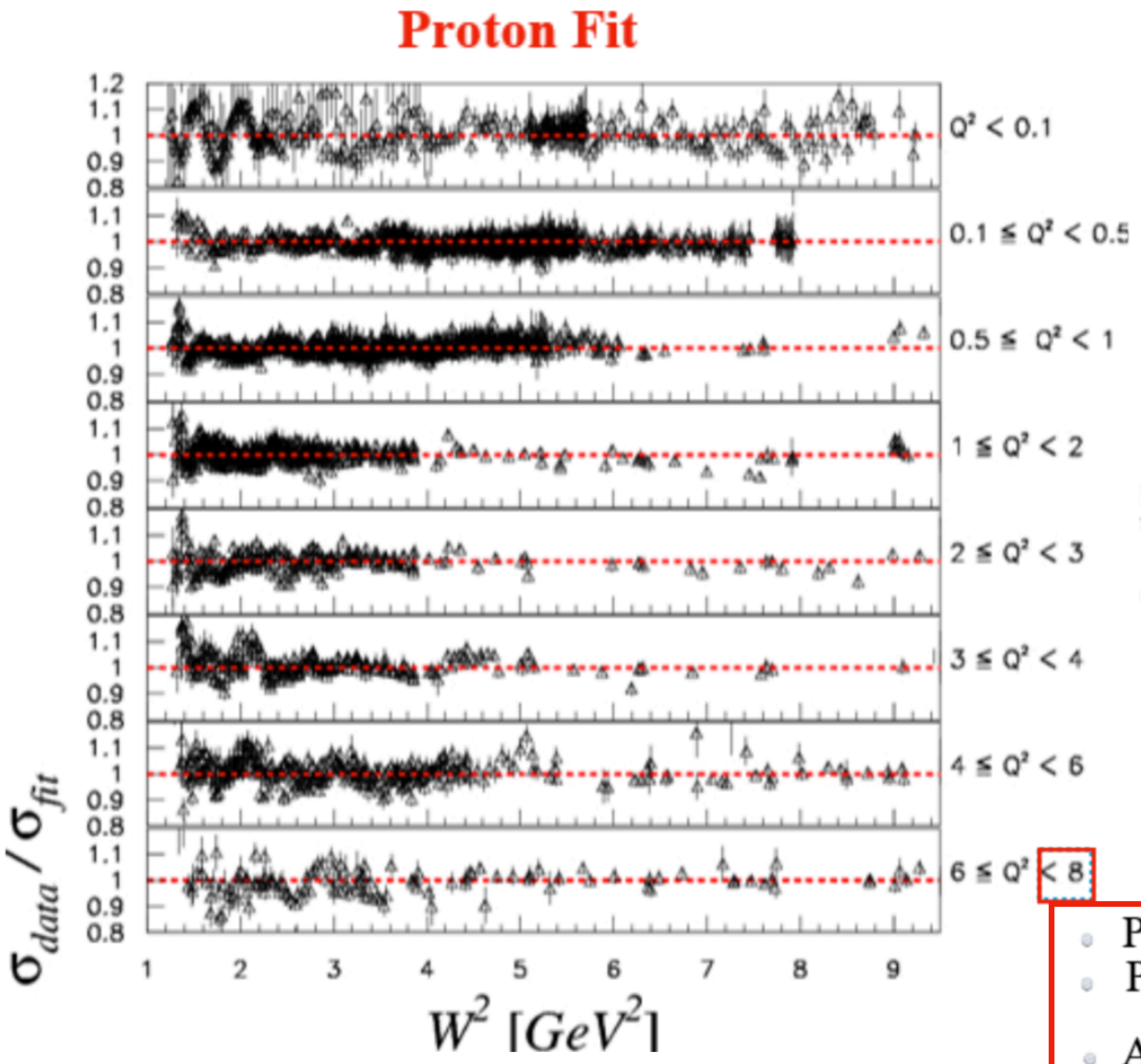
A successful lattice computation of the nucleon non-singlet moment is a fundamental test of QCD [1].

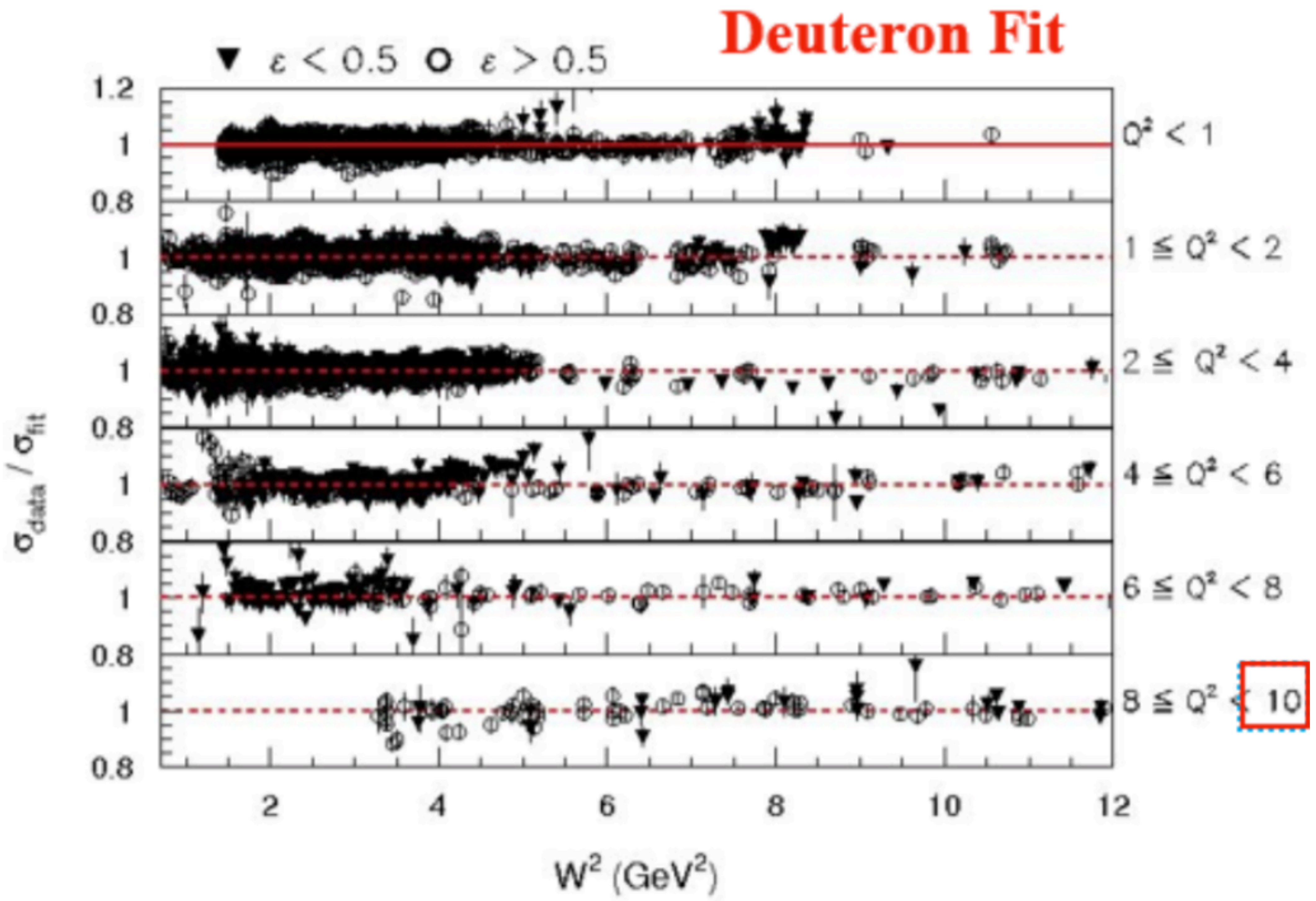
[1] M. Gockeler *et al.*, Nucl. Phys **B623**, 287 (2002).





