DOE contracts:
DE-SC0007981
DE-AC05-06OR23177

Impact of JLab22

on unpolarized PDFs at large x

Matteo Cerutti

CTEQ-JLab Collaboration

CTEQ-JLab Collaboration

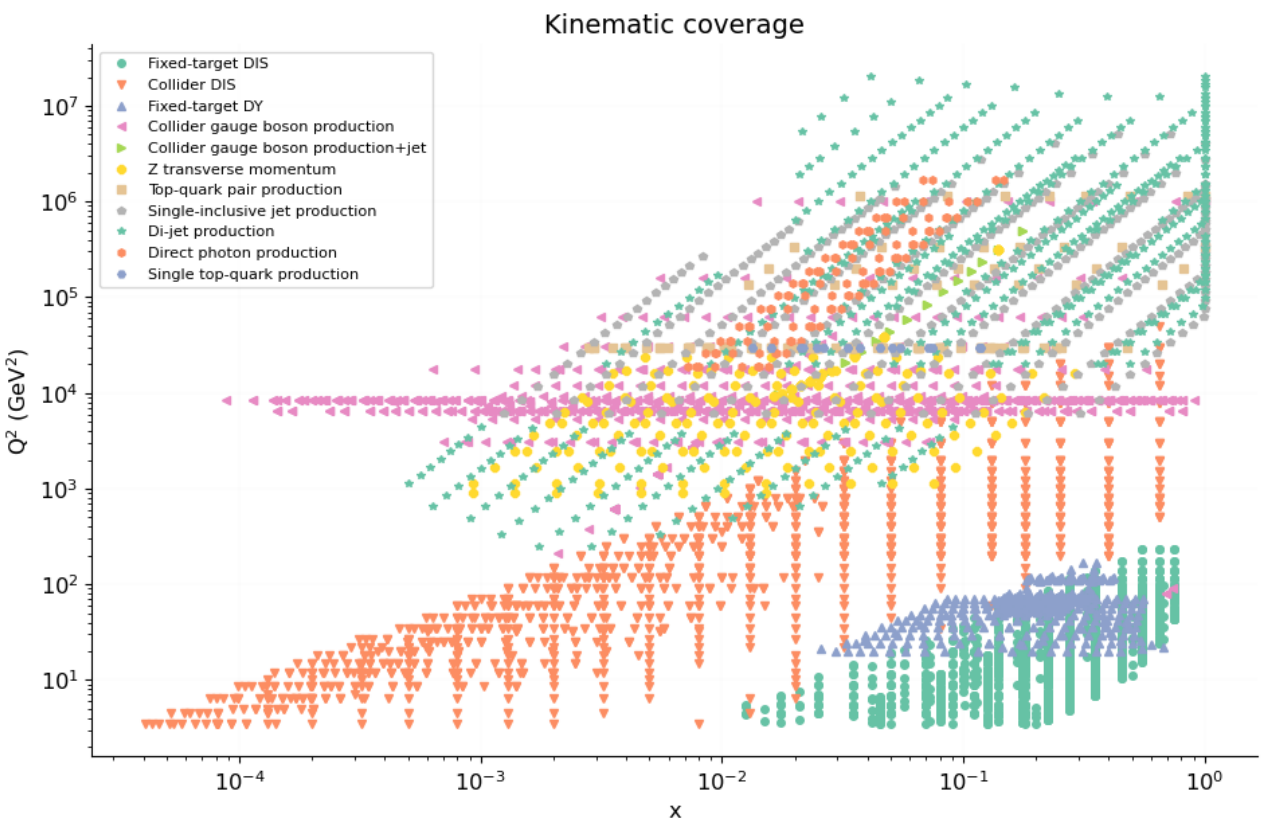
Main focus: Investigate the internal structure of nucleons in their valence region

