Cross section extraction from H(e,e') and D(e,e')

E12-10-002 Experiment HallC Jlab

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Outline

- Physics motivation
    - Constrain PDFs
    - Quark hadron duality
    - Non singlet moments
    - Resonance /DIS modelling
- Results
    - p,d cross sections ->Bill
    - d/p ratio
- Summary

Physics motivation- open questions @high x

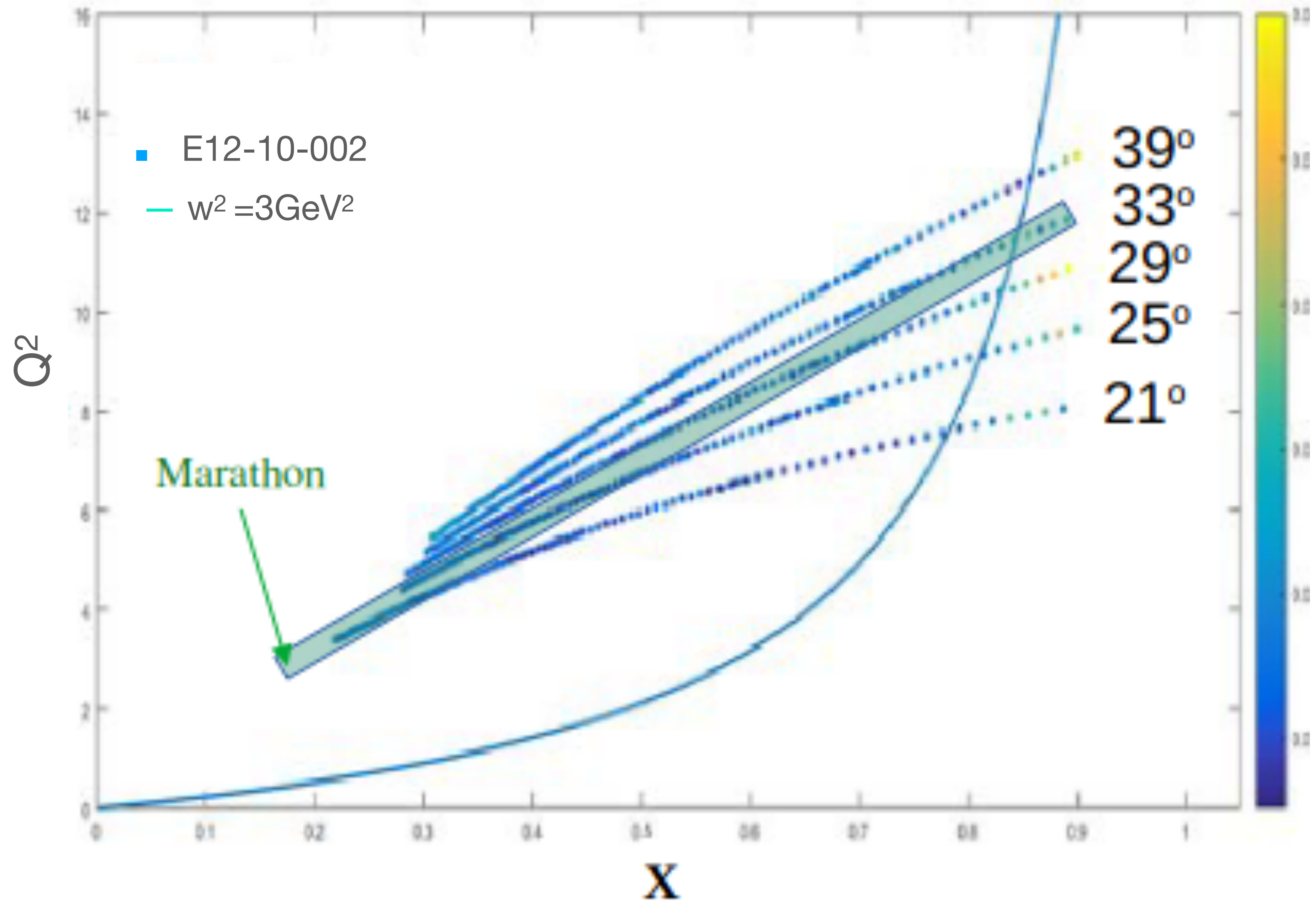
- What is F_2^n/f_2^p and d/u for large x?
- How is the deuteron made from proton and neutrons?

-EMC effects in deuteron?

-Isospin dependent off-shell effects in light nuclei?

- JLab 12 GeV experimental data should provide answers
- Hall C F_2 experiment(E-10-002): Took data to extract F_2^n and f_2^p in a wide x range (Hall C,2018)
- MARATHON: Took data on ^3H and ^3He to extract F_2^n/f_2^p (Hall A ,2018)
- BONuS12: Took data to extract F_2^n / f_2^p in a large x and Q^2 (HallB, 2020)

MARATHON+E12-10-002



Physics motivation- constrain PDFs

- Structure of proton and neutron have been studied through deep inelastic scattering experiments. At leading order,

$$F_2^p = x[\frac{4}{9}u(x) + \frac{1}{9}d(x)]$$

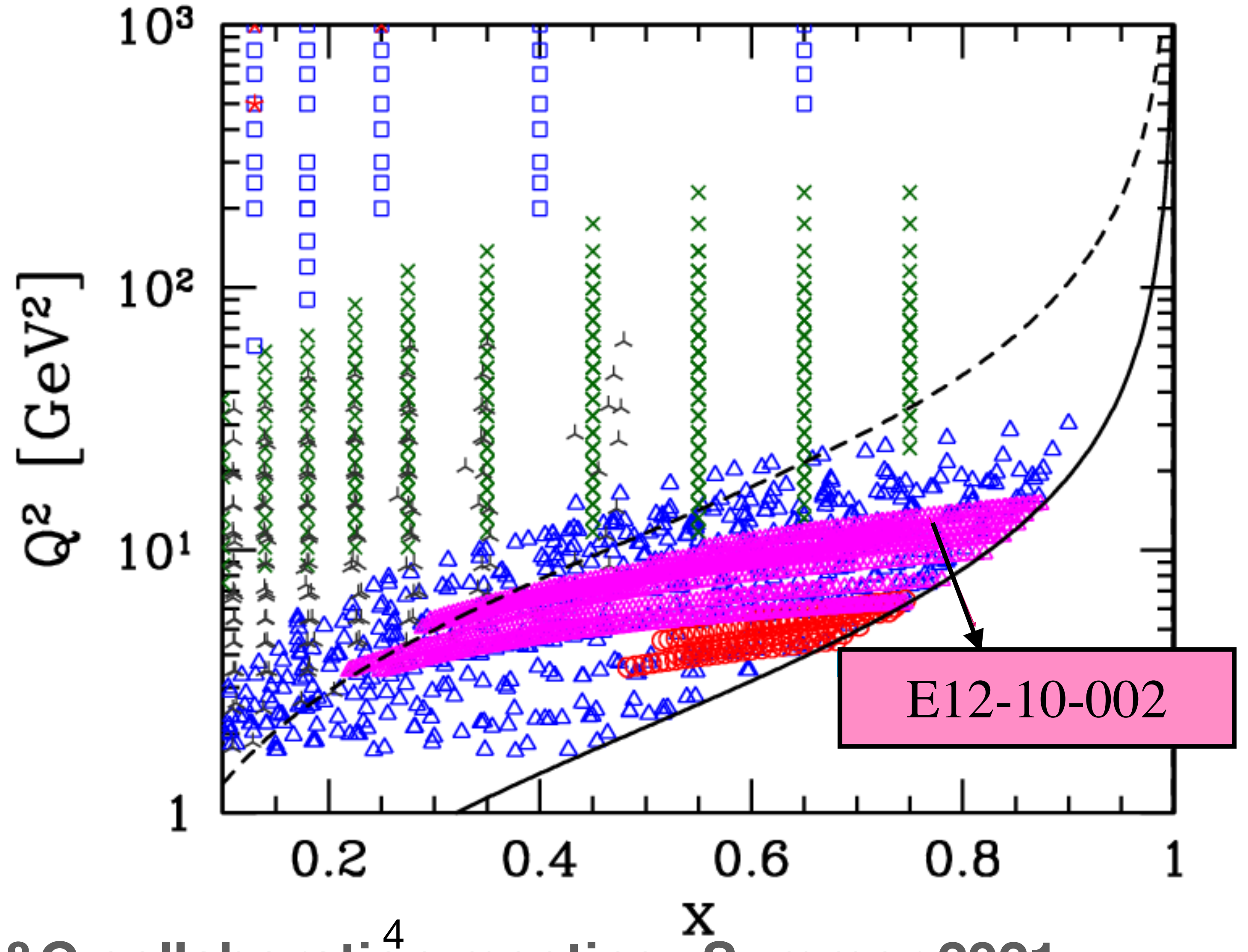
$$F_2^n = x[\frac{4}{9}d(x) + \frac{1}{9}u(x)]$$

