CJ PDF
updates and perspectives

Alberto Accardi and Shujie Li

with many thanks to our CTEQ-JLab collaborators:
I. Fernando, X. Jing, S. Park,
C.E. Keppel, W. Melnitchouk, P. Monaghan, J. Owens

PVDIS and EW Physics at JLab 12 GeV and Beyond
INT, Seattle - 30 June 2022

HAMPTON UNIVERSITY THE STANDARD OF EXCELLENCE
BERKELEY LAB
Jefferson Lab
CTEQ-Jefferson Lab Collaboration

This work is in part supported by the DOE Office of Science

Overview

- **Part 1: PDF uncertainties and large-*x* extrapolation**
  - Experimental uncertainties

    ⟶ " Why do different global fits give different PDF uncertainties? "
  - Theoretical uncertainties

    ⟶ e.g., nuclear w.f. and PDF parametrization
  - Biases at large x

    ⟶ Interplay of HT and off-shell corrections
- **Part 2: PVDIS in global fits**
  - PVDIS on p

    ⟶ " Still needed in the BONuS 12 and Marathon era? "
  - PVDIS on D

    ⟶ CSV from nuclear, HT dynamics?

- **Part 1:**
  PDF uncertainties and large-*x* extrapolation
  - Experimental uncertainties
    → " Why do different global fits give different PDF uncertainties? "
  - Theoretical uncertainties
    → e.g., nuclear w.f. and PDF parametrization
  - Biases at large x
    → Interplay of HT and off-shell corrections

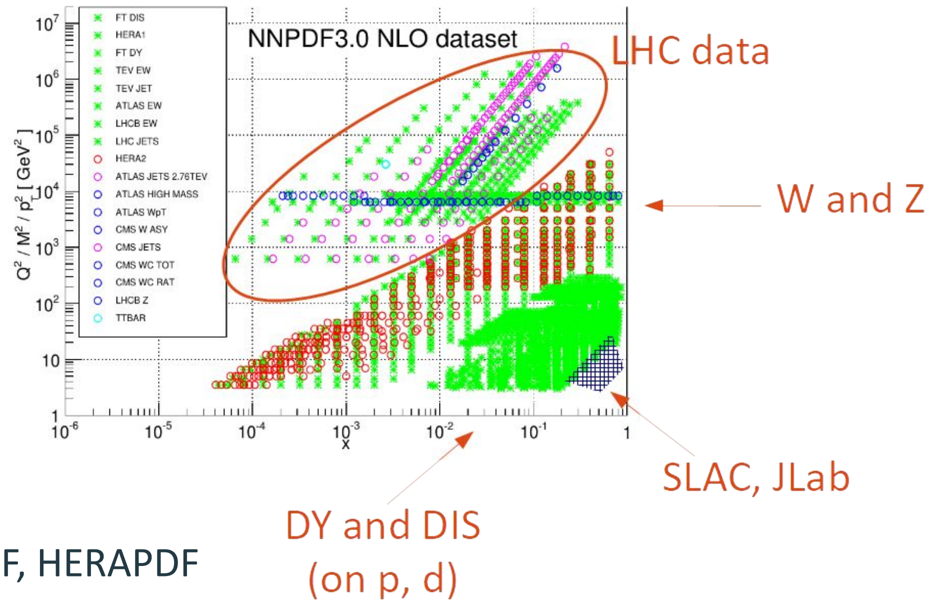
Global QCD fits

$$d\sigma_{\text{hadron}} = \sum_{f_1,f_2,i,j} \phi_{f_1} \otimes \hat{\sigma}^{f_1 f_2 \to ij}_{\text{parton}} \otimes \phi_{f_2}$$

pQCD calc.

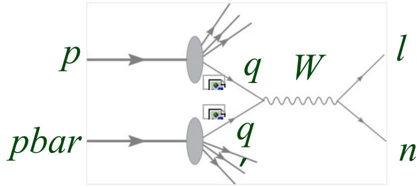
PDFs (from DIS fits)

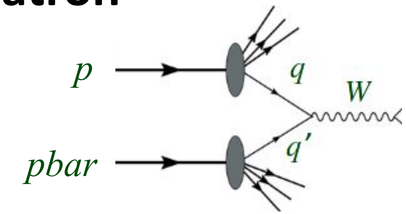
- pQCD factorization & universality:
  can fit PDFs to a variety of hard scattering data
  - Hadron-hadron collisions
    - ⟶ Jets
    - ⟶ Electro-weak boson production
  - Electron-proton DIS
  - Electron-Deuteron DIS
- >1000 data points
- 40+ years of experience,
  - "High-energy" fitters:
    - ⟶ CTEQ-TEA, MMHT, NNPDF, HERAPDF
  - Lower-energy / nuclear focus:
    - ⟶ **CTEQ-JLab, AKP**, ABMP, **JAM**



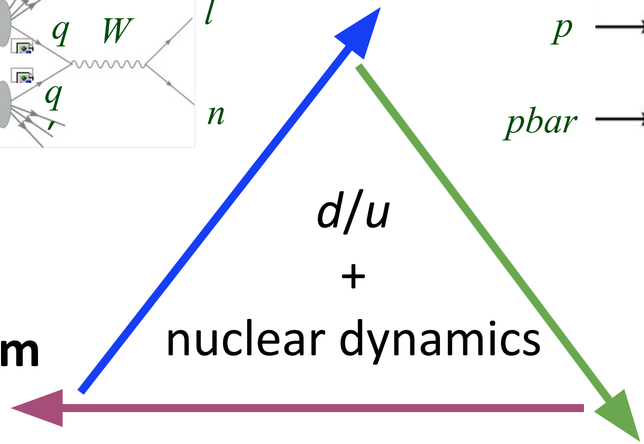
Large-x PDFs: the valence quark triangle

W bosons @ Tevatron

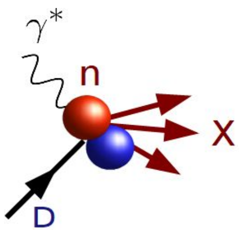




$$A_W(y) \xrightarrow{y \to y_{max}} \frac{1 - d/u}{1 + d/u}$$

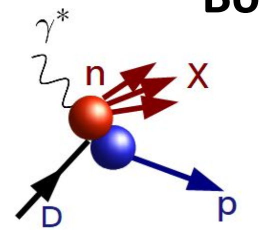


DIS on Deuterium



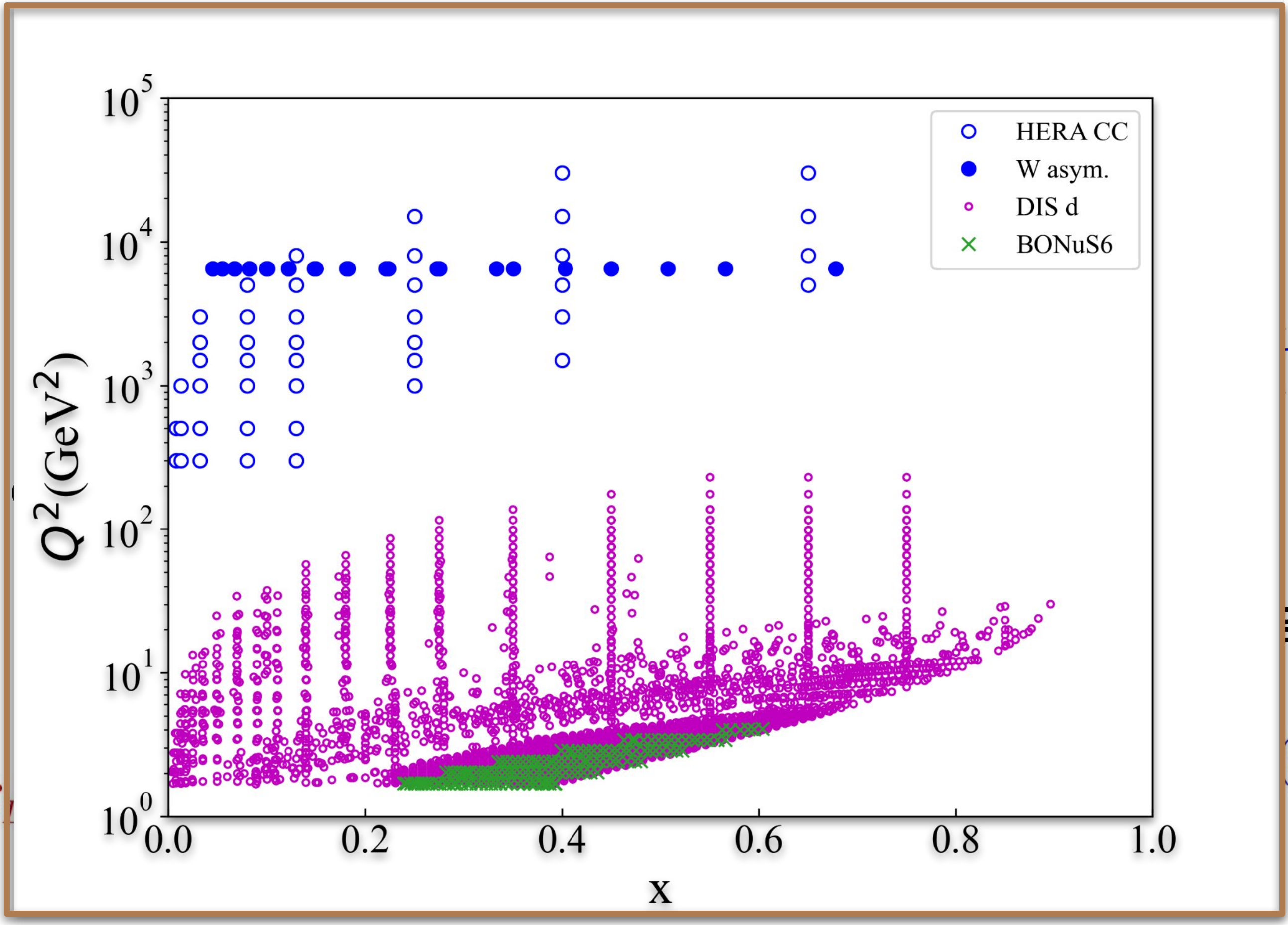
$$F_2^d \propto S_D \otimes \left[x u_{\rm off}(x) + x d_{\rm off}(x) \right]$$