Physics Motivation: Resonance/DIS modeling





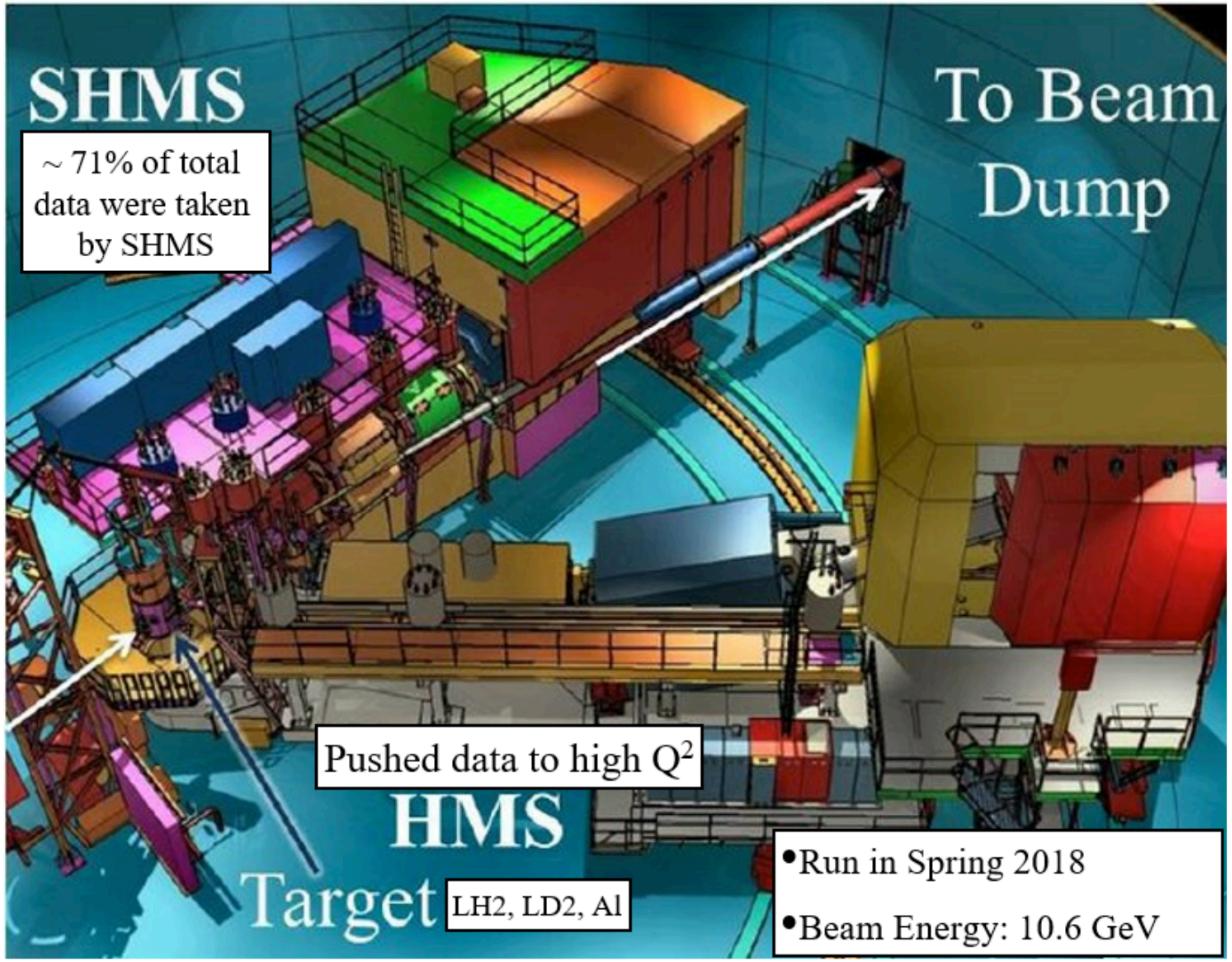
- Provides constraints to larger Q^2 – up to 16 GeV^2 for both proton and deuteron fit
- Provides a complete data set (proton and deuteron) for a precise neutron extraction
- A physics driven global fit to inclusive cross section is very valuable:
  - radiative and bin-centering corrections, rates, moments of structure functions and duality studies, dilution factors in spin structure functions, **physics of nucleon resonances / non-resonance**

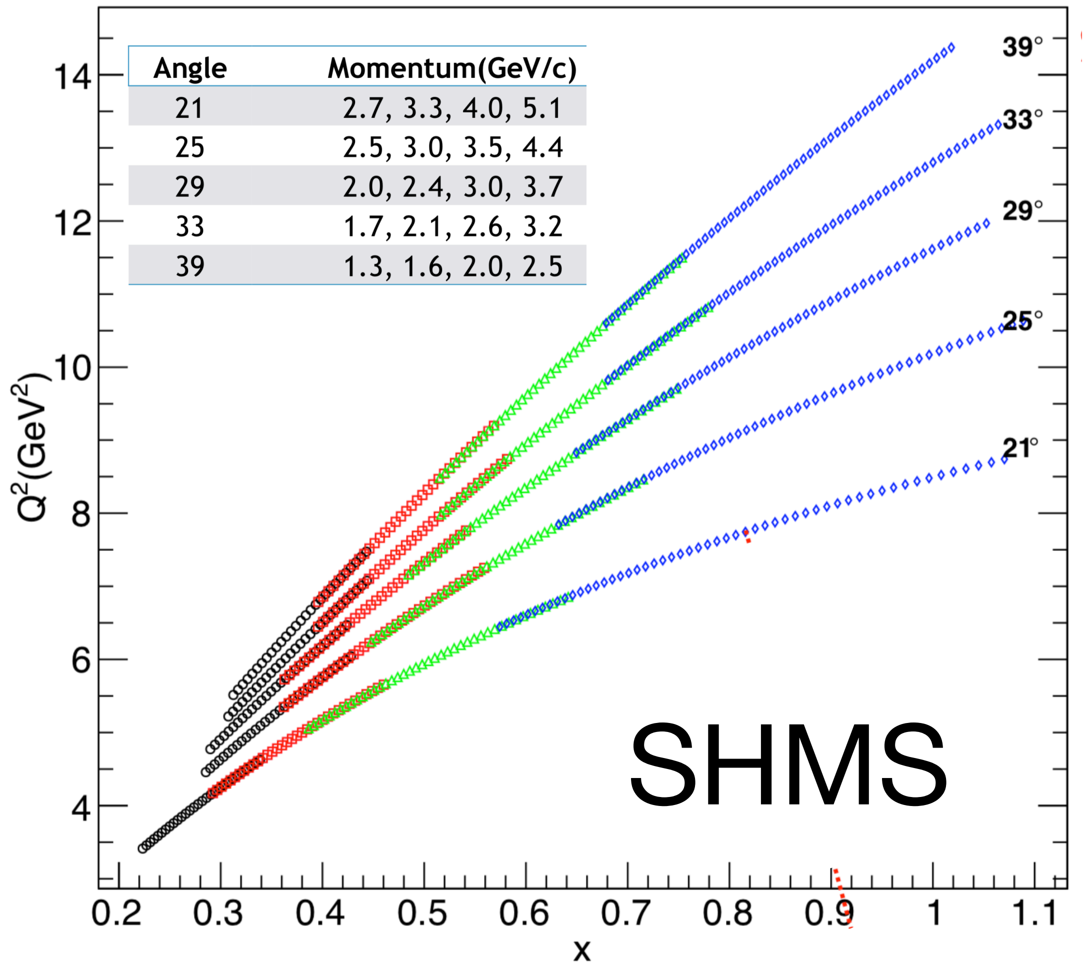
F2 Experiment Overview

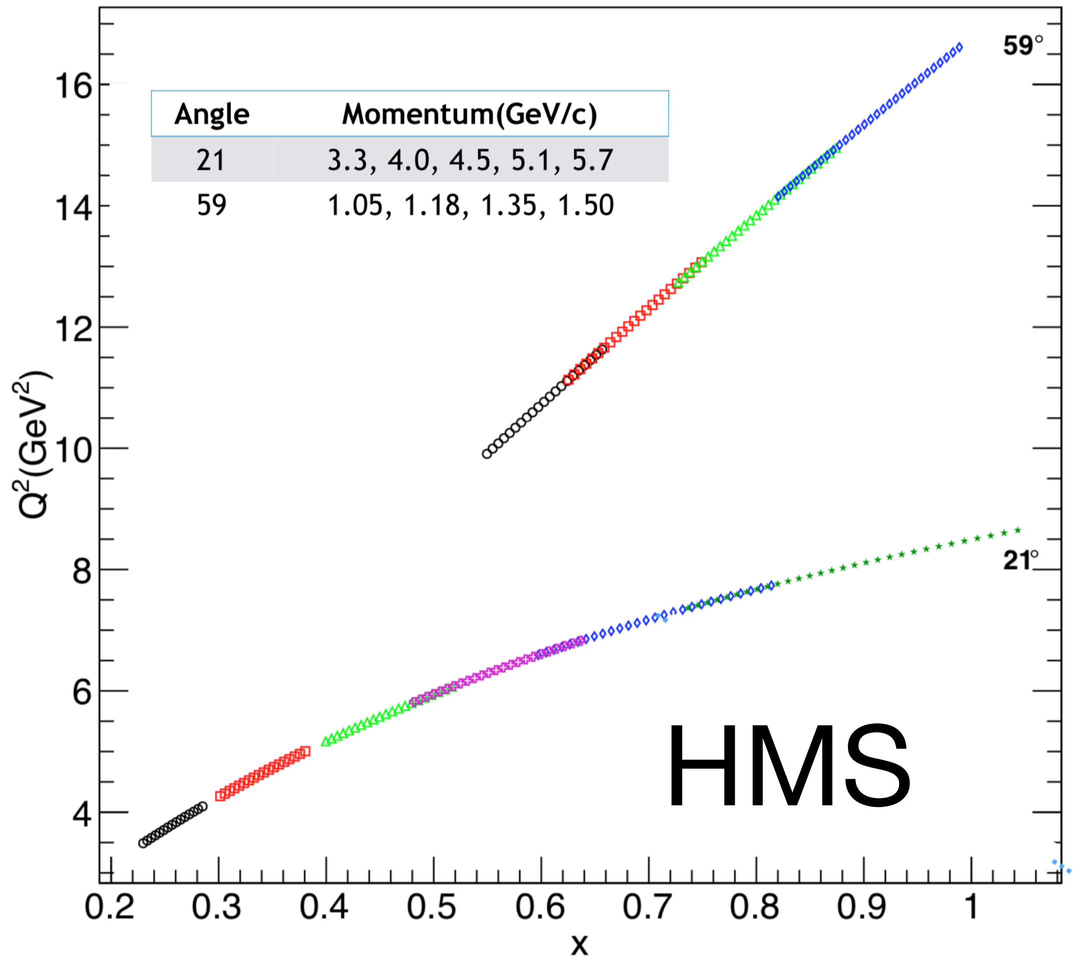
- Hall C Commisioning experiment
- Electrons detected in both SHMS and HMS
- Ran with E12-10-008 (EMC ratios in lighter nuclei)

See Abishek's talk next!

