Recent results in collinear parton distribution functions

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Contents of this talk

This talk will covering new experimental results related to unpolarized parton distribution functions.

Mainly fixed target results from JLab as well as new results for light sea quarks are highlighted.

The selection is not complete and based on personal biases.
Apologies for missing out many important results

Also see: **Summary given by S. Kuhn**
EIC impact by Filippo Delcarro

Recent progress

- Recent updates to global PDF fits with significant amount of LHC data

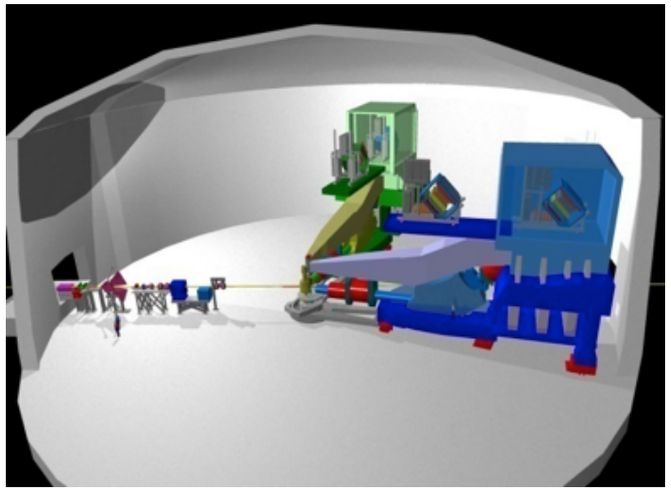
  recent publication/talks from:
  [PDF4LHC workshop https://indico.cern.ch/event/1002964/]
  [CTEQ, Tie-Jiun Hou et al, Phys. Rev. D 103, 014013]
  [NNPDF, Emanuele R. Nocer, DIS2021 WG1]
  [MSHT2020, Robert Thorne, DIS2021 WG1]

- Many new experimental results:

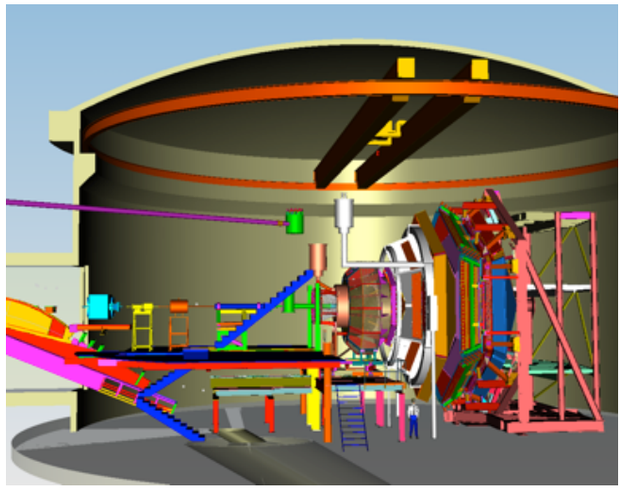
  W/Z, jet results from LHC experiments

  Fixed target results from JLab (new results from 12GeV era)
  RHIC polarized p+p observables and unpolarized cross section results

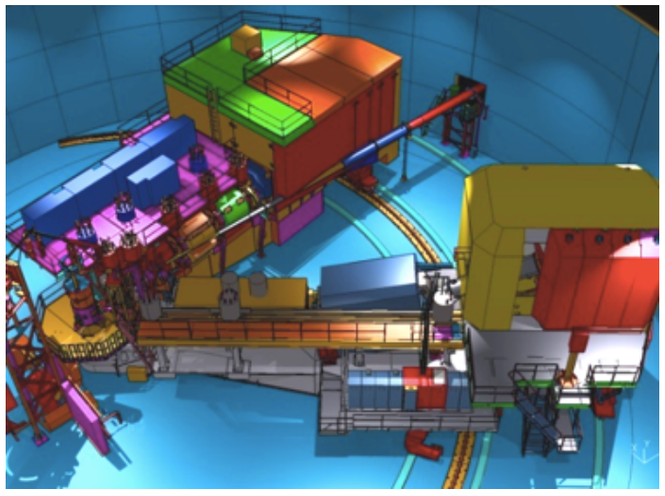
JLab CEBAF



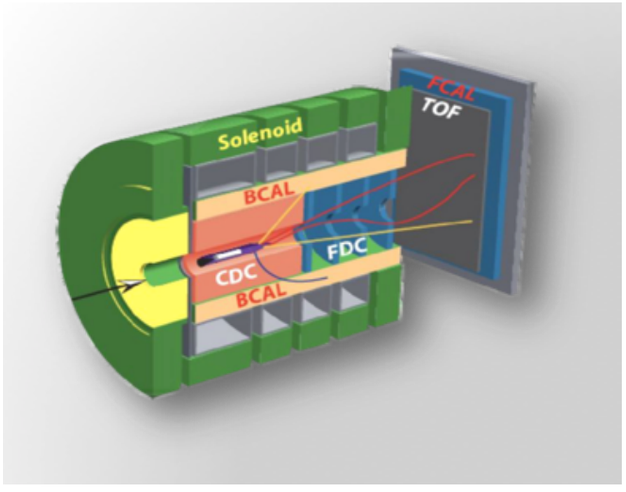
Hall A: SRC, form factors, future new experiments (MOLLER, SoLID)



Hall B CLAS12: understanding nucleon structure (GPDs and TMDs)



Hall C: precision determination of valence quark properties of nucleons and nuclei



Hall D: studying exotic mesons exploring origin of confinement

Large-x PDFs

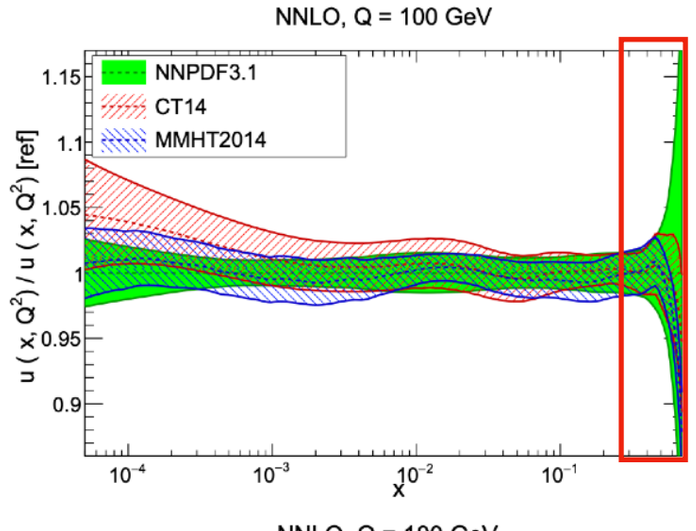
- Valence structure of hadron
- Improve constraints on PDFs at large-x

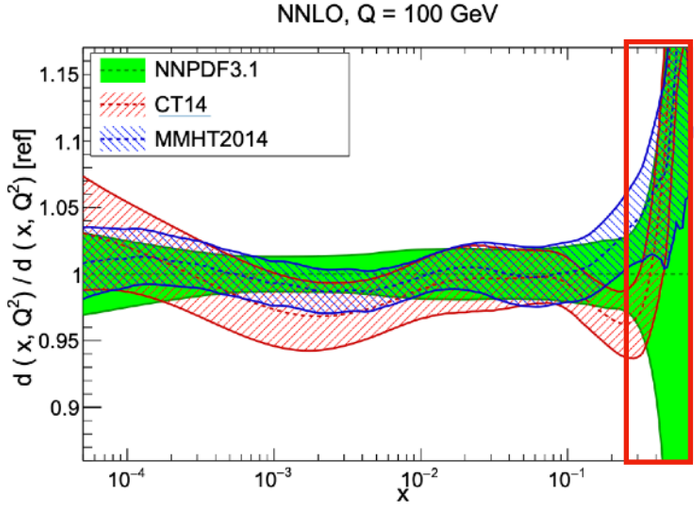
  large x, low Q2

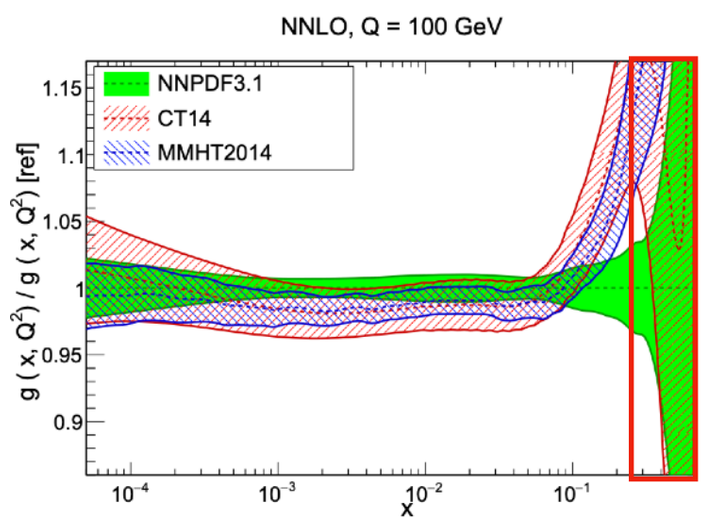
  -> (evolution) low x, high Q2

  Dominant systematic uncertainty source for precision cross sections and BSM search at LHC

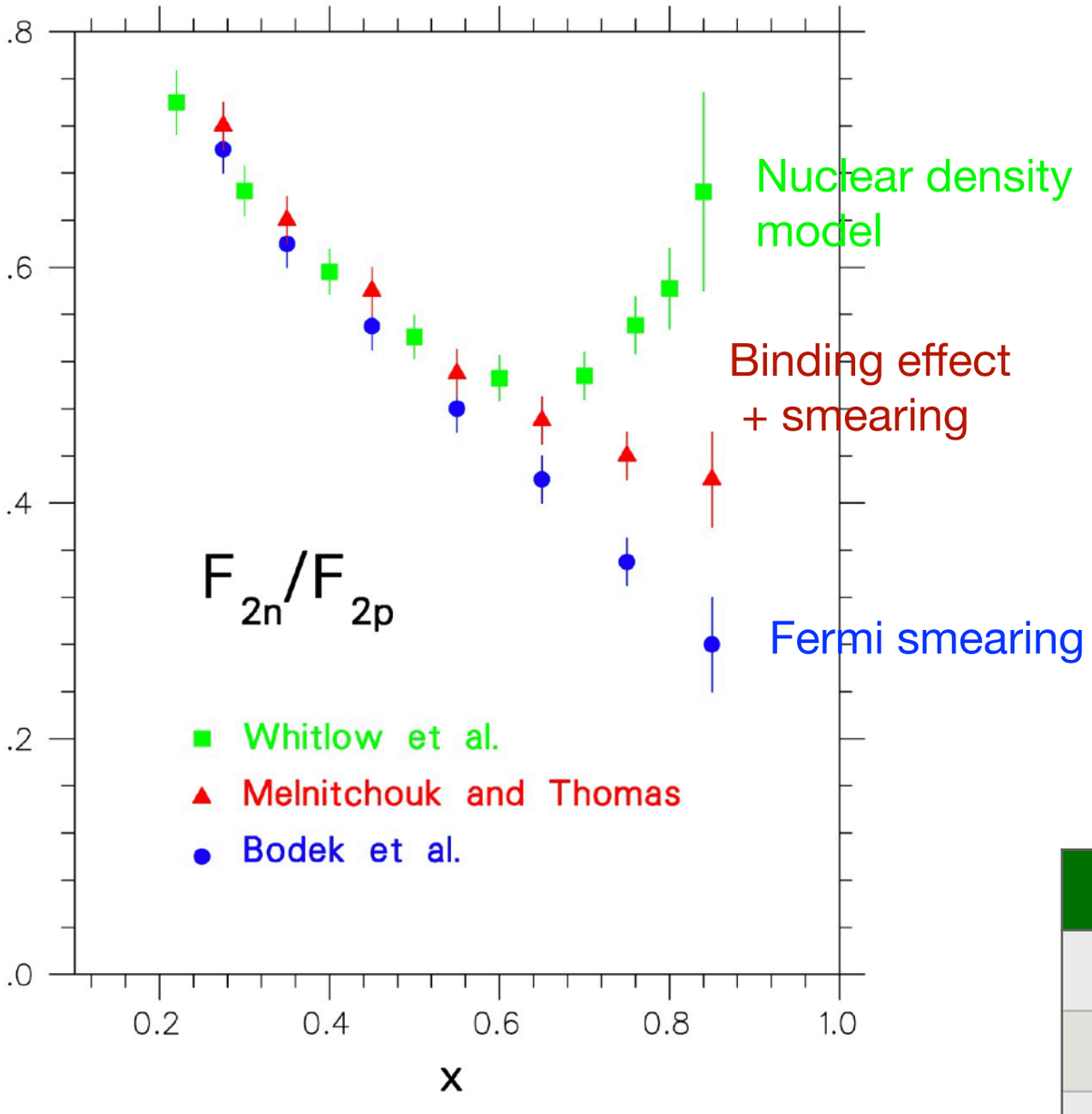
- F2n/F2p ratio: d/u ratio at x-> 1 limit
- Resonance structure of the hadron
- Quark-Hadron duality