- At large x,(x→1) $\frac{F_2^n}{F_2^p} = \frac{1+4\frac{d}{u}}{4+\frac{d}{u}}$

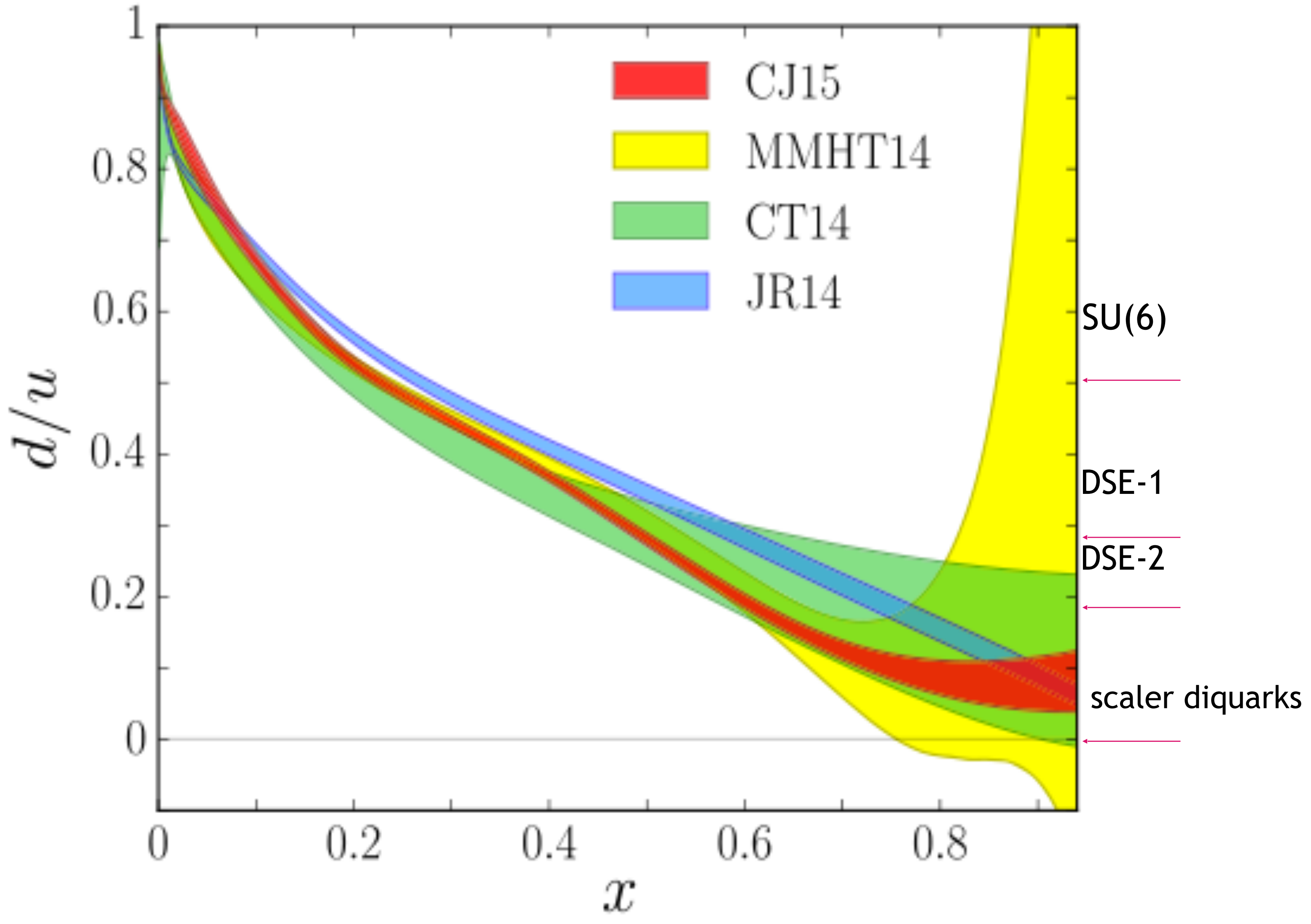
- We measured both p and d cross sections.

- CTEQ-JLab (CJ) performs global QCD fits of PDFs from data including deep-inelastic lepton-nucleon scattering, proton-proton collisions …etc

- Data were taken at large x as well as small x- constraint the nuclear corrections and the d quark at the same time