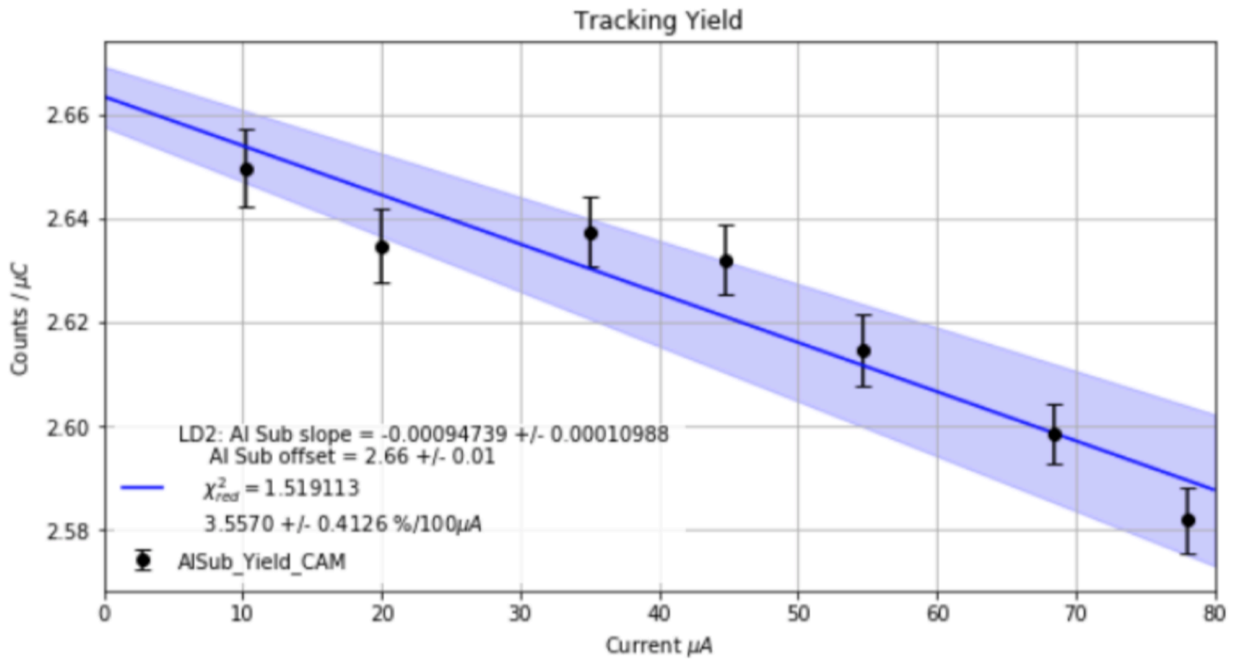
Hall C Spectrometers

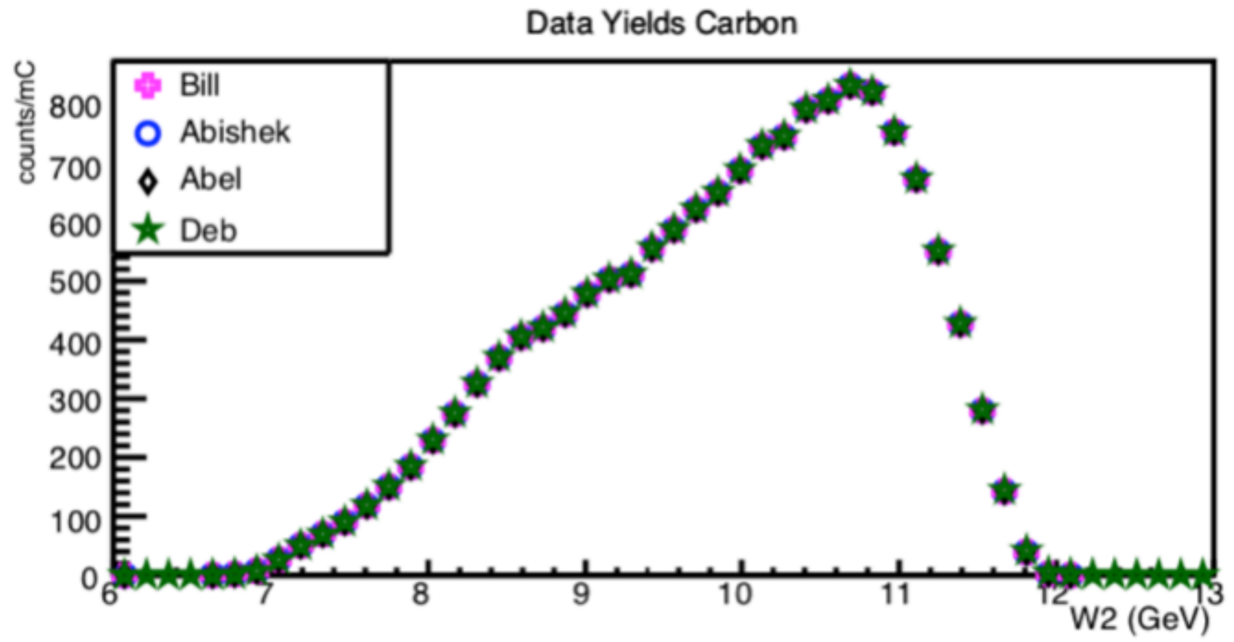


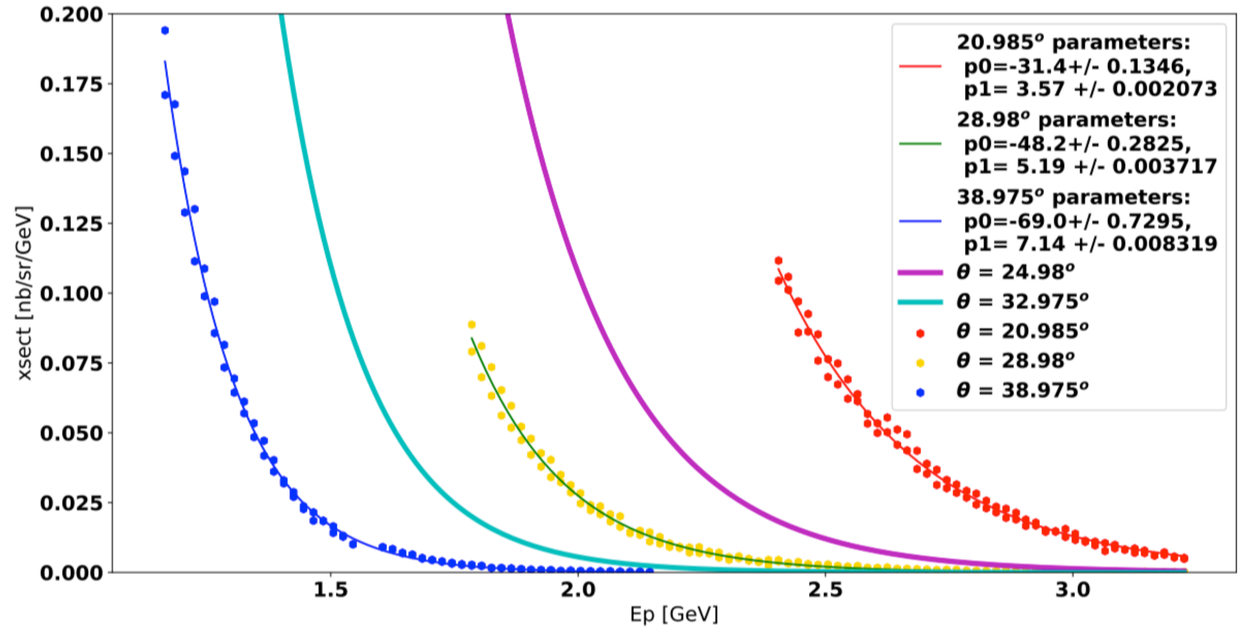




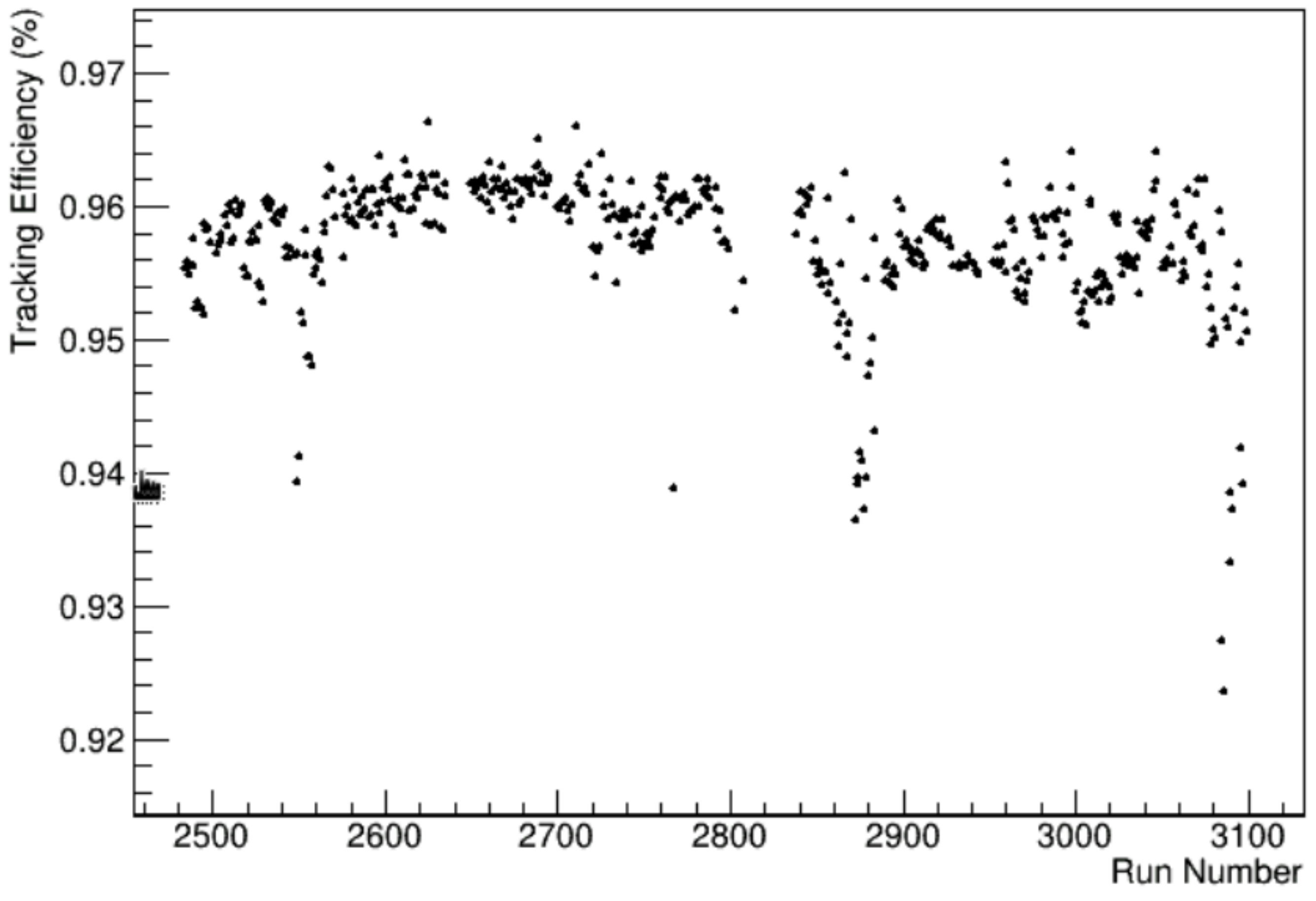
Analysis Status

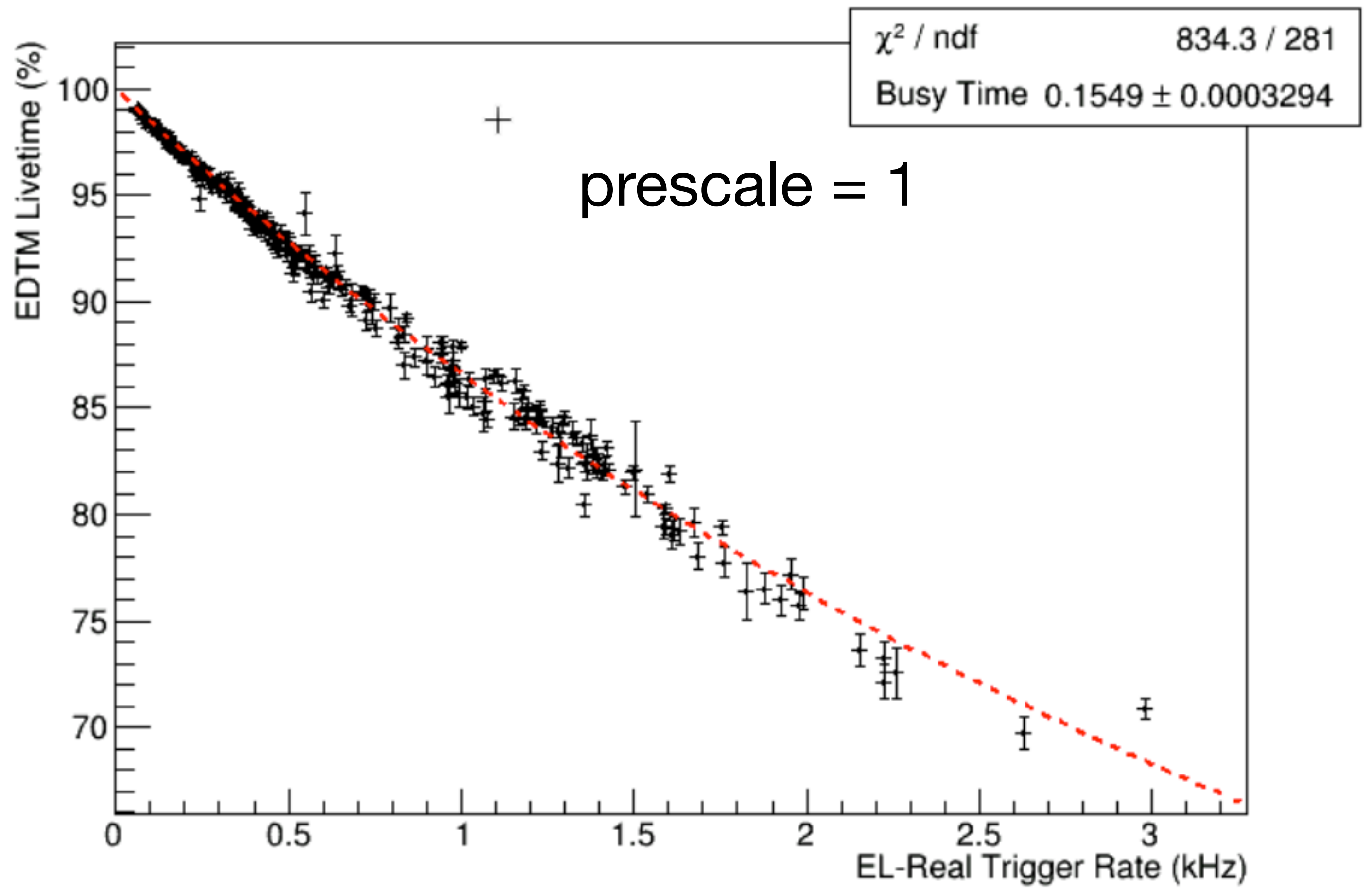






- Timing Cuts
- Detector Calibrations
  - Cherenkov
  - Calorimeter
  - Hodoscope
  - Drift Chambers
  - BCM
- Target Boiling
