Extracting Neutron Structure Functions from World DIS Data with CJ15 Nuclear Corrections

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GHP Workshop @ Denver, April 2019

University of New Hampshire

Jefferson Lab

CTEQ-Jefferson Lab Collaboration

Overview

World unpolarized DIS proton and deuterium datasets with new data from Jefferson Lab 6 GeV experiments

+

nuclear corrections from CJ15 [1] global QCD analysis

=

F2 neutron "Data"

Why create neutron dataset?

- Improve neutron excess "isoscalar" corrections
  - EMC effect
  - Neutrino experiments

- Flavor separation
  - d/u
  - Nucleon structure / confinement at large x

- Experimental values for sum rules and moments involving $\int F_2^p - F_2^n \, dx$
  - Gottfried Sum Rule (dbar - ubar)
  - Compare to lattice ($u^+ - d^+$)

- Input for PDF efforts that do not currently incorporate deuteron nuclear corrections
  - Can input F_2^n data set into ***<u>any</u>*** global fit

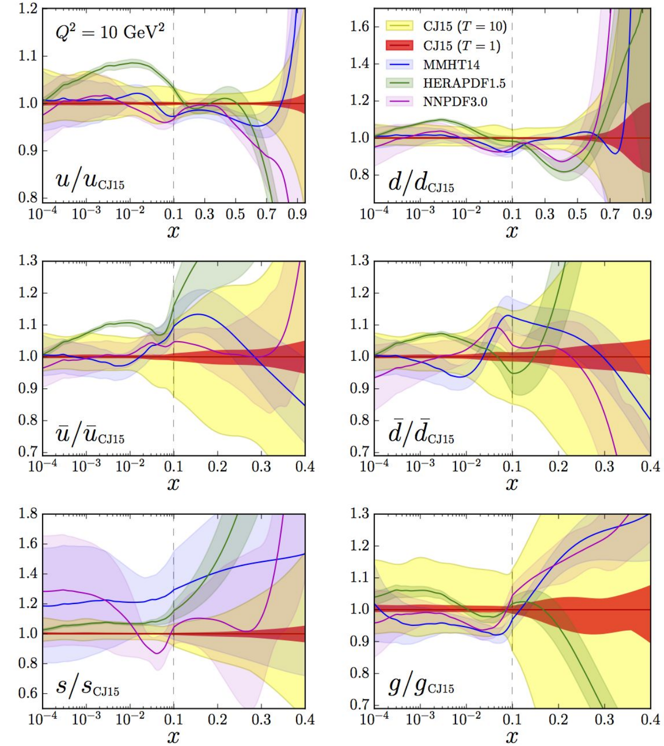
Can compare free and bound nucleons (*both* proton and neutron) in nuclei
New window on the EMC effect

CTEQ-Jefferson Lab “CJ” PDF Fits

CJ15

http://www.jlab.org/CJ

- CTEQ-based PDF fit **optimized for larger x, lower Q^2**
  - Necessary for experiments at Jefferson Lab, neutrino experiments, spin structure,…
  - Valence regime increasingly important for lattice comparisons
- Uses data previously subject to kinematic cuts (SLAC and JLab largely)
- Incorporates higher twist, target mass corrections
- Allow d/u to go to a constant
- *Need accurate deuteron nuclear corrections for DIS data*

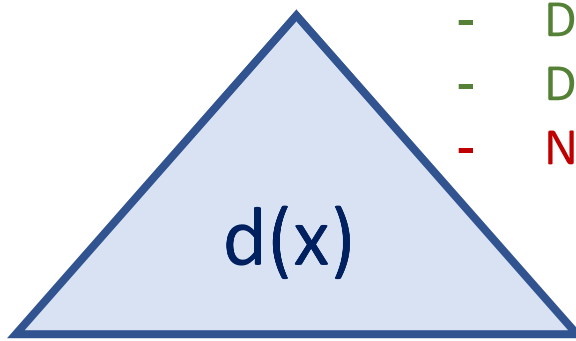


Current Data Constraints on d(x) at Large x

CJ15

D0, CDF W asymmetries

- Dominant constraint on d(x)
- Data up to x ~ 0.7
- Not much data (~a dozen points)