Collinear factorization

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

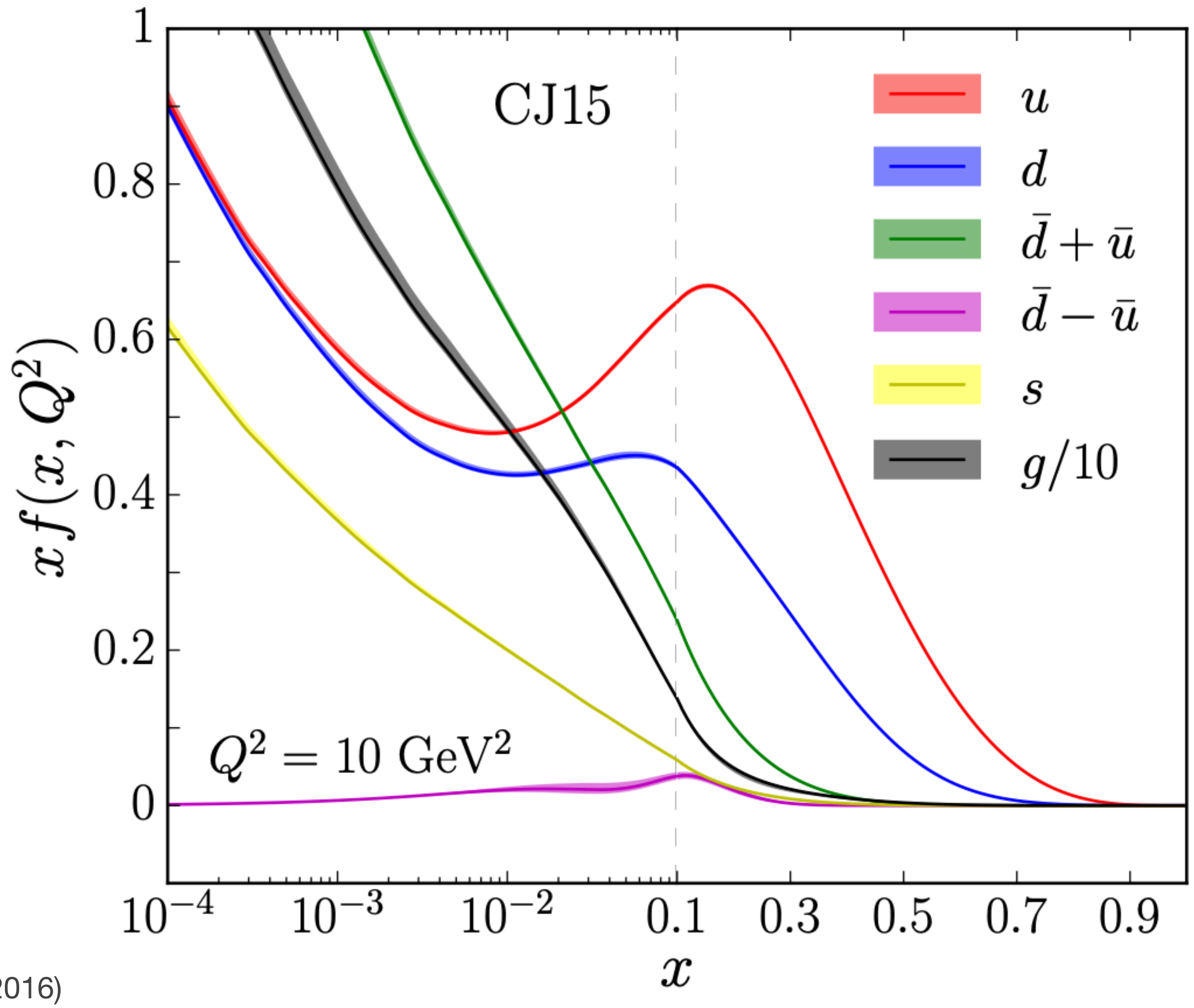
Universality

- DIS — *p/d targets*
- pp collisions — *Drell—Yan*, *W/Z production*, *jets*



CJ: PDFs at large x

Understand the behaviour of PDFs in the large-x region

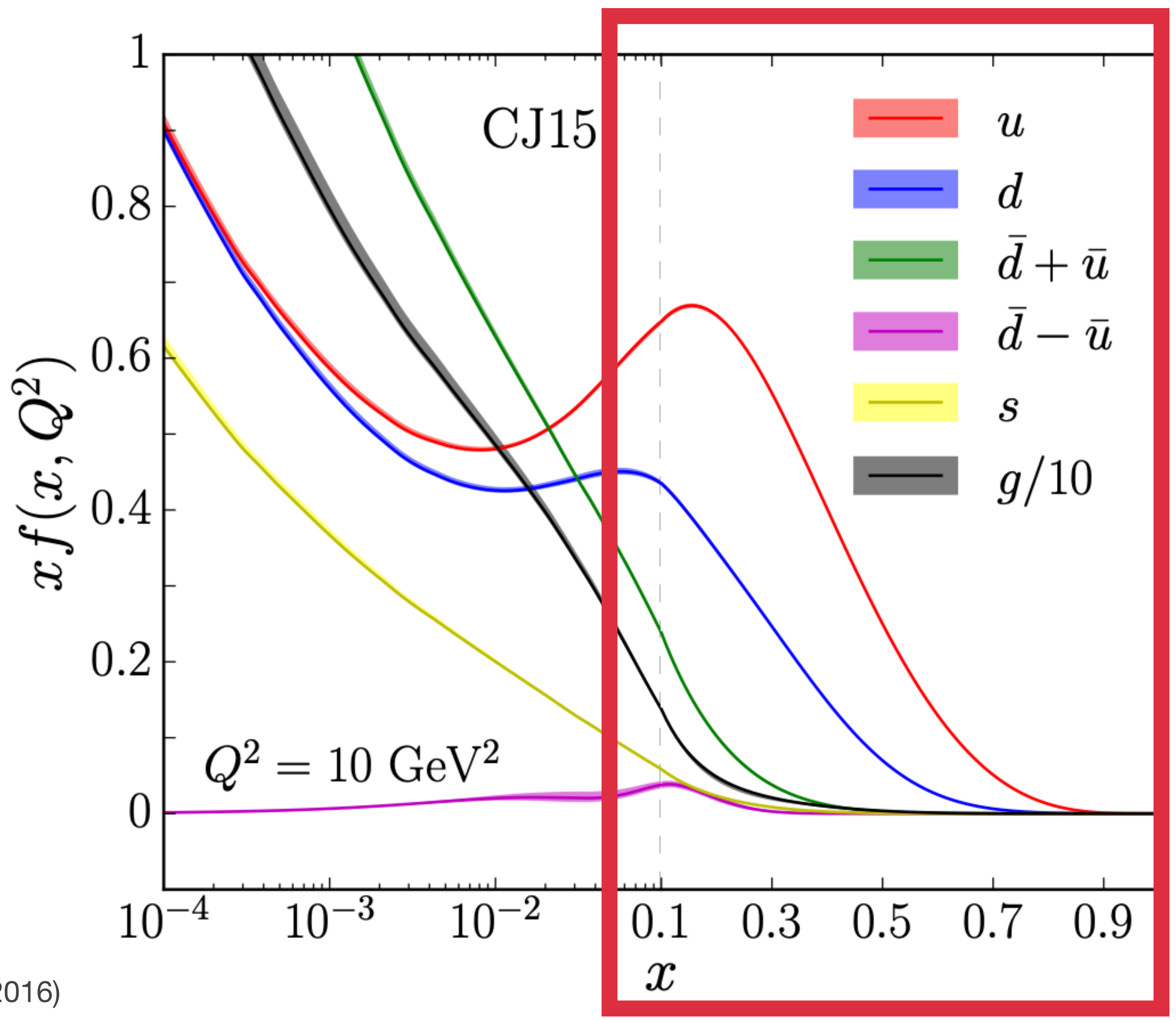


A. Accardi, et al., PRD 93 (2016)

Main focus: $\frac{d}{u}$

CJ: PDFs at large x

Understand the behaviour of PDFs in the large-x region



A. Accardi, et al., PRD 93 (2016)

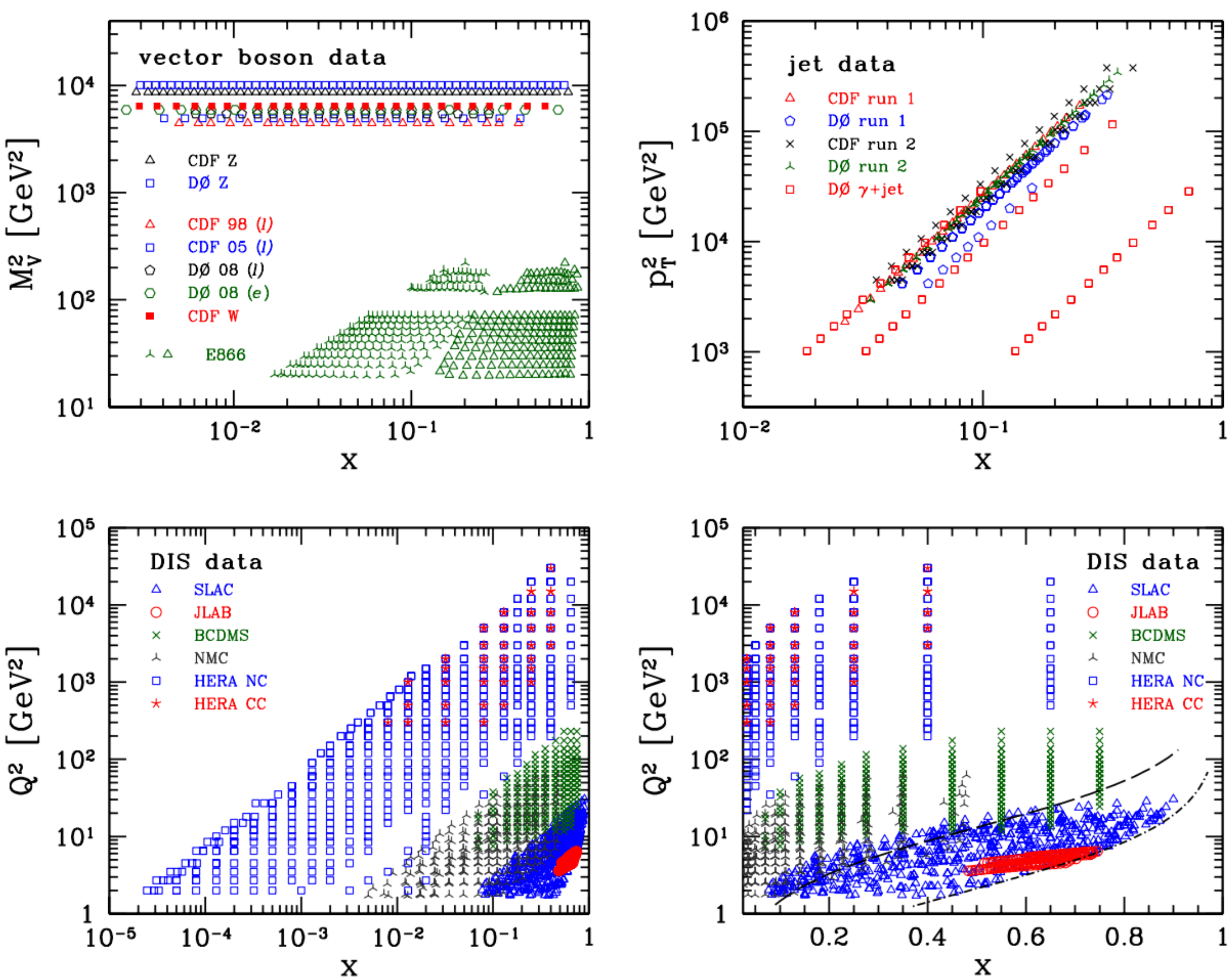
Main focus: $\dfrac{d}{u}$

CJ: PDFs at large x

Which datasets do impose constraints on this region?

J. Owens, et al., PRD 87 (2013)

Main focus: $\frac{d}{u}$



u-quark

DIS on proton target

Drell — Yan data

…

d-quark

W-boson asymmetry

DIS on Deuterium targets

Proton-Tagged DIS (BONuS)

…

We have to deal with Deuterium target at large-x

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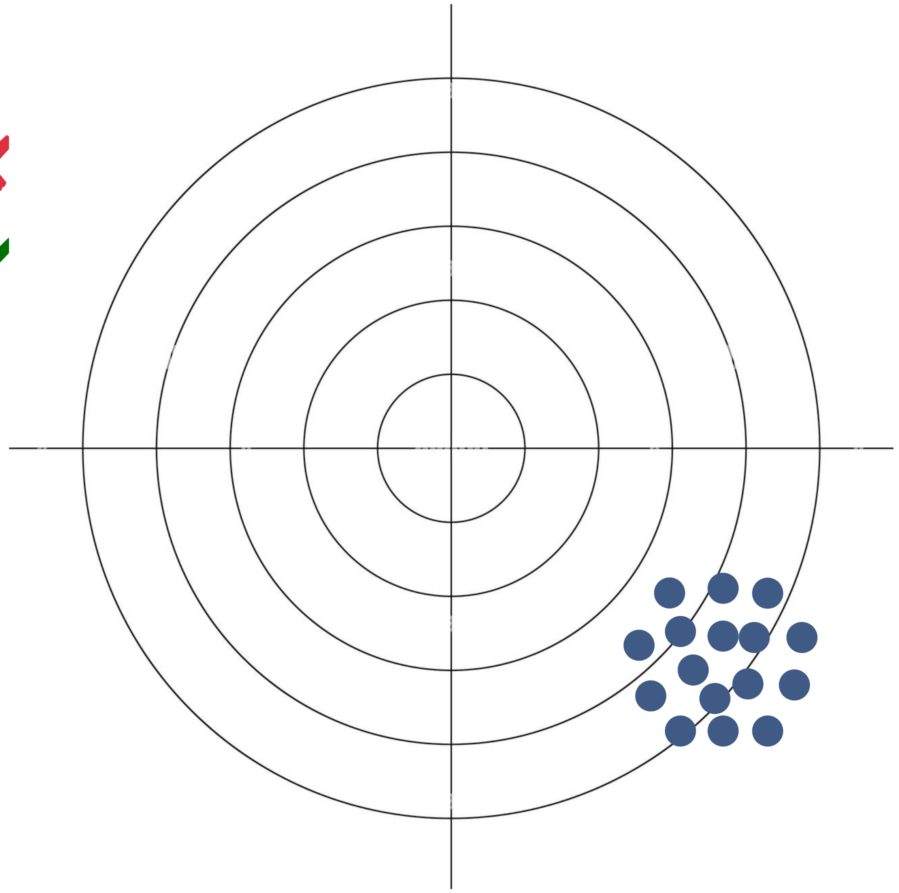
DIS on deuteron target

CJ global data set:
A. Accardi, et al., PRD 93 (2016)

- 1000+ data points
- high-x and low-Q^2
- $W^2 > 3\ \mathrm{GeV}^2$, $Q^2 > 1.69\ \mathrm{GeV}^2$

Nuclear corrections
TMC
Higher Twists

Precision ✗
Accuracy ✔



The choice of their implementation may be a source of systematic error

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DIS on deuteron target

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A. Accardi, et al., PRD 93 (2016)

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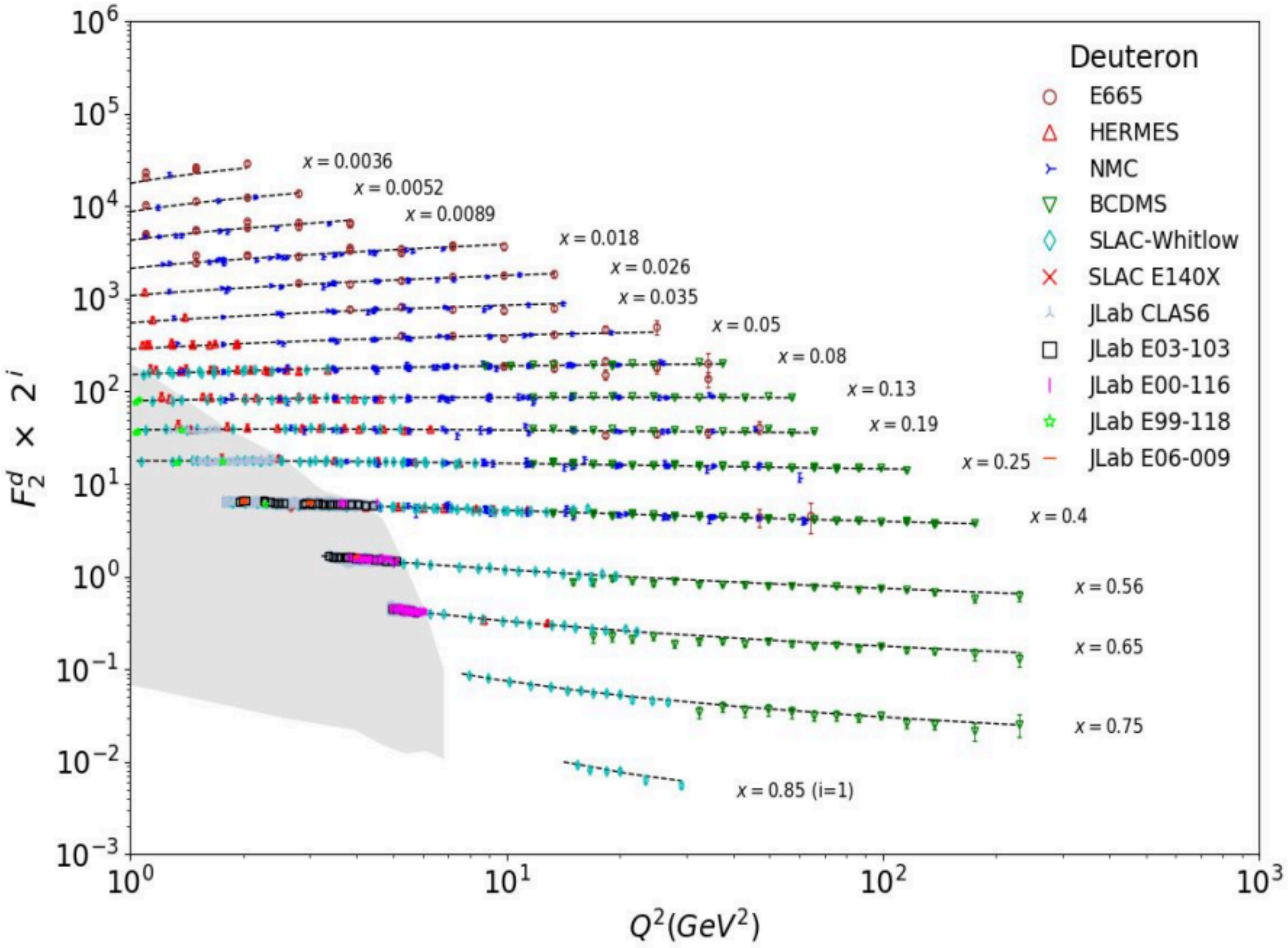

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DIS on deuteron target

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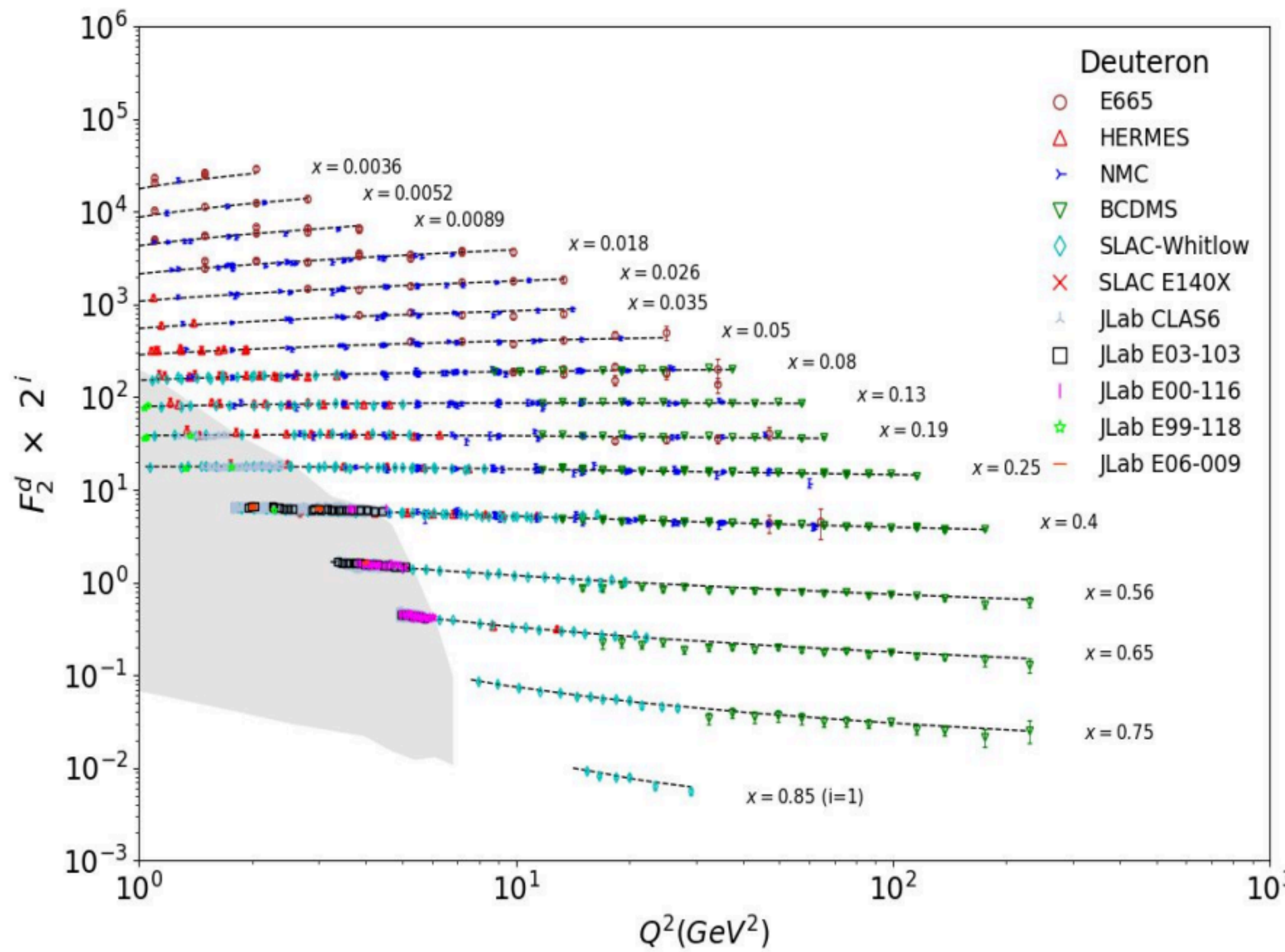