"BoNuS" tagged DIS



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

Large-x PDFs: the valence quark triangle



$- d/u$
$+ d/u$

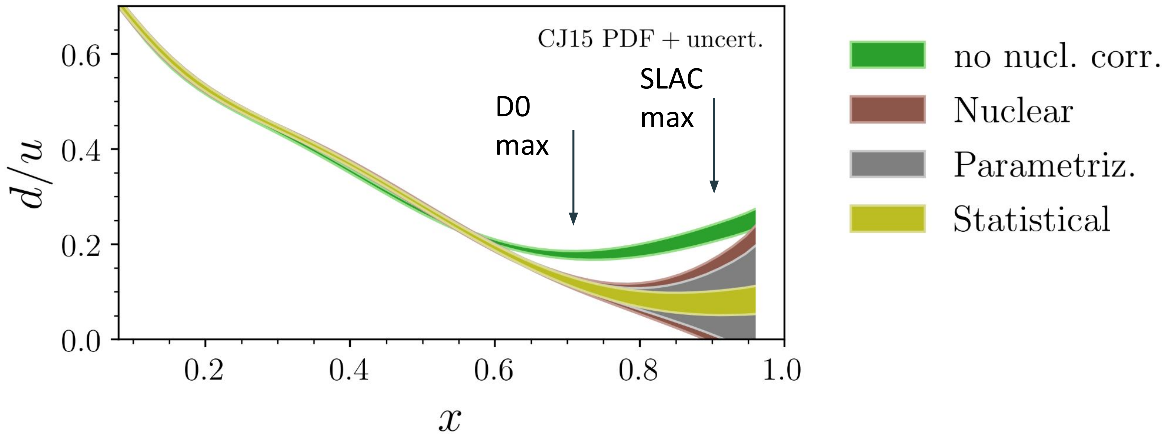
DIS

ged DIS

$F_2^d \propto S$

$(x) + 4xd(x)$

The CJ15 d/u ratio



- **Statistical uncertainties**
  - Propagated from exp. stat. errors into the PDF parameters
- **Theoretical uncertainties**: difficult to quantify, e.g.:
  - Nuclear: wave function choice
  - Off-shell uncertainties are parametrized ⟶ partly included in statistical band
  - Parametrization: *d*-quark flexibility in extrapolation region
- **Theoretical biases**: even less obvious!
  - Interplay of HT and offshell implementation choices

- **Part 1: PDF uncertainties and large-*x* extrapolation**
  - **Experimental uncertainties**

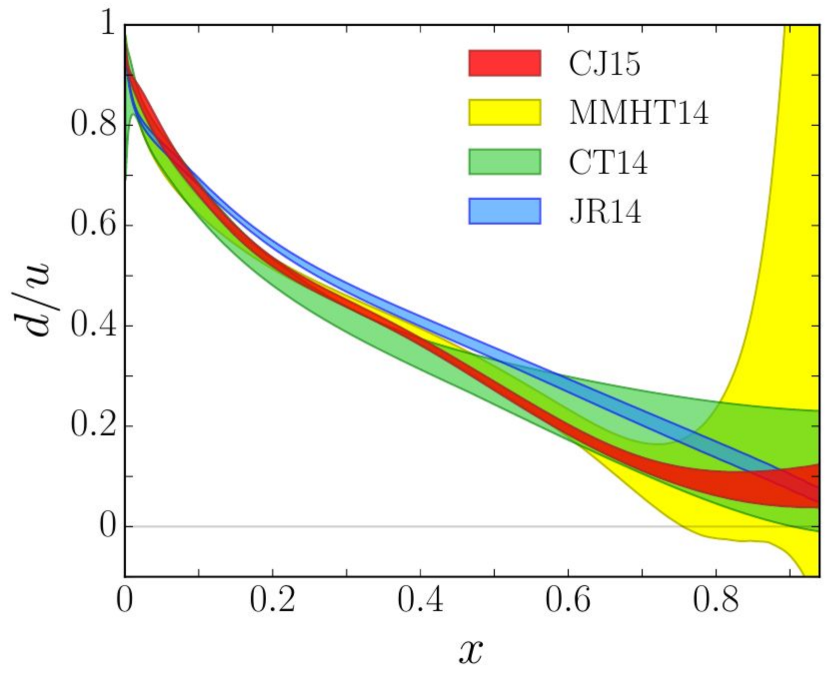
    ⟶ **" Why do different global fits give different PDF uncertainties? "**
  - Theoretical uncertainties

    ⟶ e.g., nuclear w.f. and PDF parametrization
  - Biases at large *x*

    ⟶ Interplay of HT and off-shell corrections

Global fits are not created equal…

- **Uncertainty determination**
  - Hessian (JR)
  - Hessian + "Tolerance" (*)
    - ⟶ T ~ 10 (CT14) *⟶ T. Hobbs*
    - ⟶ T ~ 5-7 (MMHT14)
    - ⟶ T = 1.646 (CJ15)
  - Data Resampling (JAM) *⟶ N. Sato*
  - DR + Cross Validation (NNPDF)



- **Parametrization**
  - $x^a (1-x)^b P(x)$ – most groups
    - ⟶ Extended or standard *d*-quark
  - Neural Nets – NNPDF

- **Data choice and coverage, …**
  - No SLAC, JLab without TMC, HT corrections
  - Highest *x* reach for d/u on proton if using reconstructed W asymmetries (vs. decay lepton asymmetries)
  - …

(*) CJ vs. CT comparison on "equal" footing:
Accardi, Hobbs, Jing, Nadolsky, EPJC 81 (2021) 7

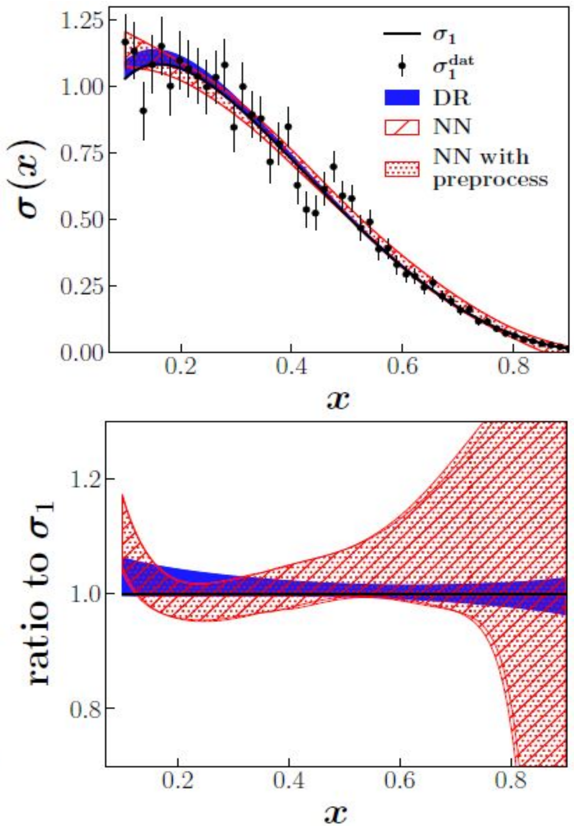
On the determination of uncertainties

- **The method can effectively modify the likelihood!**
  - Even with perfectly compatible (toy) data!

N. Hunt-Smith et al., 2206.10782

- **Bayesian Methods**
  (Markov Chain MC, Nested Sampling)
  - Explore the likelihood function
  - Well approximated by
    $\longrightarrow$ Hessian, Data Resampling (**DR**)

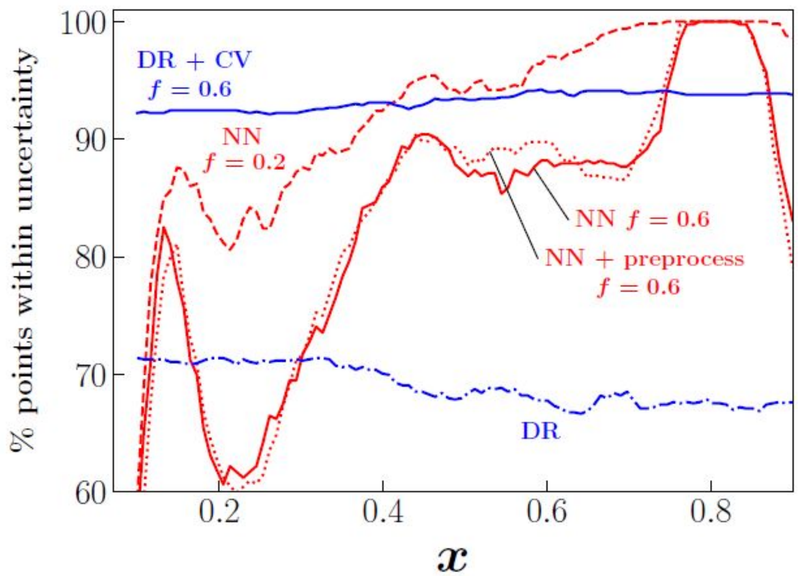
- **Cross Validation, NN-based fits**
  - Inflate the uncertainties
  - Deform the likelihood



Combining PDF fits

- **PDF4LHC**
  - Statistically combines different fits (⟶ *T. Cridge*)
  - But their likelihoods differ
    - ⟶ What's the statistical meaning of the combination?
- CT, MMHT
  - ⟶ Hessian + (different) tolerances
- NNPDF
  - ⟶ DR + Cross Validation + NN parametrization

N. Hunt-Smith et al., 2206.10782

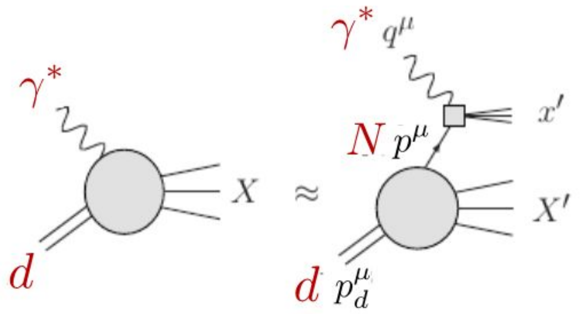


- **How should we interpret the resulting PDF4LHC error band?**

- **Part 1: PDF uncertainties and large-*x* extrapolation**
  - Experimental uncertainties
    - ⟶ " Why do different global fits give different PDF uncertainties? "
  - Theoretical uncertainties
    - ⟶ e.g., nuclear w.f. and PDF parametrization
  - **Biases at large *x***
    - ⟶ **Interplay of HT and off-shell corrections**

Deuteron 1: Fermi motion and binding

- **Weak binding approximation:**
  - Incoherent scattering from not too fast individual nucleons
  - Neglects FSI



$$F_{2d}(x,Q^2) = \int \frac{dz}{z} dp_T^2 \, \mathcal{K}(z,p^2,\gamma) \left|\psi_{N/d}(|\vec{p}\,|)\right|^2 F_{2N}(x/z,Q^2,p^2)$$

kinematic and "flux" factors

Nucleon wave function

structure function of **bound, off-shell nucleon**

→ $z = \frac{p \cdot q}{p_d \cdot q} \approx 1 + \frac{p_0 + \gamma p_z}{M} \quad \left[p_0 = M + \varepsilon, \;\; \varepsilon = \varepsilon_d - \frac{\vec{p}^{\,2}}{2M} \right]$