To improve uncertainty in d/u extraction specially at large X



Physics motivation-Quark hadron Duality

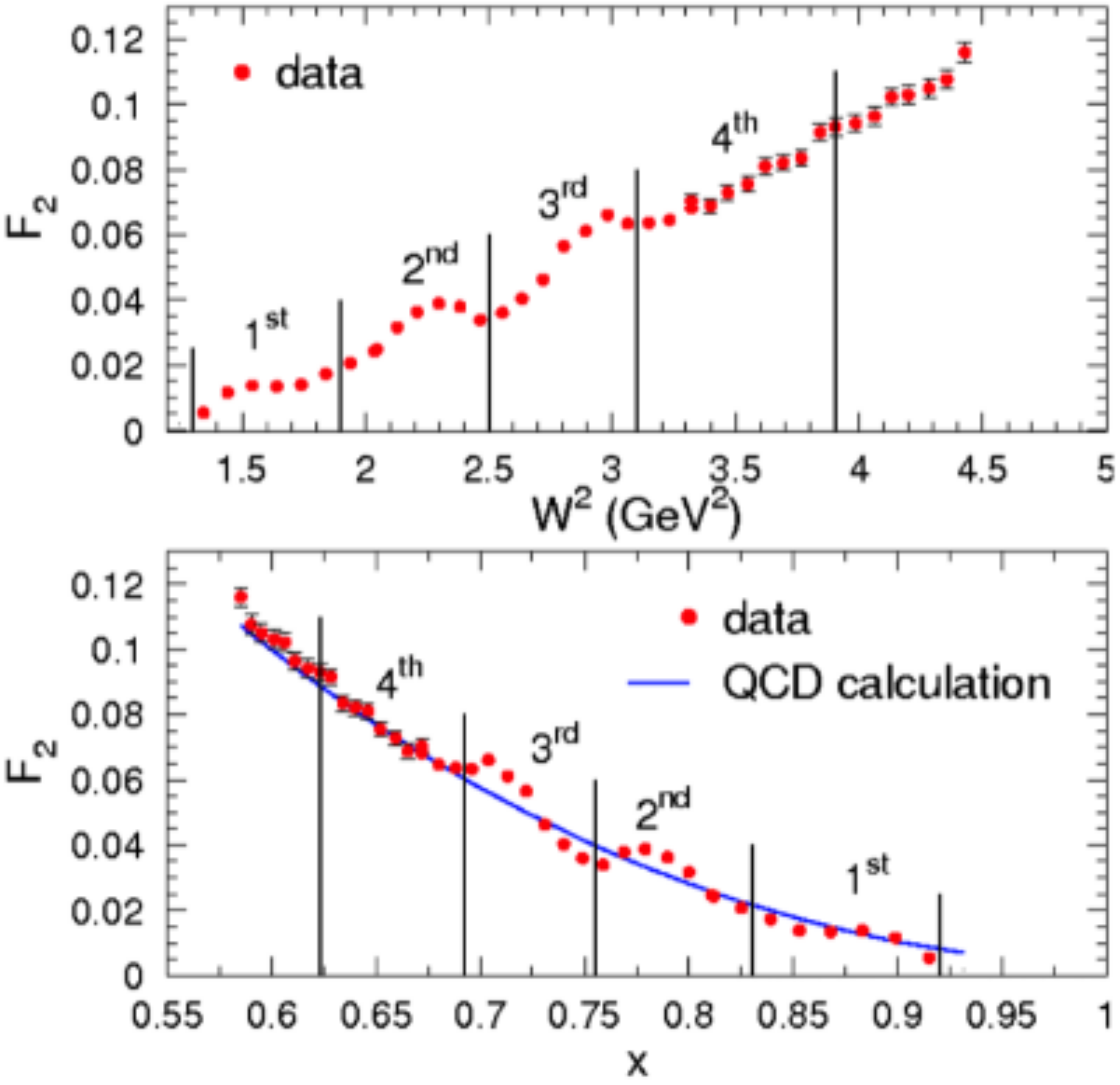
- Structure function in resonance region on average behave like structure functions in DIS regime.

- It's a fundamental property of Nucleon structure. Observed in : $F_2^p, F_L^p, F_1^P, F_2^n, F_2^d \ldots$ etc

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

- Sensitive to higher twist operators

- To understand Quark hadron duality we need large Q^2 range.