Full treatment of nuclear corrections

Binding effects, Fermi motion, off-shell corrections, Higher Twist (HT), Target Mass Corrections (TMC)

CTEQ-JLab Collaboration

DIS on deuteron target

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A. Accardi, et al., PRD 93 (2016)

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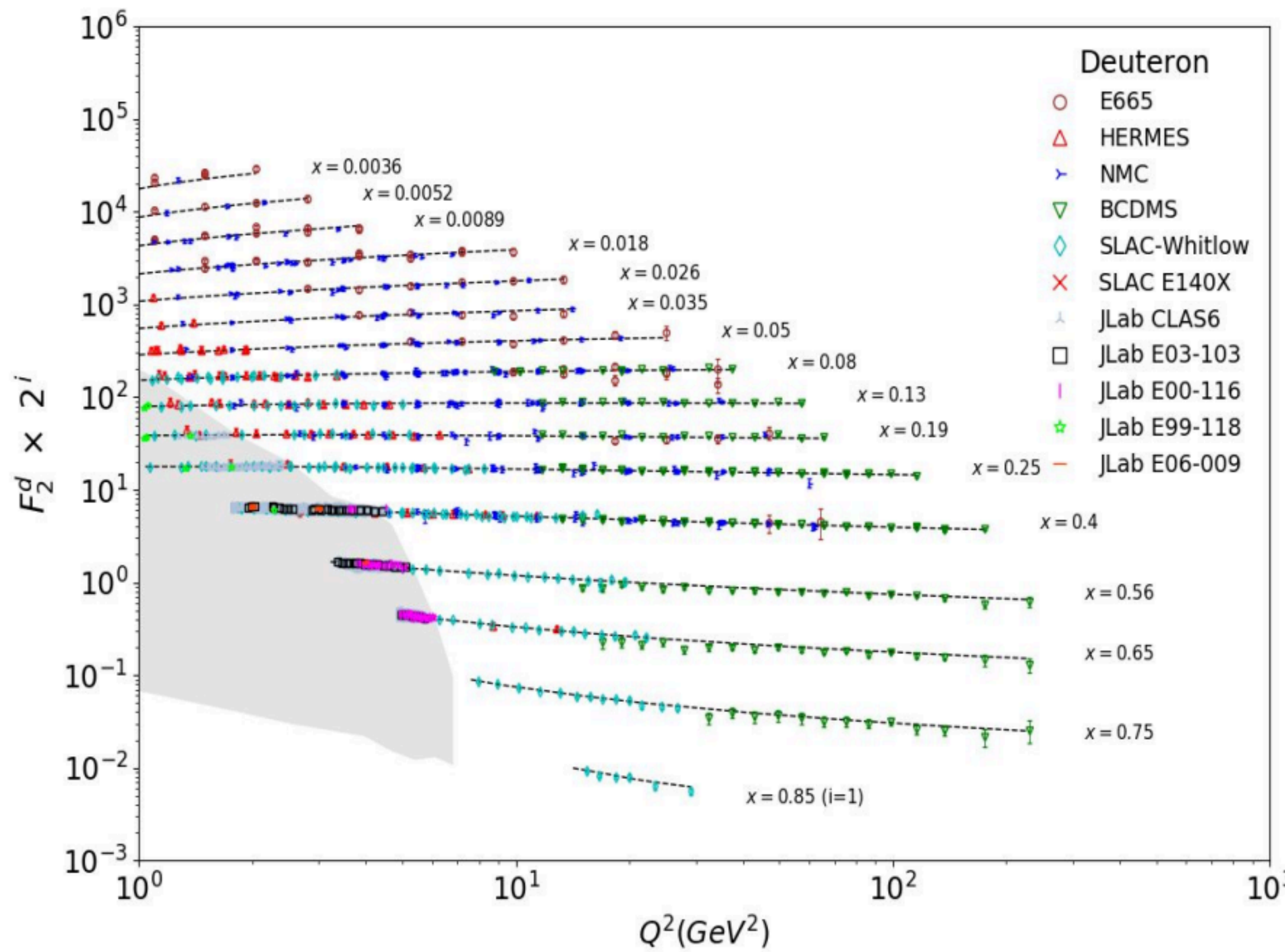


Full treatment of nuclear corrections

Binding effects, Fermi motion, off-shell corrections, Higher Twist (HT), Target Mass Corrections (TMC)

$$F_{2,D}(x_D, Q^2) = \int_{y_{Dmin}}^{y_{Dmax}} dy_D dp_T^2 f_{N/D}(y_D, p_T^2; \gamma) F_{2,N}\left(\frac{x_D}{y_D}, Q^2, p^2\right)$$

Smearing function

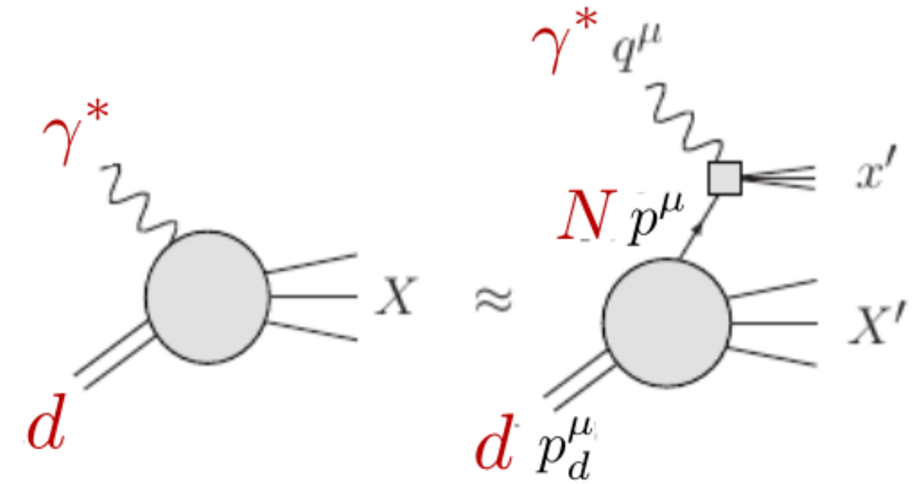
Structure function of a bound, off-shell nucleon

J. Owens, et al., PRD 87 (2013)

CJ: treatment of deuteron targets

Nuclear impulse approximation

Melnitchouk, Schreiber, Thomas, PRD 49 (1994)
Kulagin, Piller, Weise, PRC 50 (1994)
Kulagin and Petti, NPA 765 (2006)



$$F_{2,D}(x_D, Q^2) = \int_{y_{Dmin}}^{y_{Dmax}} dy_D dp_T^2 f_{N/D}(y_D, p_T^2; \gamma) F_{2,N}\left(\frac{x_D}{y_D}, Q^2, p^2\right)$$

Off-shell expansion (in nucleon virtuality p^2)

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

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

Kulagin, Piller, Weise, PRC 50 (1994)
Kulagin, Melnitchouk, et al., PRC 52 (1995)
Kulagin and Petti, NPA 765 (2006)

Free nucleon pdfs/SFs
$p^2 = m_N^2$

Off-shell function
(To be fitted)

Structure function
of a bound, off-shell nucleon

CJ: treatment of deuteron targets

Off-shell corrections

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

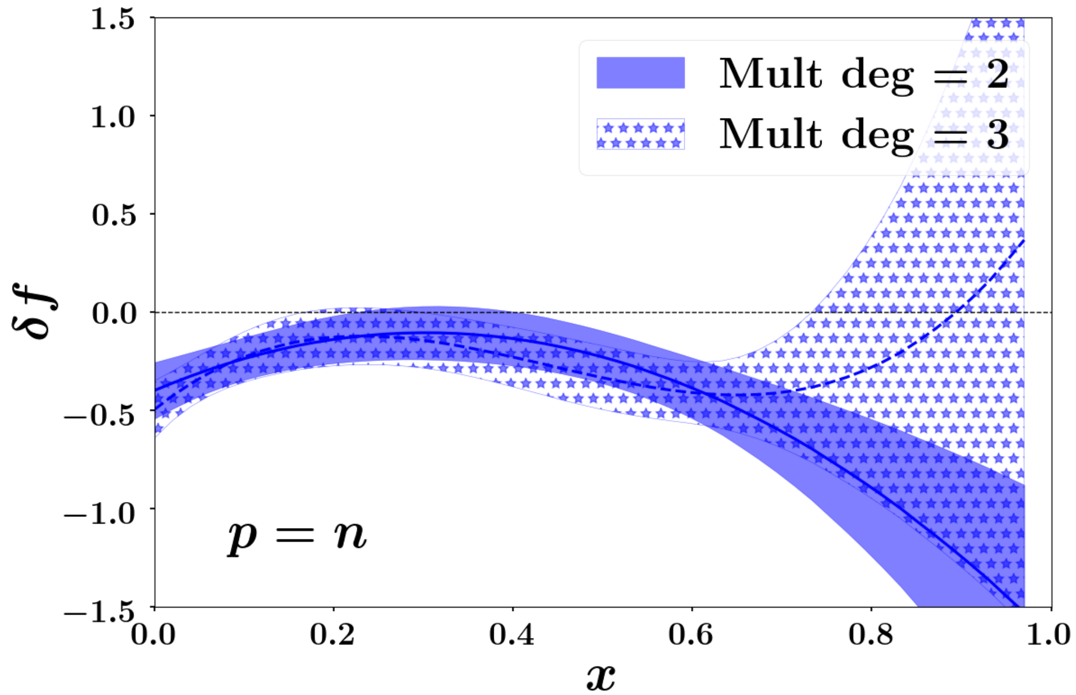
- KP-like model $\delta f^N = C(x-x_0)(x-x_1)(1+x_0-x)$

  + valence sum rule $\int_0^1 dx\, \delta f^N(x)\ [q(x)-\bar{q}(x)] = 0$

  Kulagin and Petti, NPA 765 (2006)
  Accardi, et al., PRD 93 (2016)
  Accardi, et al., PRD 107 (2023)

- Polynomial model $\delta f(x) = \sum_n a_{off}^{(n)} x^n$

  Alekhin, Kulagin, Petti, PRD 96 (2017)
  Alekhin, Kulagin, Petti, PRD 105 (2022)
  Alekhin, Kulagin, Petti, PRD 107 (2023)



⇒ Constrain power of CJ dataset only up to x = 0.6

CJ: power corrections

Higher Twist corrections

Multiplicative (CJ fits)

$$F_2(x,Q^2) = F_2^{LT}(x,Q^2)\left(1+\frac{\boldsymbol{C}(x)}{Q^2}\right)$$

$$C(x) = a_{ht}^{(0)} x^{a_{ht}^{(1)}} (1 + a_{ht}^{(2)} x)$$

Additive

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

$$H(x) = a_{ht}^{(0)} x^{a_{ht}^{(1)}} (1-x)^{a_{ht}^{(2)}} (1 + a_{ht}^{(3)} x)$$

they are related

$$F_2^{LT}(x,Q^2)\left(1+\frac{\boldsymbol{C}(x)}{Q^2}\right) = F_2^{LT}(x,Q^2) + F_2^{LT}(x,Q^2)\frac{C(x)}{Q^2}$$

$$= F_2^{LT}(x,Q^2) + \frac{\tilde{\boldsymbol{H}}(x,Q^2)}{Q^2}$$

CJ: power corrections

Are experimental observables independent of the choice of the HT?

$$\frac{F_{2,n}}{F_{2,p}} = \frac{n}{p} \xrightarrow{x \to 1} \frac{4d+u}{4u+d} \simeq \frac{1}{4}$$

(extrapolation region)

Case 1: isospin-independent HT

mHT

$C_p(x) = C_n(x) = C(x)$

$$\frac{(4d+u)(1+C/Q^2)}{(4u+d)(1+C/Q^2)} \simeq \frac{1}{4}$$

No effect of HT

aHT

$H_p(x) = H_n(x) = H(x)$

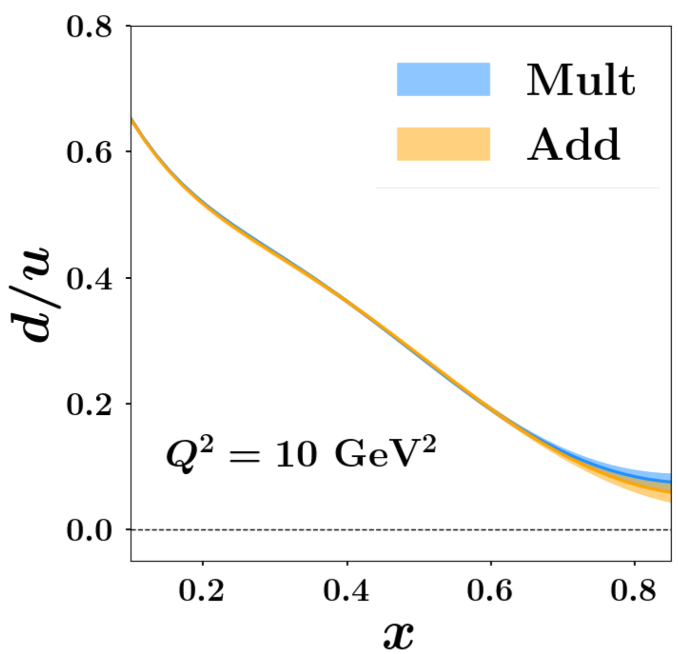
$$\frac{4d+u+H/Q^2}{4u+d+H/Q^2} \simeq \frac{1}{4} + 27\frac{H}{16uQ^2}$$