Predictions for F_2(n/p), d/u at x→1



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

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

At large x,

$$\frac{F_2^n}{F_2^p} \approx \frac{1+4(d/u)}{4+(d/u)}$$

Testing ground for hadron structure

	F_2(n/p)	d/u	A_1(n)	A_1(p)
SU(6)	2/3	1/2	0	5/9
Diquark model/Feynman	1/4	0	1	1
Quark model/Isgur	1/4	0	1	1
pQCD	3/7	1/5	1	1
QCD counting rules	3/7	1/5	1	1

$F2(d) \neq F2(n) + F2(p)$

No free neutron target exists

Deuteron is a weakly bound system

- chosen as effective neutron target

But, $F2(d) \neq F2(n) + F2(p)$

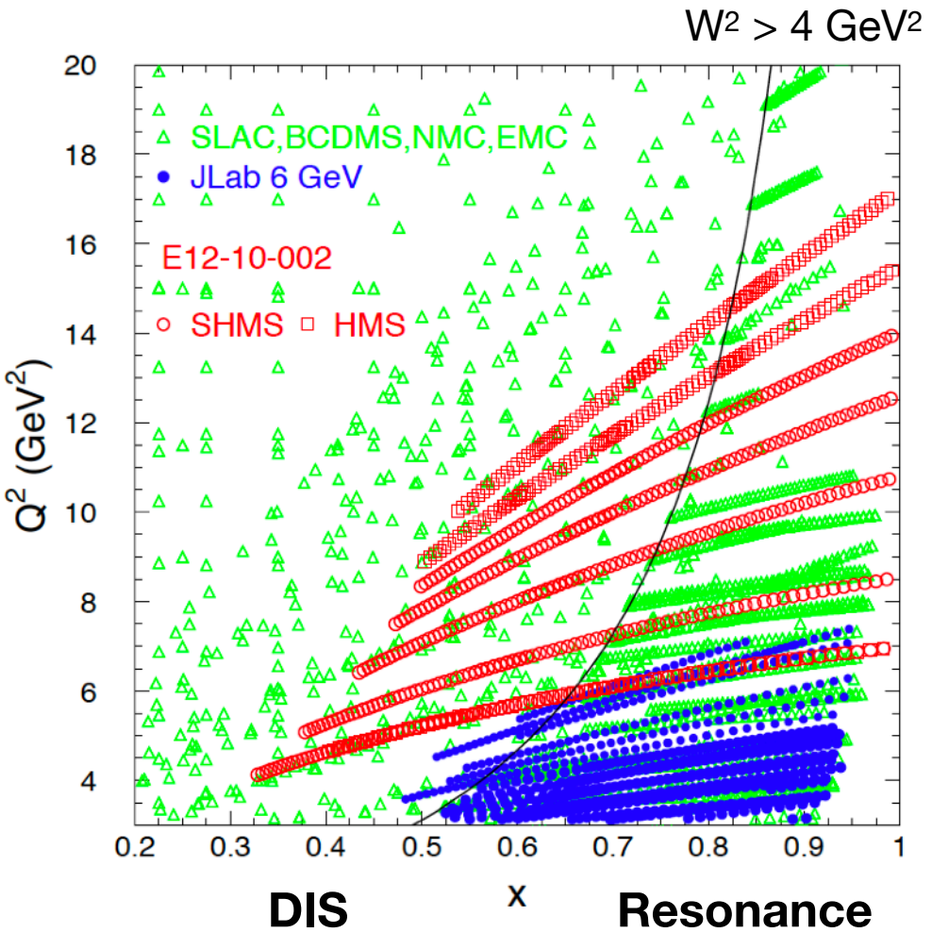
Large theory uncertainty from nuclear corrections

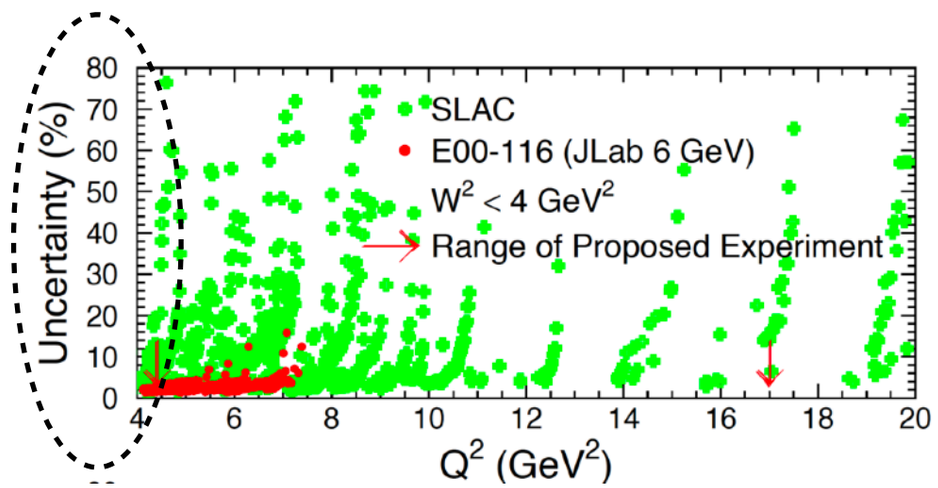
Binding and Fermi motion -> significant model dependence on Deuteron wave function

Off-shell corrections

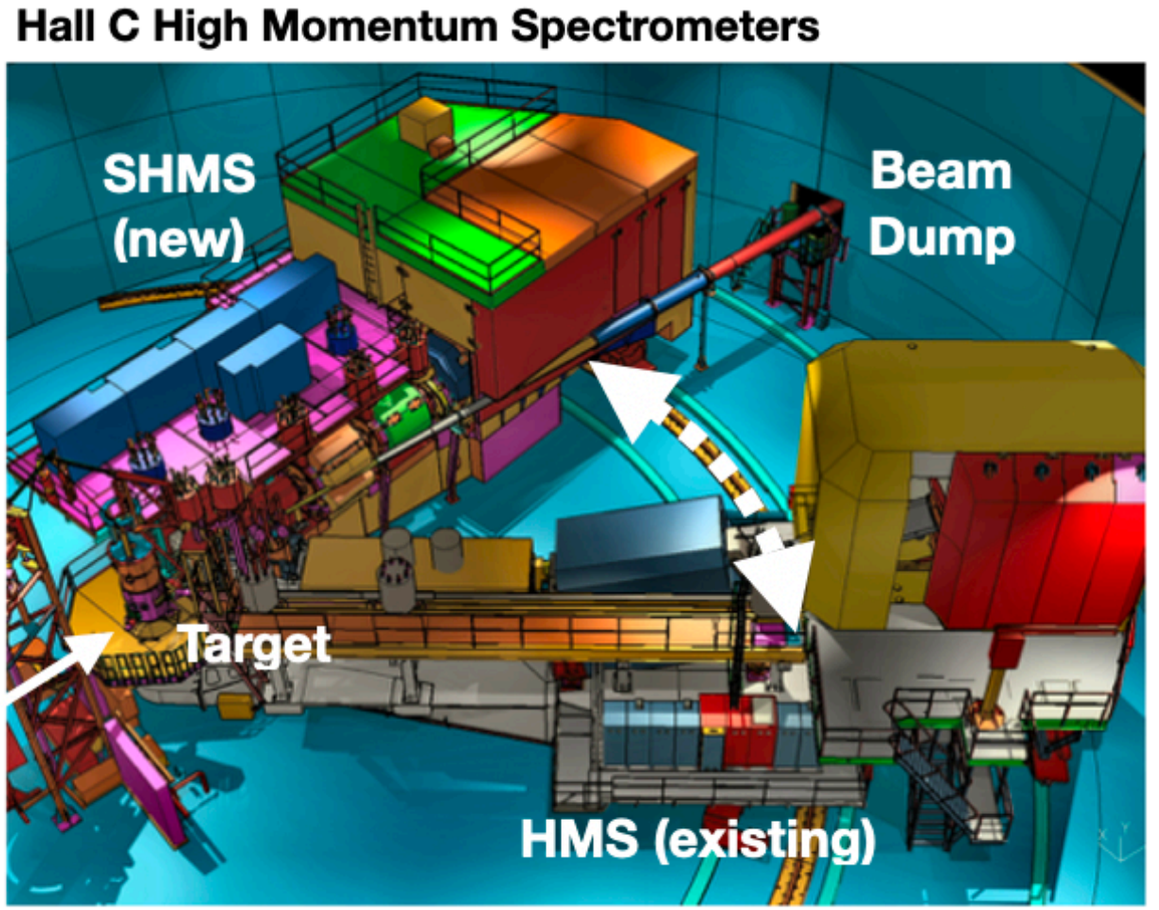
Need more precise, preferably model-independent neutron target data

Precision F_2 measurement @ Hall C





- JLab 12GeV extends Q^2 coverage with high precision
- Precise inclusive H(e,e') and D(e,e') measurements using LH2 and LD2 targets
- Took data 2018

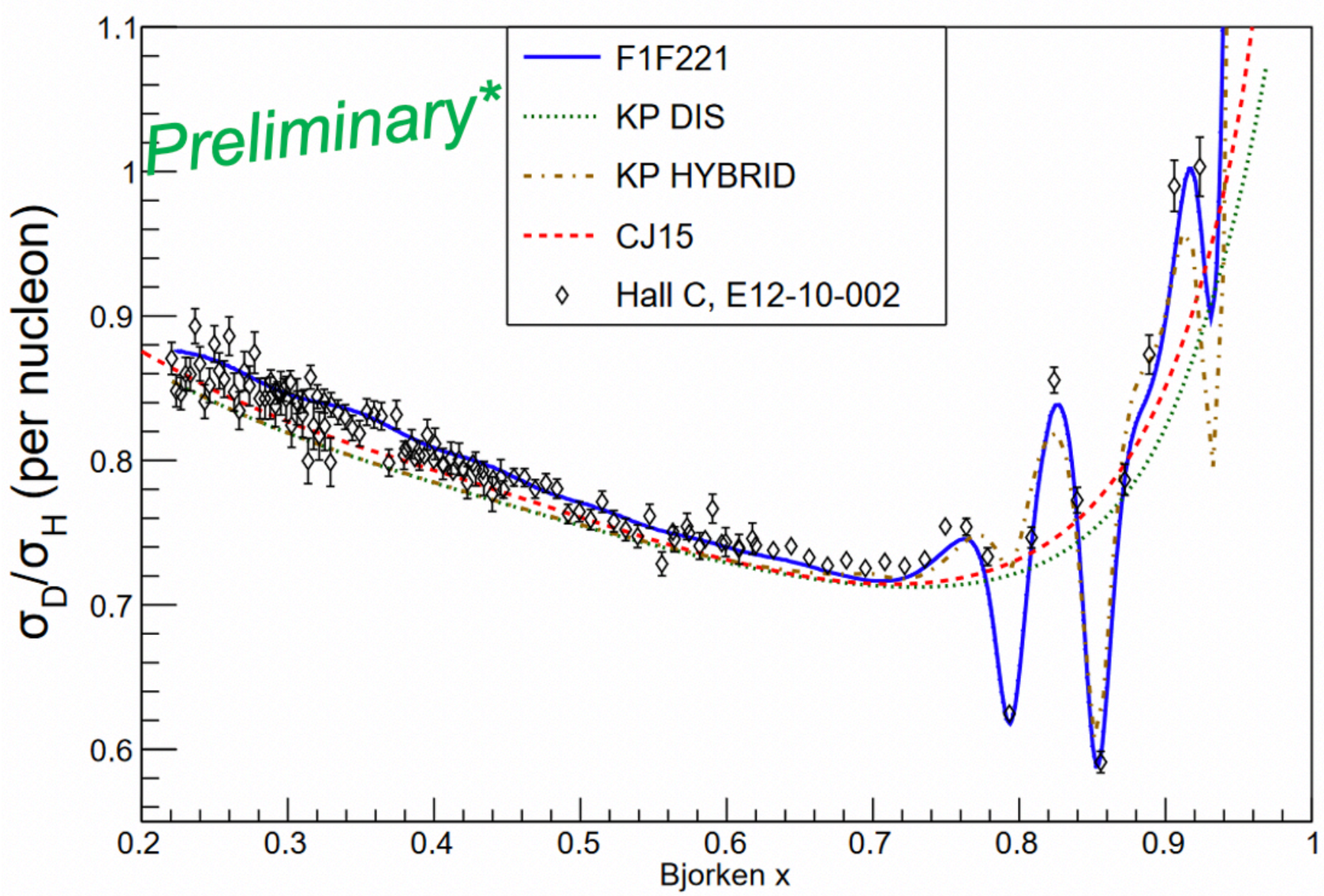


Slide by Cynthia Keppel (DIS2021)

E12-10-002: Large volume of high-precision data spanning a wide range in x and Q^2

- Additional constraints for global PDF fits
- Testing ground for hybrid models like new Kulagin-Petti
- Extends precision quark-hadron duality studies to higher Q^2 than before
- Will facilitate comparison to lattice calculations by extracting non-singlet moments
- ***Publication draft in preparation**