- Acceptance Studies
- Radiative Corrections
- Yield Cross Checks
- Efficiency Studies
  - Tracking
  - Trigger
  - Deadtime
  - PID cuts
  - Pion Containimation
- Charge Symmetric Background
- Cross Section Extraction and D/H ratios





Analysis Status: SHMS Optics Studies

The best forward SHMS Tune

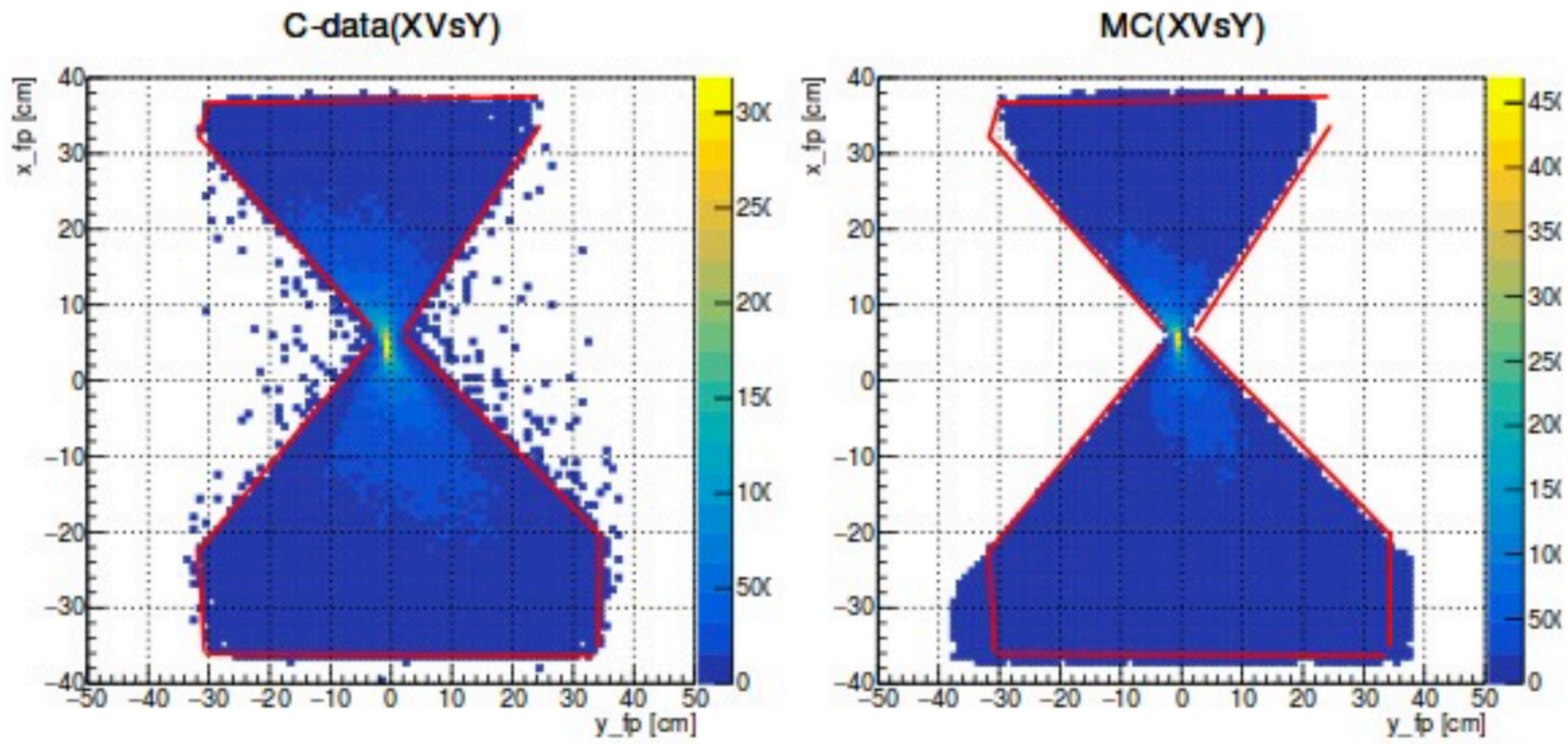
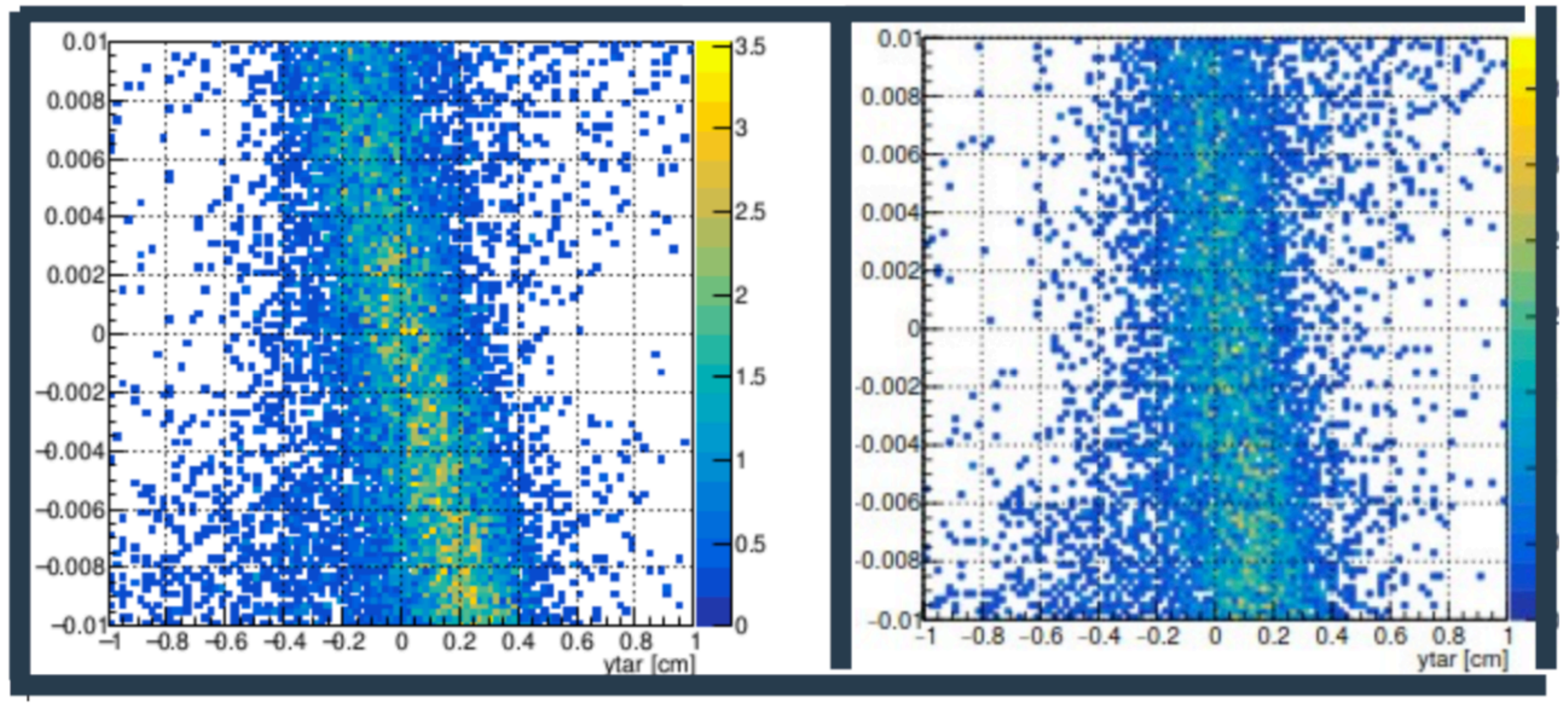