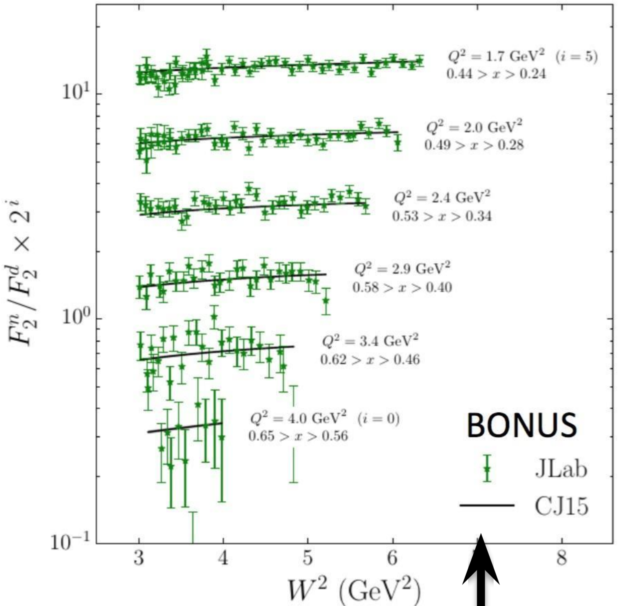


"BONuS" tagged neutron target

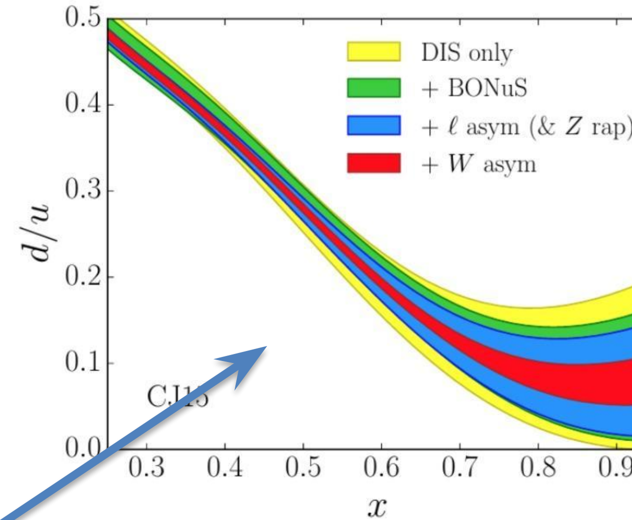
- Nearly model-independent *neutron* data
- Data obtained in 6 GeV JLab era at low W, Q

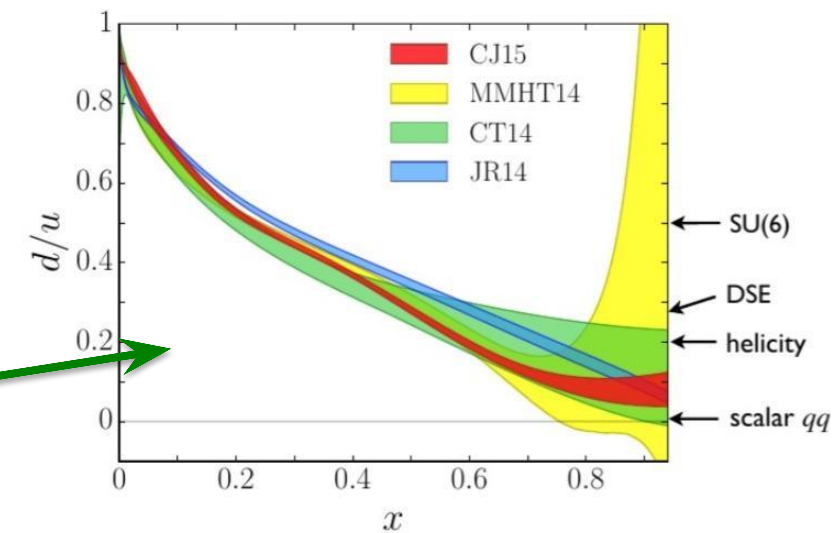
Deep inelastic deuterium

- Large body of data from multiple experiments
- Data up to x ~0.9
- Q^2 range for evolution
- Requires deuteron nuclear corrections



CJ15





- BONuS data well fit by CJ
- Effect of adding BONUS (also W, l asymmetries from D0)
- **Substantial reduction in d/u uncertainty at large x!**

A. Accardi, et al., Phys. Rev. D **93** 114017 (2016)

The CJ DIS Database

SLAC (Whitlow, E140, E140x)