D/H Ratios from one kinematic setting only



3H/3He DIS - MARATHON @Hall A

A=3 mirror nuclei

^{3}H

^{3}He

Form EMC-type ratios

$$R(^3He) = \frac{F_2^{^3He}}{2F_2^p + F_2^n} \qquad R(^3H) = \frac{F_2^{^3H}}{F_2^p + 2F_2^n}$$

Super ratio $R^* = \dfrac{R(^3He)}{R(^3H)}$

Now depends on relative difference in nuclear effects

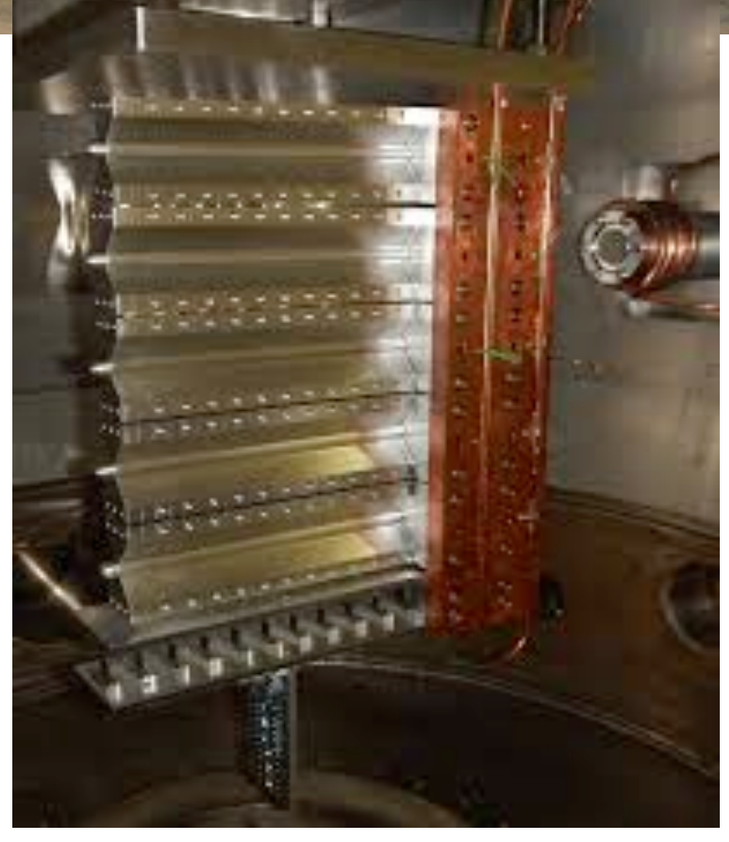
Differences in the nuclear effects small, R*≈1 (theory calculations)

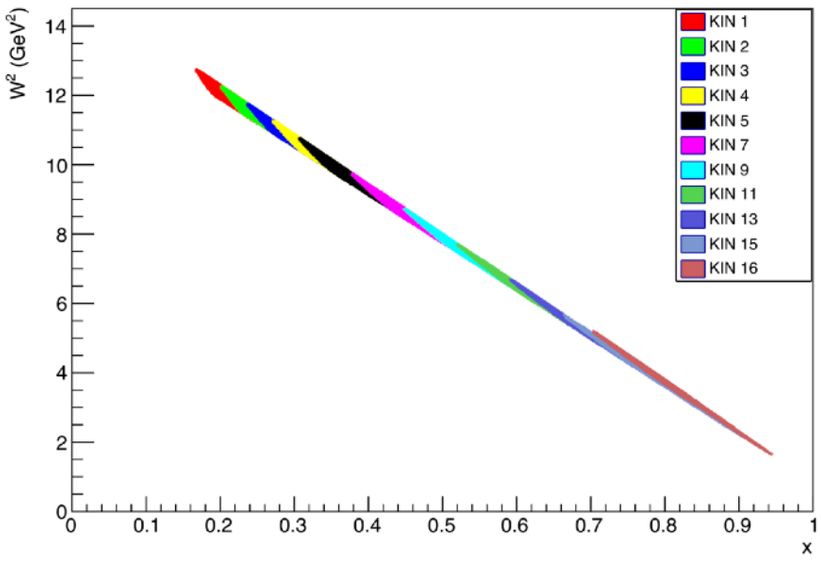
$$\frac{\sigma^{^3He}}{\sigma^{^3H}} = \frac{F_2^{^3He}}{F_2^{^3H}} = R^* \frac{2F_2^p + F_2^n}{F_2^p + 2F_2^n}$$

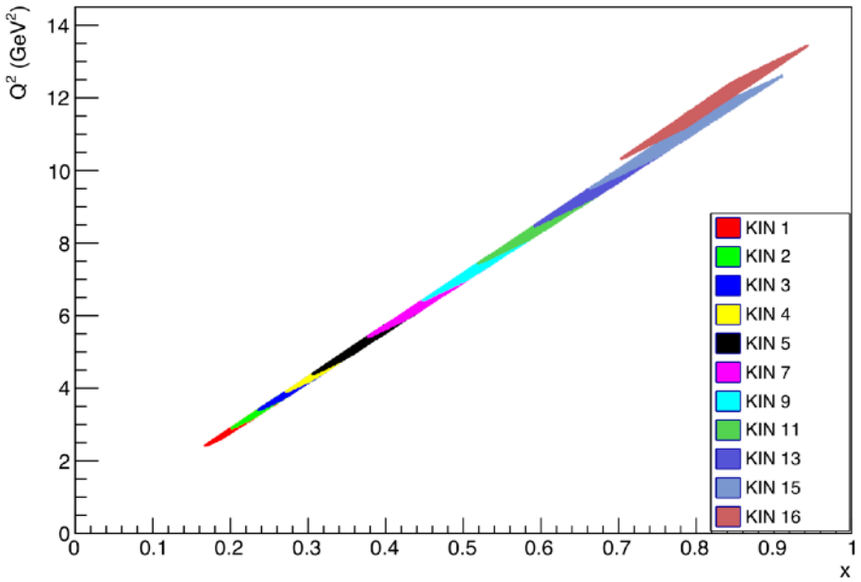
$$\frac{F_2^n}{F_2^p} = \frac{2R^* - \sigma^{^3He}/\sigma^{^3H}}{2\sigma^{^3He}/\sigma^{^3H} - R^*}$$

Tritium experiment @ Hall A

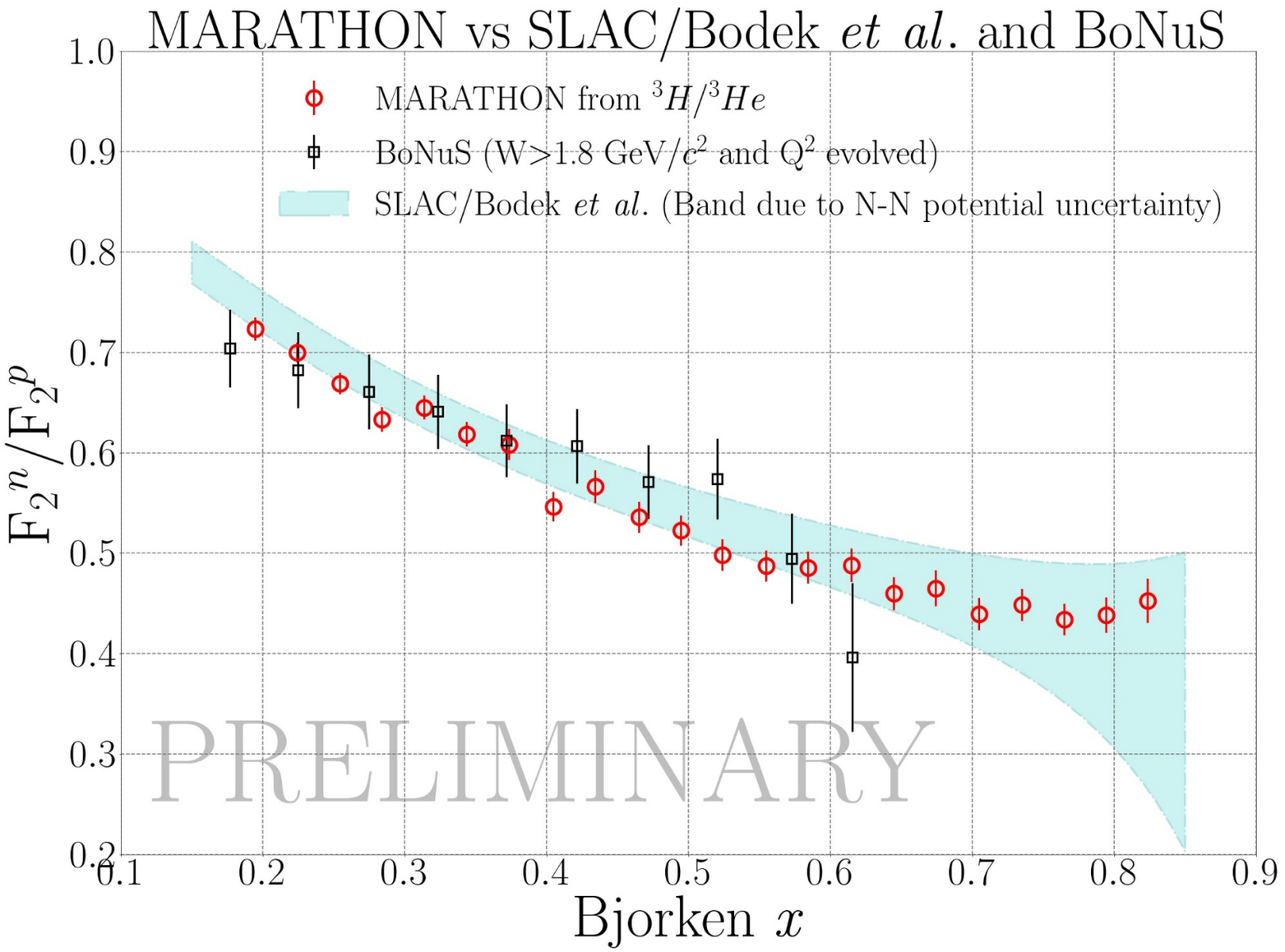
- 10.6 GeV beam, fixed scattered electron momentum (3.1 and 2.9 GeV), scattering angle 17-36 deg
- 3H, 3He, 2H, 1H targets
- Also measure EMC effects in 3He and 3H (first experimental data) and others







F2 ratio from 3H/3He

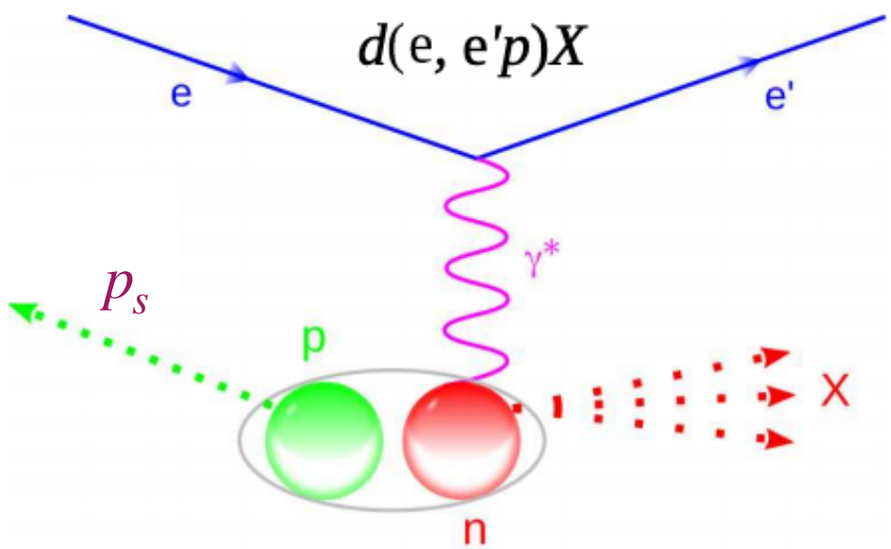


F2 neutron to proton ratio from 3H and 3He cross section ratio + R* from Kulagin and Petti model

Results finalized, paper submission imminent (to be submitted to PRL)

BoNus: Spectator tagging

Barely Off-shell Nucleon Structure experiment (@ Hall B)