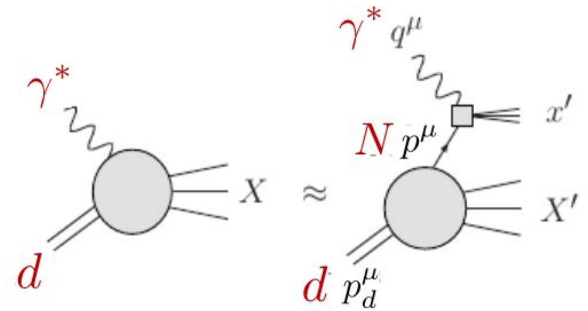
momentum fraction of d carried by N

→ at finite Q^2, $\gamma = \sqrt{1 + 4x^2p^2/Q^2}$

quantifies how far the nucleon is from the light cone (γ = 1)

Off-shell corrections in Deuteron

- **Nucleons are bound in the deuteron:**
  - $p^2 < M^2$
  - Structure functions are deformed (but not too much if x not too large)



- **Offshell expansion:**
  - Expand PDFs in nucleon's virtuality $q_N(x,Q^2,p^2) = q_N^{\text{free}}(x,Q^2)\left[1 + \frac{p^2 - M^2}{M^2}\delta f_q^N(x)\right]$
  - With flavor-independent δf

$$F_{2N}(x,Q^2,p^2) = F_{2N}^{\text{free}}(x,Q^2)\left[1 + \frac{p^2 - M^2}{M^2}\delta f(x)\right]$$

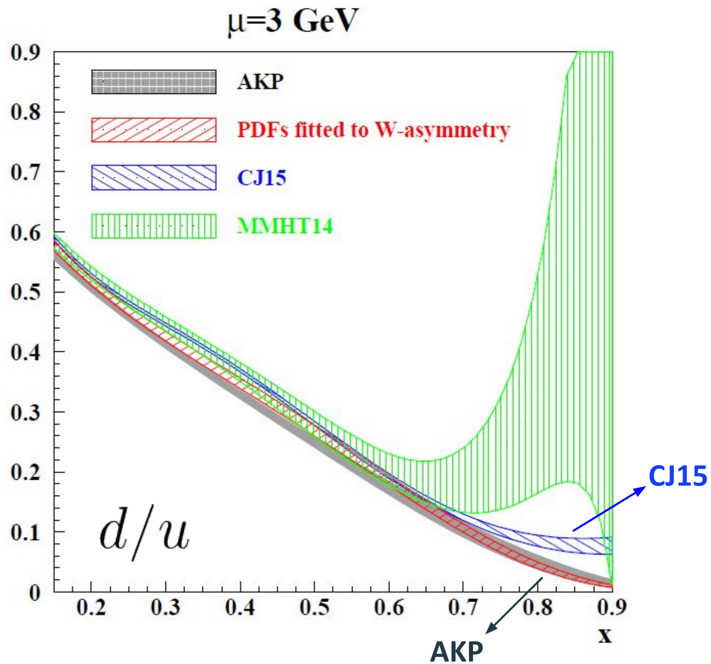
Free proton, neutron structure function

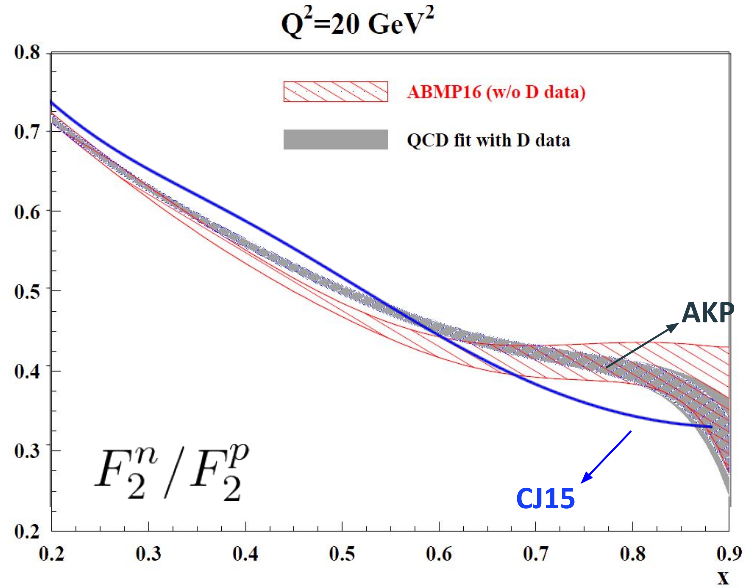
"offshell function"

When fitted, this effectively becomes a phenomenological "catch-all" term (see later)

  - Parametrized and fitted (see the earlier triangle)
    $\longrightarrow$ **CJ15, AKP, JAM**

CJ15 and AKP: free nucleons

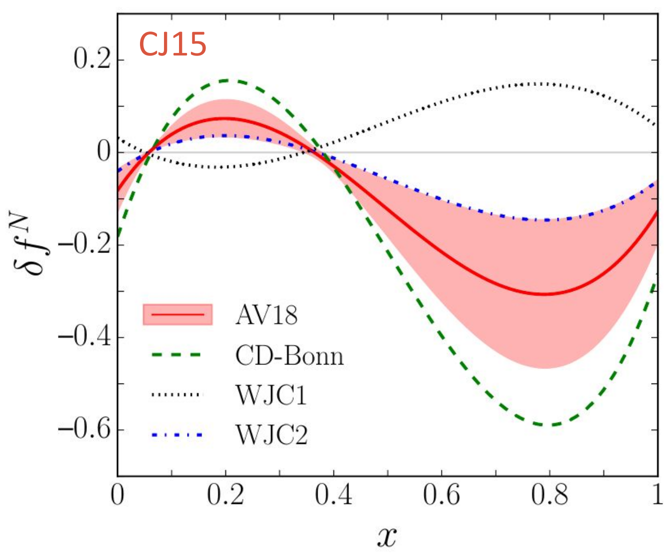


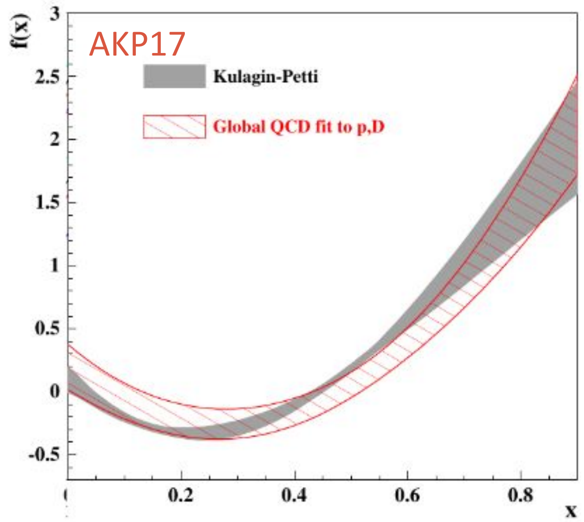


CJ15: *PRD 93 (2016) 114017*
AKP: *PRD 96 (2017) 054005*
(see also 2203.07333)

- **AKP has smaller *d/u* but bigger *n/p* ???**
  - Not possible at Leading Twist!
  - ⟶ **Large HT contributions to high-*x* *n/p* ratio**

CJ15 and AKP17: off-shell function





Kulagin, Petti (e+A fits), NPA 765 (2006) 126

Alekhin + KP (e+d global fits) PRD96 (2017) 054005

CJ15: *PRD 93 (2016) 114017*

- **Different shape and size ??**
- **But many (<u>MANY</u>) differences**
  - Extended d-quark (CJ15) vs. conventional (AKP, d/u-->0)
  - Fit real W asymetry vs. only decay lepton W ⟶ l + (n) asymmetry
  - **Off-shell, HT choices**, and their interplay
  - ...

Ongoing CJ + AKP benchmarking effort

The most important, in our opinion!

HT systematics

CTEQ-JLab study, in progress
See also Accardi, talk at DNP 2020

- **HT assumptions**
  - Additive vs. Multiplicative
    - ⟶ In both cases, Q^2-independent
  - Isospin symmetric or not

$$F_2(x,Q^2) = F_2^{LT}(x,Q^2) + \frac{H(x)}{Q^2}$$
$$F_2(x,Q^2) = F_2^{LT}(x,Q^2)\Big(1 + \frac{C(x)}{Q^2}\Big)$$

- **Isospin and Q^2 assumptions are not independent**
  - *e.g.*, a Q^2–independent, isospin symmetric multiplicative HT generates an equivalent additive HT that depends on both

$$\widetilde{H}_{p,n}(x,Q^2) = C(x)\, F_{2p,n}^{LT}(x,Q^2)$$

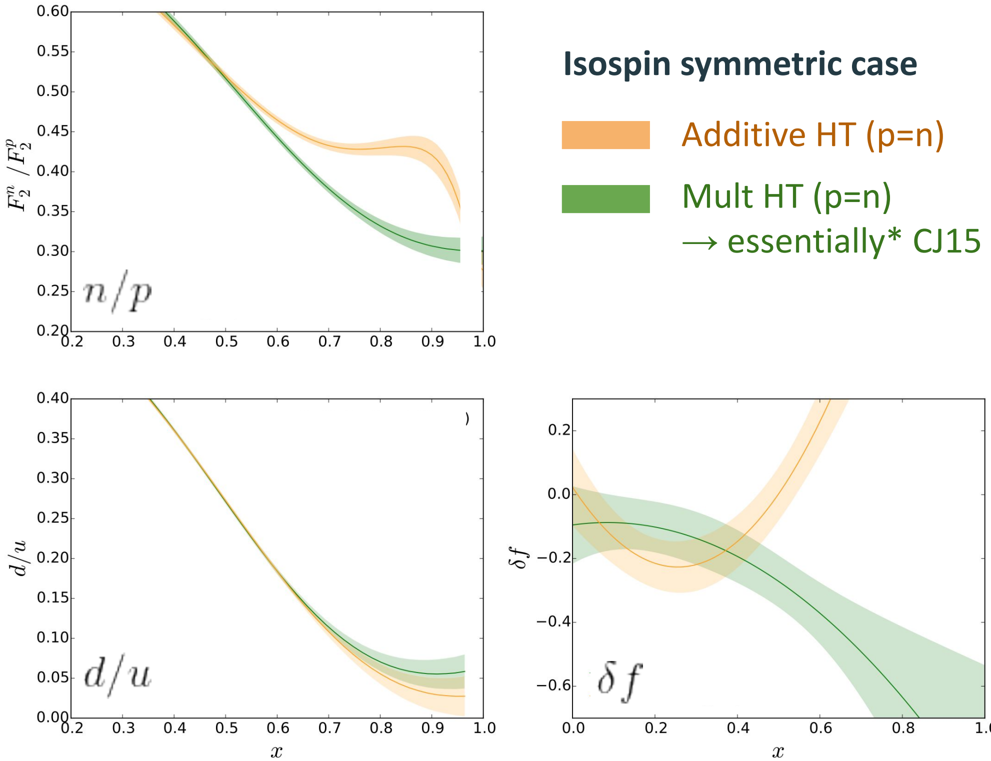
- **Non-negligible large-*x* bias**
  - **if using isospin-independent coefficients**
    - ⟶ Multiplicative (CJ15) underestimates
    - ⟶ Additive (AKP17) overestimates ($H > 0$)

$$\frac{n}{p} \xrightarrow[x\to 1]{} \begin{cases} \frac{1}{4} & \text{mult. } p = n \\ \frac{1}{4} + \frac{H}{u} & p \neq n \\ \frac{1}{4} + 3\,\frac{H}{u} & \text{add. } p = n \end{cases}$$