JLab (JLCEE96, E06-009, E94-110, E03-103, E99-118, E00-116, CLAS6, BoNus)

- 2000+ new data points

NMC, BCDMS, HERMES, HERA, E665 …

Revisited correlated systematics for NMC, SLAC, etc

A = data is available but not collected 10001-10070 = data ID in JAM databsae

Experiment	σ_r	F2	R
SLAC-Whitlow	p: 10014	p: 10010	p: 10064
	d: 10015	d: 10011	d: 10065
	d/p: 10034	d/p (*): 10034	
SLAC-E140			d: 10066
SLAC-E140x	p: 10037	p: 10035	p: 10067
	d: 10038	d: 10036	d: 10068
NMC	p: 10022	p: 10020	
	d: 10040	d: 10039	
	d/p:10021	d/p (*):10021	
BCDMS	p: 10018	p: 10016	p: 10069
	d: 10019	d: 10017	d: 10070
JLab E06-009	d: 10042	d: 10041	

The full database will come to public soon …

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JLab BoNuS F2 Neutron Data with 4.223 and 5.262 GeV beam

Data files:

xlsx: neutron csv: neutron

Source:

https://userweb.jlab.org/~narbe/BoNuS/analysis/deut-fit/checks/tables/resnr/v1/

References:

1-- S. Tkachenko et al. (CLAS Collaboration), Phys. Rev. C 89, 045206 – Published 24 April 2014

2-- K. A. Griffioen et al., Phys. Rev. C 92, 015211 – Published 21 July 2015

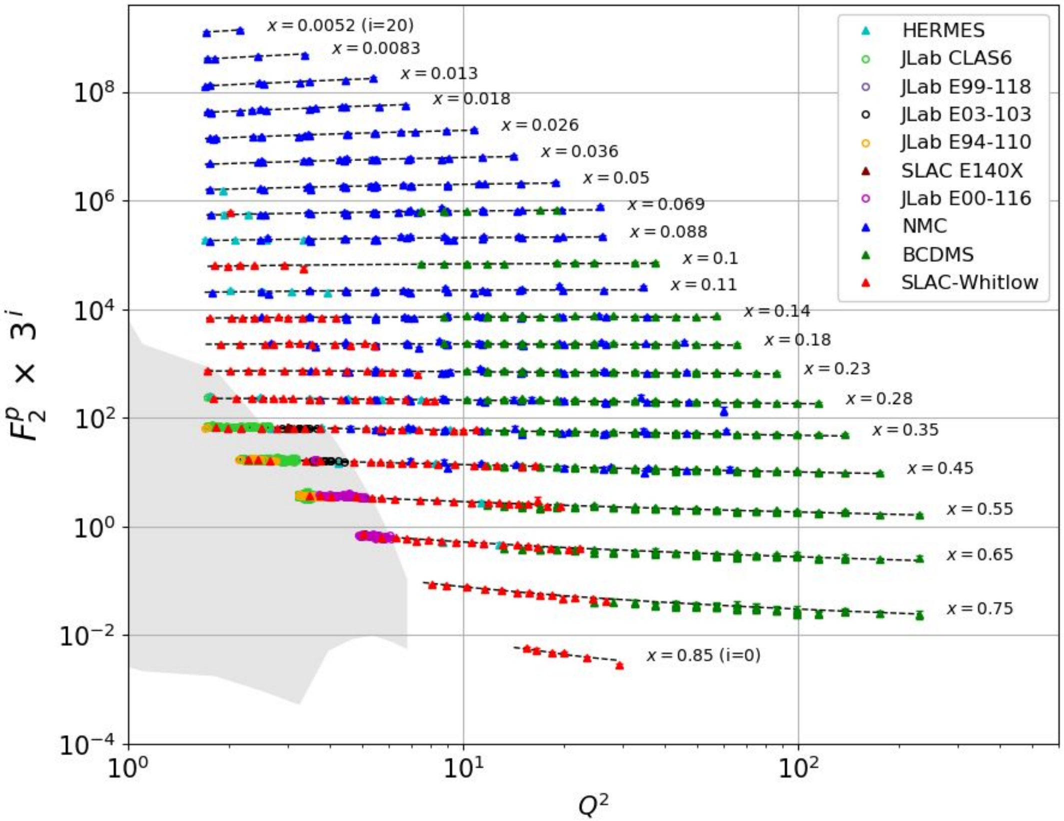
Uncertainties:

The full database will come to public soon …

F2 p kinematics

Markers: DIS data after rebinned in x_bj. Shaded area: JLab data.