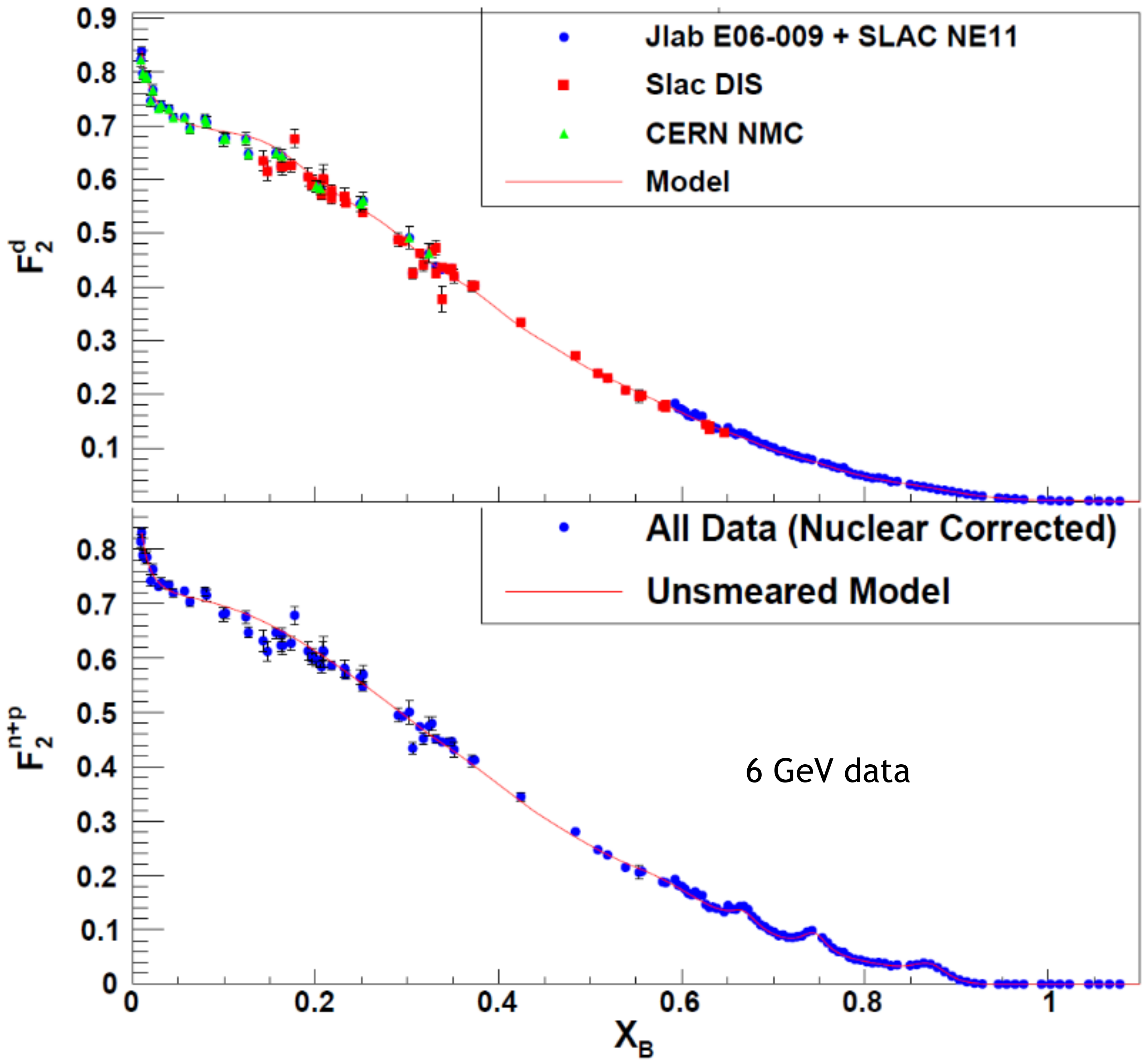


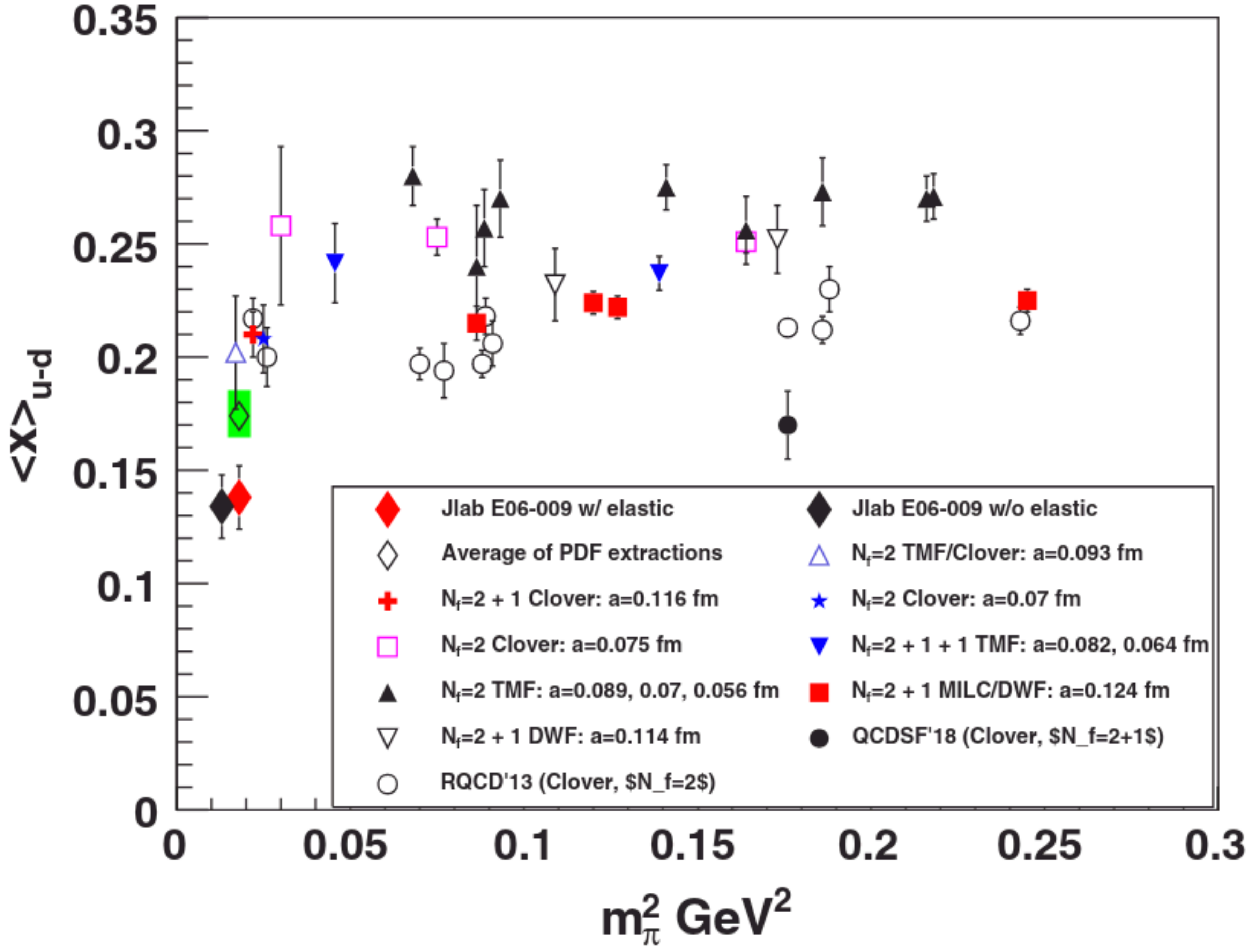
Physics motivation:Non singlet moments

-Test LQCD calculations by comparing non-singlet moments from LQCD to those extracted from data.

-Study structure function moments(proton-neutron moments can be directly compared to lattice)

$$M_2^{NS} \approx M_2^P - M_2^N \approx 2M_2^P - M_2^{P+N}$$





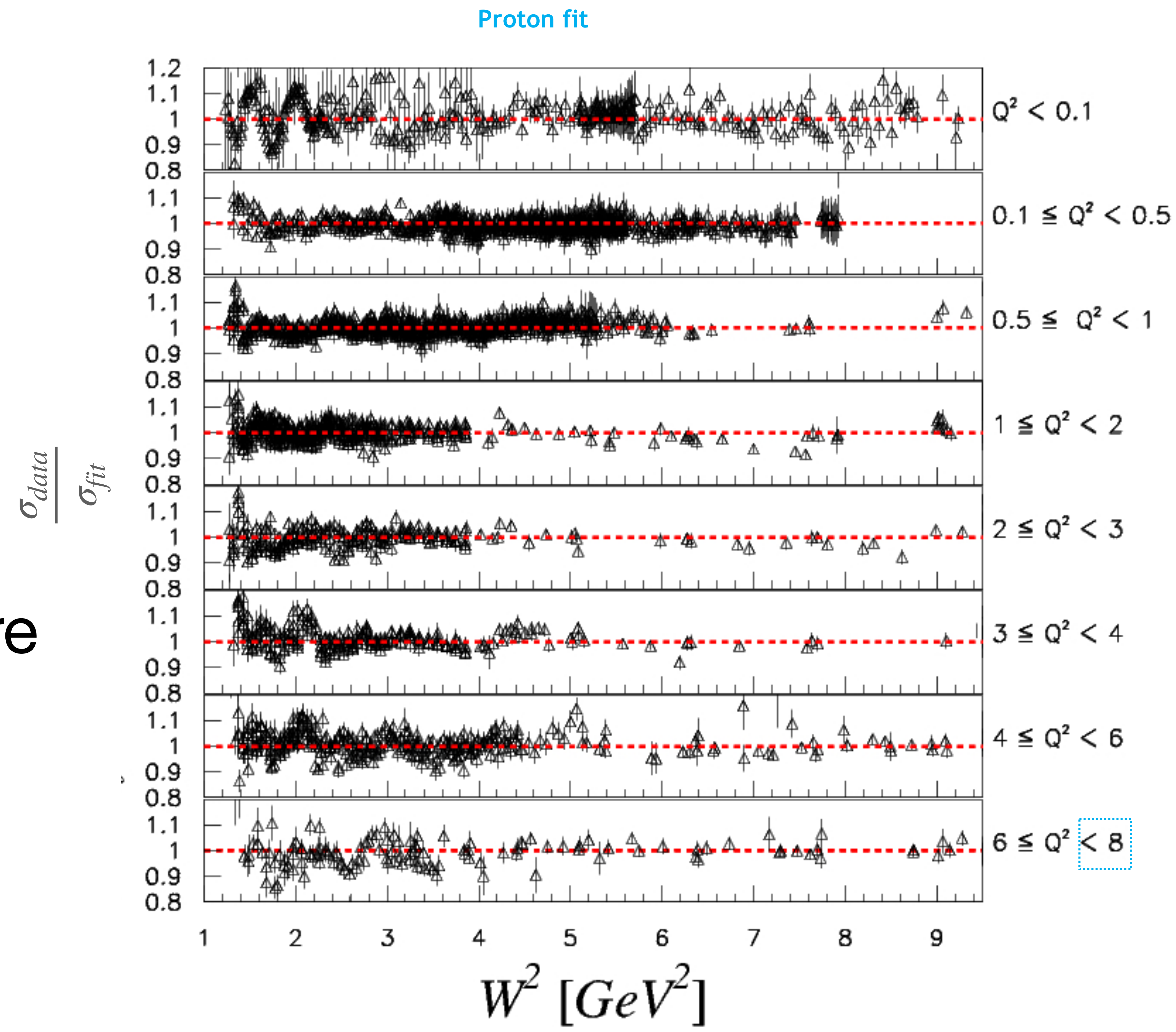
By I.Albayrak,V.mamyan,M.E.Christy et al.
Ref:https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.123.022501