CJ fits - isospin symmetric HT

CTEQ-JLab study, in progress
See also Accardi, talk at DNP 2020

- Additive *n/p*
  - Larger than Mult *n/p*
  - Even if *d/u* is smaller
- Fitted offshell function compensates *n/p* bias
  - *D/p* well fitted, indeed
- **CJ15/AKP17 differences are reproduced!**
  - And explained

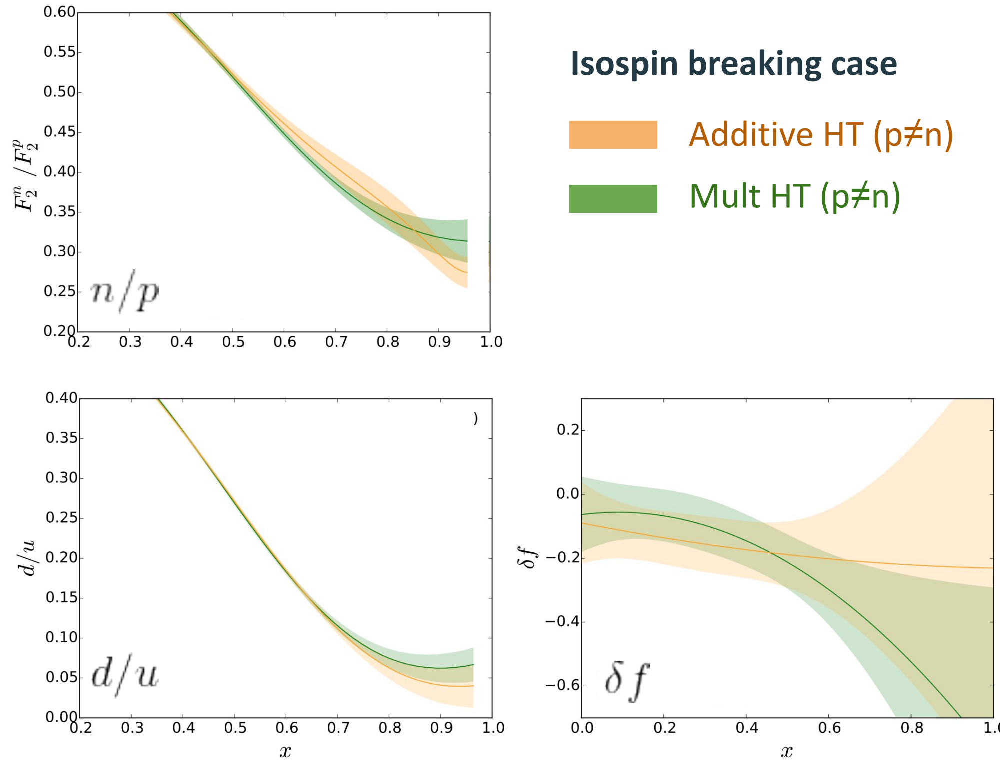


* uses generic 2nd order polynomial δf

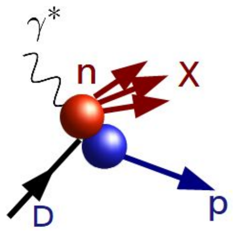
CJ fits - isospin breaking HT

CTEQ-JLab study, in progress
See also Accardi, talk at DNP 2020

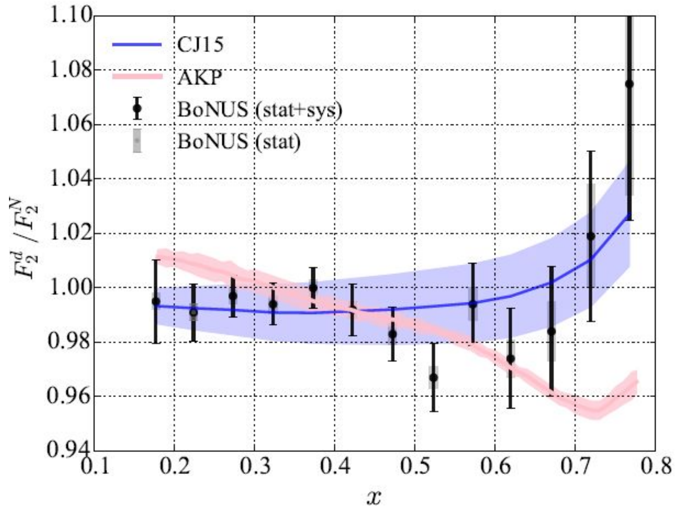
- **Bias removed !!!**
  - Small systematics remains
- ***n/p & d/u***
  - **Much closer to CJ15**
  - Attention when using AKP!
- Small δf offshell correction
  - When averaged over *p* and *n*
  - Large cancellation is possible, but need A=3 data to confirm
    (Tropiano et al., PRC 2019)
    (Cocuzza et al., PRD 2021)

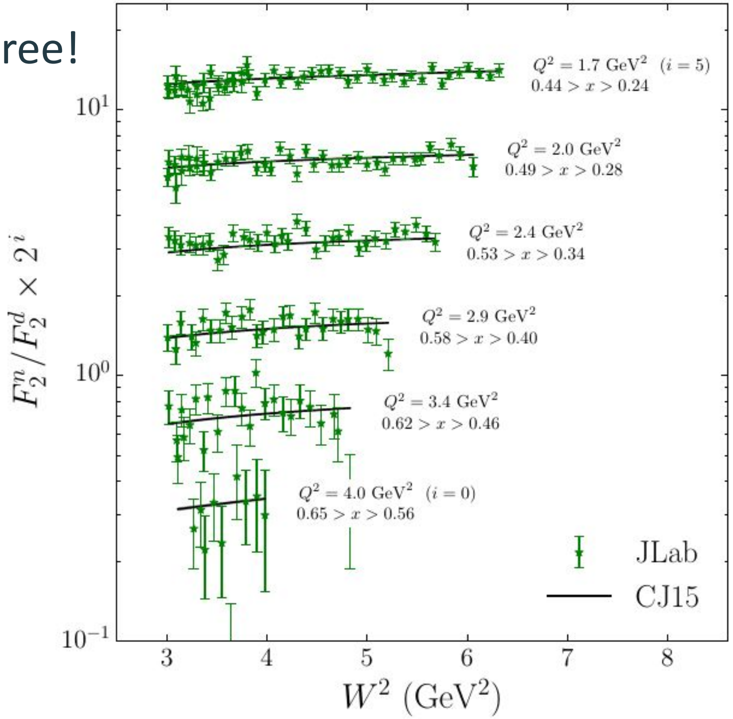


Open questions 1



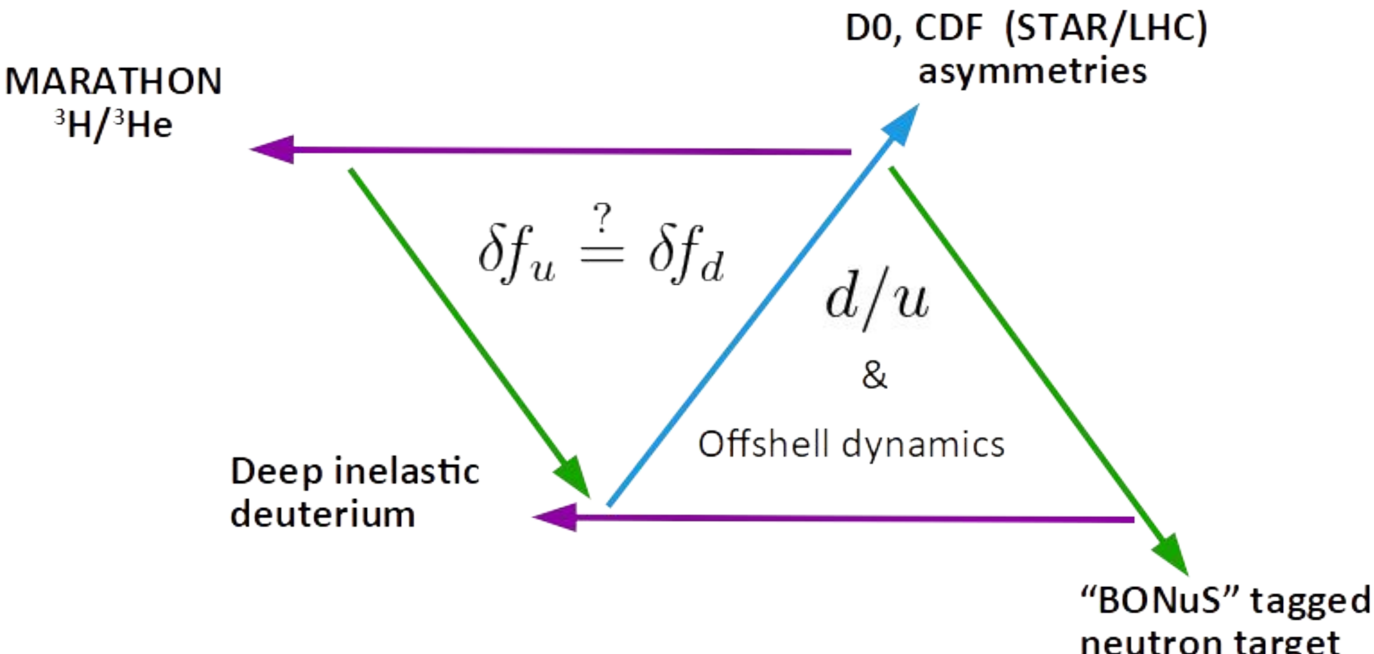
- Can we confirm the picture just painted? Is *δf* zero or negative?
  - **Need direct experimental sensitivity to *δf***
  - **Tagged DIS** experiments at **JLab 6, 12 and EIC**
- To start with, BONuS 6 don't seem to disagree!
  - But may not be precise enough at large *x*