Tagging spectator protons in coincidence with the scattered electrons

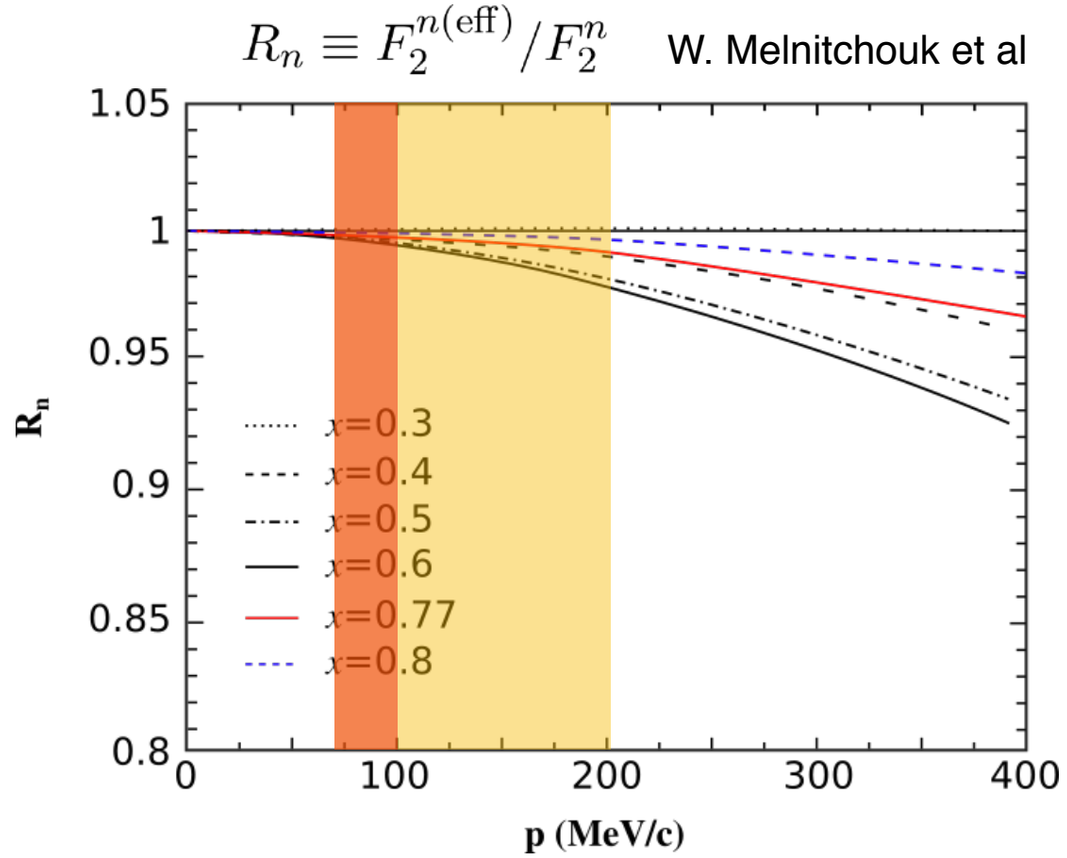
$$e + d \rightarrow e' + p_s + X$$

Proton with small momentum in the backward hemisphere

$$p_s \leq 100 MeV$$

$$\theta_{pq} \geq 100$$

→minimize probability of rescattering of spectator proton with hadronic debris



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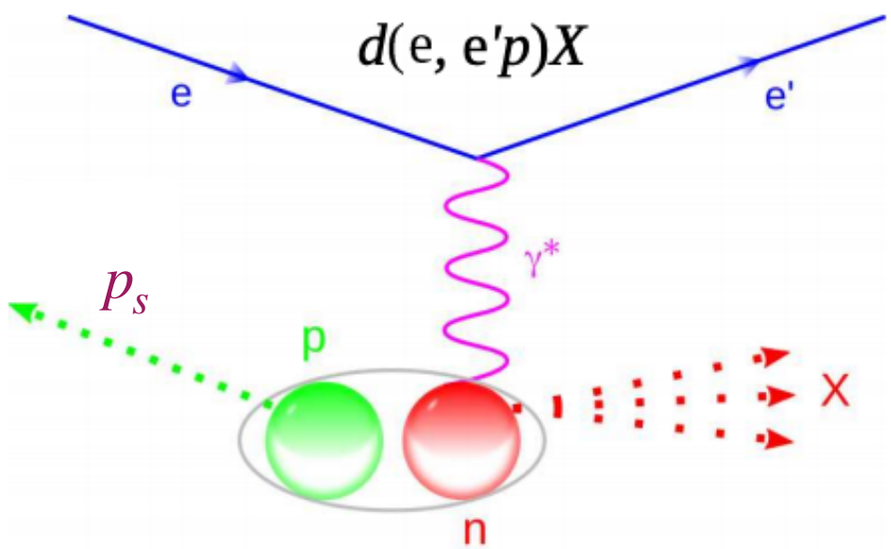

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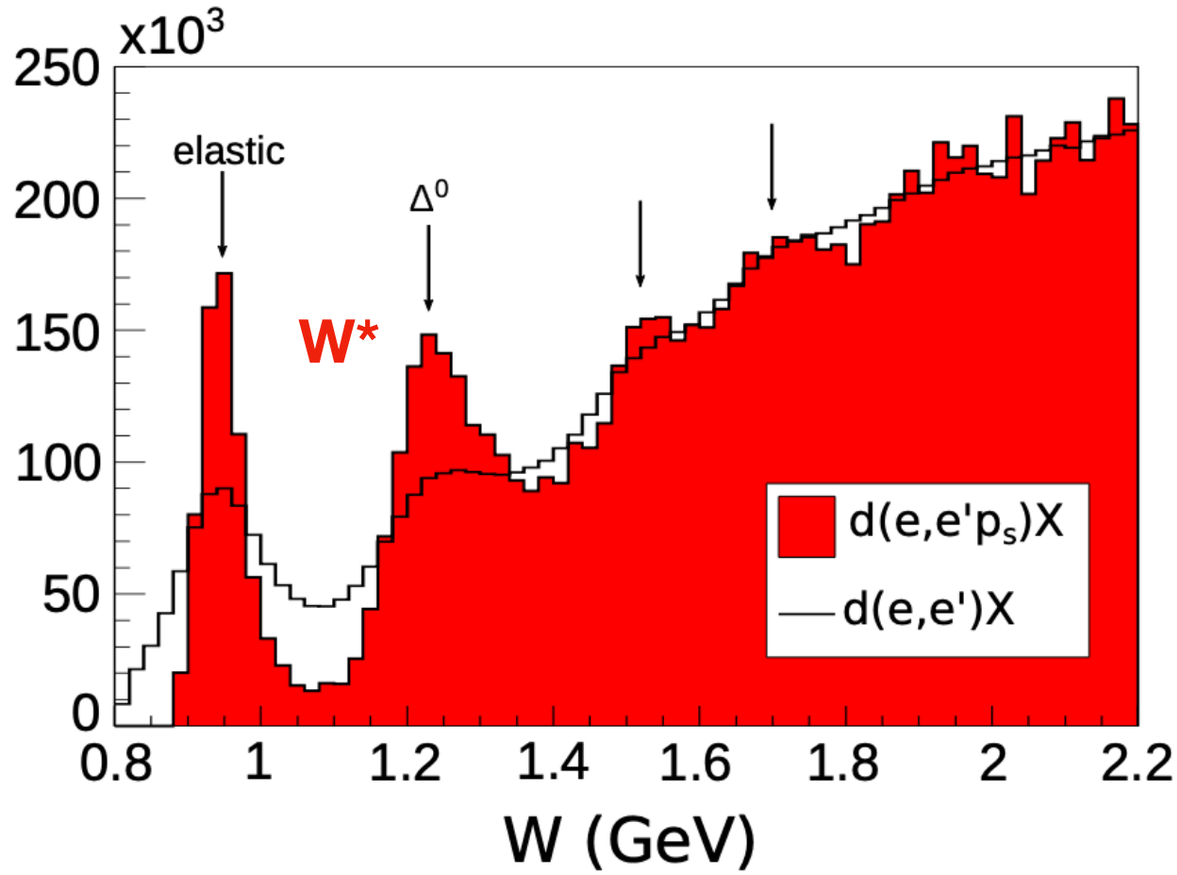
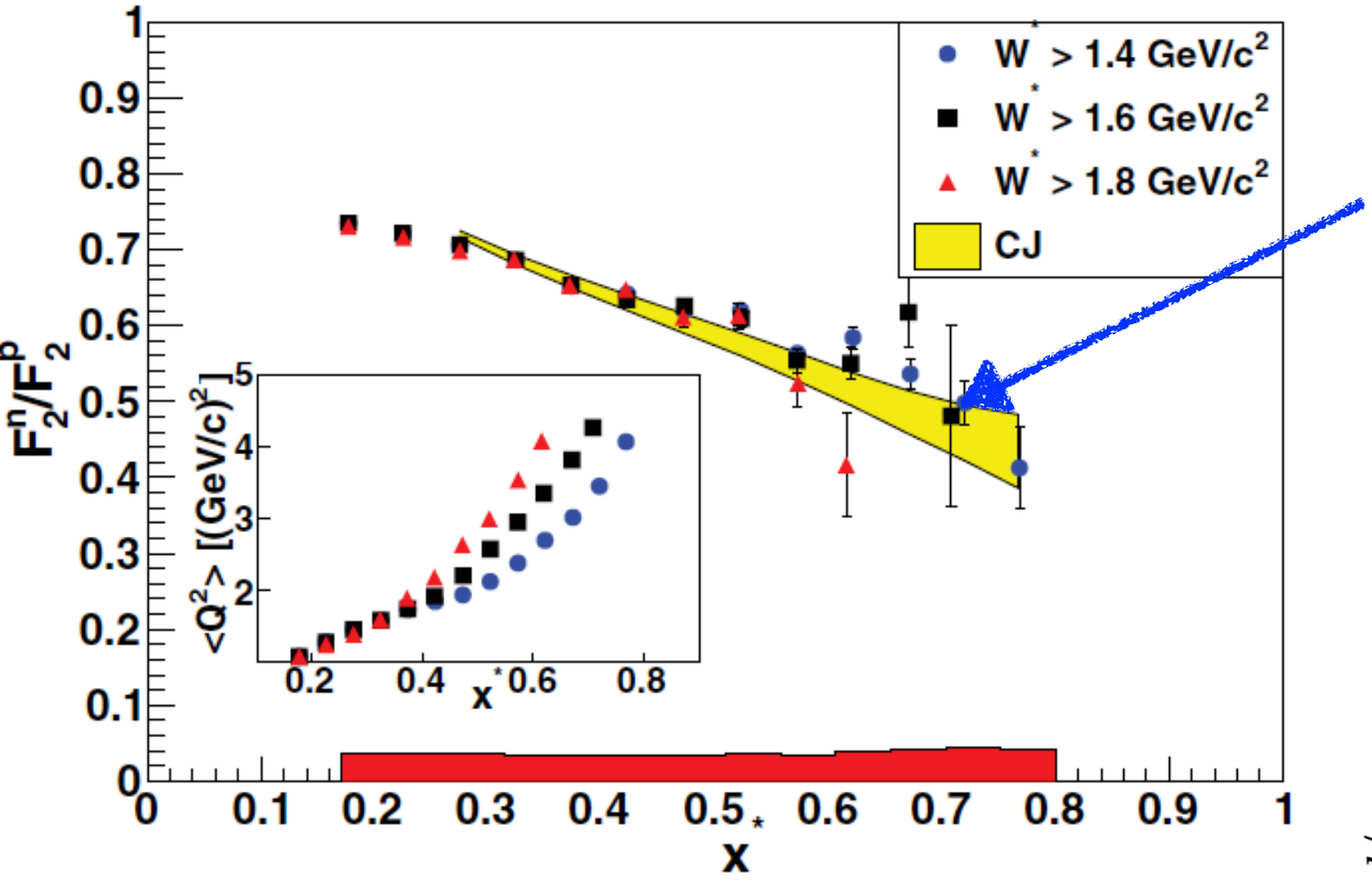