Physics Motivation:DIS modelling/Resonance

- Provides constraints to larger Q^2 up to 16 GeV2 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 sections is very valuable-Moments of structure functions and duality, physics of nucleon resonances/non-resonance …



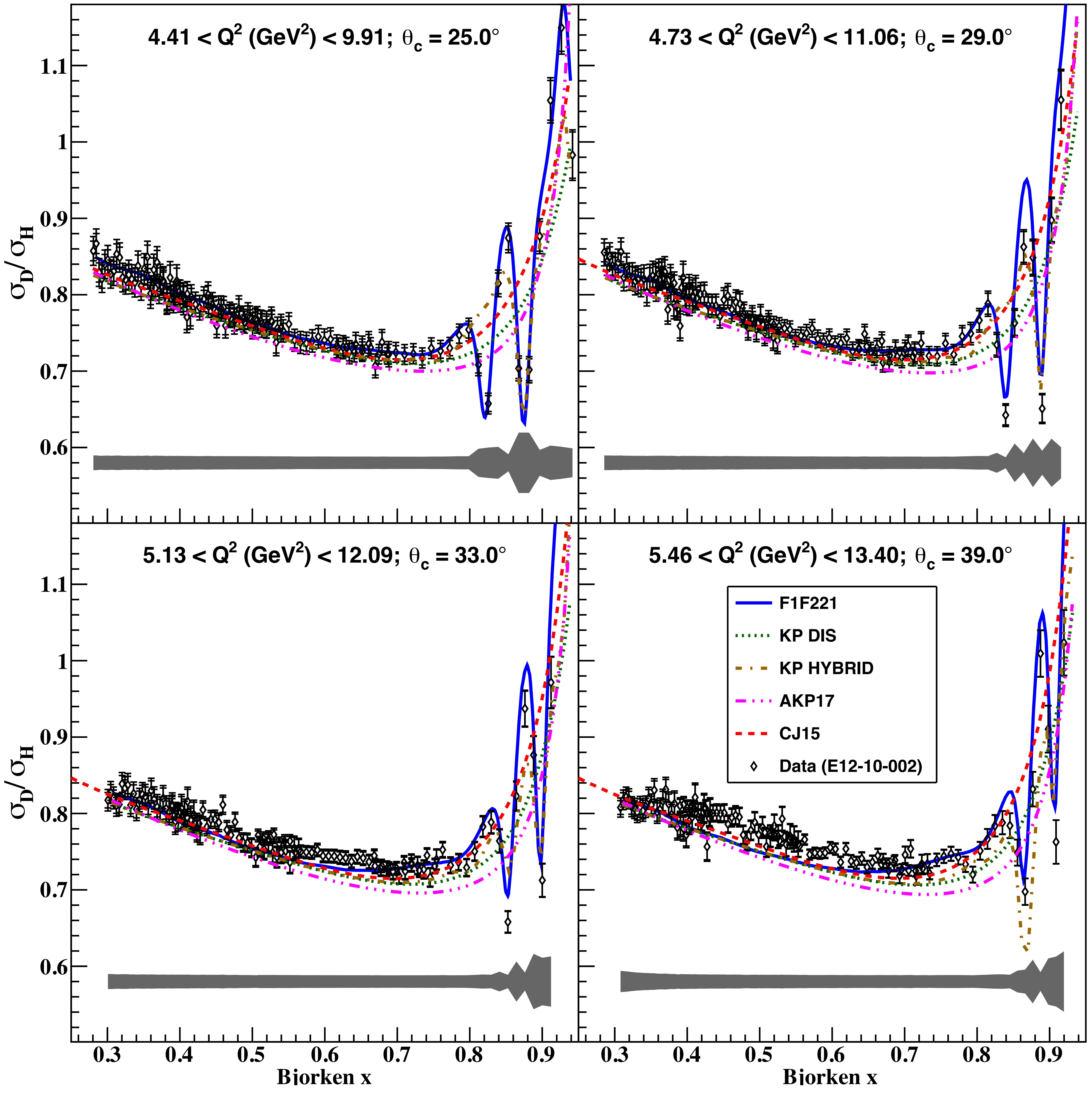
Results of d/p ratios

- The d/p ratio plots for 25 ,29, 33 and 39 deg in SHMS

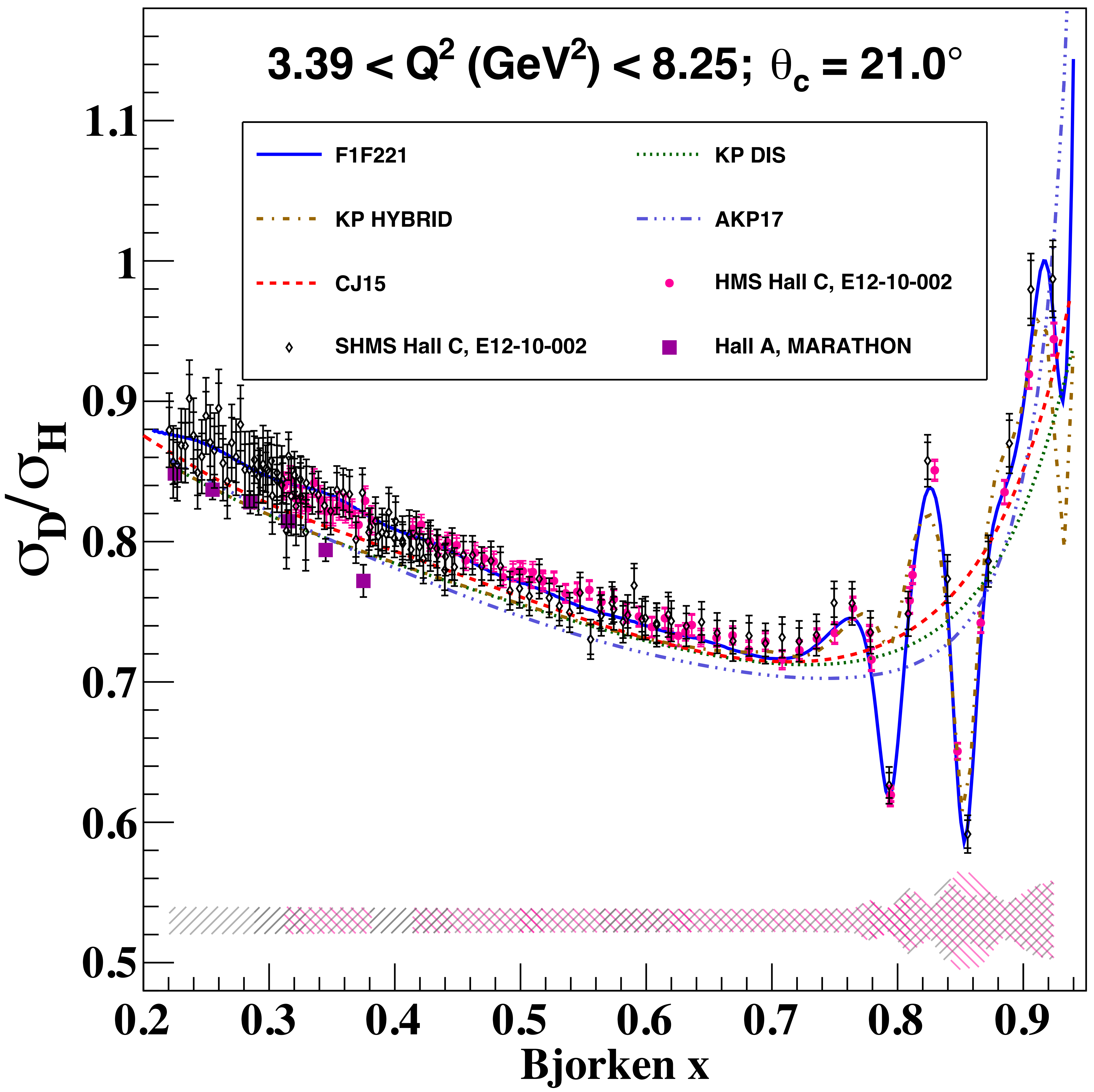
D/H ratios is being drafted with submission planned before this Fall.