Open questions 2

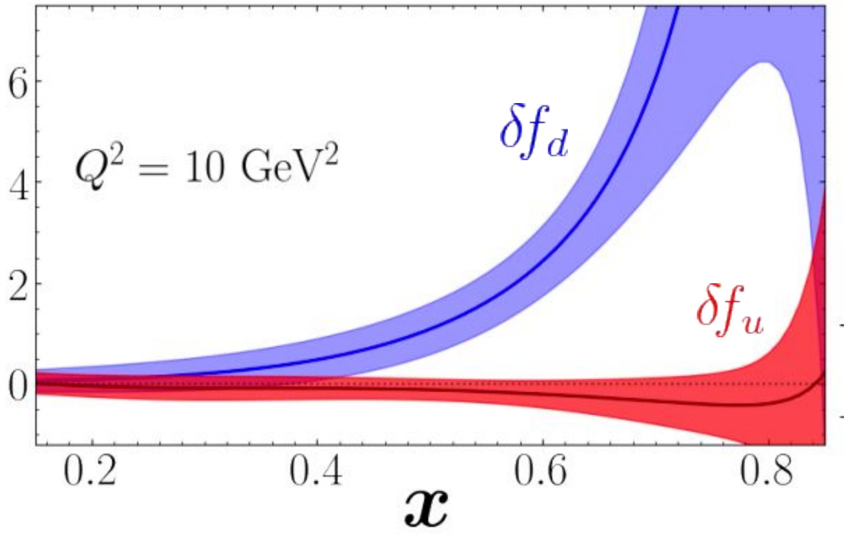
- Can extend the large-*x* triangle to a parallelogram
  - ⟶ **and verify if off-shell is flavor independent or not !!**
  - ⟶ …hence if off-shell protons ~ off-shell neutrons



Open questions 2

- Can extend the large-*x* triangle to a parallelogram
  - ⟶ **and verify if off-shell is flavor independent or not !!**
  - ⟶ …hence if off-shell protons ~ off-shell neutrons

C. Cocuzza et. al., arXiv:2104.06946



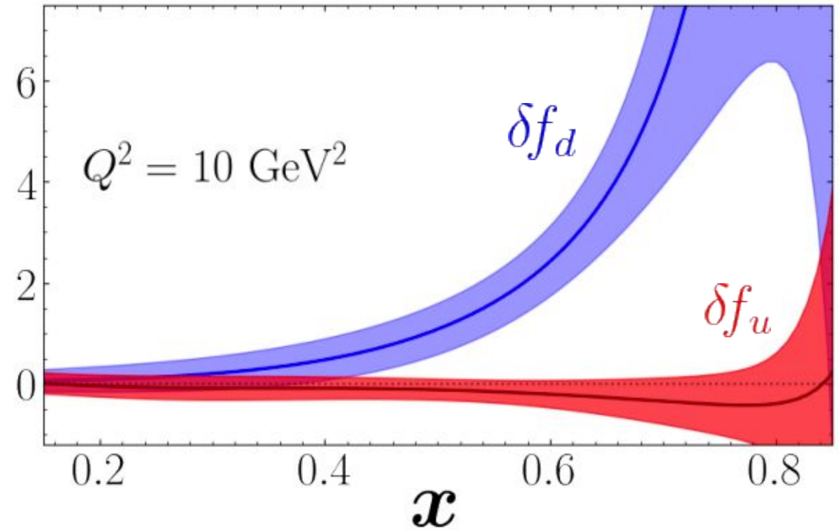
$$\delta f|_{\mathrm{CJ}} = \frac{u\,\delta f_u + d\,\delta f_d}{u+d} \approx 0$$

by accident!

Open questions 2 and 3

- Can extend the large-*x* triangle to a parallelogram
  - ⟶ **and verify if off-shell is flavor independent or not !!**
  - ⟶ …hence if off-shell protons ~ off-shell neutrons

C. Cocuzza et. al., arXiv:2104.06946



$$\delta f|_{\rm CJ} = \frac{u\,\delta f_u + d\,\delta f_d}{u+d} \approx 0$$

by accident!

Open Questions 3:

⟶ But is also $\delta f_u^p \stackrel{?}{=} \delta f_d^n$ as assumed in the JAM analysis?

⟶ **Are there nuclear-level CSV effects?**

⟶ How to tell?

- **Part 2: PVDIS in global fits**
  - **PVDIS on p**

    ⟶ **" Still needed in the BONuS 12 and Marathon era? "**
  - PVDIS on D

    ⟶ CSV from nuclear, HT dynamics ?

PVDIS on protons

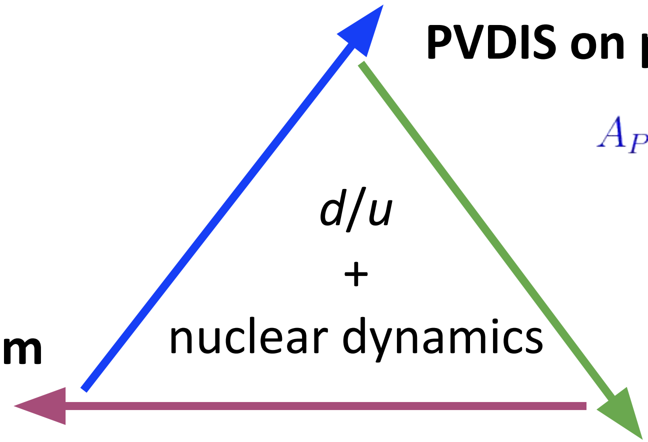
W bosons

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

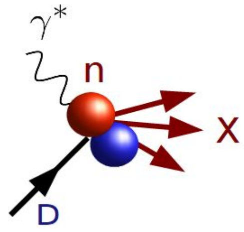
PVDIS on p

$$A_{PV} \approx \frac{1 + 0.91\, d/u}{1 + 0.25\, d/u} + HT + Y_3\, a_3$$

ν's can help

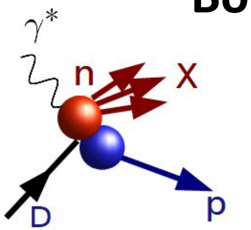


DIS on Deuterium



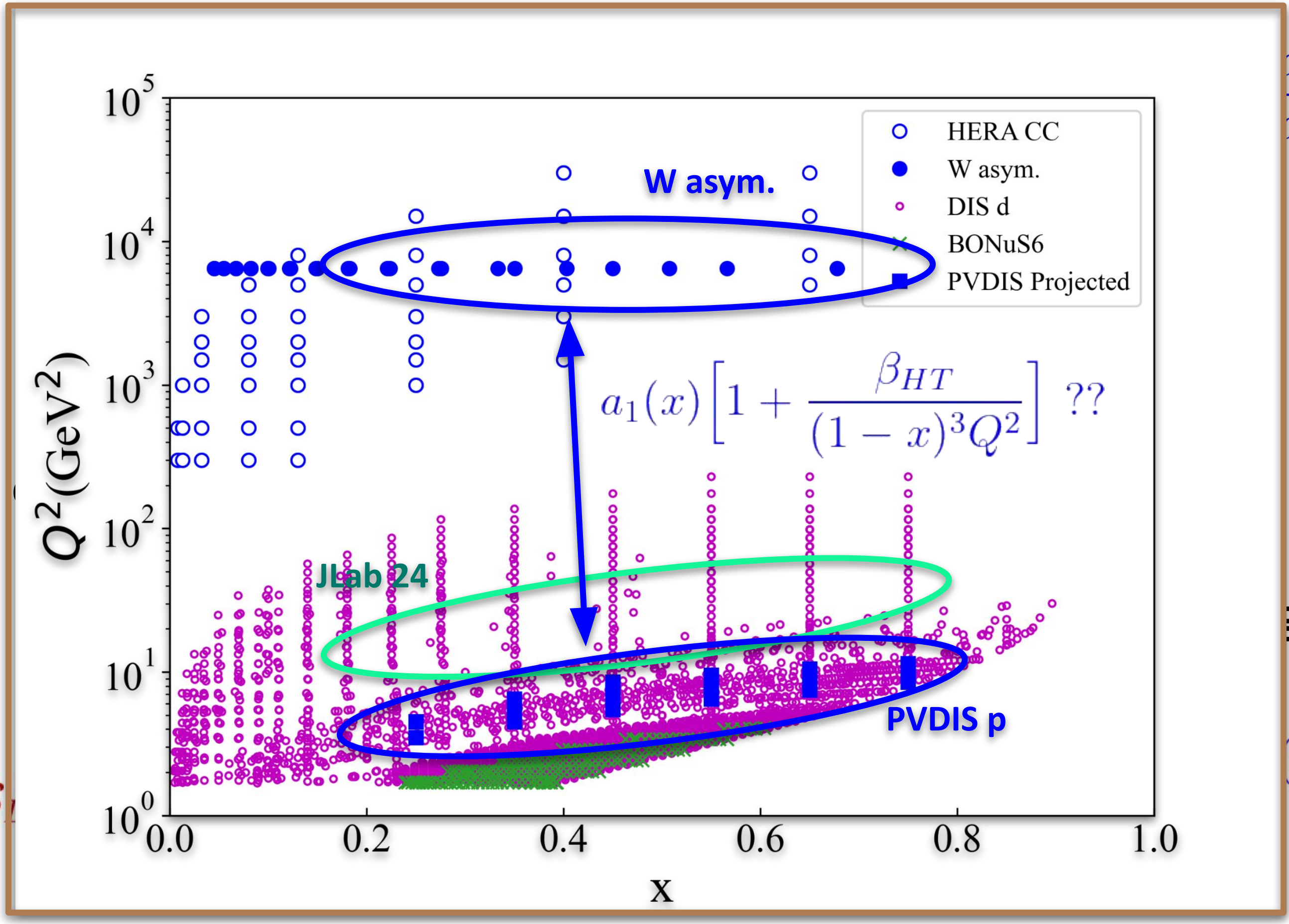
$$F_2^d \propto S_D \otimes \left[x u_{\rm off}(x) + x d_{\rm off}(x) \right]$$

"BoNuS" tagged DIS



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

PVDIS on protons



DIS

ged DIS

$F_2^d \propto S$

d/u

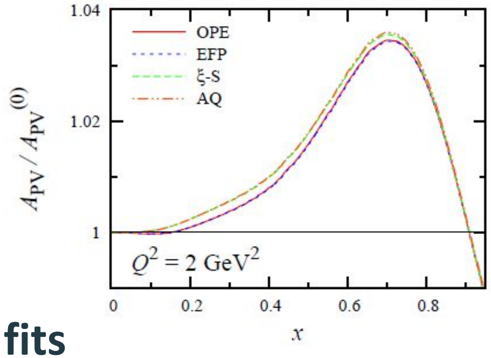
d/u

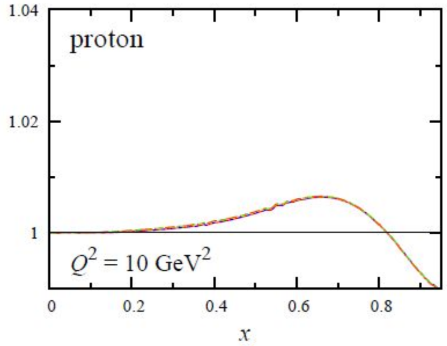
$HT + Y_3\, a_3$

$x) + 4xd(x)$

PVIDS on protons - notes

Brady, AA, TH, WM, PRD 84 (2011)