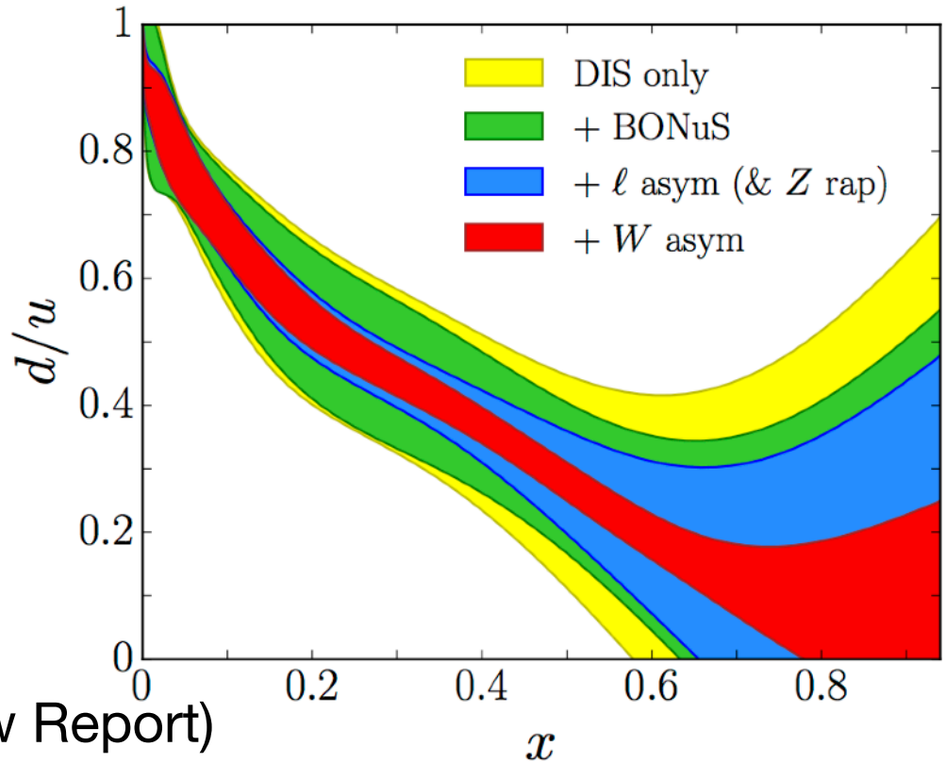
BoNus 6GeV results

S. Tkachenko et al., Phys. Rev. C 89, 045206 (2014)



Relaxing W cut add statistical power, but also start showing resonance structure

Impact of BoNus data
-> Included to CJ15



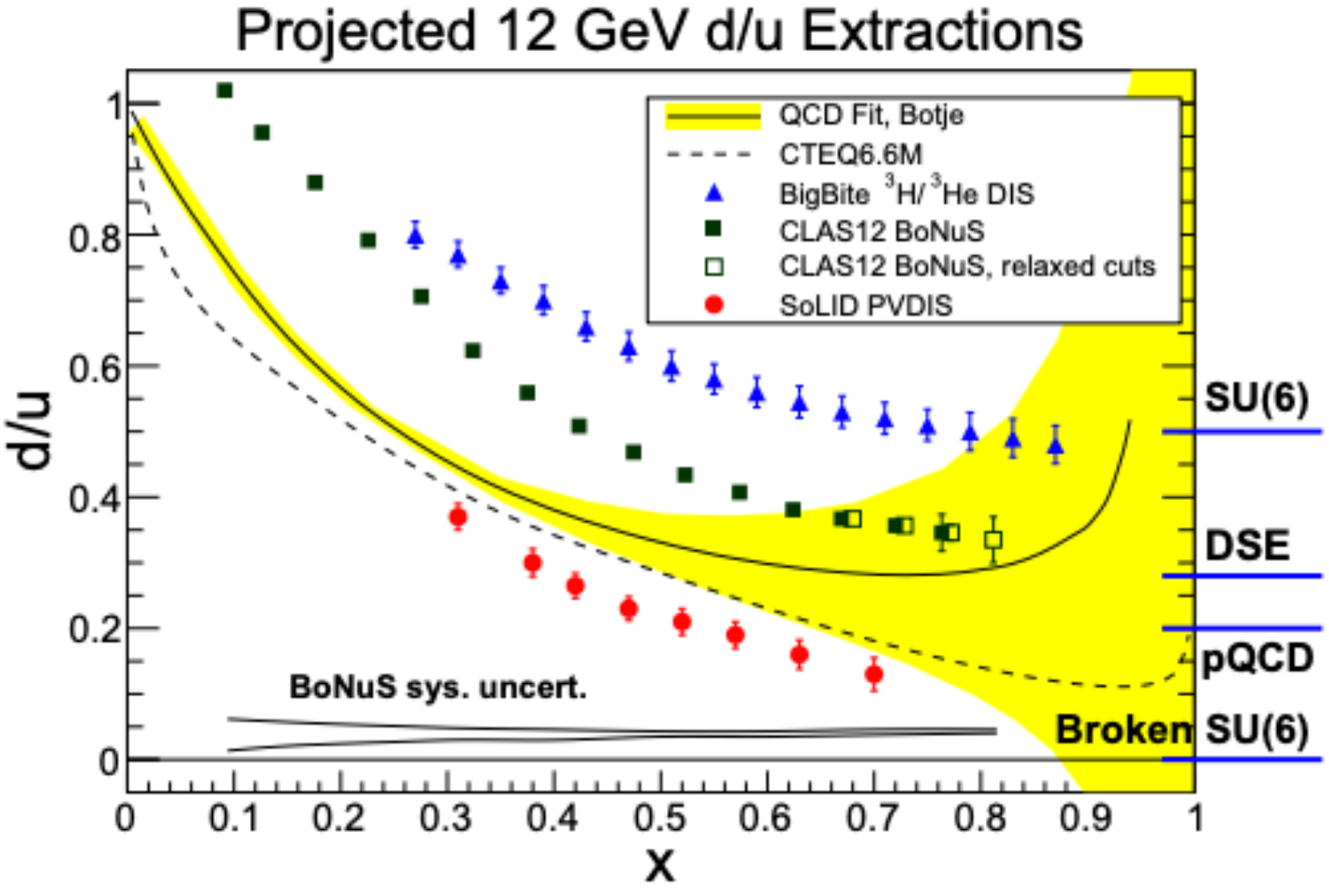
Successor experiment BoNus12 took data in 2020

Extends kinematic coverage:

$0.1 < x < 0.8$, Q^2 of 1-14 GeV^2, W up to 4GeV

Also, at EIC! (EPJ Web Conf. 112 (2016) 01022 and Yellow Report)

Constraints on d/u from JLab 12GeV



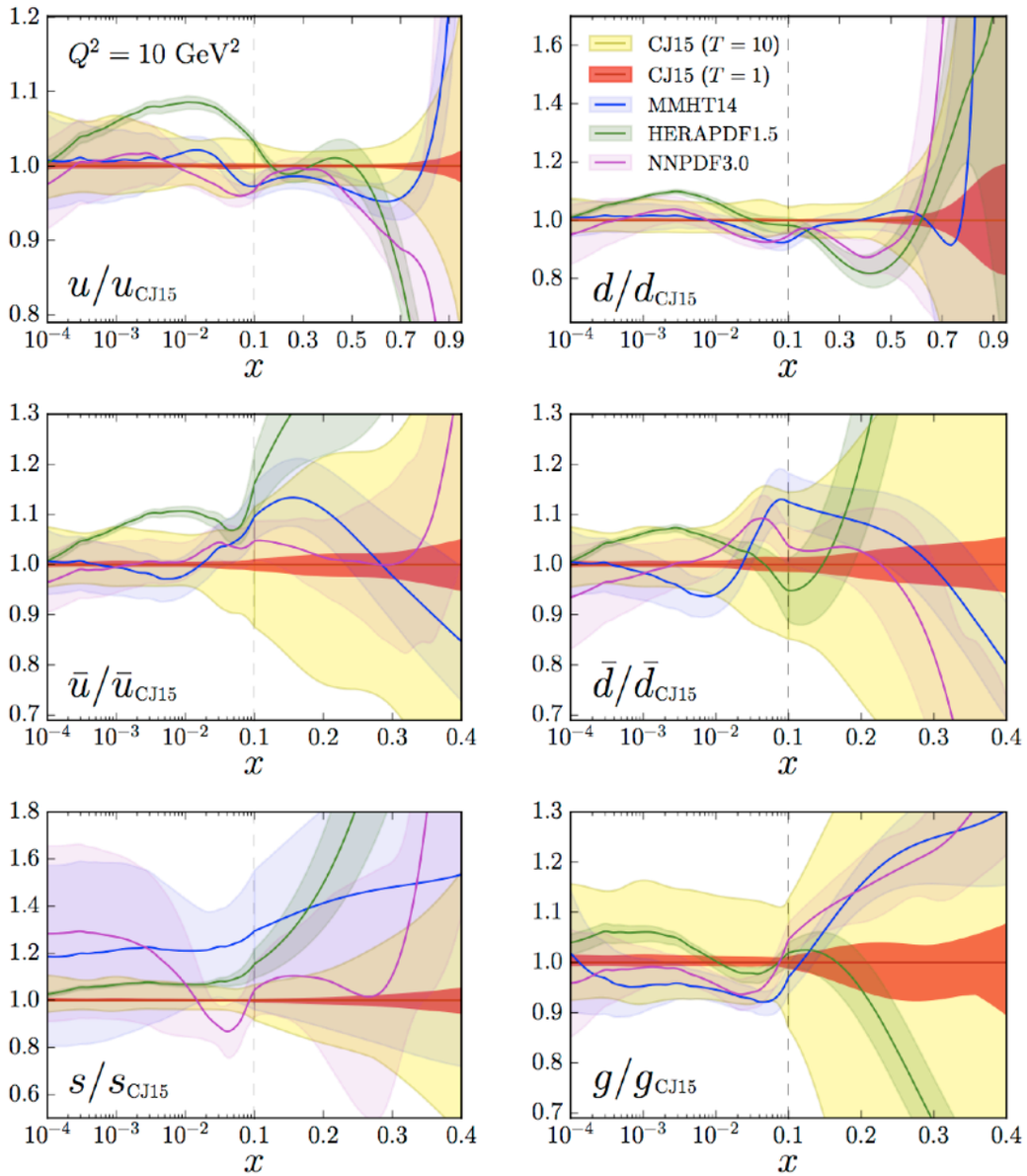
- Model dependent approach: Traditional Inclusive Measurements with deuterium

- Less model dependent approaches:
  3H/3He ratio (MARATHON) - results finalized, expect publication very soon
  Spectator tagging (BoNus12) took data in 2020

- Model independent approach:
  Future PVDIS on proton (SoLID)

CTEQ-JLab Collaboration

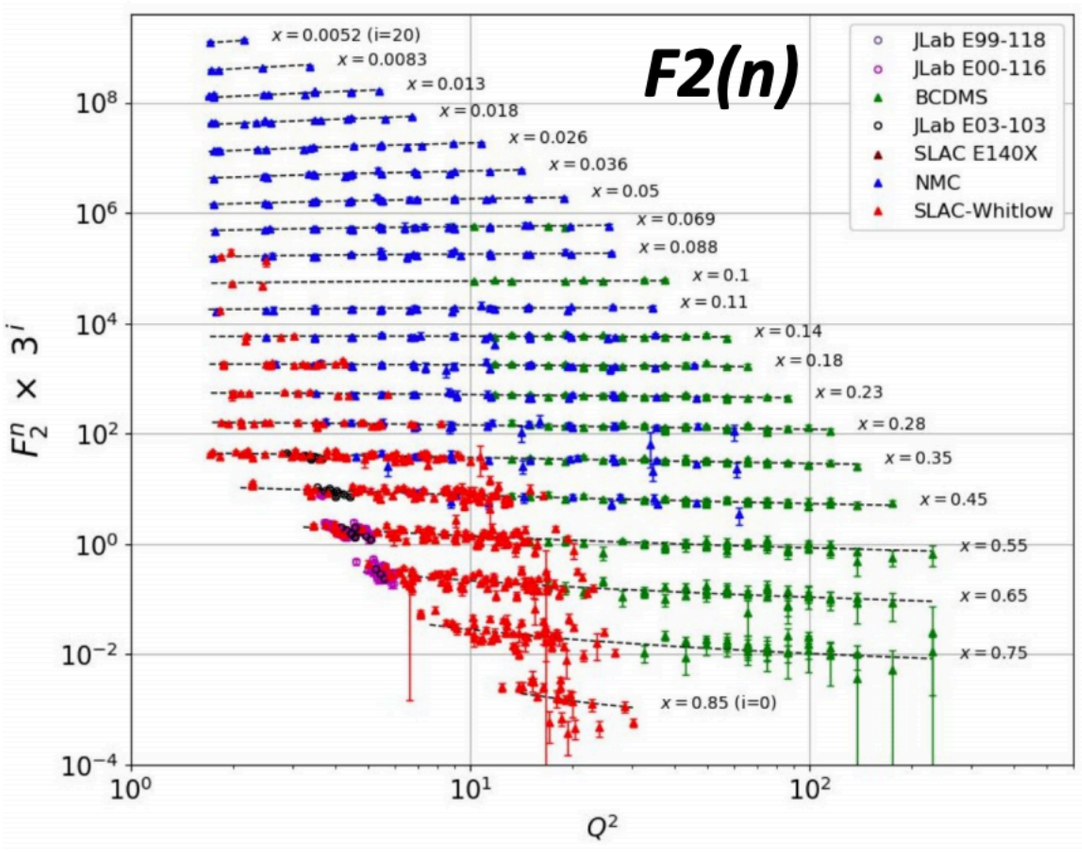
- CTEQ-based NLO QCD analysis with focus on large-x region (https://www.jlab.org/theory/cj)
- Relaxing kinematic cuts, maximizing use of large-x DIS data
- Large-x treatment, nuclear corrections
- Latest public release: CJ15 (A. Accardi et. al, Phys. Rev. D 93 114017 (2016))
- Recent developments/Ongoing efforts:
  - Including full JLab 6GeV, LHC, RHIC, DY data
  - Nuclear corrections for deuteron target
  - F2 neutron extraction
  - EIC impact studies