Table of the correction factors obtained by forward transport studies.

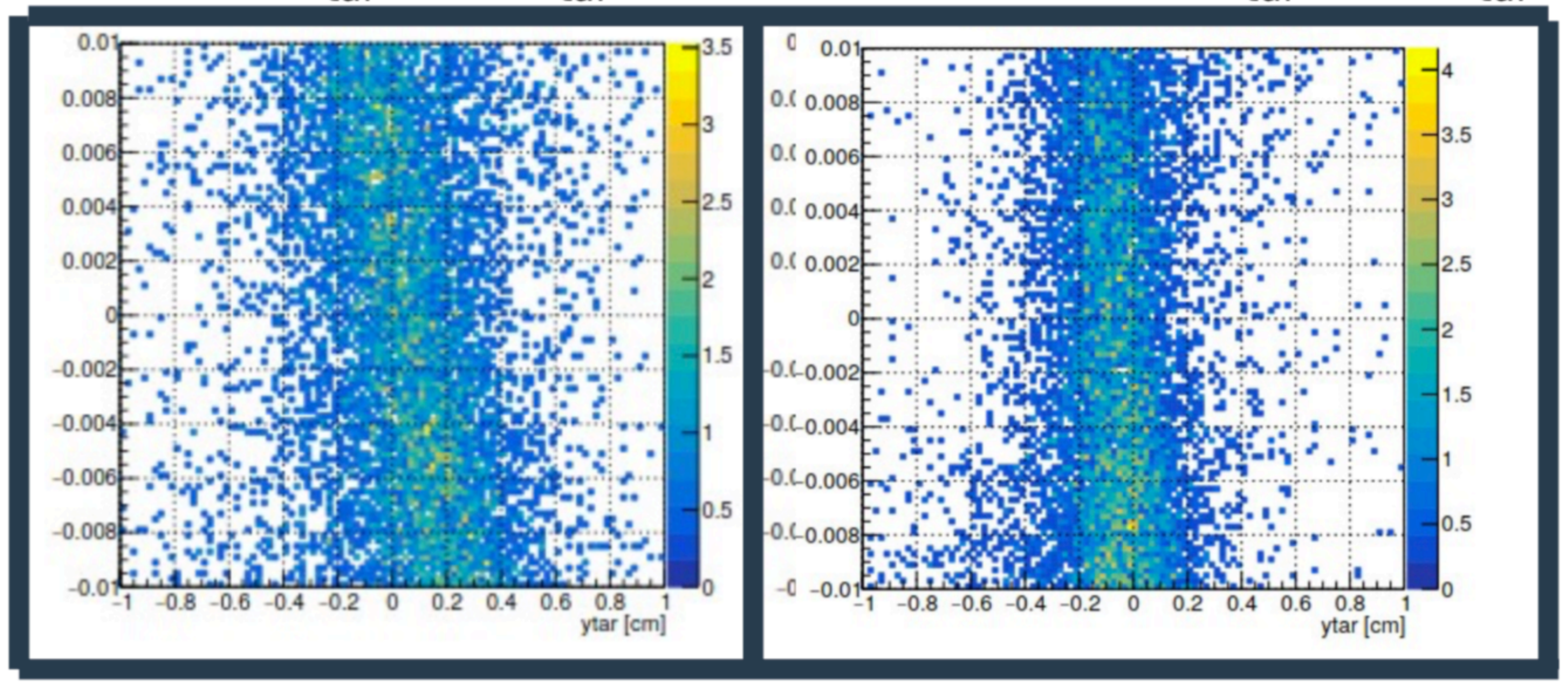
Magnet	Correction factor
Q1	1.018
Q2	1.027
Q3	1.018
HB	1

Reconstruction Optics Study

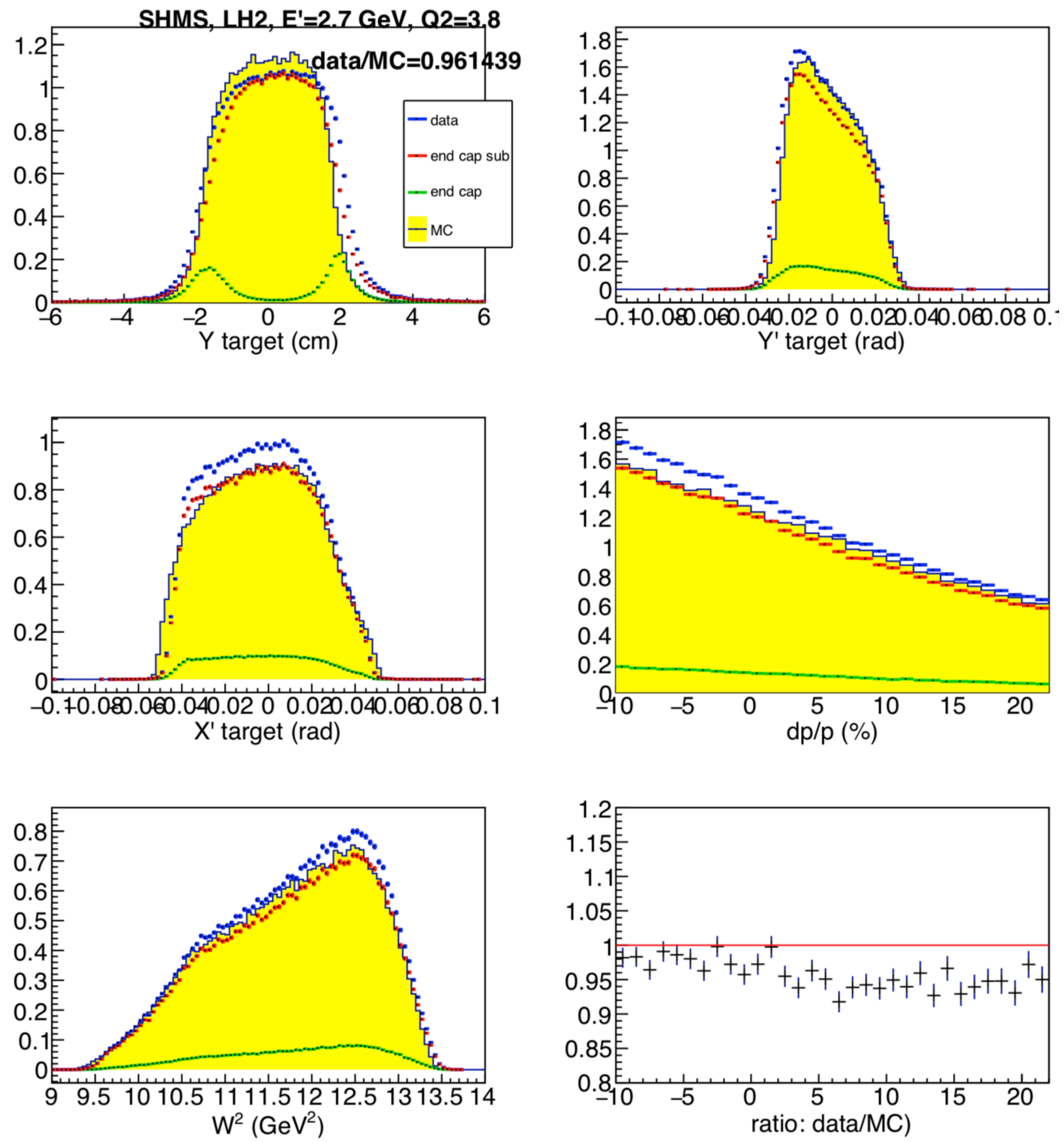
ME Jan 2019 C data y_{tar} Vs Y'_{tar} → ME April 2019 C data y_{tar} Vs Y'_{tar}