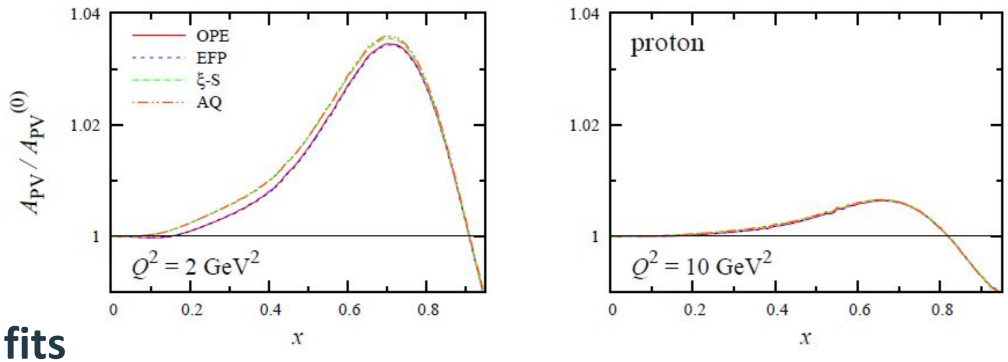


- **Can focus on dynamical HT**
  - TMCs are under control
  - Kinematics far enough from x=1 end point
- **Clean access to d/u in global fits**
  - Large effective Q^2 leverage
    - ⟶ Power corrections efficiently removed Global fits can extract d/u
- **JLab 24: higher Q^2**
  - More precision for HT extraction
    - ⟶ hence more statistics for d/u fitting
  - Less kinematic shift $x \longrightarrow \xi$:
    - ⟶ higher x reach for d/u

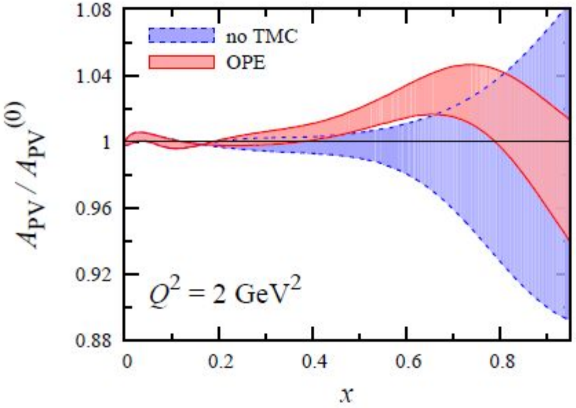
PVIDS on protons - notes

Brady, AA, TH, WM, PRD 84 (2011)

- **Can focus on dynamical HT**
  - TMCs are under control
  - Kinematics far enough from x=1 end point



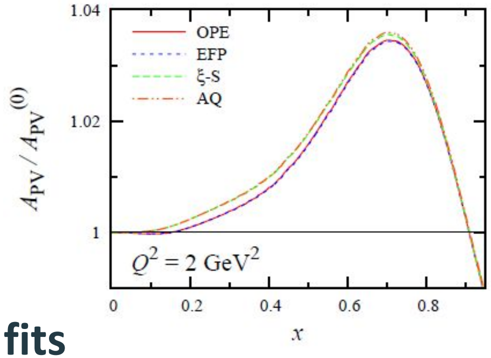
- **Clean access to d/u in global fits**
  - Large effective Q^2 leverage
    - ⟶ Power corrections efficiently removed
    - Global fits can extract d/u
- **JLab 22: higher Q^2**
  - More precision for HT extraction
    - ⟶ hence more statistics for d/u fitting
  - Less kinematic shift $x \to \xi$:
    - ⟶ higher *x* reach for d/u

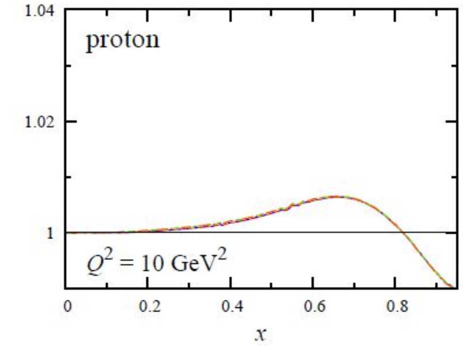


PVIDS on protons - notes

Brady, AA, TH, WM, PRD 84 (2011)

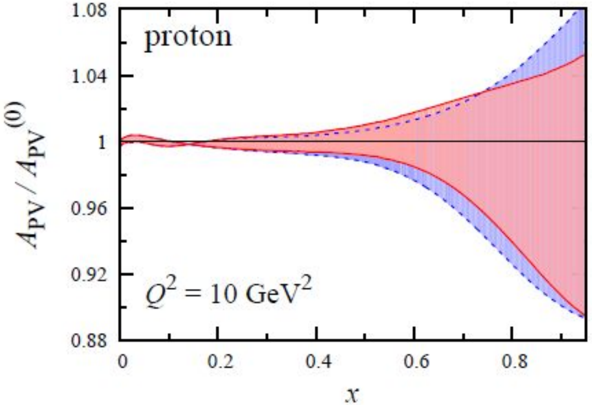
- **Can focus on dynamical HT**
  - TMCs are under control
  - Kinematics far enough from x=1 end point





- **Clean access to d/u in global fits**
  - Large effective Q^2 leverage
    - ⟶ Power corrections efficiently removed
      Global fits can extract d/u

- **JLab 22: higher Q^2**
  - More precision for HT extraction
    - ⟶ hence more statistics for d/u fitting
  - Less kinematic shift $x \longrightarrow \xi$:
    - ⟶ higher x reach for d/u

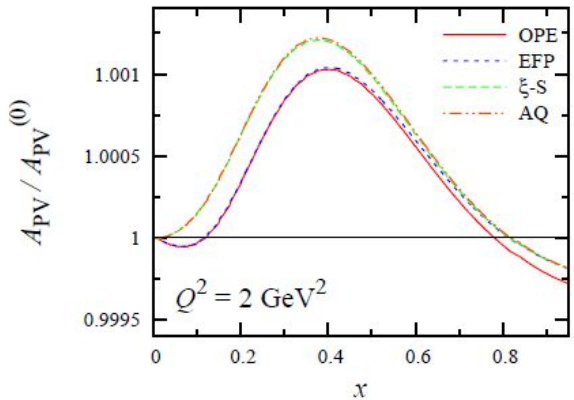


- **Part 2: PVDIS in global fits**
  - PVDIS on p
    - ⟶ Still needed in the BONuS 12 and Marathon era?
  - **PVDIS on D**
    - ⟶ **CSV from nuclear, HT dynamics ?**

PVDIS on Deuterons

- **TMC**
  - Per mille level, very small model dependence
  - Don't forget the kinematic shift
- **Nuclear corrections**
  - Likely small, too
  - (But not quantified)

Brady, AA, TJH, WM, PRD 84 (2011)



- **Higher twists - analogous to proton discussion**
  - Large Q^2 lever arm when analyzed in a global fit
  - Need to fit HT(p) ≠ HT(n) to avoid biases
    - ⟶ Formulate this at quark level and impose/verify charge symmetry
    - ⟶ Attention to HT/offshell interplay

$$HT_u^p \stackrel{?}{=} HT_d^n \, ; HT_d^p \stackrel{?}{=} HT_u^n$$

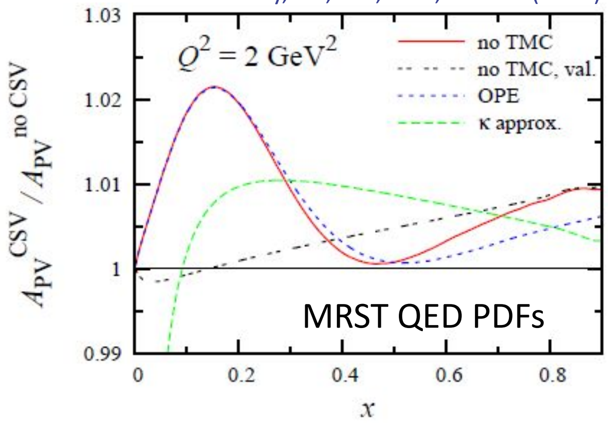
$$\delta f_u^p \stackrel{?}{=} \delta f_d^n \, ; \delta f_d^p \stackrel{?}{=} \delta f_u^n$$

PVDIS on Deuterons

- **CSV from nuclear and HT dynamics, as well?**

$$R^{CSV} = \underbrace{R^{CSV}_{pdf} + R^{CSV}_{off}}_{\text{How to tell?}} + R^{CSV}_{HT}$$

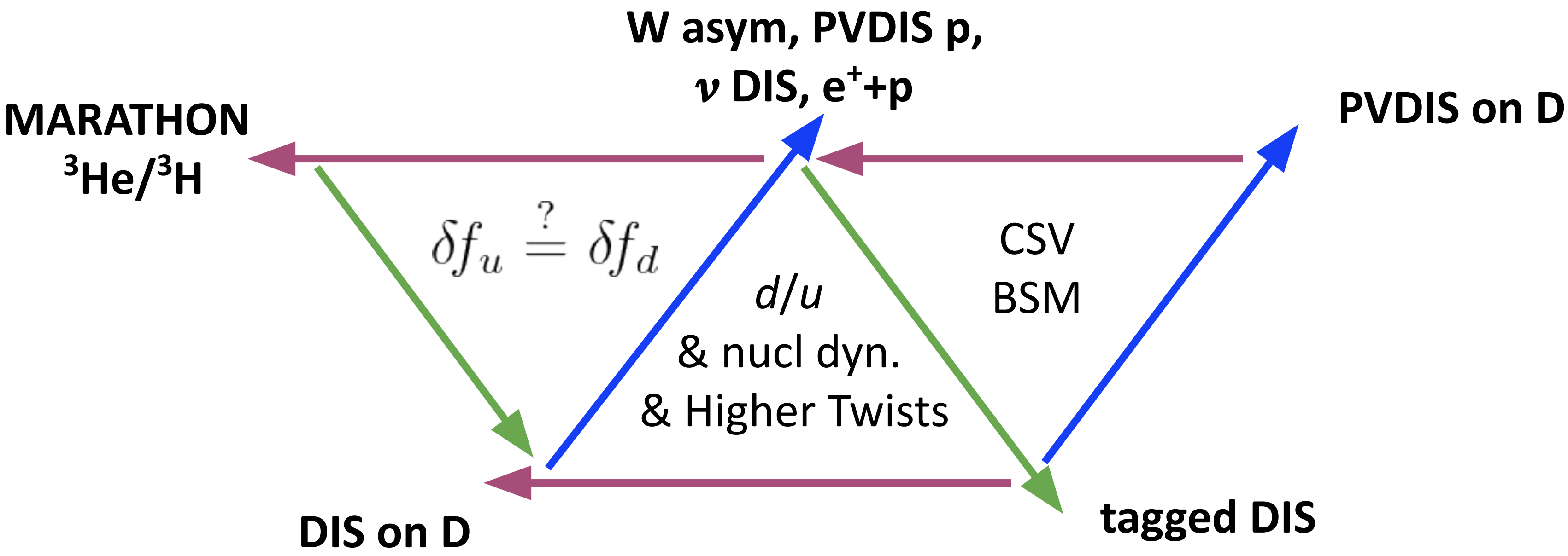
Brady, AA, TJH, WM, PRD 84 (2011)



- **If we find an "anomaly": is it BSM or nuclear physics?**
  - ⟶ Remember the NuTeV anomaly
  - ⟶ Here we have a deuteron, no p/n asymmetry to possibly trick us
  - ⟶ Still, let's keep our eyes and minds open

Need half a honeycomb, at least!