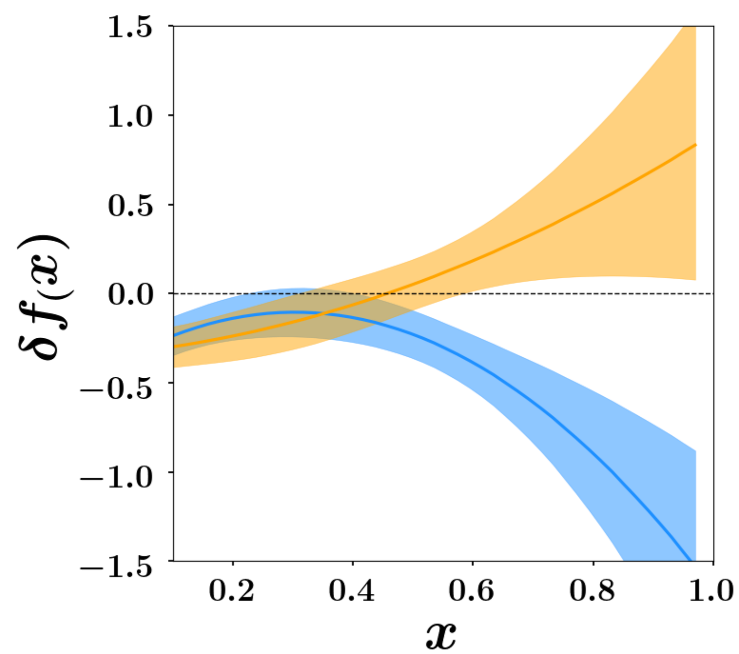
Strong effect of HT

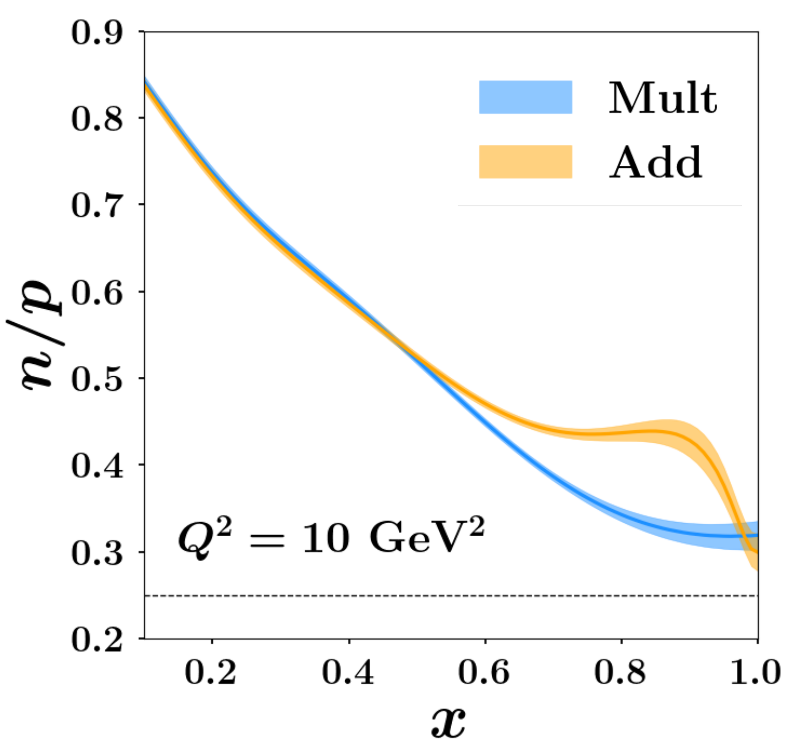
Bias identified!!