D and H cross sections are being finalized.

Bill's talk

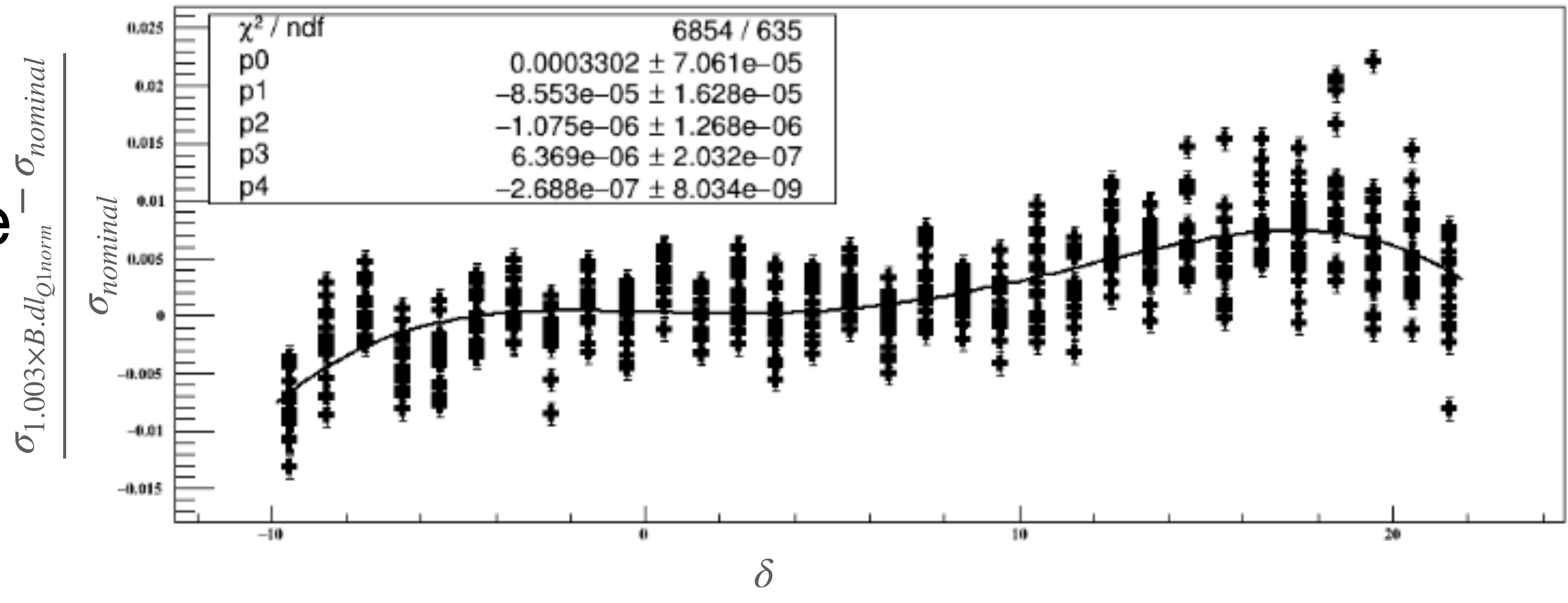


- Comparison between F2 experiment D/H cross section ratio with QCD fits and MARATHON experiment.
- Good agreement between SHMS and HMS data at 21 deg.