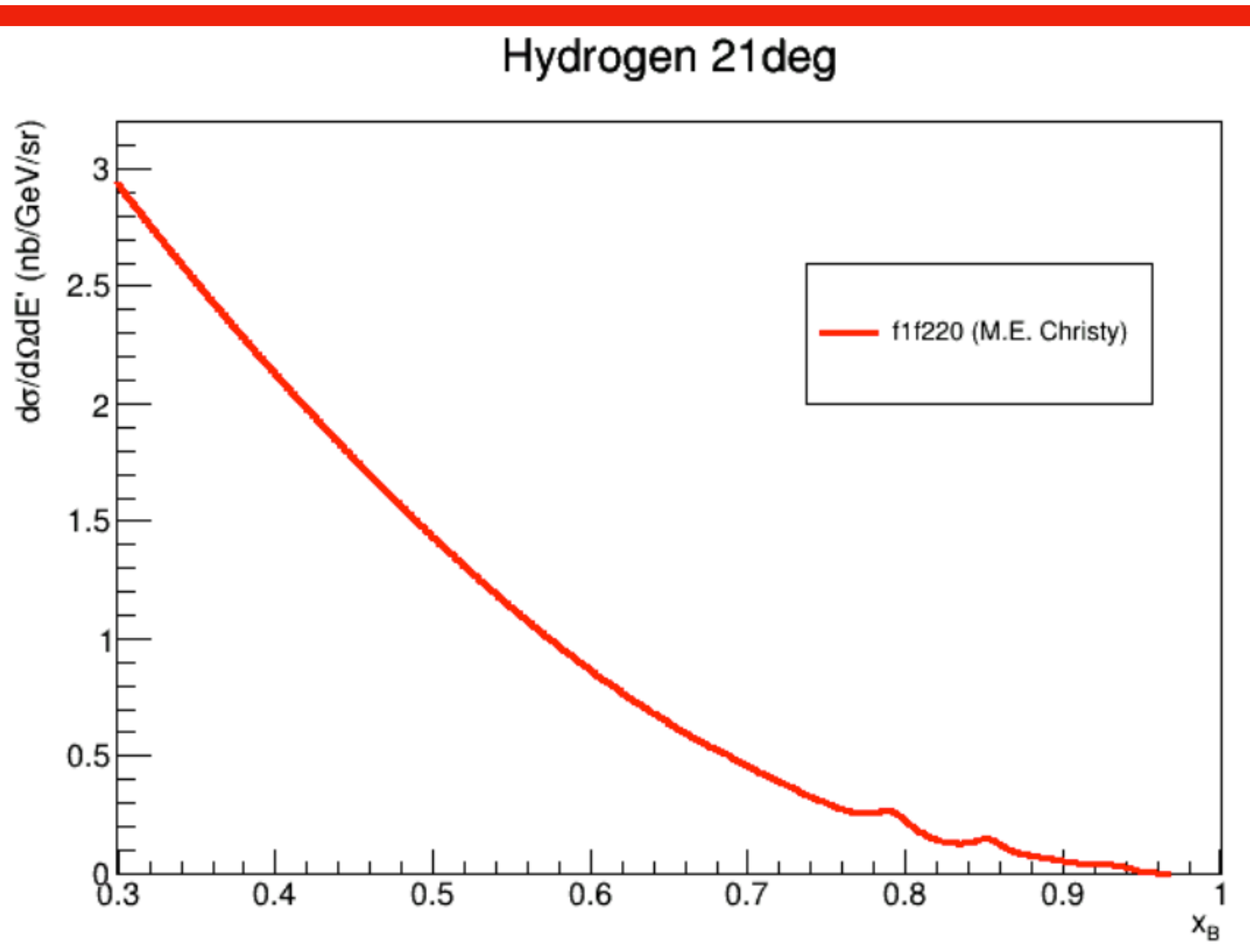


ME April 2020 C data y_{tar} Vs Y'_{tar} → ME corrected saturation Q1Q3 C data y_{tar} Vs Y'_{tar}