CJ fit: results

Case 1: isospin-independent HT

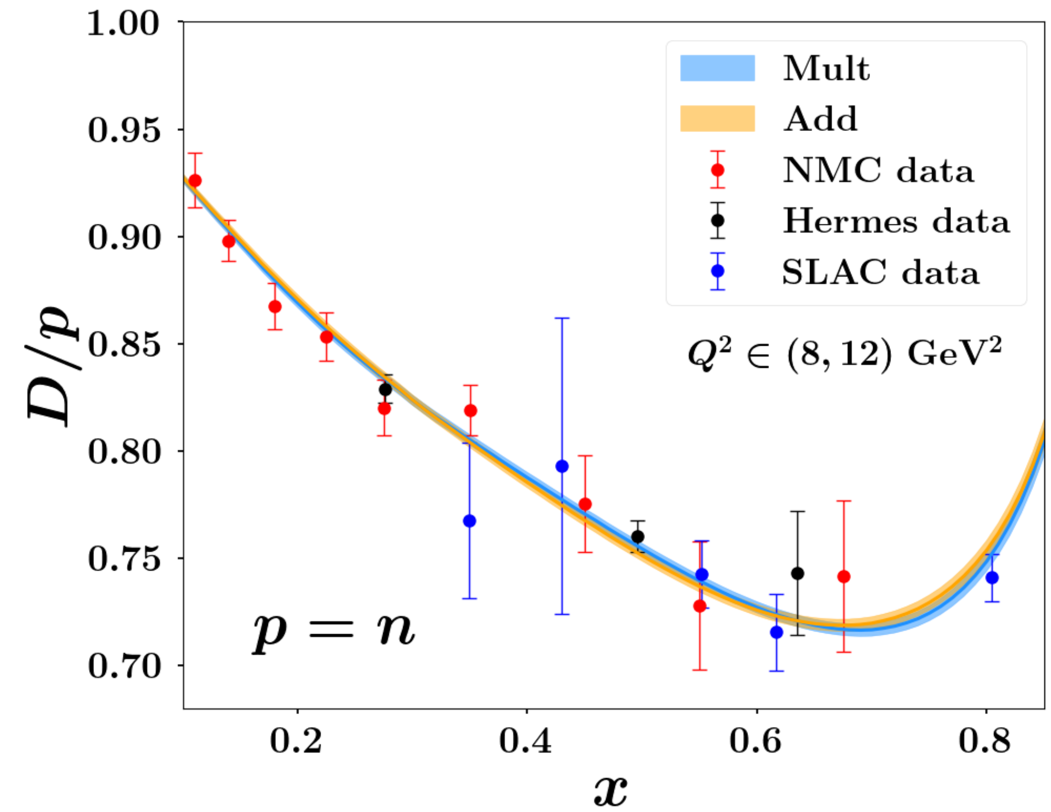






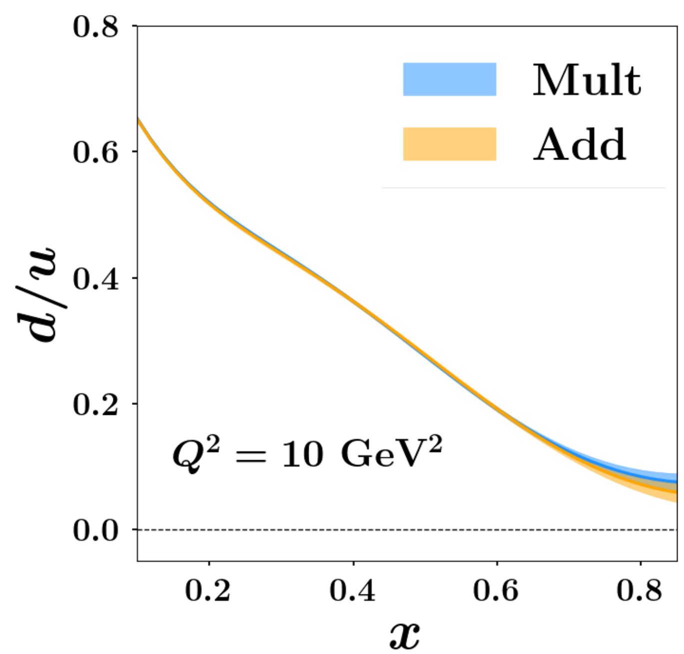
Bias identified

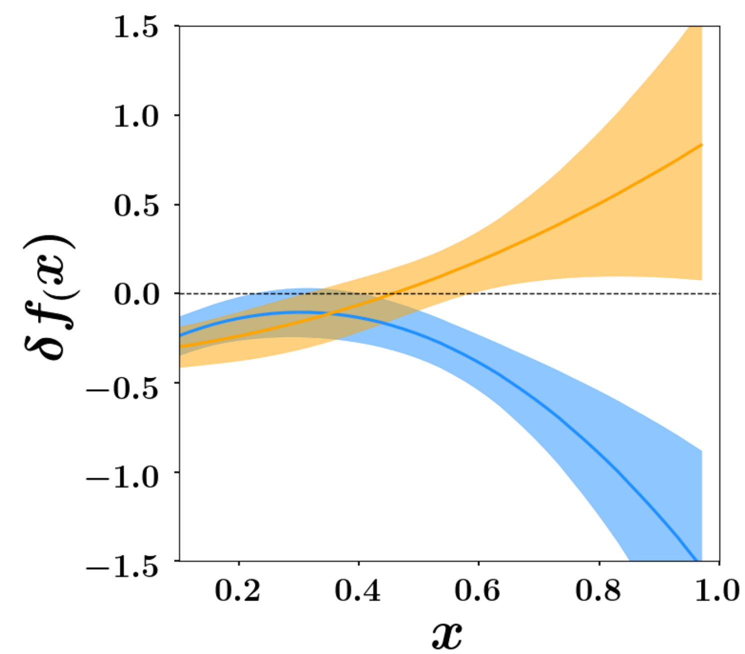
Off-shell compensates n/p

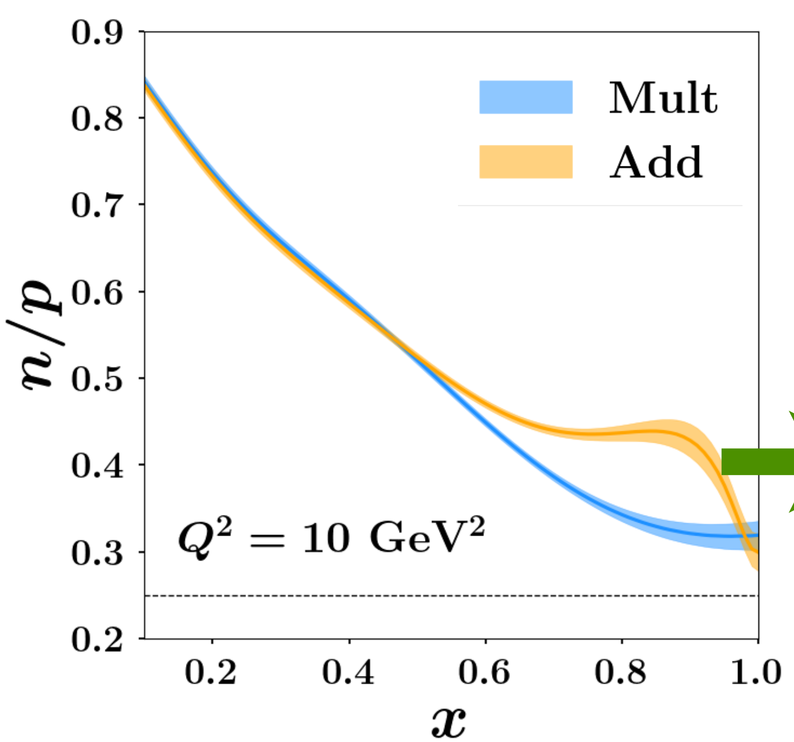


CJ fit: results

Case 1: isospin-independent HT





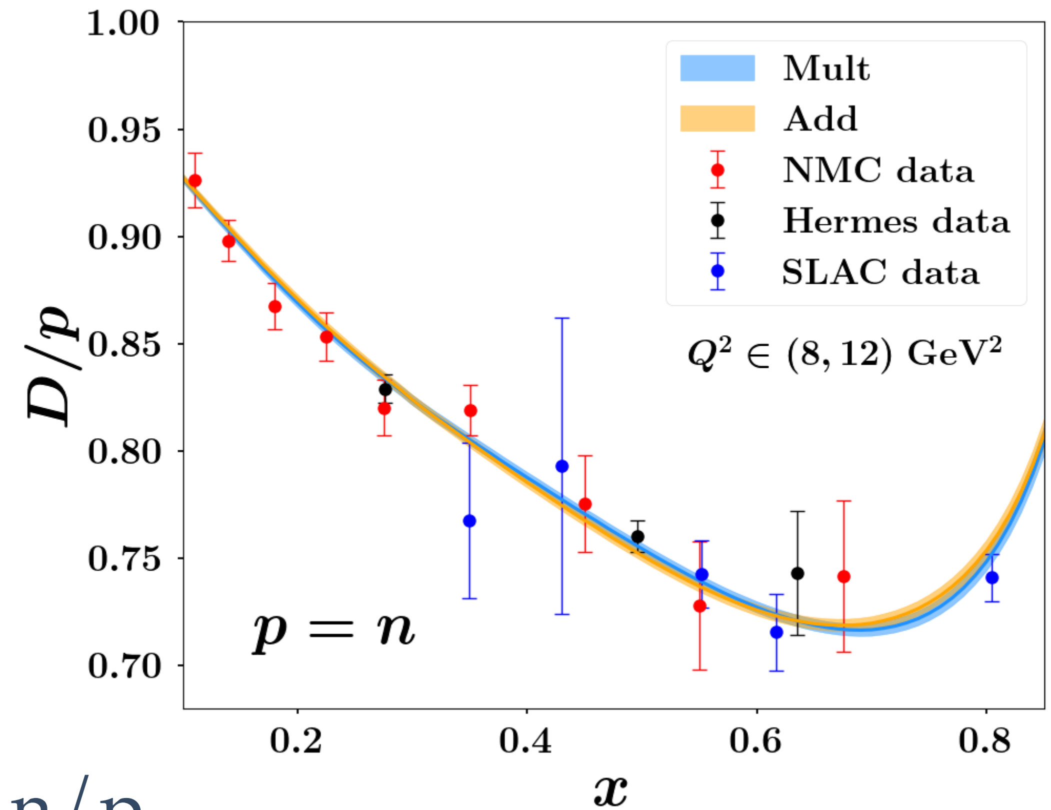


Artificially large n/p

BUT smaller d/u than Mult

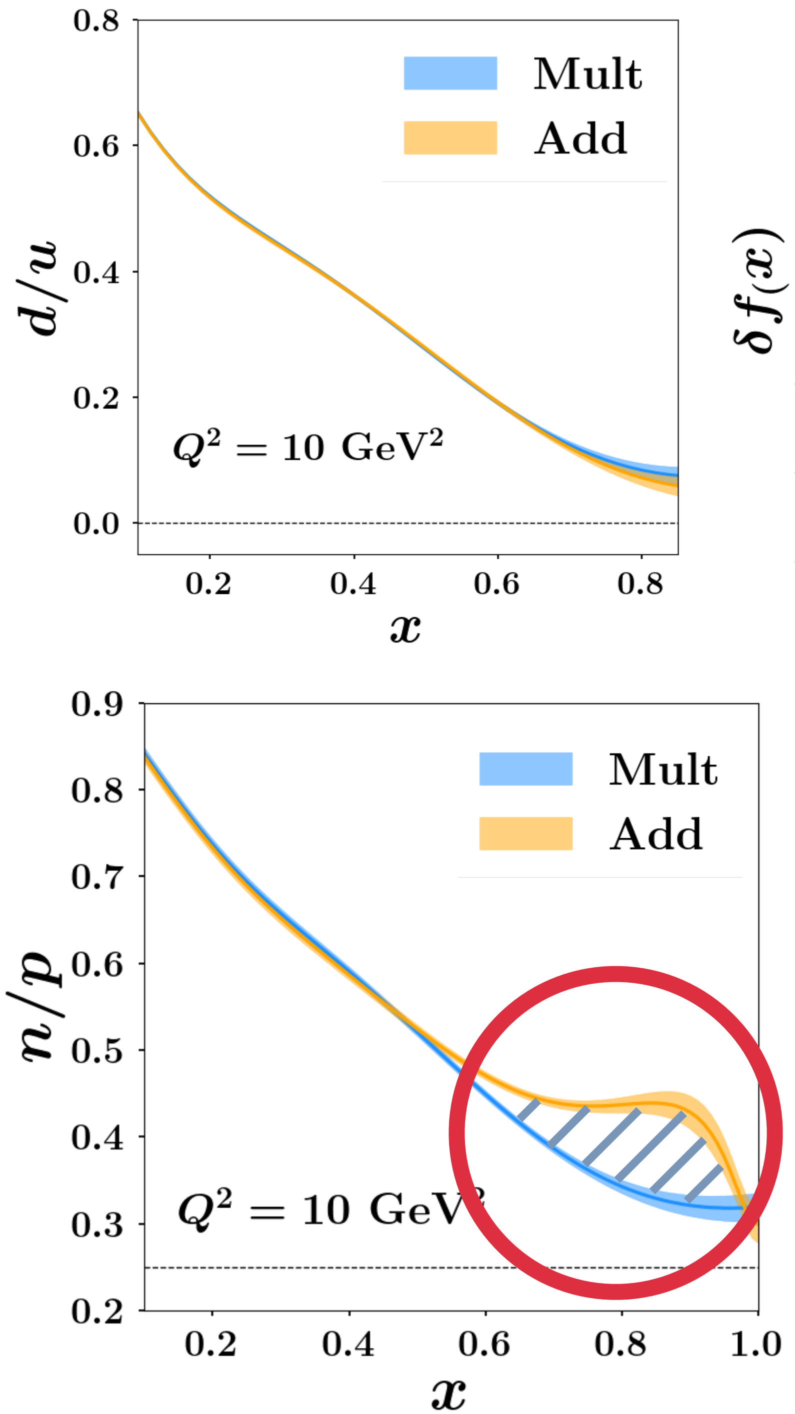
Bias identified

Off-shell compensates n/p



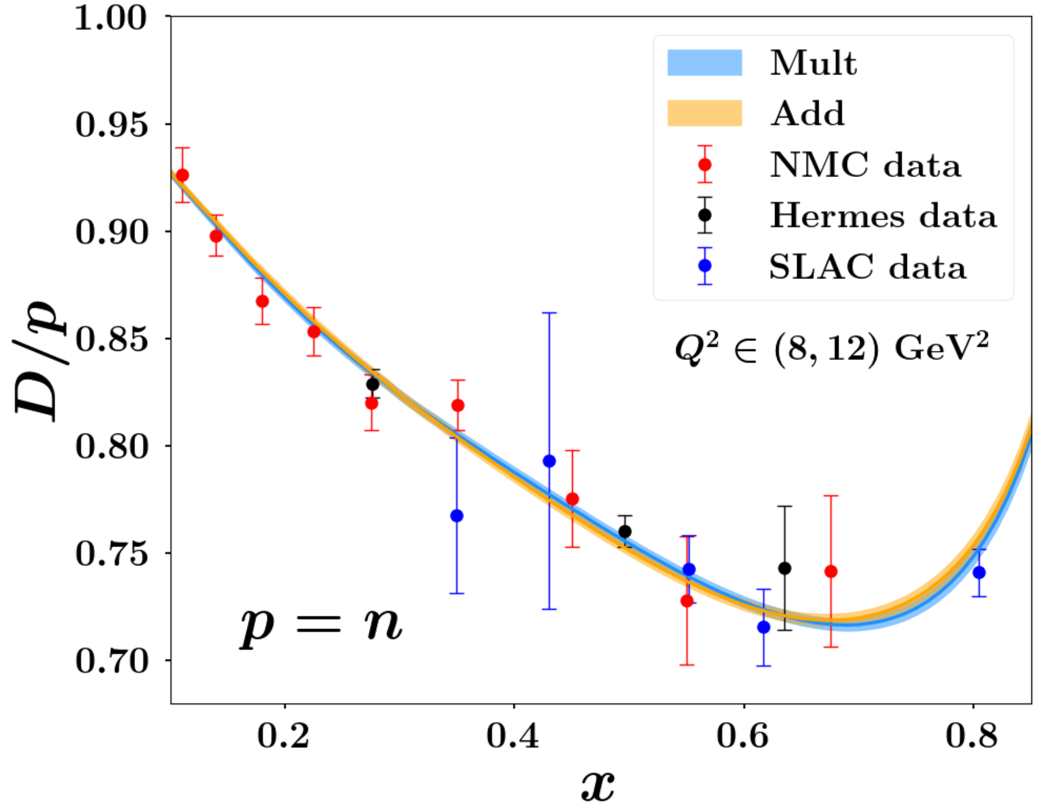
CJ fit: results

Case 1: isospin-independent HT



Bias identified

Off-shell compensates n/p



Systematic "implementation" uncertainty in a region of extrapolation

CJ: possible solution

Are experimental observables independent of the choice of the HT?

$$\frac{n}{p} \xrightarrow{x \to 1} \frac{1}{4}$$ **LT** **Mult HT** $C_p(x) = C_n(x) = C(x)$

Case 2: isospin-dependent HT

aHT

$H_p(x) \neq H_n(x)$

$$\frac{u + H_n/Q^2}{4u + H_p/Q^2} \simeq \frac{1}{4} + 9\,\frac{4H_n - H_p}{16uQ^2}$$

$H_p(x) = H_n(x)$ → $$\frac{1}{4} + 27\frac{H}{16uQ^2}$$

$H_p(x) = 2H_n(x)$ → $$\frac{1}{4} + 9\frac{H}{16uQ^2}$$

n/p ratio is smaller

mHT

$C_p(x) \neq C_n(x)$

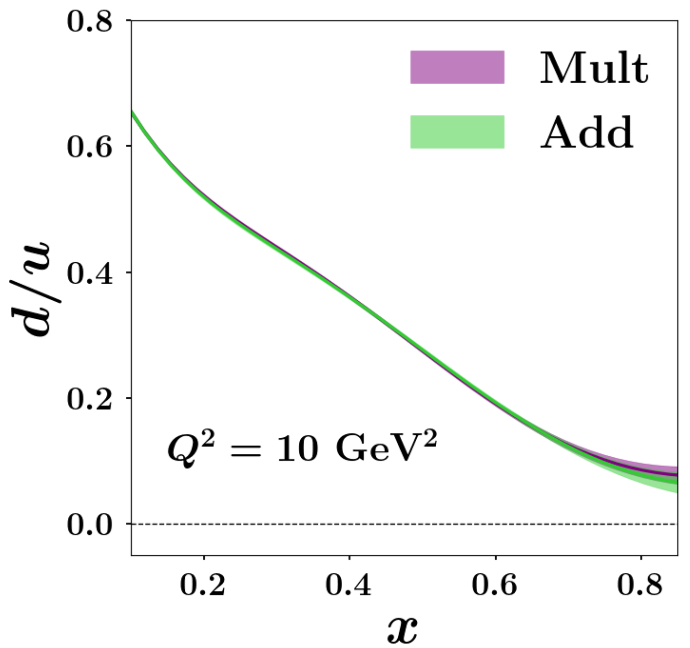
$$\frac{u + \tilde{H}_n/Q^2}{4u + \tilde{H}_p/Q^2}$$

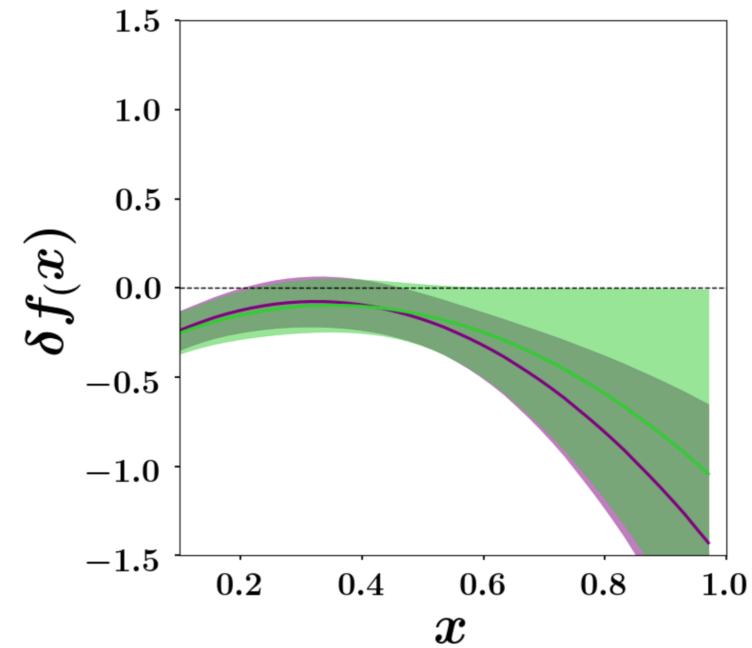
same as Add

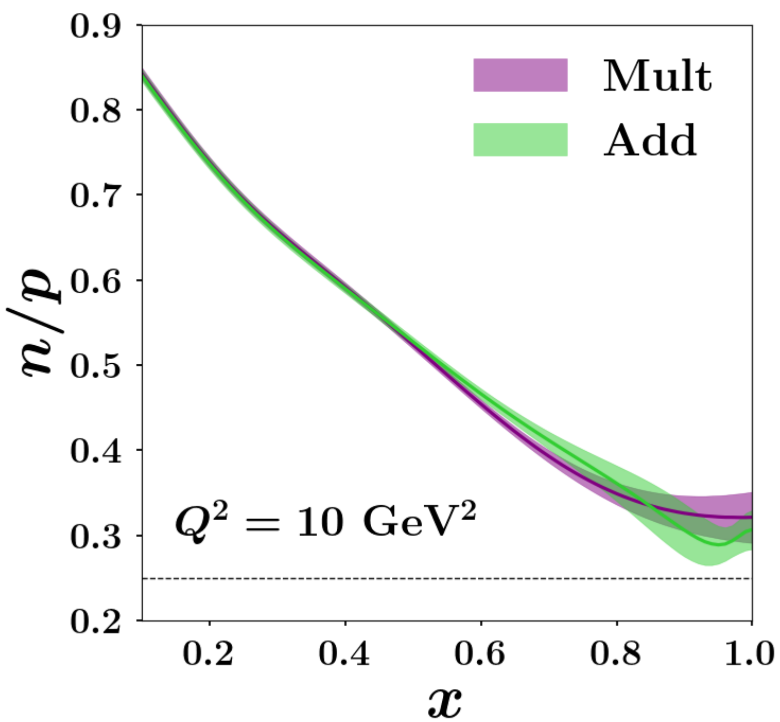
Bias removed!