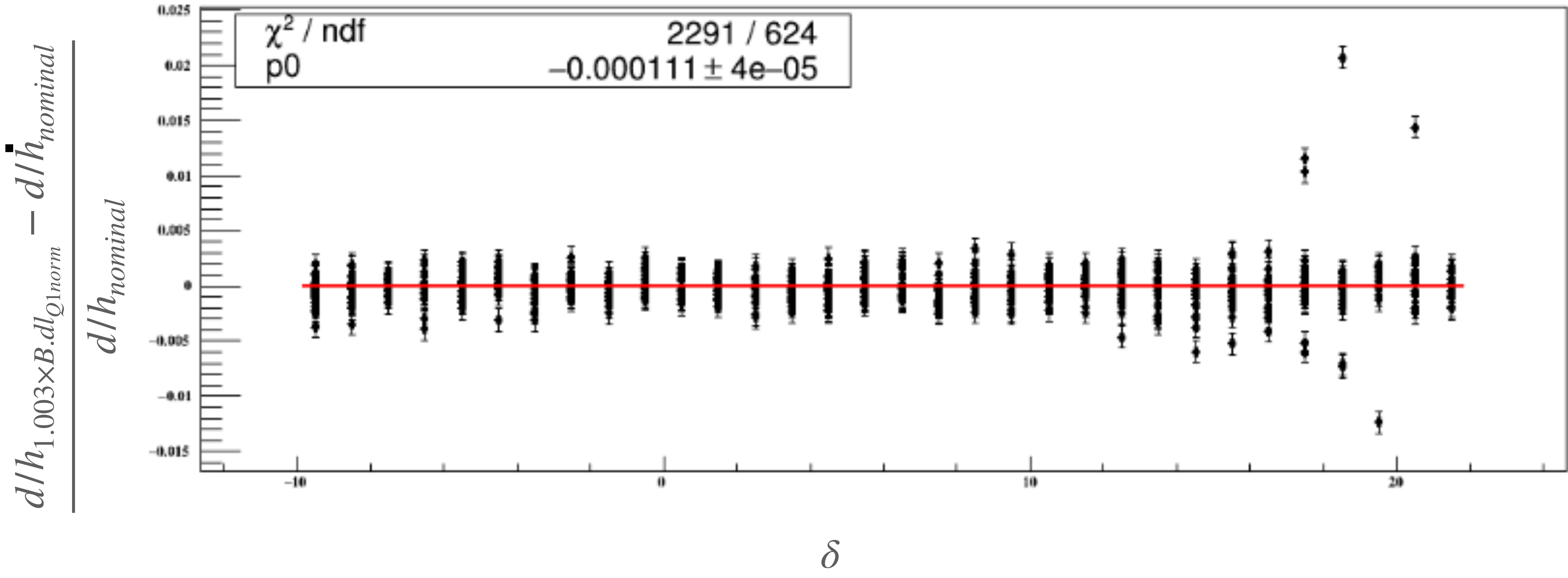


- Most of the uncertainty canceled in the cross section ratio.
- But for absolute cross sections these are still unknown.
- SHMS acceptance is much more sensitive to understand the forward transport of the spectrometer.(field integrals of HB and Q1,Q2 and Q3)
- With the field integral change by 0.3% the d/h ratio does not change. But absolute cross section shows δ dependance.

SHMS d cross section



SHMS d/h cross section



Summary

- The F2 experiment will provide essential data to constrain PDF fits (CJ) in the resonance and large x regime .

- It will add to our understanding of Quark-Hadron duality, provide a benchmark for LQCD, and improve DIS and resonance region fits .

- Data analysis is mostly finalized for d/p (per nucleon) results.

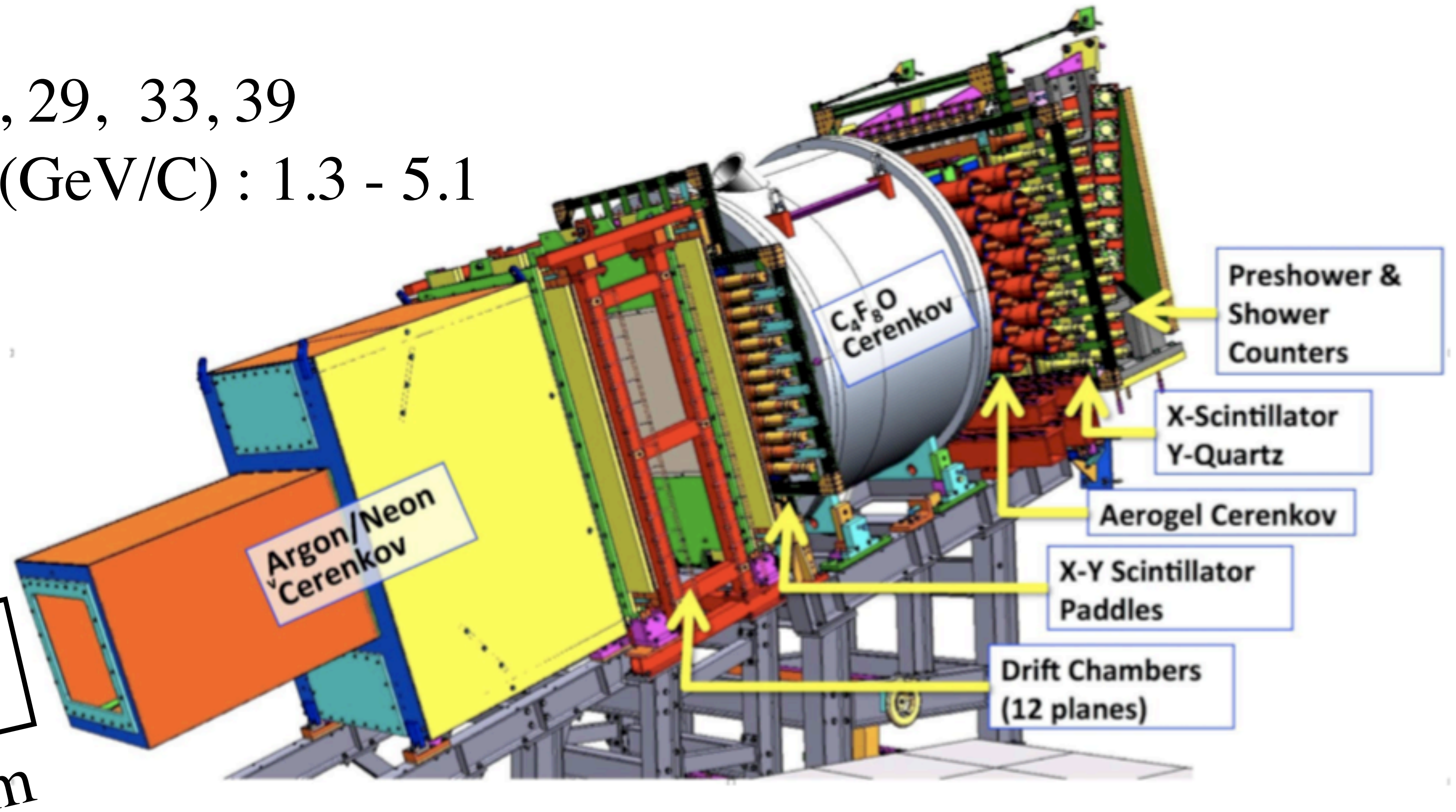
- A PRL publication with d/p ratios is being drafted with submission planned before Fall 2021

- The results from E12-10-002 experiment will enrich physics at the large-X Bjorken region.