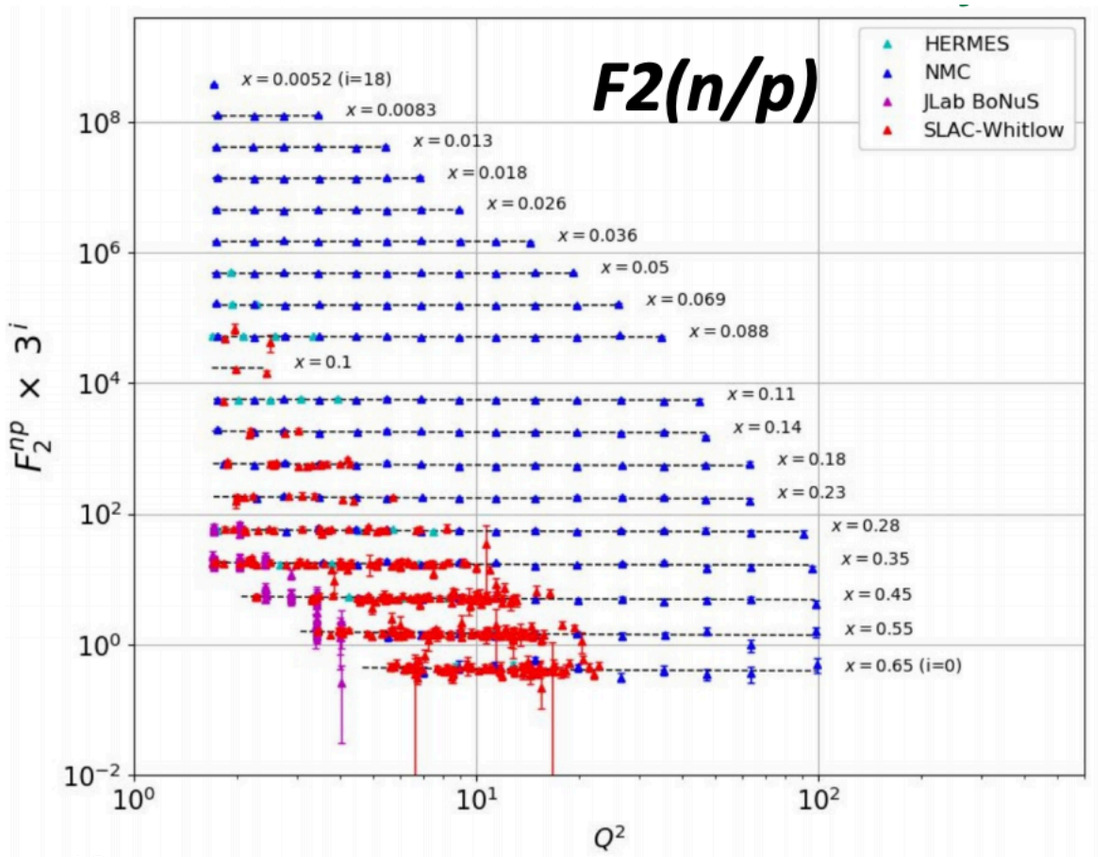


Database of neutron F_2

- F_2^n extraction from world DIS data
- Unpolarized proton and deuterium DIS data (F_2 and ratios) + nuclear corrections from global QCD analysis → F_2 neutron
- Extract $F_2^n, F_2^p, F_2(n/p)$, nonsinglet moment
- In preparation of publication,

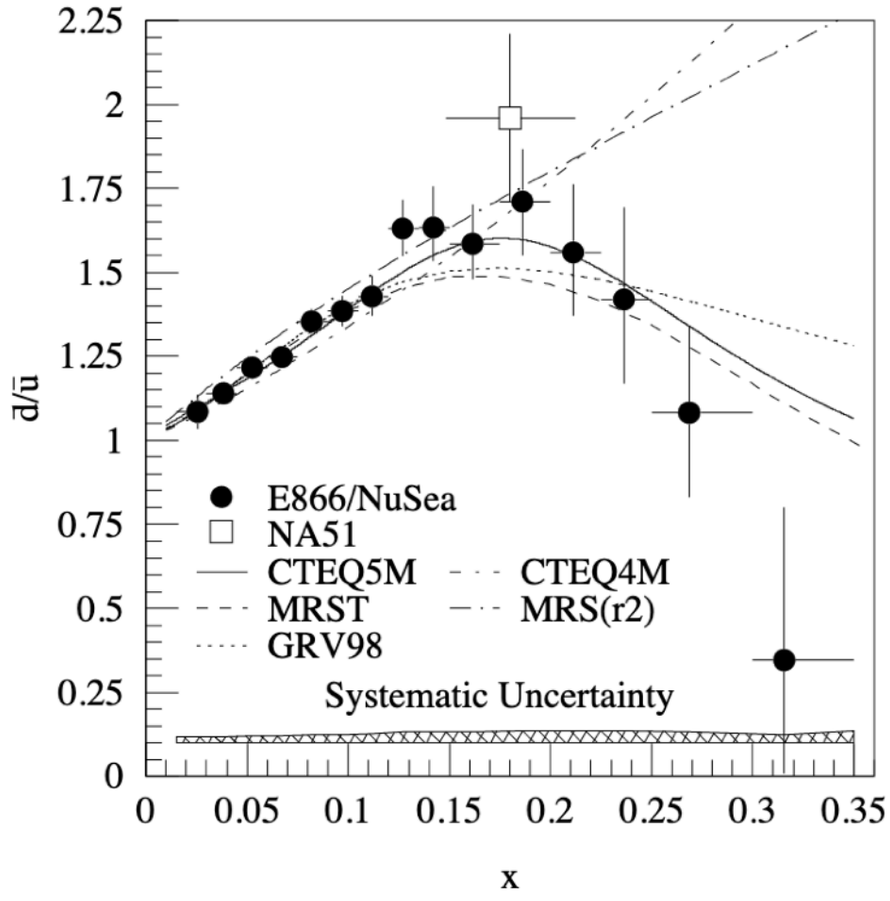
[Talk by Shujie Li, APS2021 S15]





Flavor asymmetry of nucleon sea

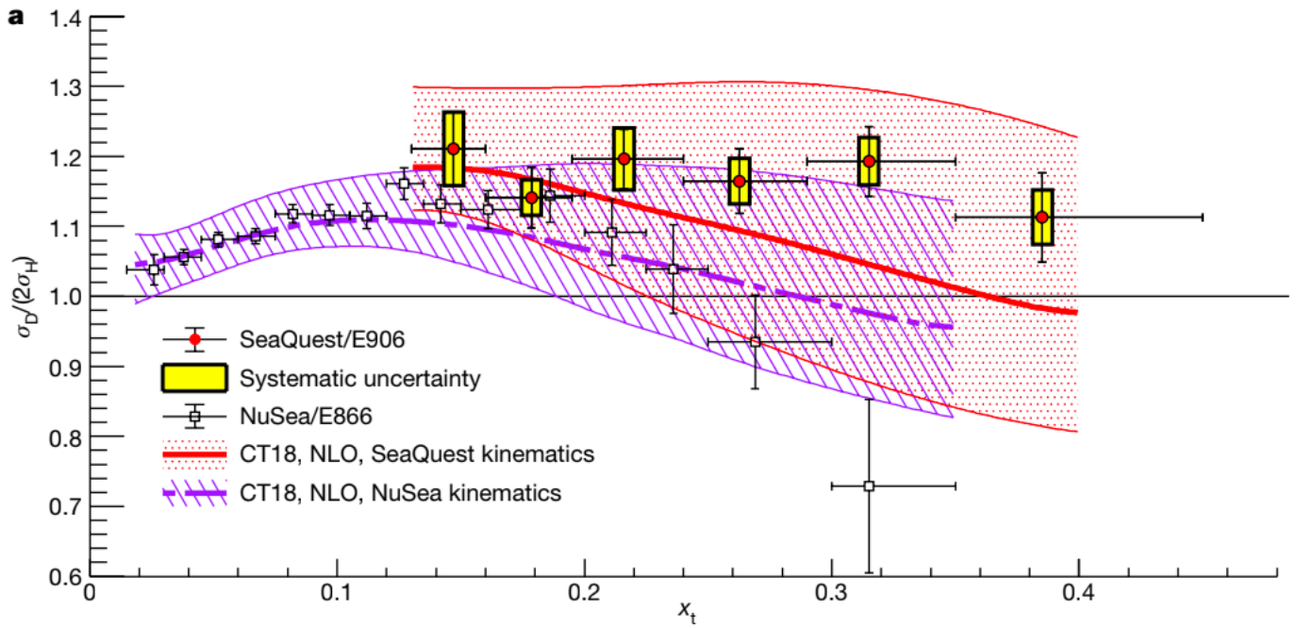
- First hint of flavor asymmetry by NMC (1991) PRL 66 (1991) 2712
- Significant flavor asymmetry confirmed as well as x-dependence by Drell-Yan data
- $\bar{d} - \bar{u}$ sign change at x ~ 0.3?
  No complete model description of the data (E866)

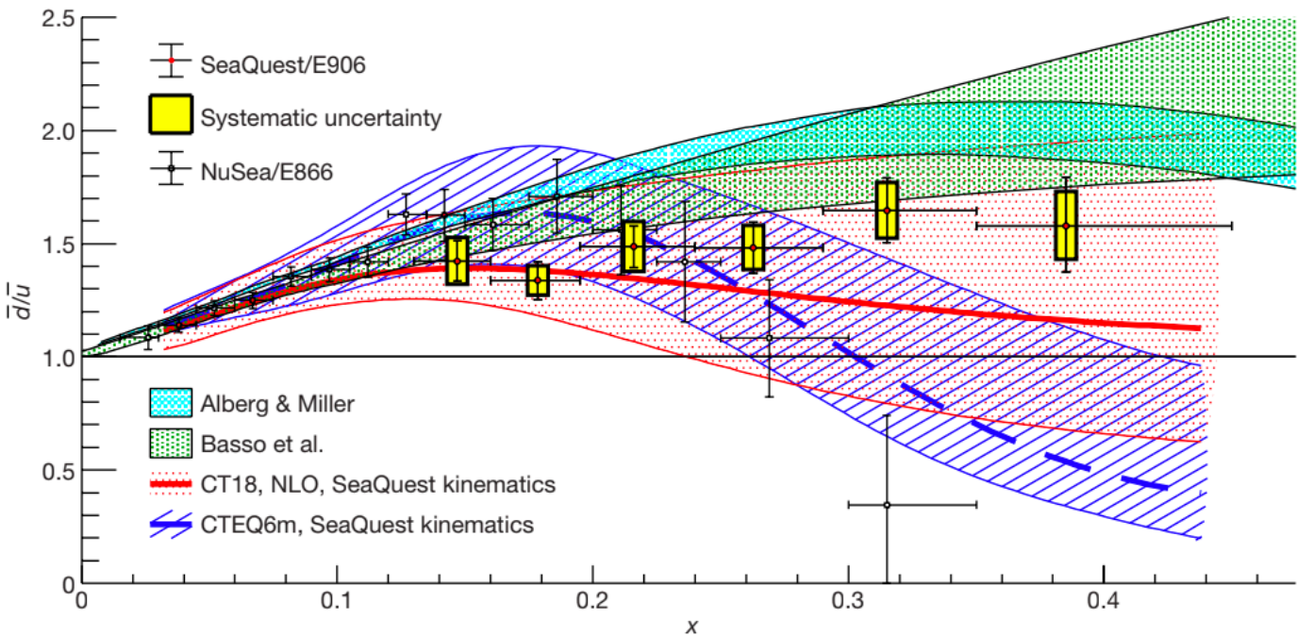


- E866 currently provides the strongest constraint on $\bar{d}/\bar{u}$ - need more data!
  - Motivated SeaQuest experiment - extending x coverage up to x ~ 0.5.
    Preliminary result show $\bar{d} - \bar{u}$ stays positive ($\bar{d}/\bar{u} > 1$)
  - STAR W data

SeaQuest result

Nature 590, 561 – 565 (2021)