CJ fit: results

Case 2: isospin-dependent HT





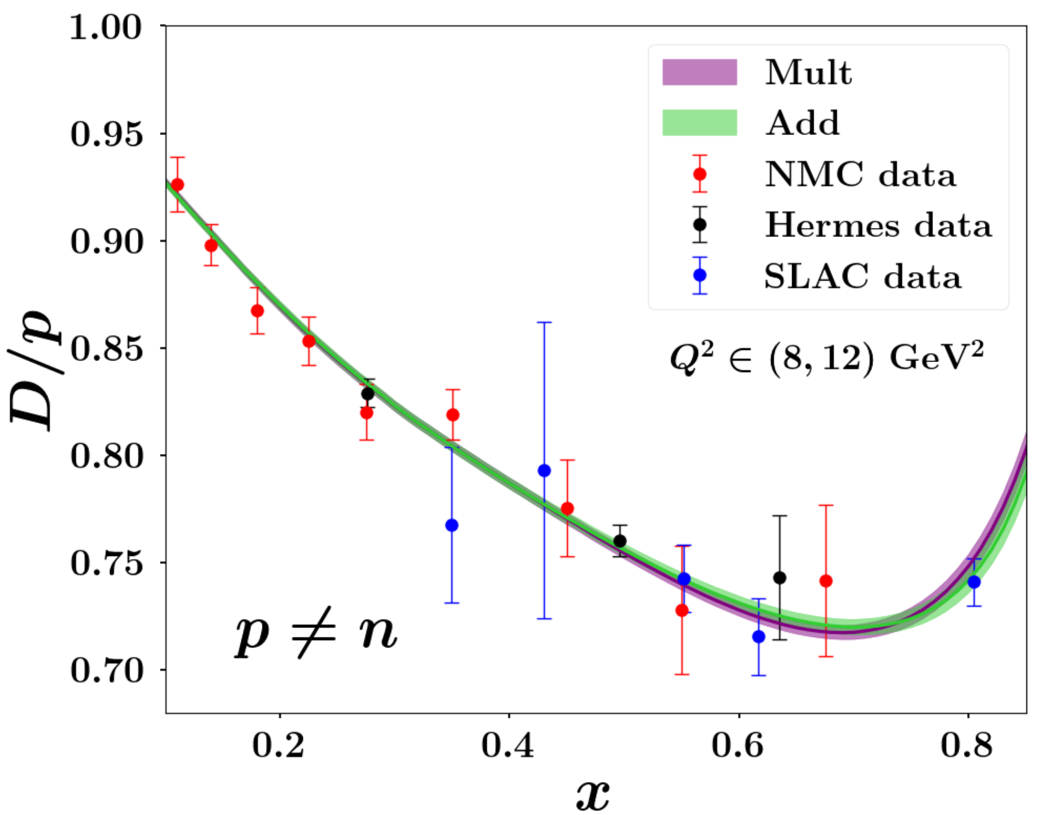


Compatible n/p

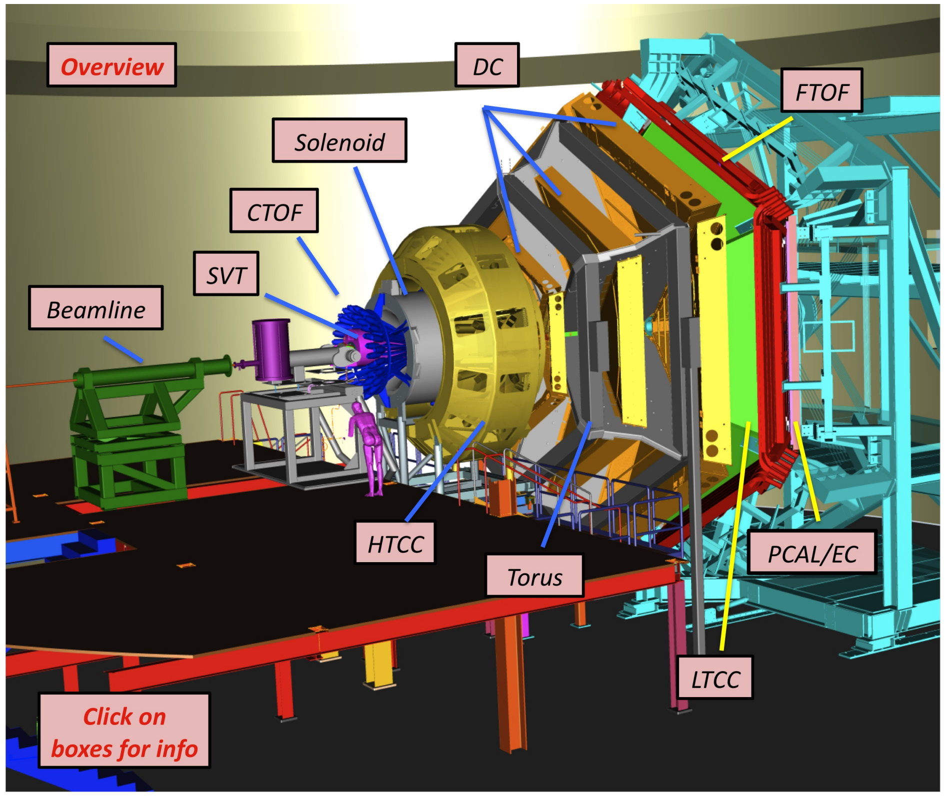
Bias removed

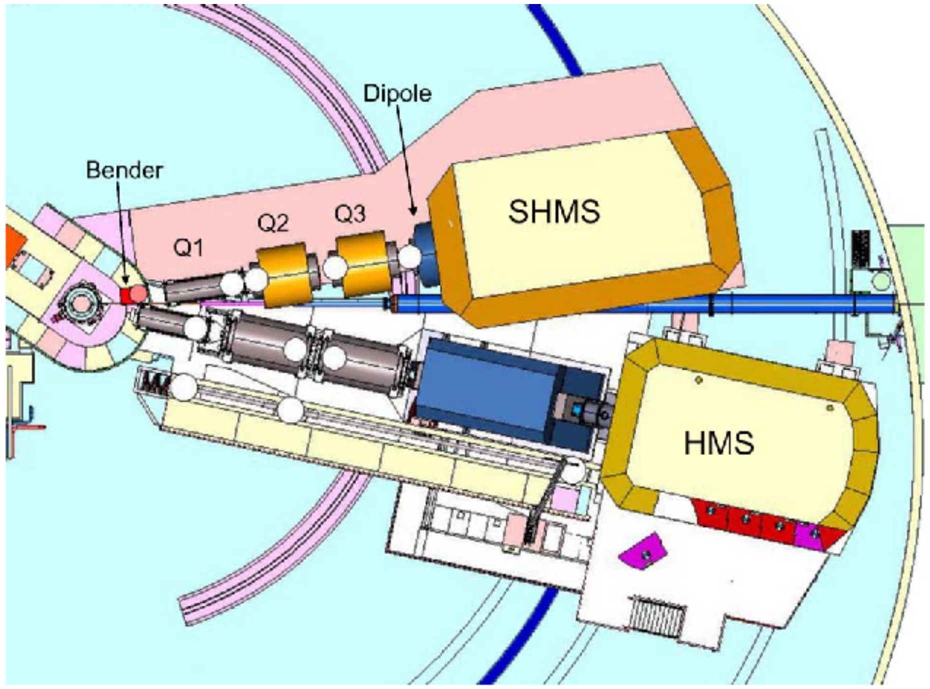
No need of compensation by off-shell

Theory expectations confirmed!



More data are needed: present





CLAS12 (BoNUS12)

$$e + d \to e' + p + X$$

Hall C

$$e + p/D \to e' + X$$

Biswas, et al., 2409.15236

New experimental data in the large-x region are needed to understand the correct interconnection of d/u, n/p ratios and off-shell corrections

More data are needed: future

Study of the impact of 22 GeV experimental data from Jefferson Lab

JLab22 pseudodata: kinematics

Pseudodata generated in
Hall C kinematics

Shujie Li

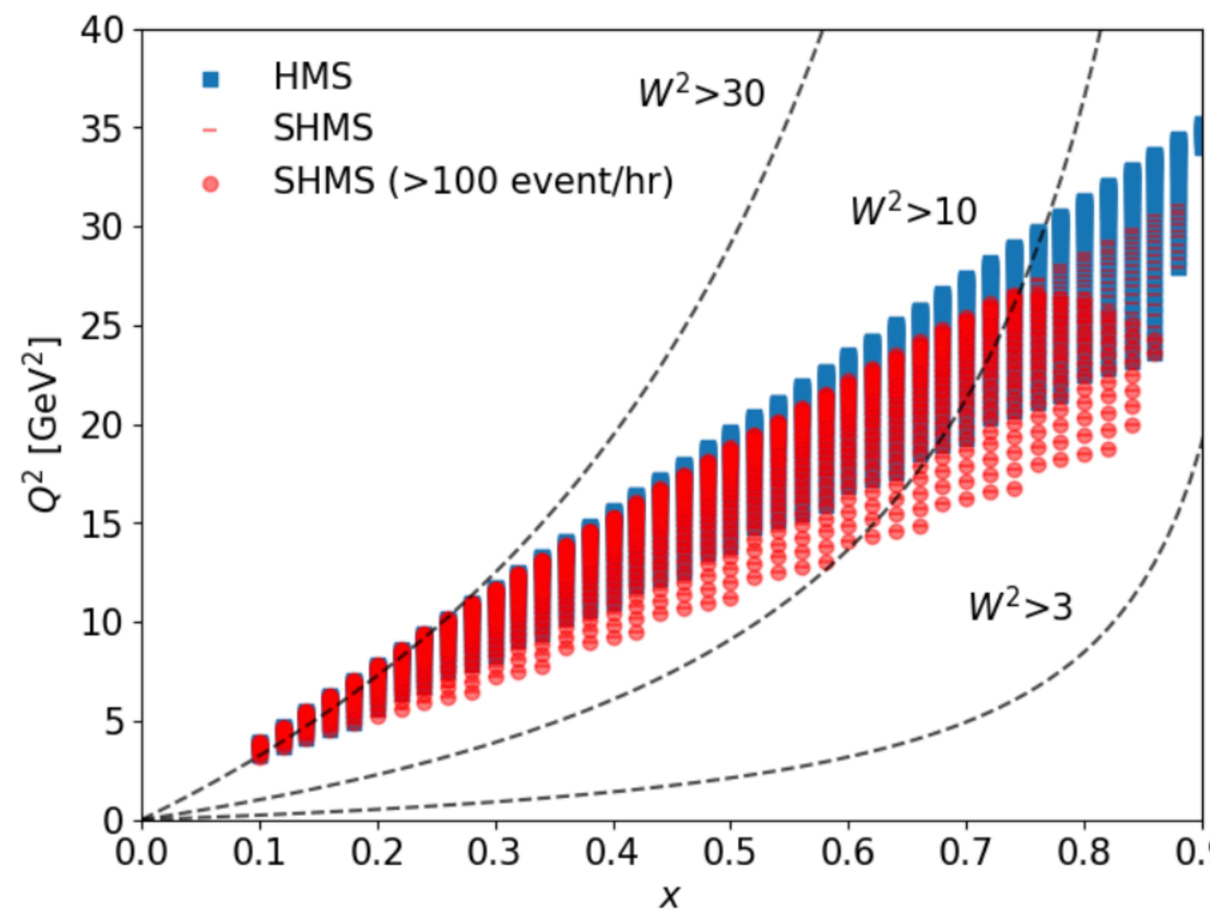
HOME MADE

Disclaimer:

We need help for a more reliable and precise generation of pseudodata

- **Detector: Standard SHMS@Hall C**
  - Momentum: up to 11 GeV/c
  - scattering angle: up to 40 degrees
  - Acceptance: 50mrad x 18mrad x ±10%
- **Luminosity:** 50uA on liquid hydrogen target ⇒ 10^{38}/s/cm^2
- **Cross Section model:** F1F2in21 (DIS only) + radiative corrections
- **Systematics**:
  - Point-to-point: 4% on absolute xsection, 2% on ratio
  - Normalization: 1%