Back up slides

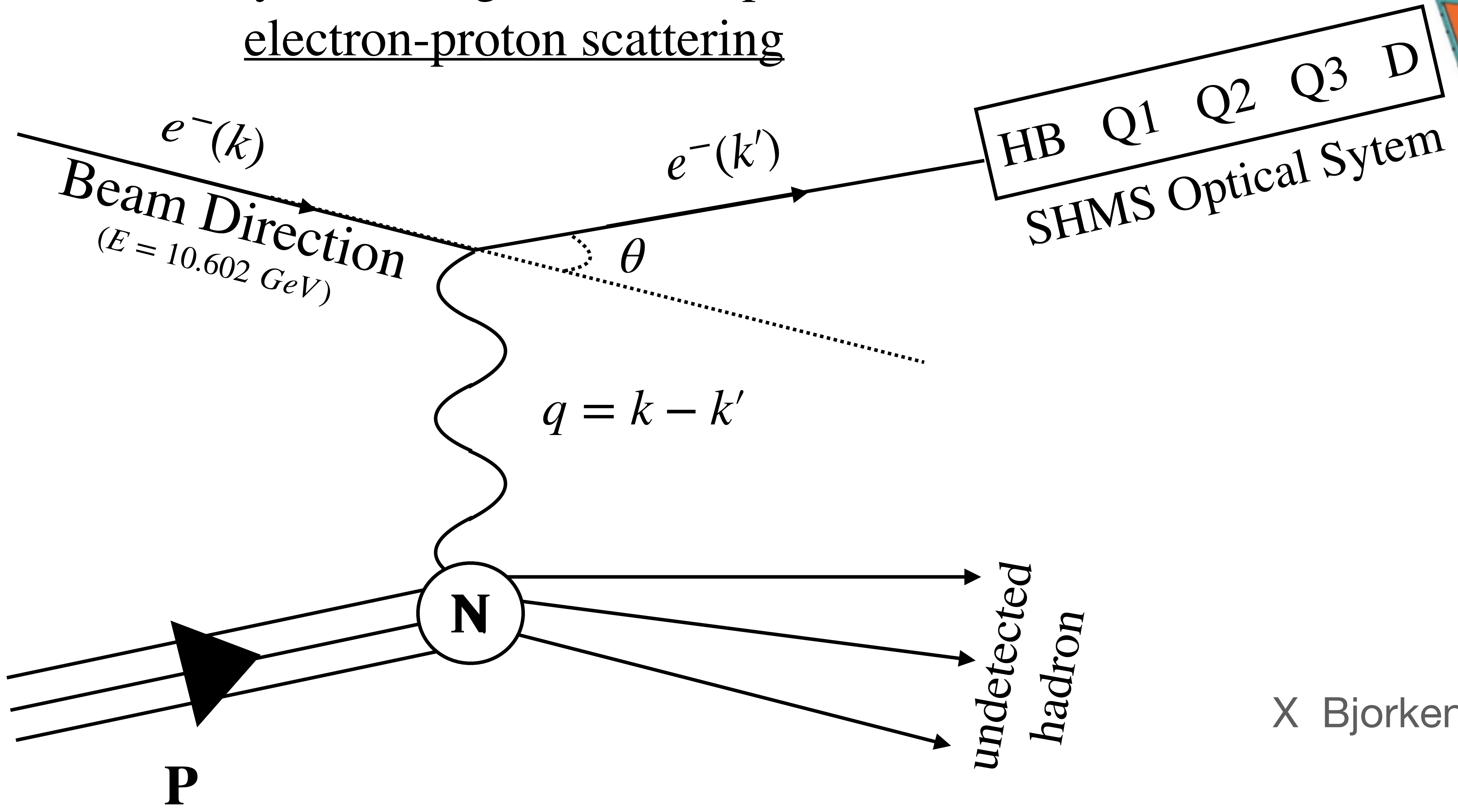
E12-10-002 : inclusive electron-nucleon scattering experiment in Hall C

- Ran in the spring 2018 in parallel with EMC
- Targets LH2, LD2, Al
- Angle (deg) : 21, 25, 29, 33, 39
- Central Momentum (GeV/C) : 1.3 - 5.1



SHMS Detector System
71% data were taken by SHMS, rest with HMS(not in picture)

Basic Feynman diagram for deep inelastic electron-proton scattering



- HMS pushed the data to higher Q^2 up to 16 GeV^2
- HMS 21 deg : to cross calibrate with SHMS data

X Bjorken: $X = \frac{Q^2}{2M\nu}$

Definitions of several kinematic variables

M = nucleon mass

k = incoming electron four momenta

k' = outgoing scattered electron four momenta

E = Beam energy, E' = recoil energy of electron

$\nu = E - E'$ = virtual photon energy

$Q^2 = 4EE'Sin^2\frac{\theta}{2}$

$W^2 = M^2 + 2M\nu - Q^2$

Cross-Section Extraction Method

- The method used to extract the cross-section : **Monte-Carlo Ratio Method**

- For each bin in $(\Delta E', \Delta\Omega)$, number of total electrons detected by the spectrometer

$$N^{e-} = L \times (\frac{d\sigma}{d\Omega dE'}) \times (\Delta E' \Delta\Omega) \times \epsilon_{tot} \times A(E', \theta) + BG \qquad \ldots(1)$$

where, L = Integrated Luminosity = $N^{e-}_{beam} \times \frac{N_{target}}{Area}$

ϵ_{tot} = Total Efficiency

$A(E', \theta)$ = Acceptance for the bin

BG = Background

- Hence the efficiency corrected yield is defines as -

$$Y = \frac{N^{e-} - BG}{\epsilon_{tot}} = L \times \sigma \times (\Delta E' \Delta\Omega) \times A(E', \theta) \qquad \ldots(2)$$

Cross-Section Extraction Method

- Efficiency corrected yield can be measured from the experiment (Y_{data}) and also from the Monte-Carlo (Y_{MC})

$$Y_{data} = L \times \sigma^{data} \times (\Delta E' \Delta\Omega) \times A(E', \theta) \qquad \ldots (3)$$

$$Y_{MC} = L \times \sigma^{MC} \times (\Delta E' \Delta\Omega) \times A_{MC}(E', \theta) \qquad \ldots (4)$$

- Taking ratio of equation (3) and (4)

$$\frac{Y_{data}}{Y_{MC}} = \frac{L \times \sigma^{data} \times (\Delta E' \Delta\Omega) \times A(E', \theta)}{L \times \sigma^{MC} \times (\Delta E' \Delta\Omega) \times A_{MC}(E', \theta)} \qquad \ldots (5)$$

- Considering $A(E', \theta) = A_{MC}(E', \theta)$ and Monte-Carlo generated with same luminosity with data-

$$\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}} \qquad \ldots (6)$$

Cross-Section Extraction Method

$$\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}}$$

Bill showed in detail in the last talk

- F1F220 (by M. Eric Christy) model is used to get the σ^{MC}
- F1F220 is a fit to the inclusive reduced cross-sections of global data which produces F_1 and F_2
- The structure functions are related to the reduced cross-sections as follows-

$$\sigma_T = \frac{4\pi\alpha}{KM} F_1 \qquad \sigma_L = \frac{4\pi^2\alpha}{KM\nu}[(1+\frac{\nu^2}{Q^2})MF_2 - \nu F_1]$$

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma[\sigma_T(x,Q^2) + \epsilon\sigma_L(x,Q^2)]$$

- For the Monte-Carlo events (≥ 1 *million*) of scattered electrons are generated uniformly in $(E', X' \equiv \frac{dY}{dZ}, Y' \equiv \frac{dY}{dZ})$ space using the program mc-single-arm
- Born approximation is just the first order approximation in α of electron-nucleon scattering by one photon exchange. To mimic the reality we multiply the each events of MC by $\frac{\sigma^{model}_{rad}}{\sigma^{model}_{Born}}$ where, σ^{model}_{born} = model Born cross-section, σ^{model}_{Rad}= total radiative model cross-section
- The Monte-Carlo yield need to be calculated with the same luminosity as data. Physics weighted, (uniformly) generated Monte-Carlo events are multiplied with a factor to get the Y_{MC} :

$$Y_{MC}(E', \theta) = N^{e-} \times scale\ factor$$

scale factor is defined as the ratio of data and MC luminosity:

$$scale\ factor = \frac{L_{data}}{L_{MC}} \times \epsilon_{tot} \times \frac{E_{LT} \times C_{LT}}{PS}$$, where

$$L_{data} = target\ density \times target\ length \times Avogadro's\ number \times \frac{1}{atomic\ mass} \times \frac{beam\ charge}{elementary\ charge}$$

$$L_{MC} = \frac{generated\ events}{\Delta E'\ \Delta\Omega}$$