- **Global QCD analysis is a powerful tool:**
  - ⟶ d/u, nuclear dynamics, parton correlations, CSV
  - ⟶ PVDIS still relevant in BONuS 12 / Marathon era !!



Finally...

Final thoughts

- **Large-*x* data analysis in global QCD fits**
  - Needs careful attention to evaluation of statistical errors
  - Can have large systematic bias due to HT assumptions
    - ⟶ That deforms the extracted offshell function
  - **Isospin-asymmetric HT parameterization is needed**
    - ⟶ Better formulate this at parton level, though

- **PVDIS in a global QCD analysis**
  - Best control, extraction of HT corrections
    - ⟶ Will revitalize theory in that sector
    - ⟶ Would benefit from nDIS, positron data for gamma-Z str. fns.
  - Proton: will contribute to *d/u* fit precision and accuracy
  - Deuteron: with HT under control, can focus on CSV / BSM

- **High-quality data expected**
  - **Need high-quality phenomenology and theory**
    - ⟶ We are in time to develop this

Final thoughts

- **High-quality data is expected**
  - **Need high-quality phenomenology and theory**
    - ⟶ We are in time to develop this

- For example,
  - Nuclear/off-shell and CSV corrections currently assume

$$D = \mathcal{S} \otimes [p+n] = \mathcal{S} \otimes \left[(u^* u^* d^* + \ldots) + (u^* d^* d^* + \ldots) \right]$$

    - ⟶ Neglects higher Fock hadronic states
    - ⟶ Off-shell function may just be a phenomenological, cover-all blanket
    - ⟶ An adequate concept for the aims of the PVDIS program?
  - Maybe better to describe teh Deuteron at parton level

$$D = \left[u\, u\, d\, u\, d\, d + \ldots \right]$$

    - ⟶ Lattice QCD powerful enough these days, can guide pheno assumptions

References

Large-x fits with nuclear corrections

- **CJ15**: Accardi et al., PRD 93 (2016) 114017
  - Accardi, DNP 2020 / Fernando, GHP 2021 / Accardi, APS 2022
- **AKP**: Alekhin, Kulagin, Petti, PRD 96 (2017) 054005 & arXiv:2203.07333
- **JAM**: Cocuzza et al. (JAM), PRL 127 (2021) 24

PDF uncertainties

- Hunt-Smith, Accardi, Melnitchouk, Sato, Thomas, White, arXiv:2206.10782

PVDIS study

- Brady, Accardi, Hobbs, Melnitchouk, PRD 84 (2011) 074008

Light quark asymmetry, QCD analysis

- Park, Accardi, Jing, and Owens, arXiv:2108.05786
- Guzzi et al. (CT), arXiv:2108.06596
- Cocuzza et al. (JAM), PRD 104 (2021) 074031

General References

QCD global analysis from protons to nuclei:

- Accardi, PoS DIS2015 (2015) 001
- Jimenez-Delgado, Melnitchouk, Owens, *J.Phys.G40 (2013) 093102*
- Ethier, Nocera, *Ann.Rev.Nucl.Part.Sci. (2020) 70, 1-34*

QCD global analysis and statistical methods:

- Kovarik, Nadolsky, Soper, *Rev.Mod.Phys. 92 (2020) 4, 045003*

Thank you!

Thank you!

Are we done with (nuclear) corrections?

Theoretical choices →

Corrections (increasing-x) ↓

	KP	AKP	CJ15	AKP-like
shadowing	yes	yes (which one?)	MST x<0.1	(same)
smearing	Paris	AV18	AV18 x>0.1	(same)
pi-cloud	yes	yes	----	----
TMC	GP O(Q4)?	GP O(Q4)??	GP approx.	(same)
HT	H (p=n ??)	H (p=n)	C (p=n)	H & C, p=n & p!=n
HT(x)	??	5 pt. spline	parametrized	parametrized
off-shell	O(p2-M2)	O(p2-M2)	O(p2-M2)	(same)
df(x)	factorized	polyn. 2nd/3rd	factorized + sum rule	polyn. 2nd/3rd
pi thresh.	yes	yes	----	----

Are we done with (nuclear) corrections?

Theoretical choices →

Corrections (increasing-x) ↓

	KP	AKP	CJ15	AKP-like
shadowing	yes	yes (which one?)	MST x<0.1	(same)
smearing	Paris	AV18	AV18 x>0.1	(same)
pi-cloud	yes	yes	----	----
TMC	GP O(Q4)??	GP O(Q4)??	GP approx.	(same)
HT	H (p=n ??)	[illegible]	[illegible]	H & C, p=n & p≠n
HT(x)	??	5 pt. spline	parametrized	parametrized
off-shell	O(p2-M2)	[illegible]	[illegible]	(same)
df(x)	factorized	polyn. 2nd/3rd	[illegible] rule	polyn. 2nd/3rd
pi thresh.	yes	yes	----	----

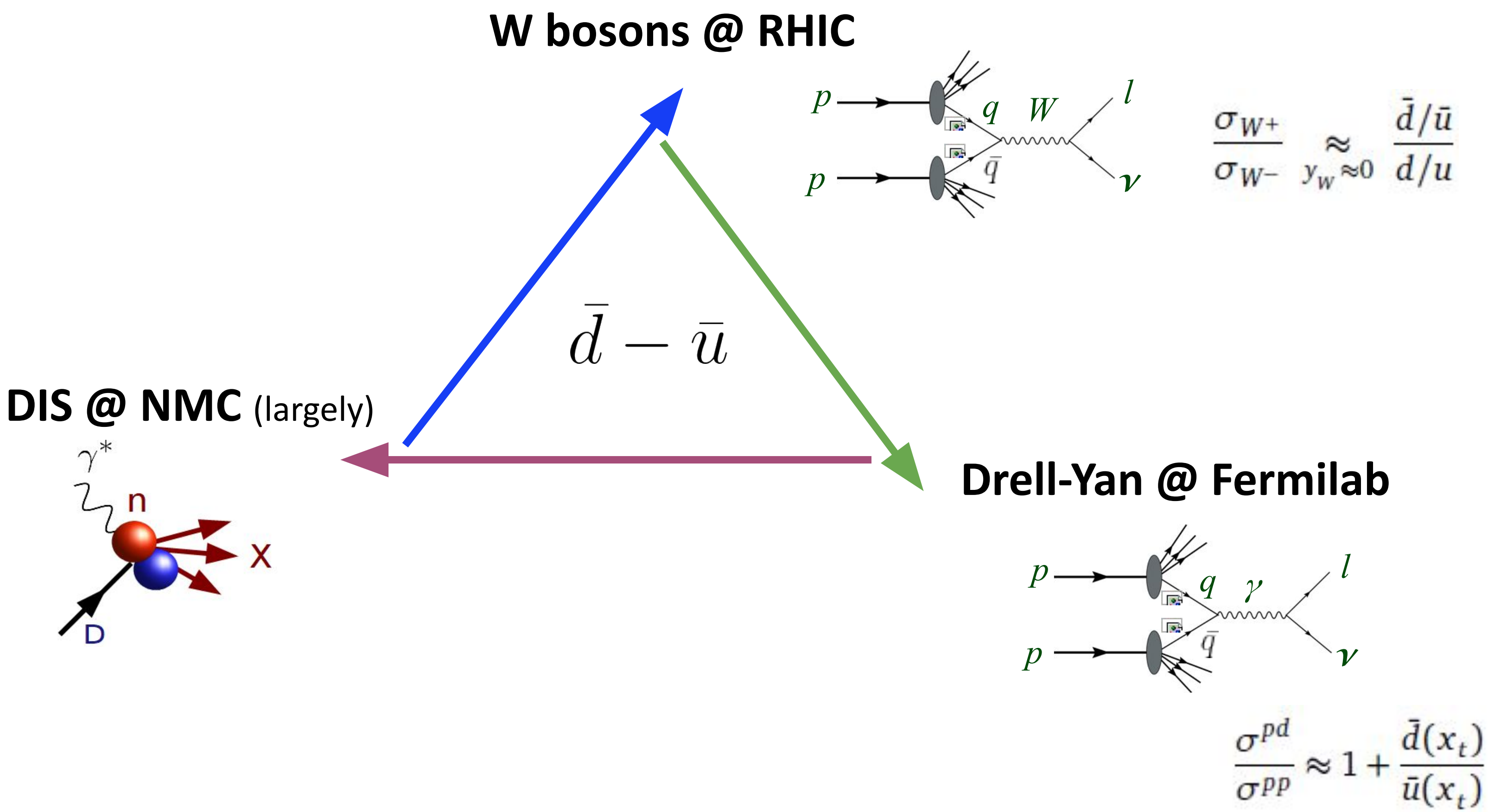
There is no "off-the-shelf" nuclear correction model:

One needs to know and pay attention to the detail

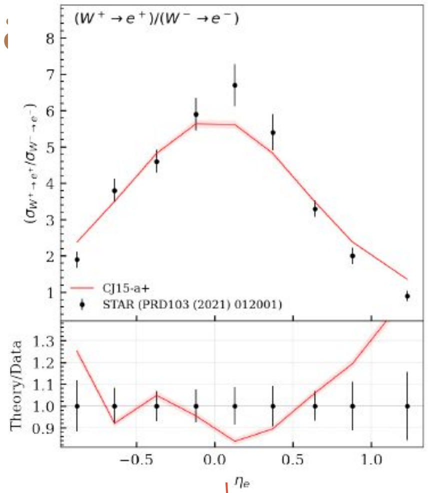
(yes: that means reading the theory papers without rush….)