Cross Section Extraction



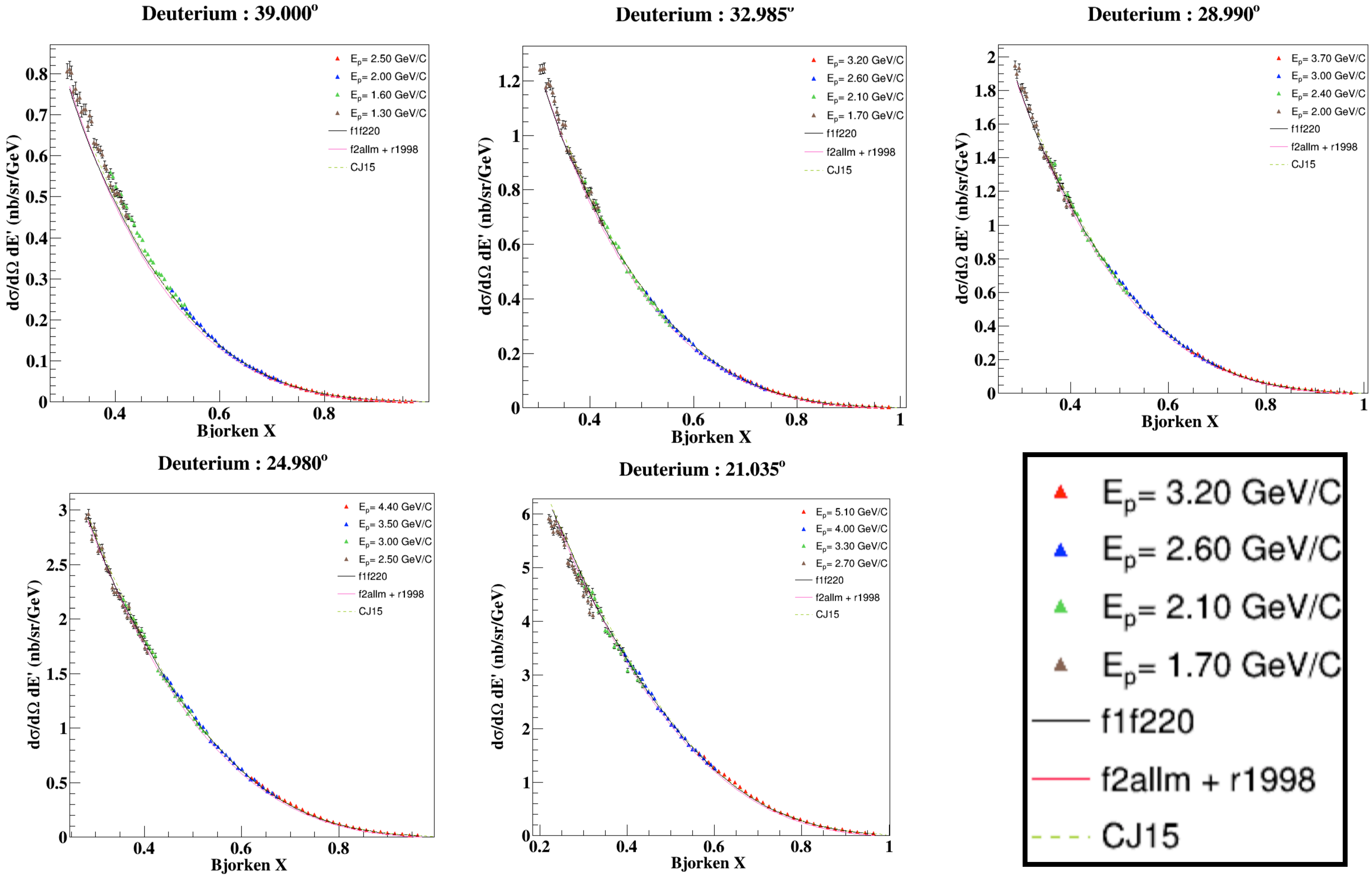


$$\sigma_{data} = \frac{Yield_{data}}{Yield_{MC}} * \sigma_{MC}$$

- Data
- End cap
- End Cap Subtracted
- MC

- SHMS, LH2

Preliminary Cross Sections



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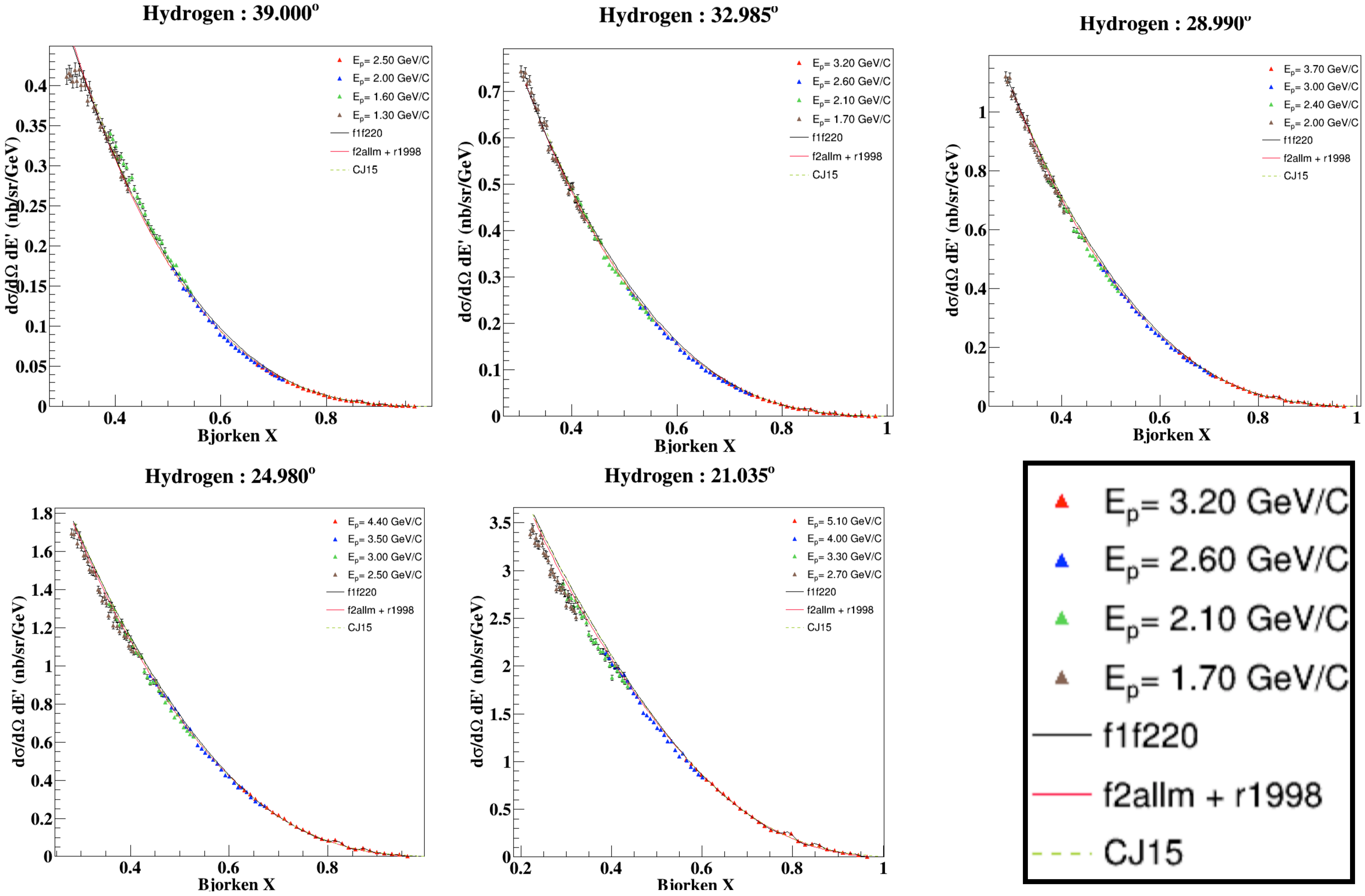
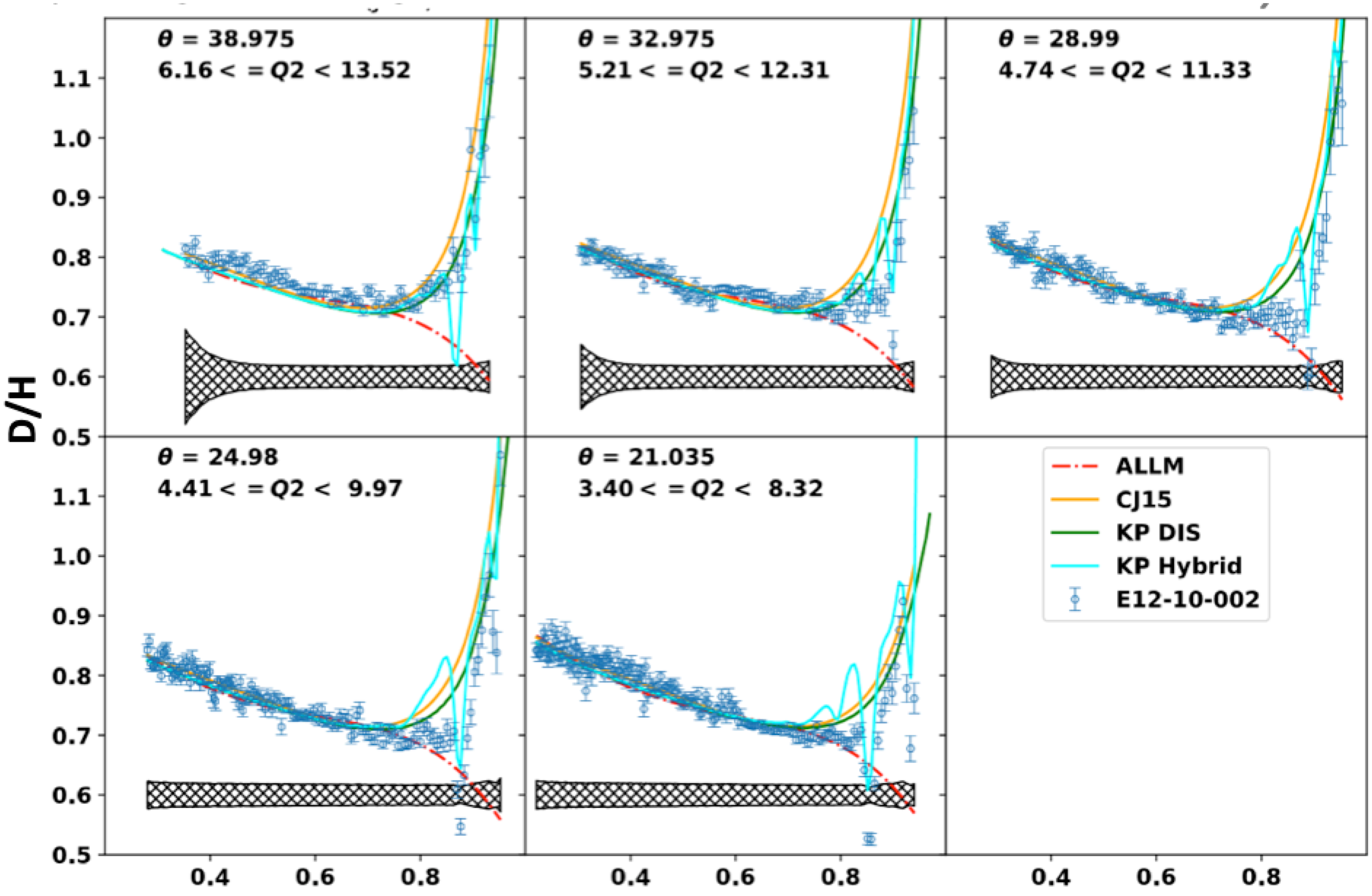


Preliminary Cross Sections



Summary and Outlook

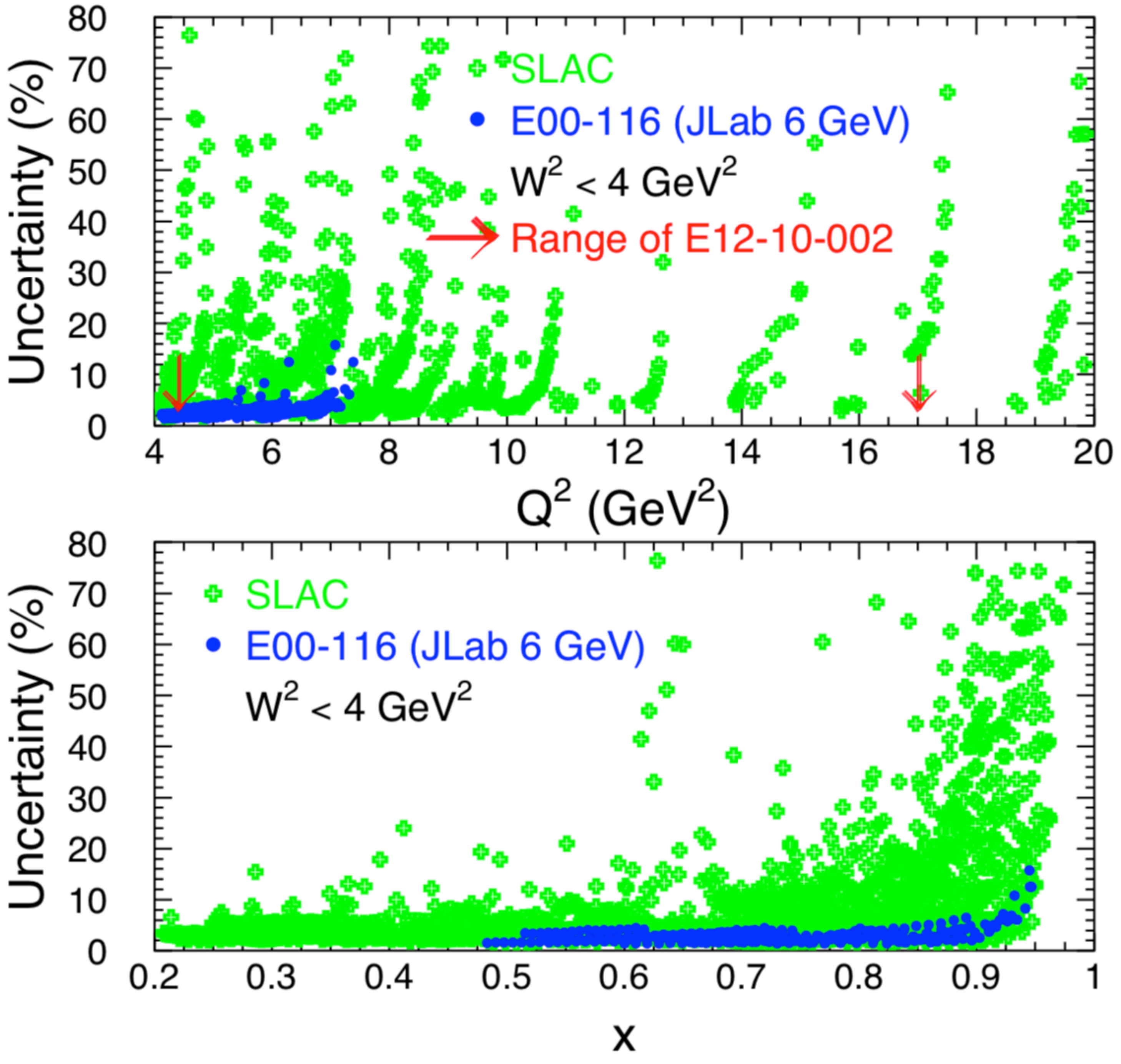
- The F2 experiment will provide essential data to constrain PDF fits (CJ) in the resonance and large x regime
- Additionally, it will add to our understanding of Quark-Hadron duality, provide a benchmark for LQCD, and improve DIS and resonance region fits . A PRL publication with D/H ratios is being drafted with submission planned this Fall
- D and H cross sections are being finalized
- Lots of exciting physics to follow!