- HMS TBD



JLab22 pseudodata: values and errors

Central value: mHT CJ fit

F_2^p F_2^d

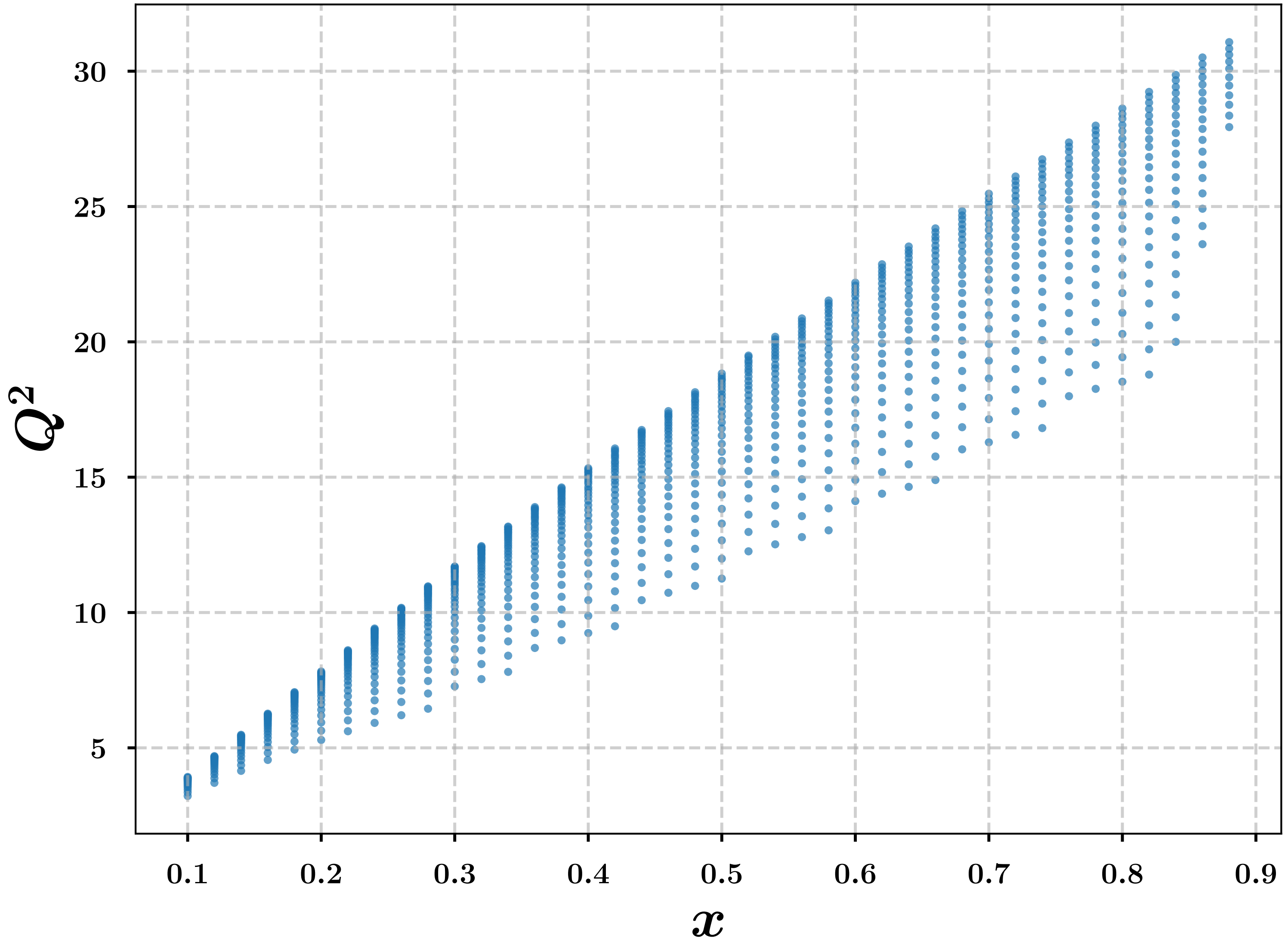
Errors:

- stat —> $1/\sqrt{\Delta t N}$

  $\Delta t = 100$ days

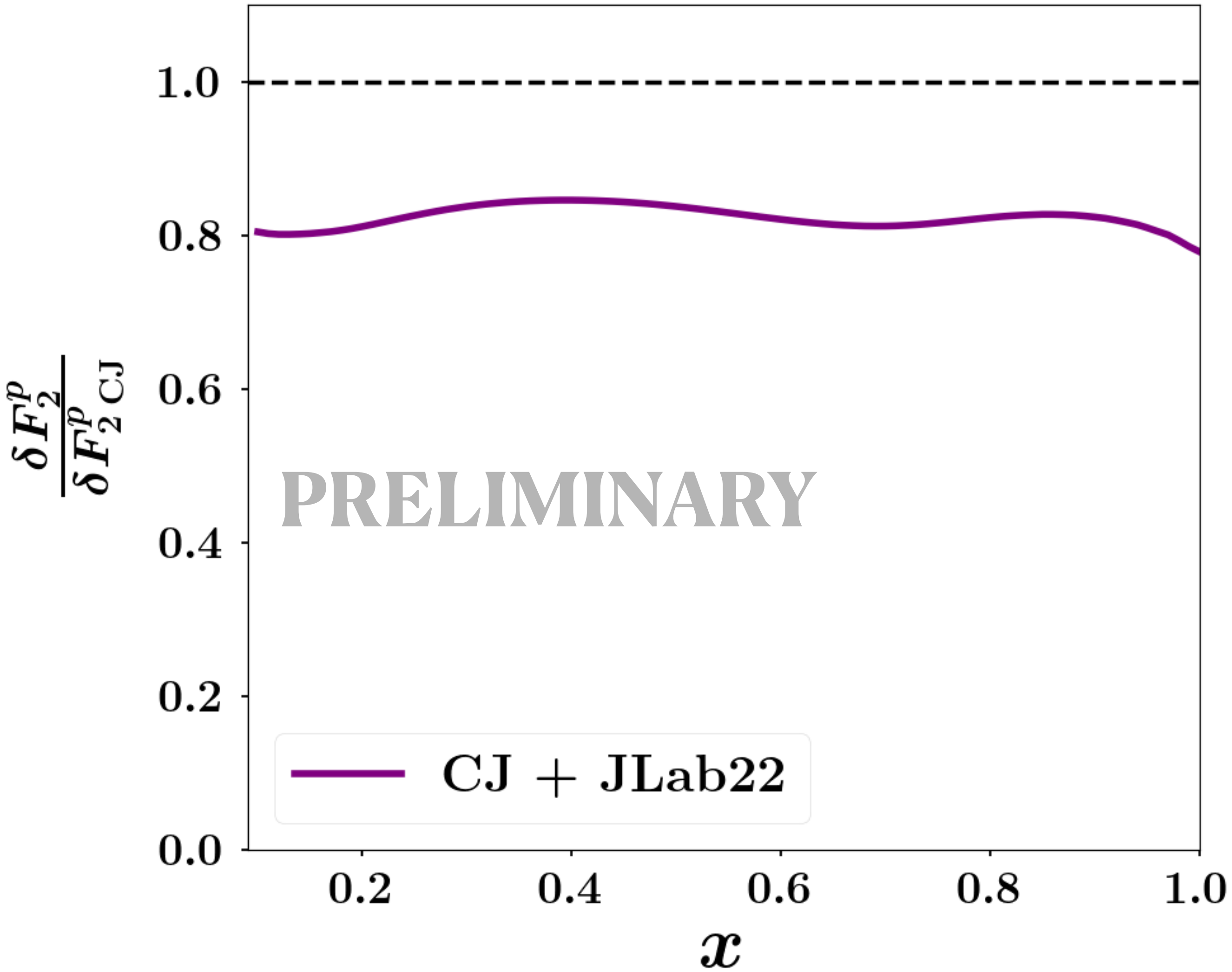
- syst —> 2 %

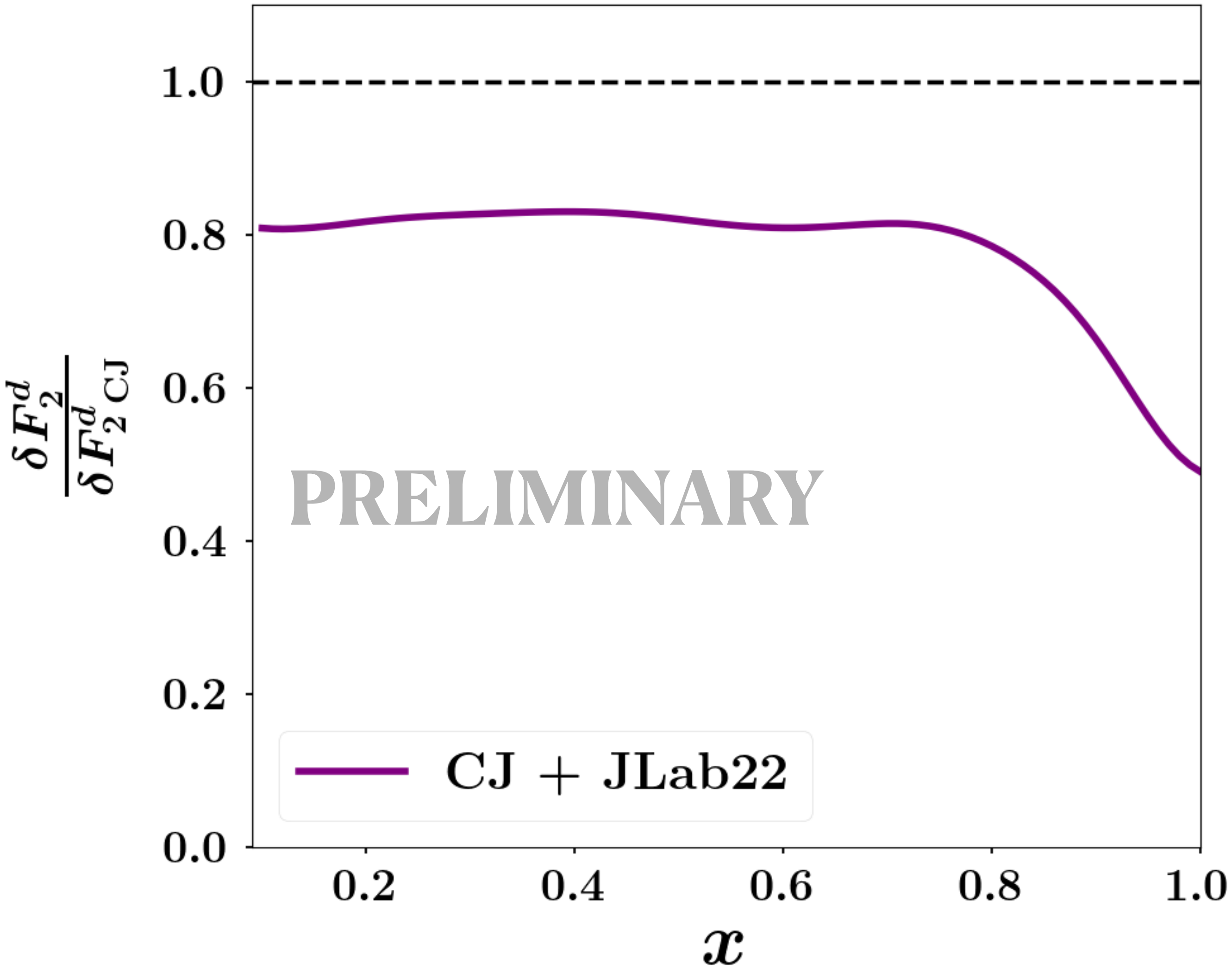
- norm —> 1 %



Impact study: results

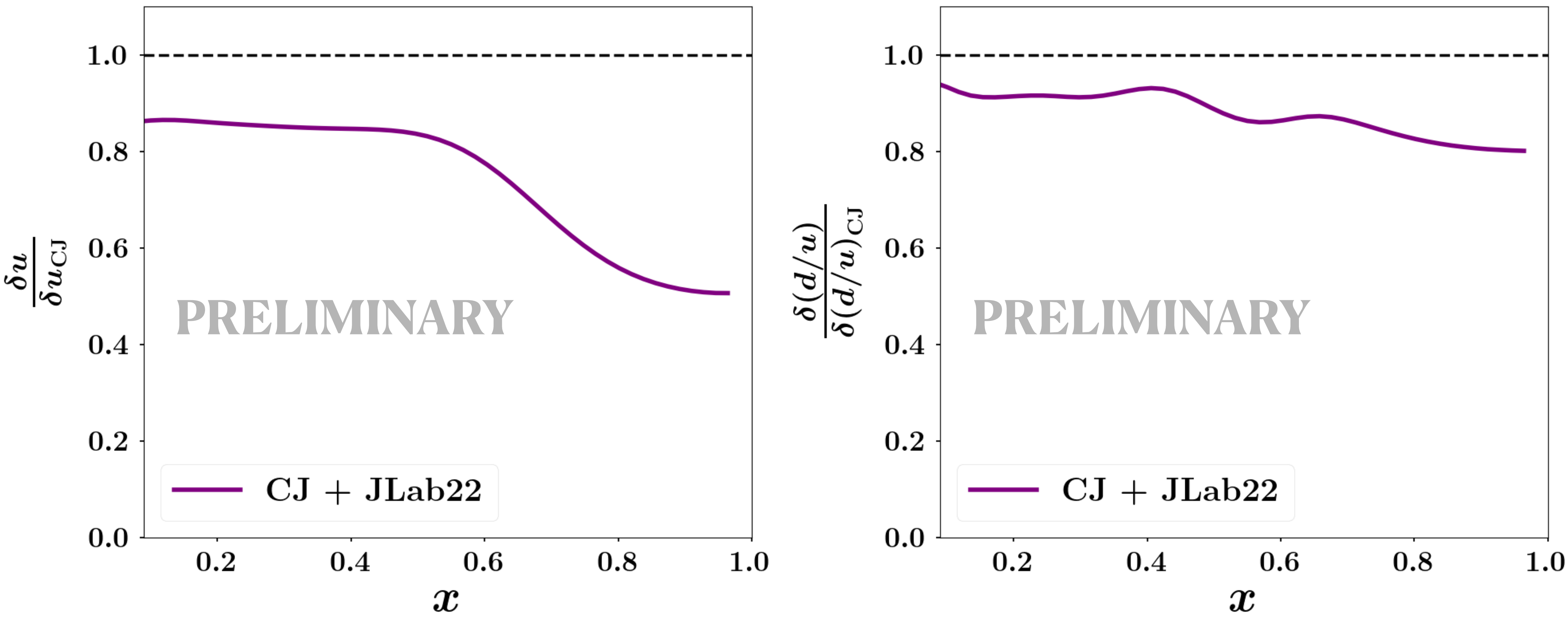
Impact on the observables: reduction of $\simeq 20\,\%$