120 GeV proton beam on LH2 and LD2 targets

More abundant $\bar{d}$ than $\bar{u}$ over a wide range of x

30% of anticipated statistics, more data being analyzed

SeaQuest result already begins included in other PDF analyses

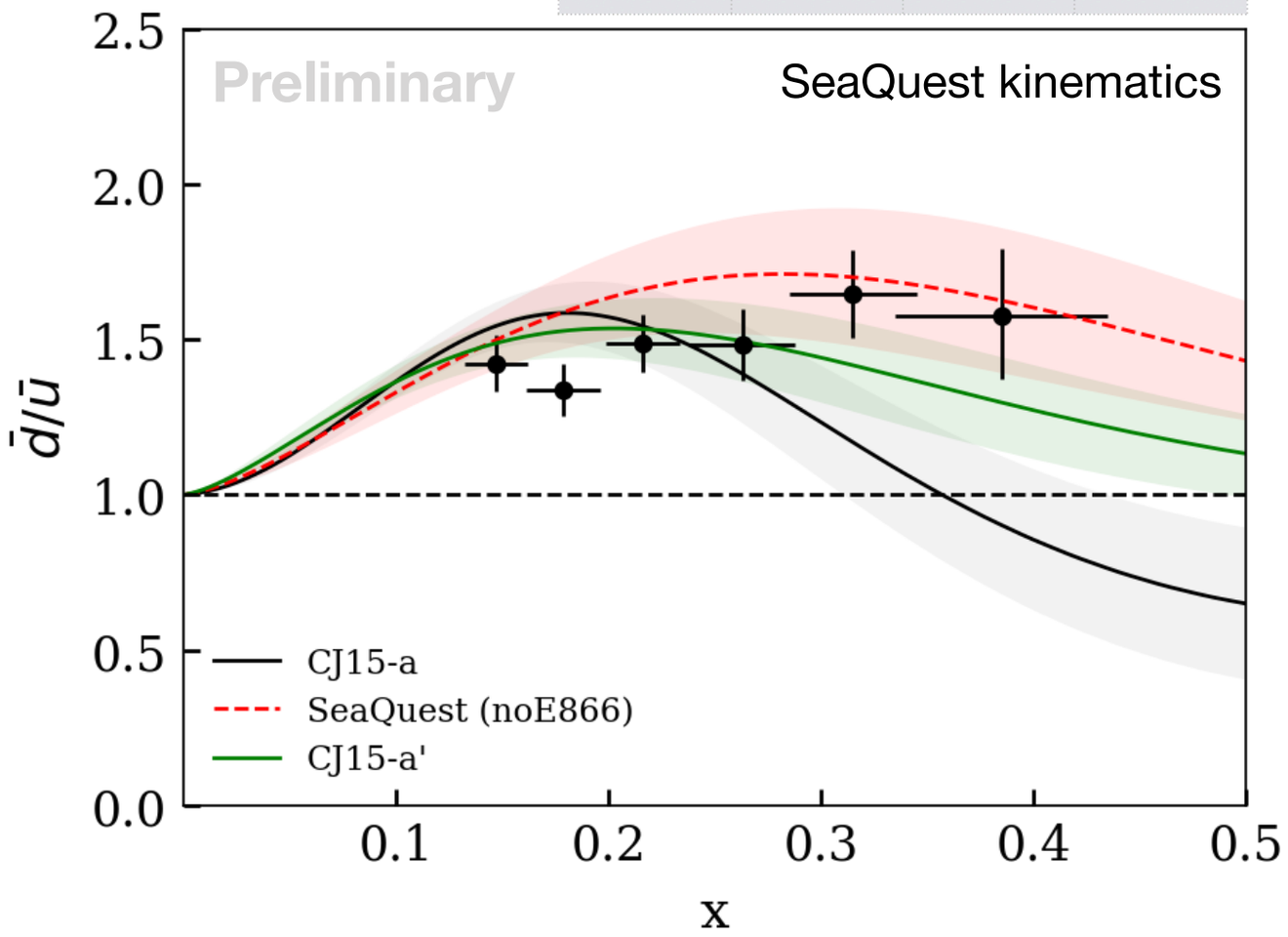
Preliminary SeaQuest fits

Incorporating the spectrometer acceptance corrections

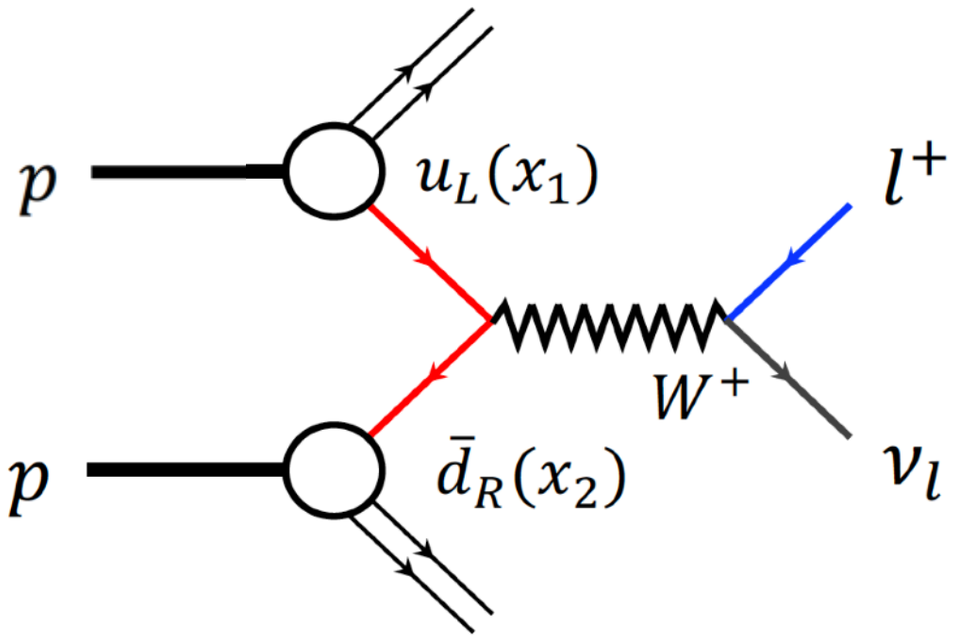
$$\left(\frac{\sigma_D}{2\sigma_H}\right)_i = \frac{\sum A_{ij}\,\sigma_D^{calc}(x_t, x_b, M)}{2\sum A_{ij}\,\sigma_H^{calc}(x_t, x_b, M)}$$

Datasets/ Fits	E866 cross sections	E866 Ratio	SeaQuest
——	✓		
·····			✓
——		✓	✓

x_t \ x_b	0.30–0.35	0.35–0.40	0.40–0.45	0.45–0.50	0.50–0.55	0.55–0.60	0.60–0.65	0.65–0.70	0.70–0.75	0.75–0.80
0.130–0.160						0.0007 0.589 0.158 4.54	0.0064 0.628 0.153 4.60	0.0175 0.675 0.148 4.68	0.0304 0.723 0.144 4.77	0.0370 0.772 0.144 4.92
0.160–0.195				0.0007 0.489 0.191 4.56	0.0071 0.528 0.184 4.63	0.0188 0.576 0.178 4.74	0.0299 0.624 0.176 4.91	0.0366 0.673 0.176 5.09	0.0432 0.722 0.176 5.27	0.0471 0.772 0.175 5.45
0.195–0.240		0.0001 0.394 0.235 4.55	0.0023 0.433 0.225 4.65	0.0105 0.477 0.217 4.78	0.0205 0.524 0.216 4.99	0.0298 0.574 0.215 5.21	0.0384 0.623 0.215 5.43	0.0456 0.672 0.214 5.63	0.0510 0.722 0.215 5.84	0.0557 0.772 0.214 6.04
0.240–0.290		0.0015 0.383 0.267 4.76	0.0078 0.427 0.264 4.99	0.0176 0.475 0.263 5.24	0.0270 0.524 0.262 5.50	0.0364 0.574 0.262 5.75	0.0436 0.623 0.262 6.00	0.0499 0.672 0.262 6.24	0.0550 0.722 0.261 6.46	0.0591 0.771 0.262 6.69
0.290–0.350	0.0002 0.341 0.324 4.95	0.0035 0.379 0.319 5.18	0.0120 0.426 0.316 5.46	0.0207 0.475 0.316 5.76	0.0298 0.524 0.316 6.05	0.0379 0.574 0.315 6.33	0.0455 0.623 0.315 6.60	0.0518 0.673 0.315 6.85	0.0544 0.722 0.314 7.10	0.0568 0.771 0.314 7.34
0.350–0.450	0.0006 0.339 0.384 5.38	0.0052 0.377 0.390 5.72	0.0125 0.425 0.386 6.04	0.0203 0.474 0.386 6.38	0.0268 0.524 0.385 6.69	0.0336 0.573 0.384 7.00	0.0374 0.623 0.384 7.29	0.0405 0.672 0.384 7.58	0.0415 0.722 0.383 7.85	0.0413 0.771 0.382 8.11



W/Z from RHIC



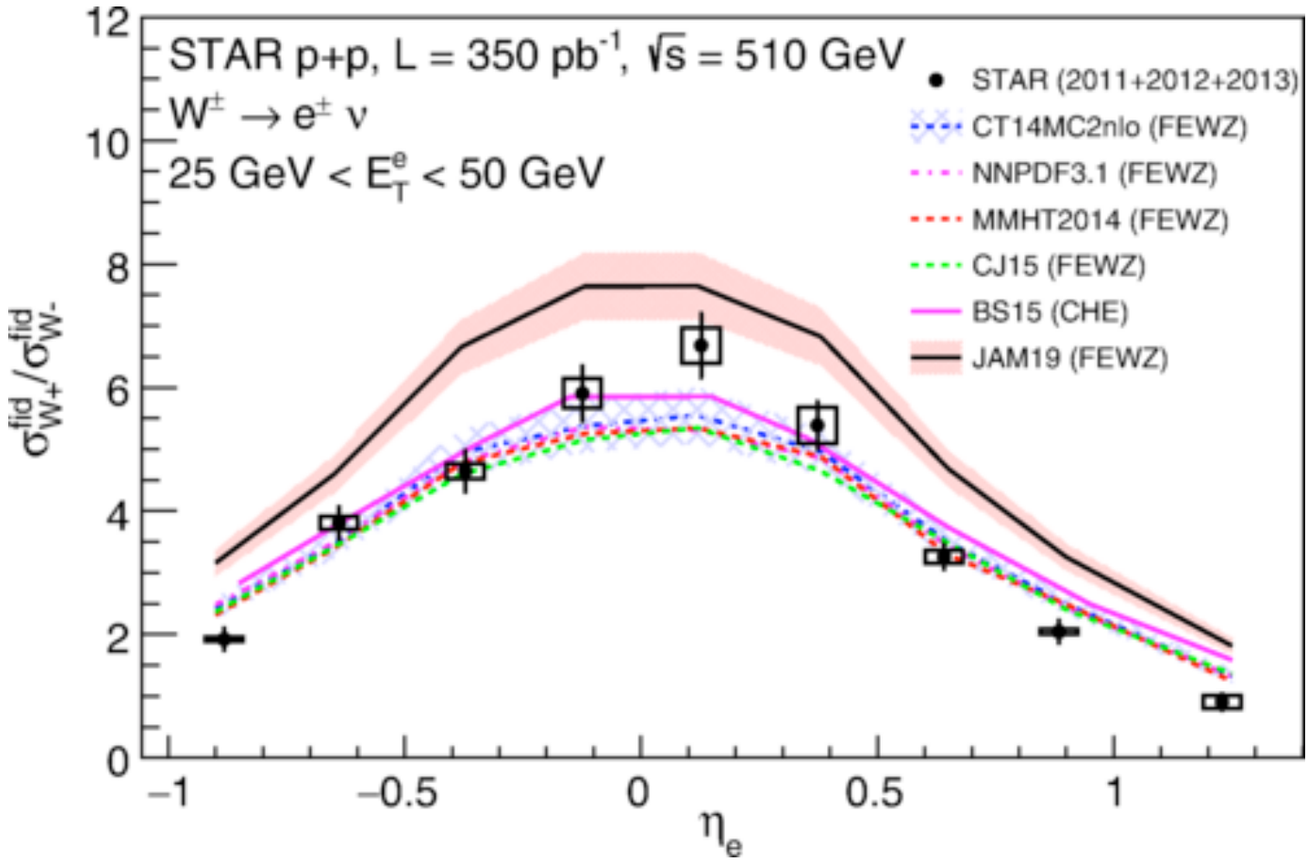
$$\frac{\sigma^{W+}}{\sigma^{W-}} \approx \frac{u(x_1)\bar{d}(x_2) + u(x_2)\bar{d}(x_1)}{d(x_1)\bar{u}(x_2) + d(x_2)\bar{u}(x_1)}$$

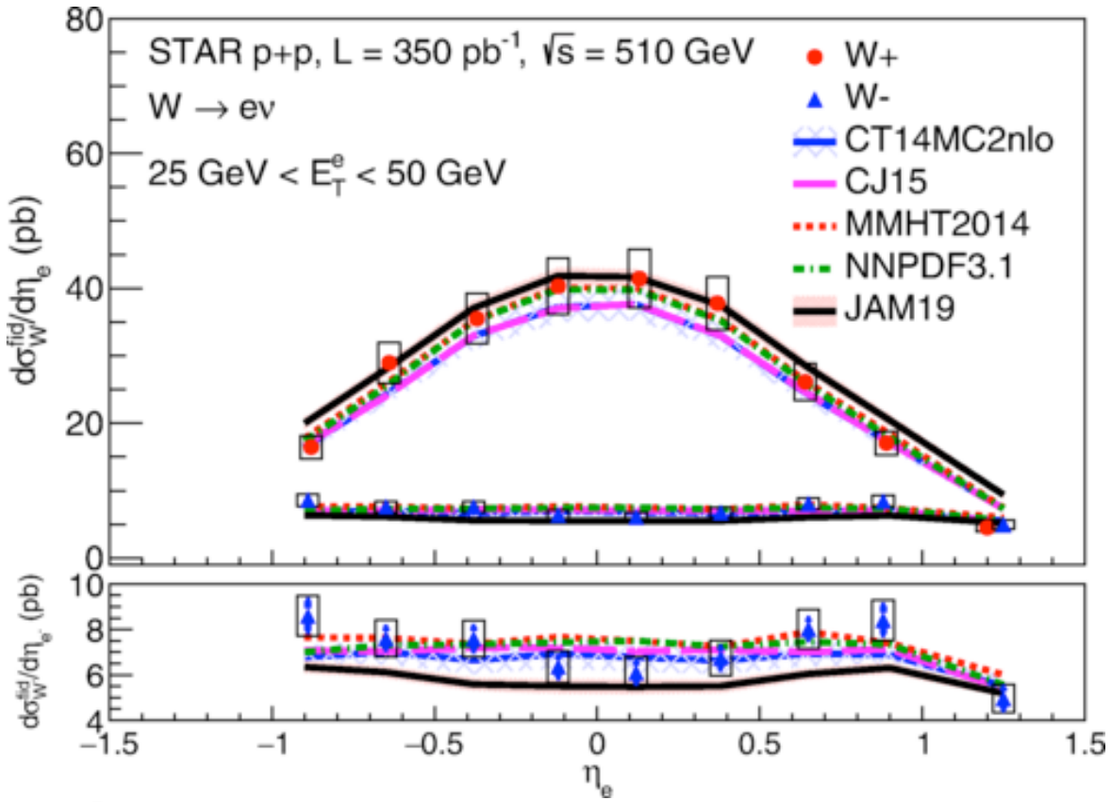
- Unique access to sea quarks, complimentary to other observables (DIS, Drell-Yan)