Light quark sea

Medium-x PDFs: the light sea triangle



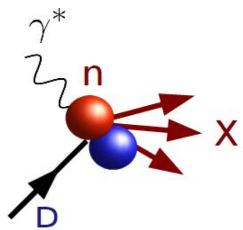
Medium-x PDFs: the light sea tri



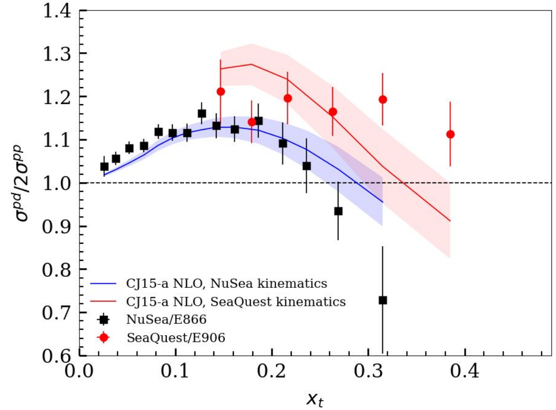
W bosons @ RHIC

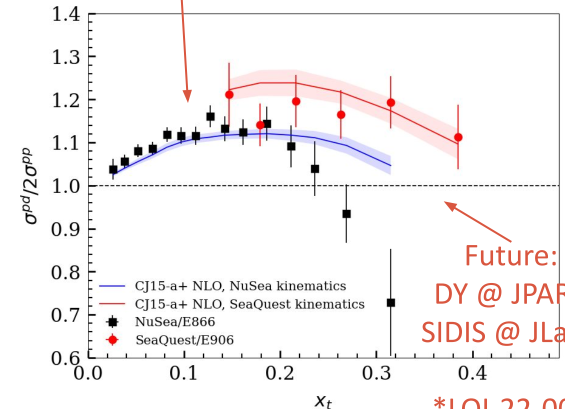
$$\bar{d} - \bar{u}$$

DIS @ NMC (largely)



Drell-Yan @ Fermilab

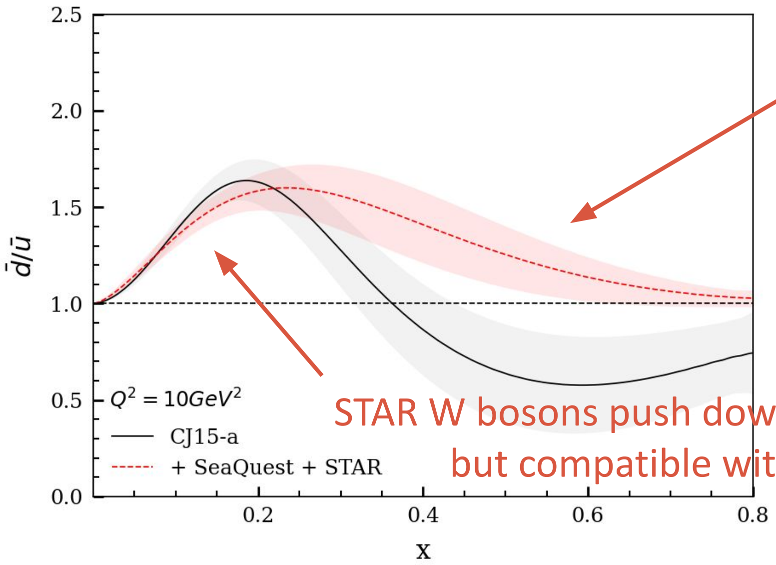




Future:
DY @ JPARC
SIDIS @ JLab*

*LOI-22-002

Medium-x PDFs: the light sea triangle



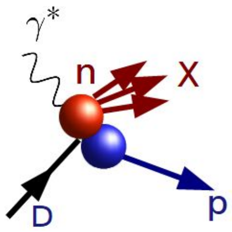
SeaQuest pulls ratio up
⟶ **Tension with E866**
⟶ **How to quote PDF errors?**

STAR W bosons push down a bit,
but compatible with E866

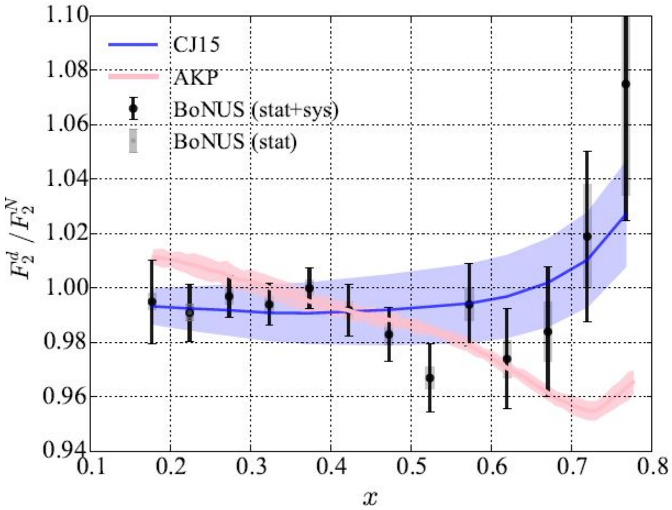
Tagged DIS to the rescue

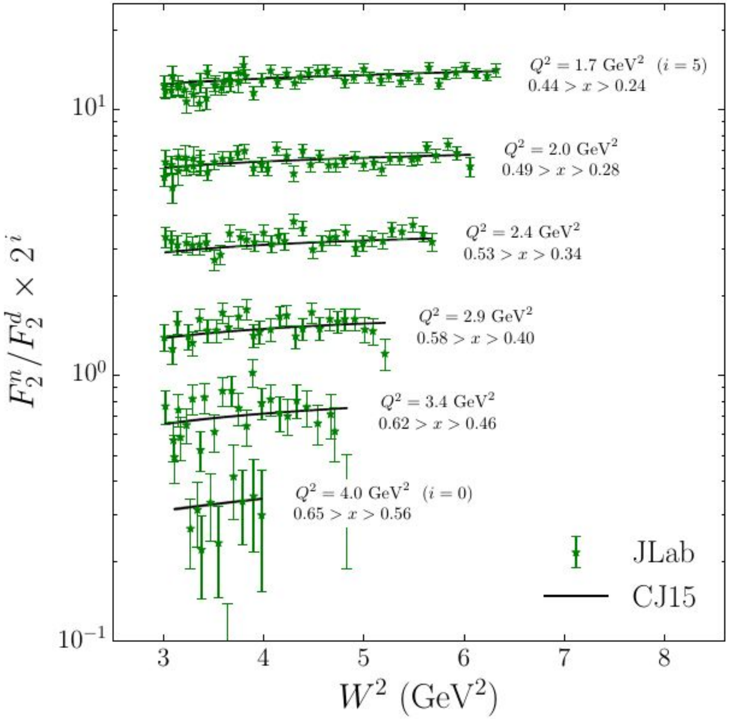
Open questions

- Can we confirm the picture just painted? Is *δf* negative?
  - **Need direct experimental sensitivity to *δf***
  - **Tagged DIS** experiments



- BONuS 6 data don't seem to disagree!
  - But may not be precise enough at large *x*





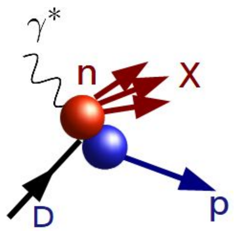
Open questions

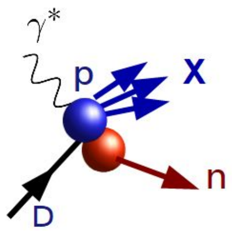
- Is the simple proposed factorization correct?
  - Or at least phenomenologically acceptable ?

$$F_{2N}(x, Q^2, p^2) = F_{2N}^{free}(x, Q^2)\left[1 + v\,\delta f(x)\right]$$

$$v = \frac{p^2 - M^2}{M^2}$$

- Are FSI negligible?
  - Inclusive DIS only probes small off-shellness



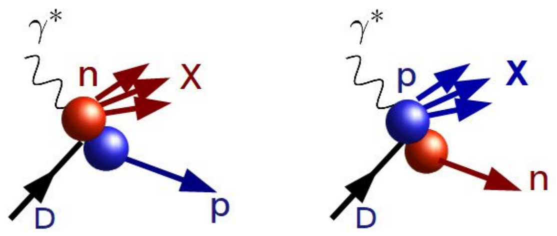


More data, please!

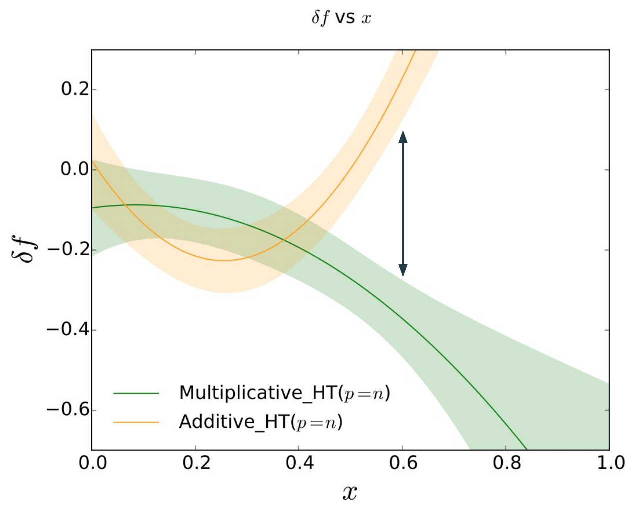
- **One can extract *δf***

$$\frac{F_{2N}}{F_{2N}^{free}} = 1 + v\,\delta f(x)$$

  - Experiment by experiment
  - or in a global QCD fit

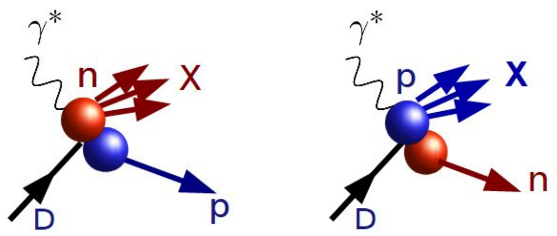


- **Need more tagged DIS data with**
  - FSI under control (small *v*, backward *φ*)
  - Large lever arm, good resolution on *v* (or p_s)
  - x>0.6 would clearly distinguish the two cases



More data, please!

- **At JLab:**
  - BONuS 12, TDIS-n, BAND, LAD…
  - Proton and neutron tagging



- **At the EIC**
  - Simulated Data *(C.Weiss et al. - JLab LDRD 2014)*
    - ⟶ Proton tagging + on-shell extrapolation method
  - Fits by *X.Jing and S.Li*

EIC yellow report, arXiv:2103.05419