Impact study: results

Impact on the PDFs: reduction of $\simeq 10 - 20\,\%$



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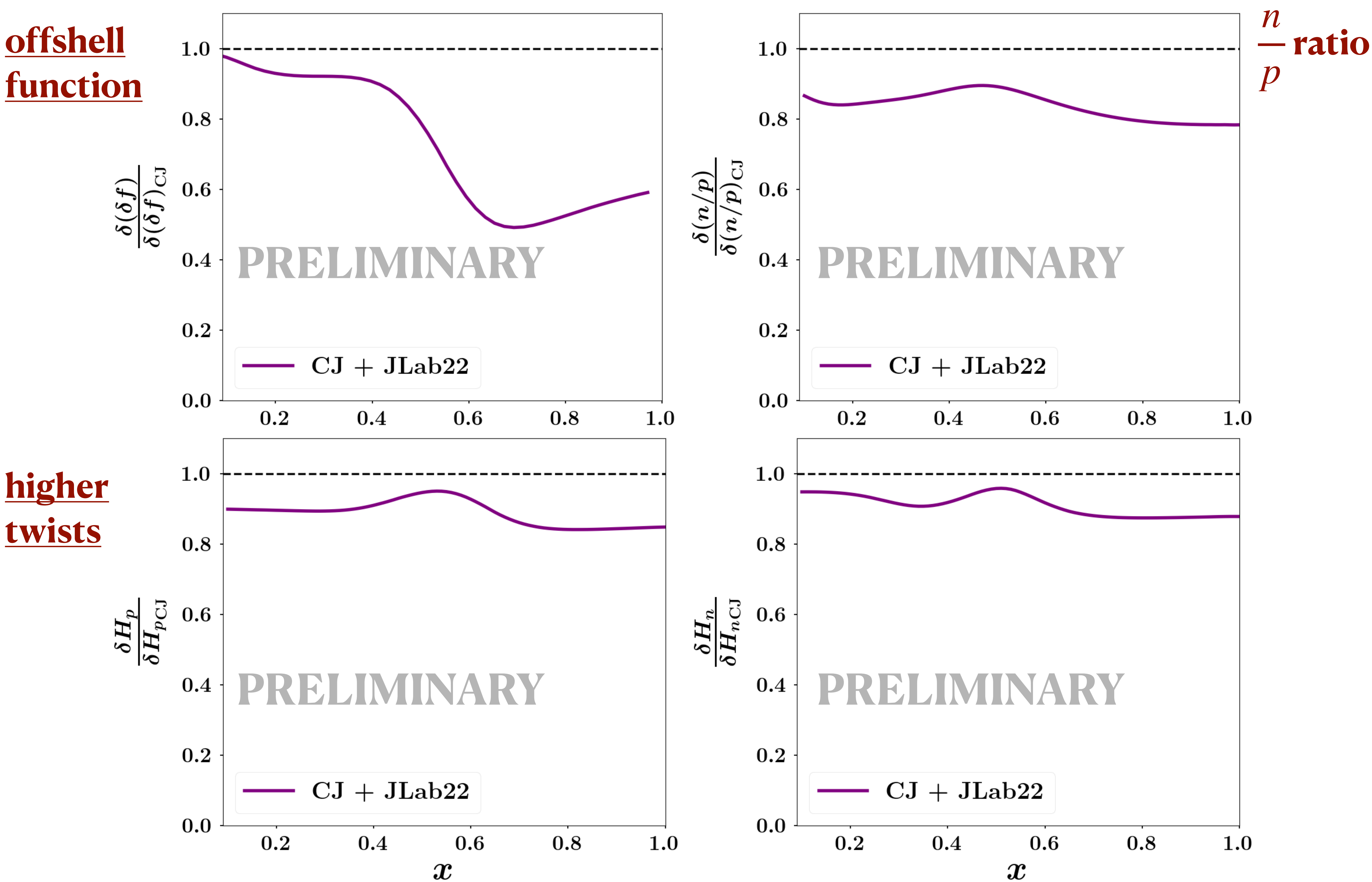


JLab22 pseudodata: HT model

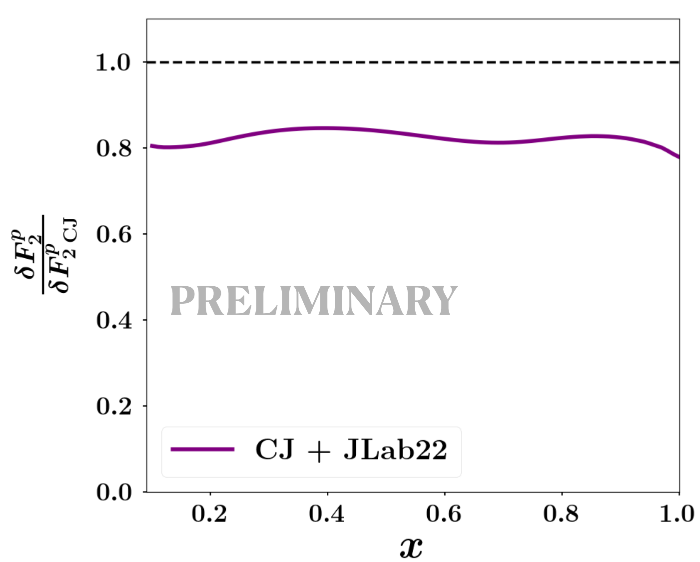
mHT

Pseudodata generation

↑

New fit

(impact just shown)



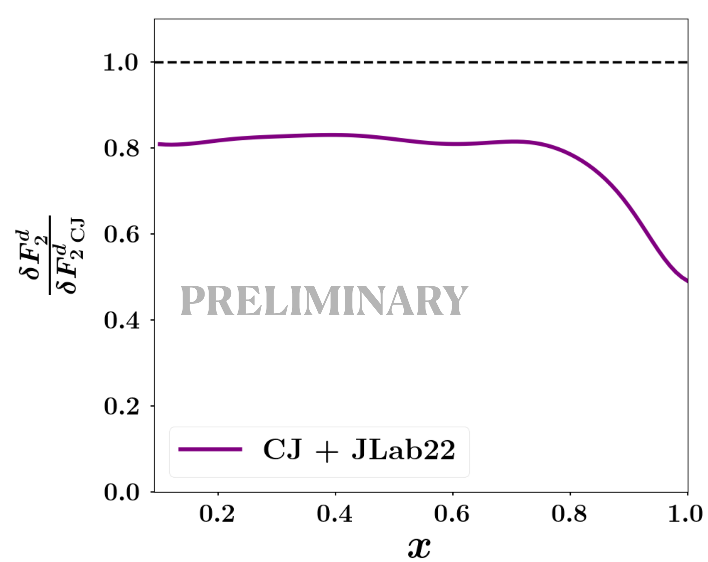
aHT

Pseudodata generation

↑

New fit

(similar impact)



JLab22 pseudodata: HT model

mHT

aHT

Pseudodata generation

New fit

F_2^p	$\chi^2/N < 1$
F_2^d	$\chi^2/N \sim 3$

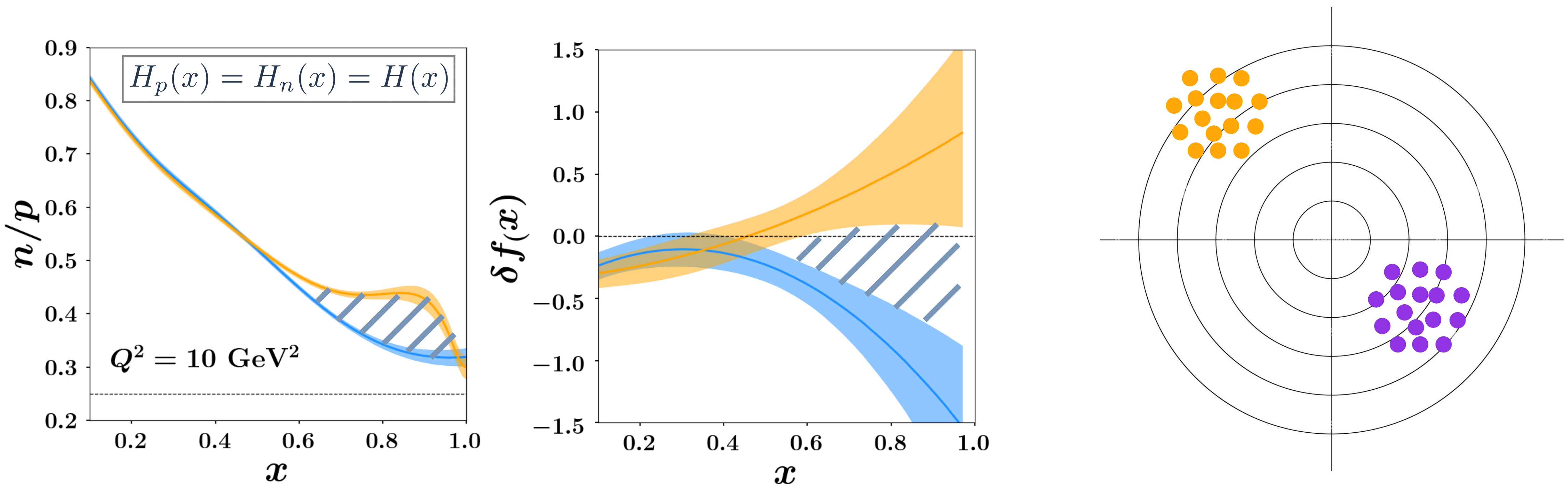
There is disagreement with large-x deuteron data

Large $Q^2 \Rightarrow$ no compensation of different pheno assumptions

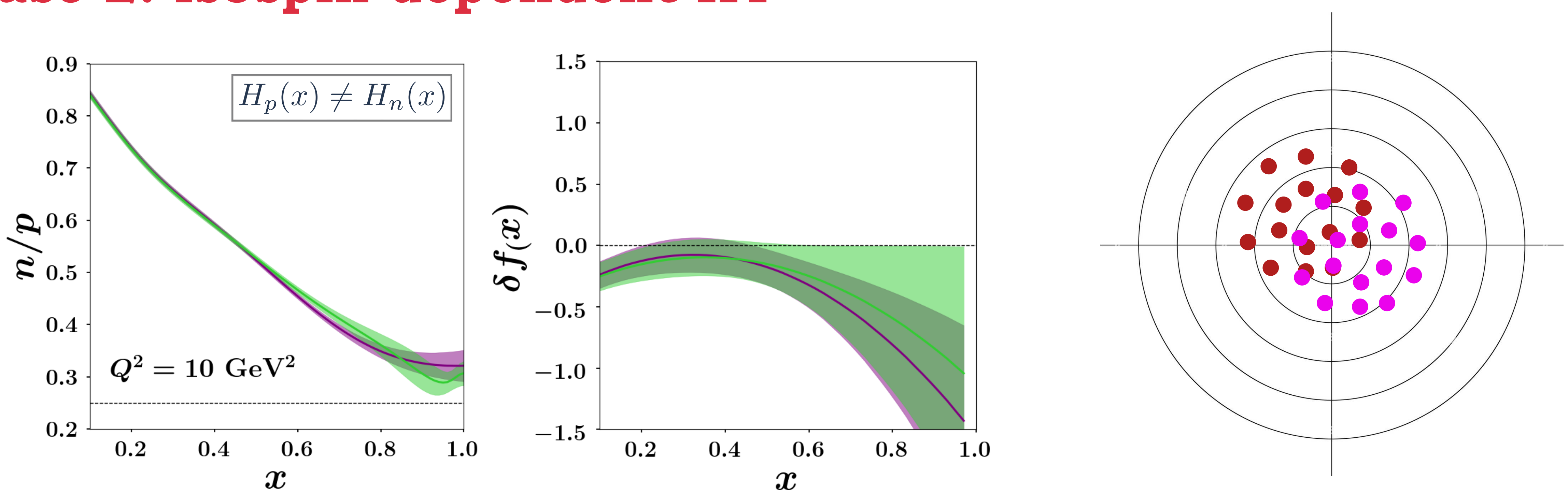
With new data from JLab22 we may select the model for HT and nuclear corrections

Conclusions and Outlook

Case 1: isospin-independent HT



Case 2: isospin-dependent HT



Conclusions and Outlook

- **We need new precise data for DIS at large** x
  - JLab6 cross sections
  - JLab12 new data
- **We have the tools to study the impact of JLab22 at large** x
  - Sizable reduction of uncertainties in the fit **d/u** **HT** $\boldsymbol{\delta f}$
  - Potential of selecting model implementation of HT and nuclear corrections
  - Extraction of δf with data at larger Q^2 (smaller correlation to HT)