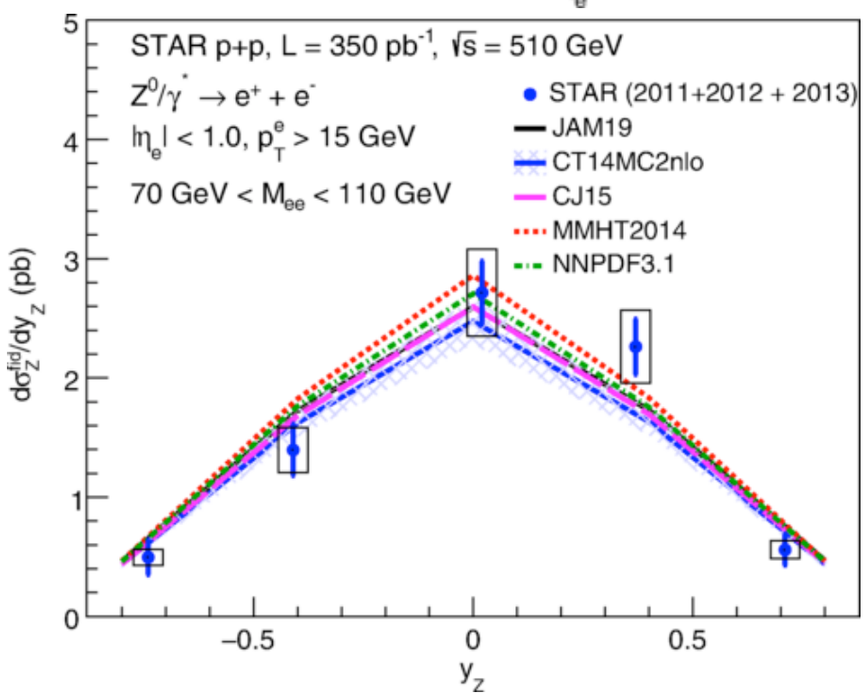
- STAR experiment at RHIC has measured the W/Z cross sections and their ratios. The data covers the range of ~ 0.1< x < 0.3 (overlapping region with FNAL DY data at different $Q^2 \sim M_W^2$

W/Z from STAR

[STAR Collaboration, Phys. Rev. D 103 012001 (2020)]

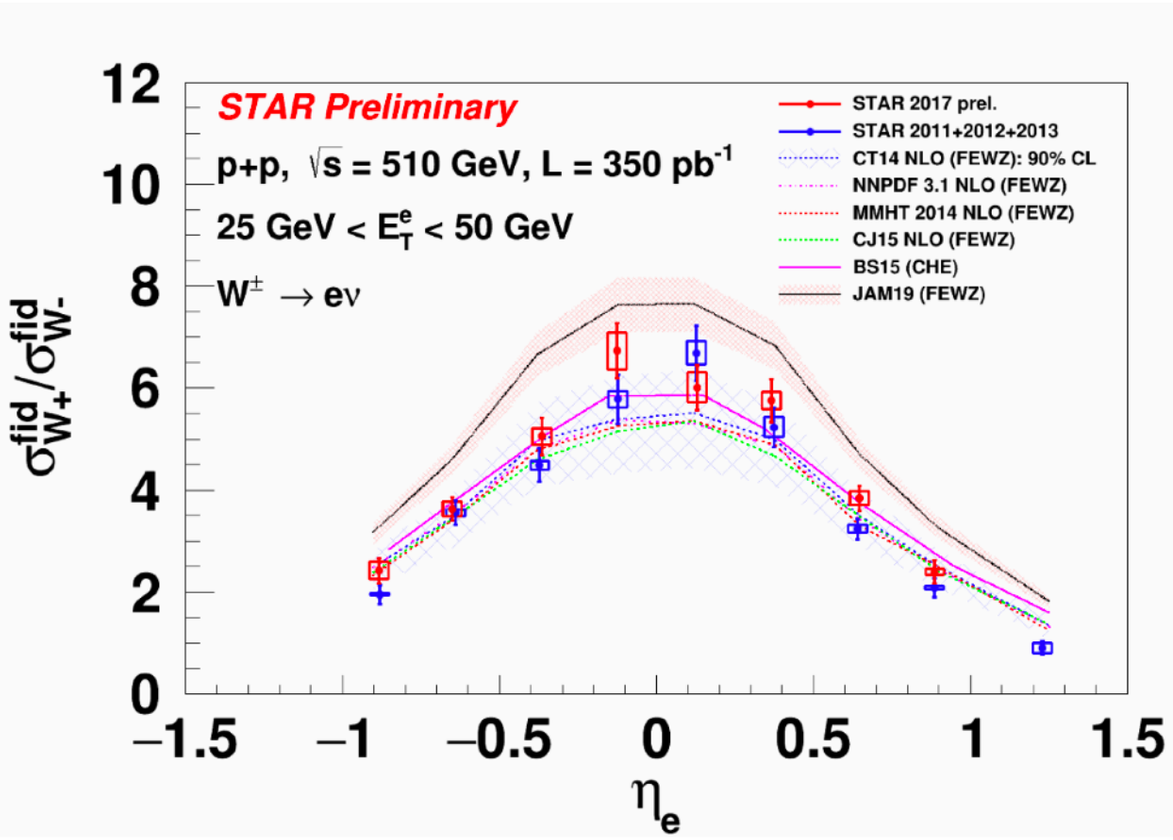


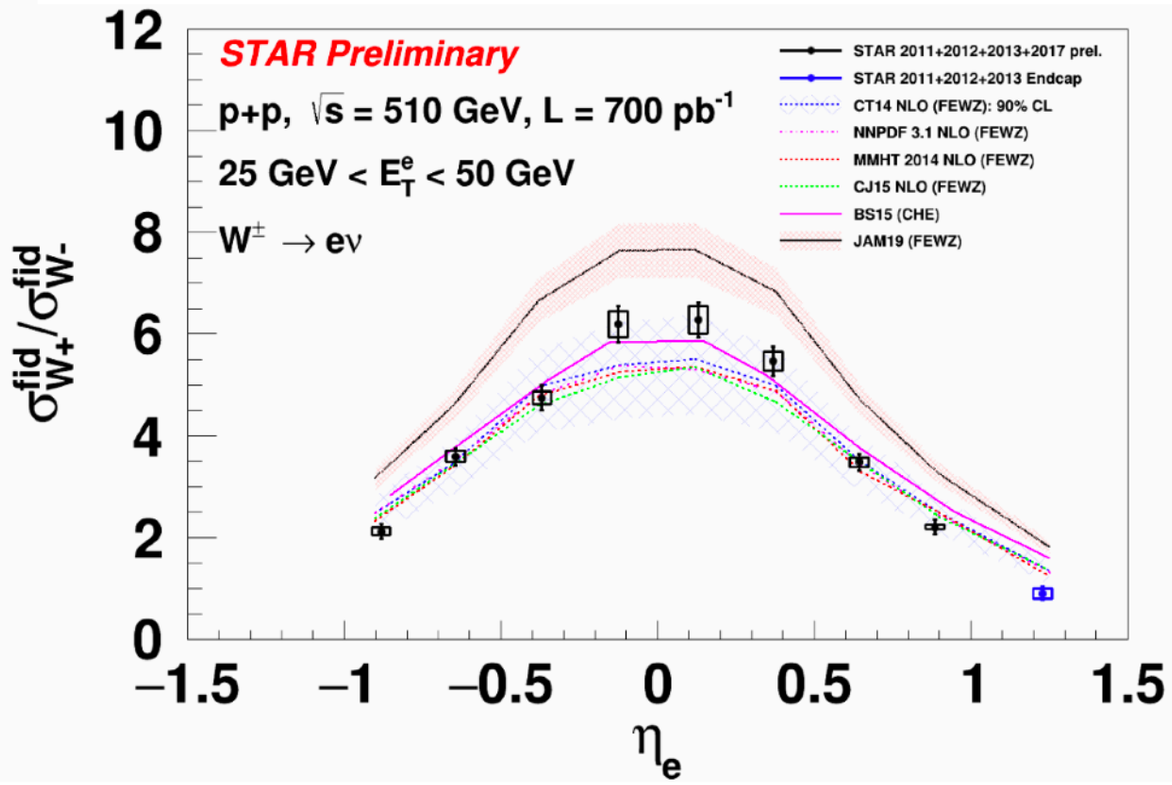




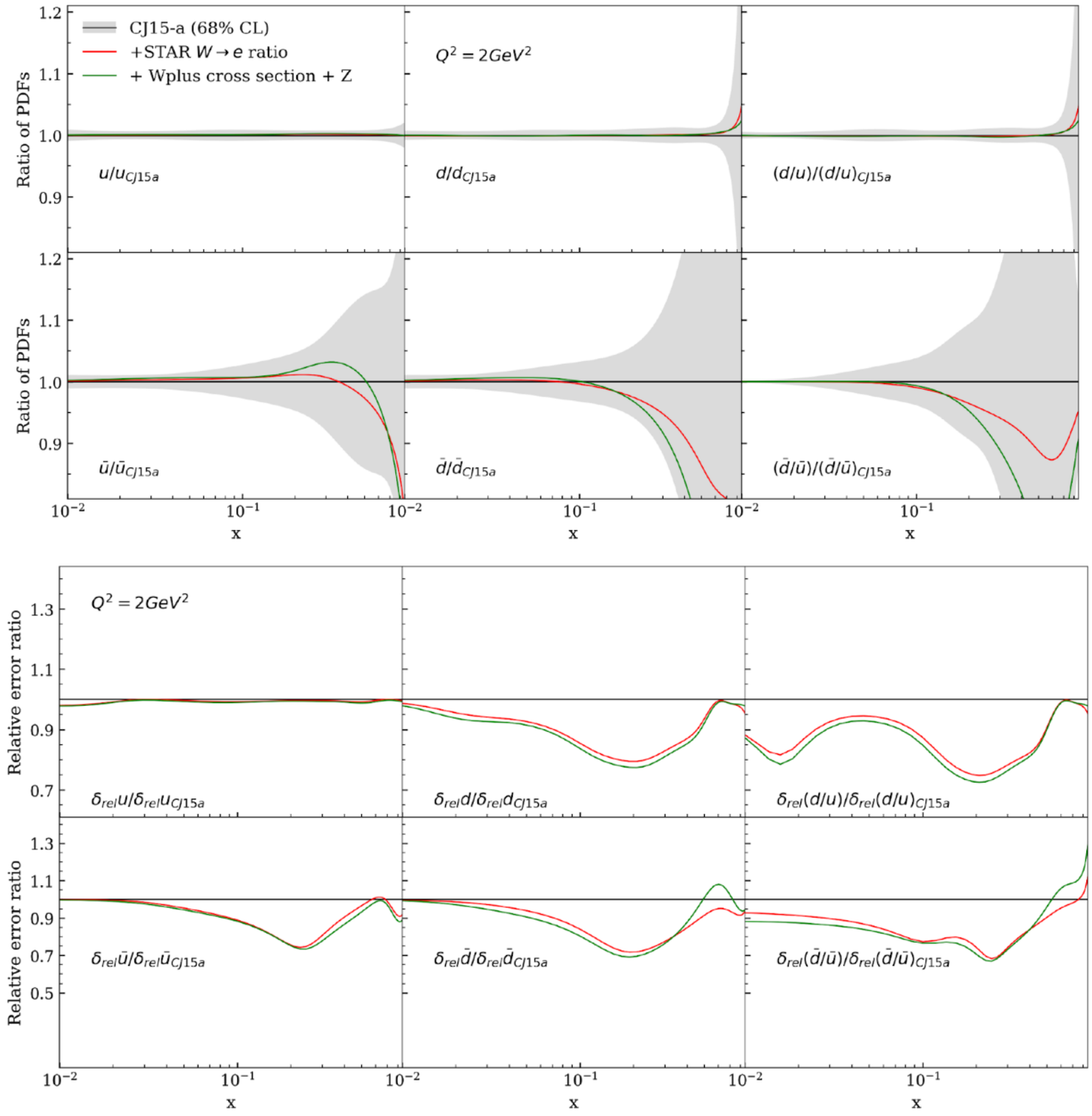
W/Z from STAR

New preliminary results from 2017 data taking





Impact of STAR data in CJ



- Published results are included in the CJ global analysis
- Ratio to the baseline CJ15-a
- Lepton charge ratio has most constraining power over $\bar{d}/\bar{u}$

Summary

- Many recent theoretical and experimental progress has made and ongoing efforts to improve our understanding of the nucleon structure

- More results to expect from JLab 12GeV program for large-x region

- New results of sea flavor asymmetry and detailed studies of the impact are already taking place by global analysis groups

- Active studies and discussion for the future EIC physics

Thank you for your attention!