BACKUP

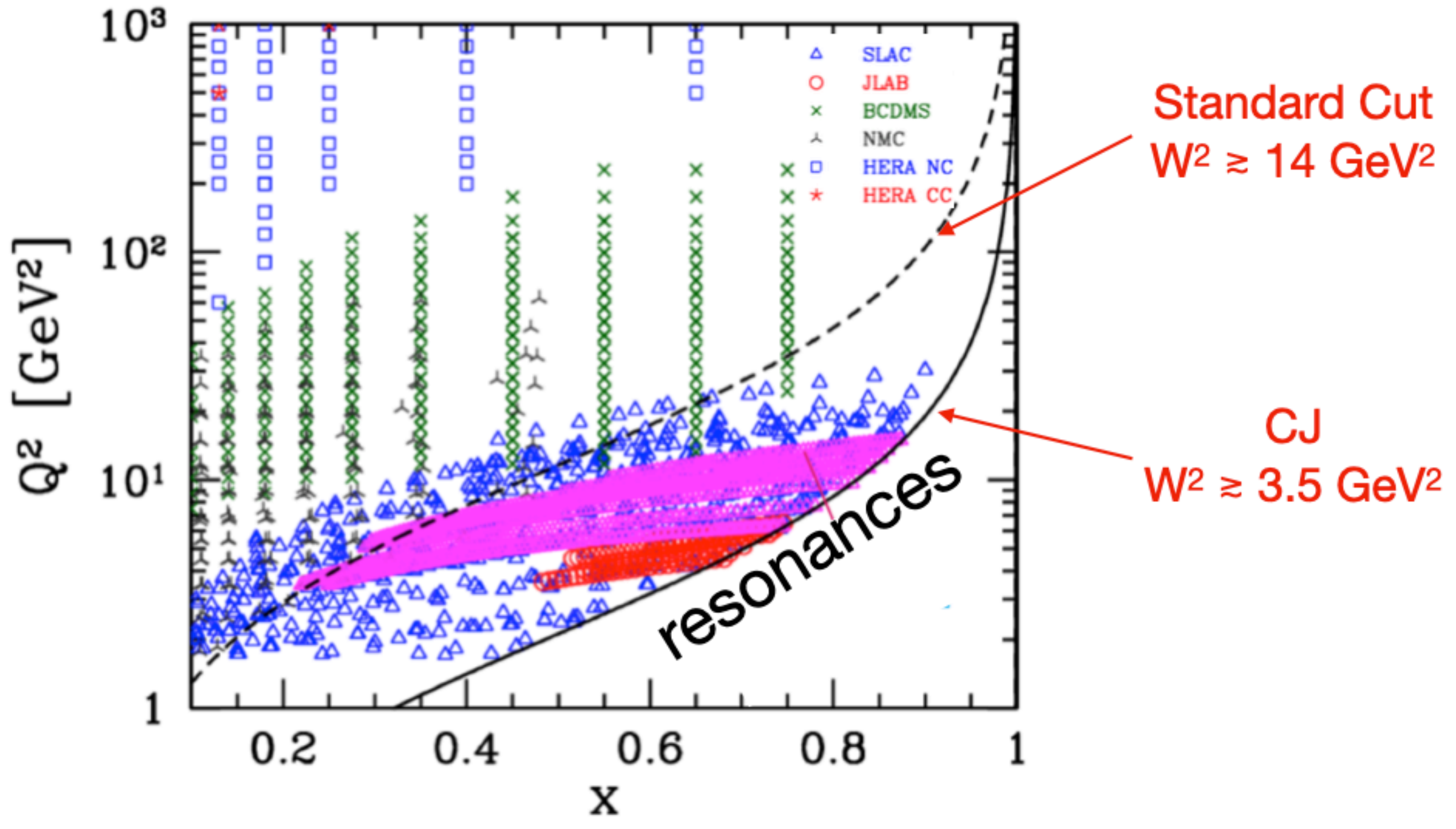
BACKUP

Physics Motivation: Constrain Global PDF Fits

- 12 GeV upgrade allows access to higher Q2 when compared with the previous Hall C experiment

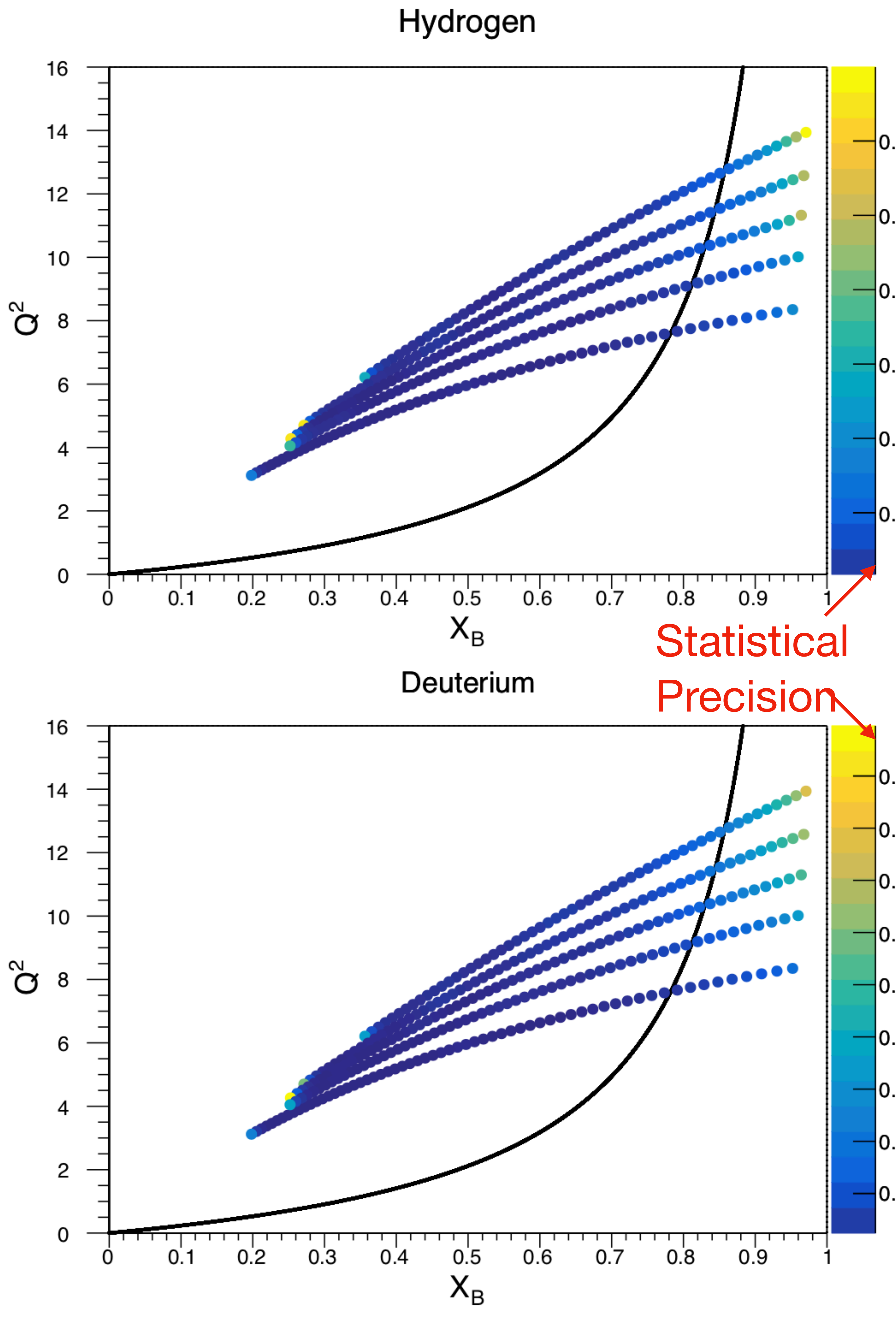


DIS - Proton and Dueteron



- F2 surpasses the precision of previous data

E12-10-002 SHMS Data



Preliminary Cross Sections