Dashed line: CJ15 calculation



F2 d kinematics

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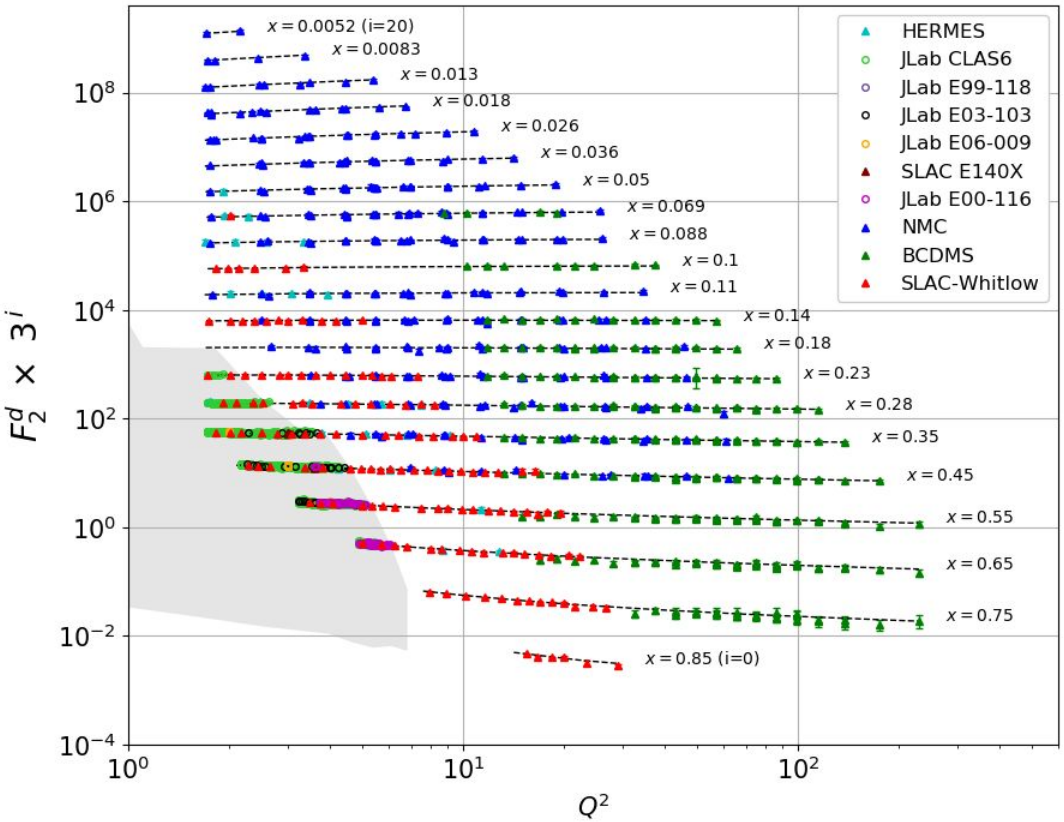


Data Selection

1. **Pass DIS cuts:**
   a. $Q^2 > 1.691$ GeV^2/c^2
   b. $W^2 > 3.5$ GeV^2

2. **Within each experiment**, we match the proton and deuteron data points by requiring:
   a. same beam energy,
   b. $|x_{proton} - x_{deuteron}| < 0.01$,
   c. $|Q^2_{proton} - Q^2_{deuteron}| < 1\%$.

Experiments	# of Proton F2 Data Points	# of Deuteron F2 Data Points	# of Constructed Neutron Points
SLAC-Whitlow [2]	564	582	470
BCDMS	351 [3]	254 [4]	254
HERMES [5]	45	45	45
JLab E-00-116 [6]	136	136	120
NMC [7]	275	275	258
SLAC-E140x [8]	9	13	9
JLab E-03-103 [9]	37	69	37
JLab CLAS6	609 [10]	1723 [11]	0
JLab E-94-110 [12]	112	0	0
JLab E-06-009 [13]	0	79	0
JLab E-99-118 [14]	2	2	2

F2 Neutron Extraction

we use CJ15 to remove nuclear effects in F_2 deuteron data. The free nucleon (proton + neutron) F_2

$$(p+n)_{data} = d_{data} * (p+n)_{cj} / d_{cj}$$

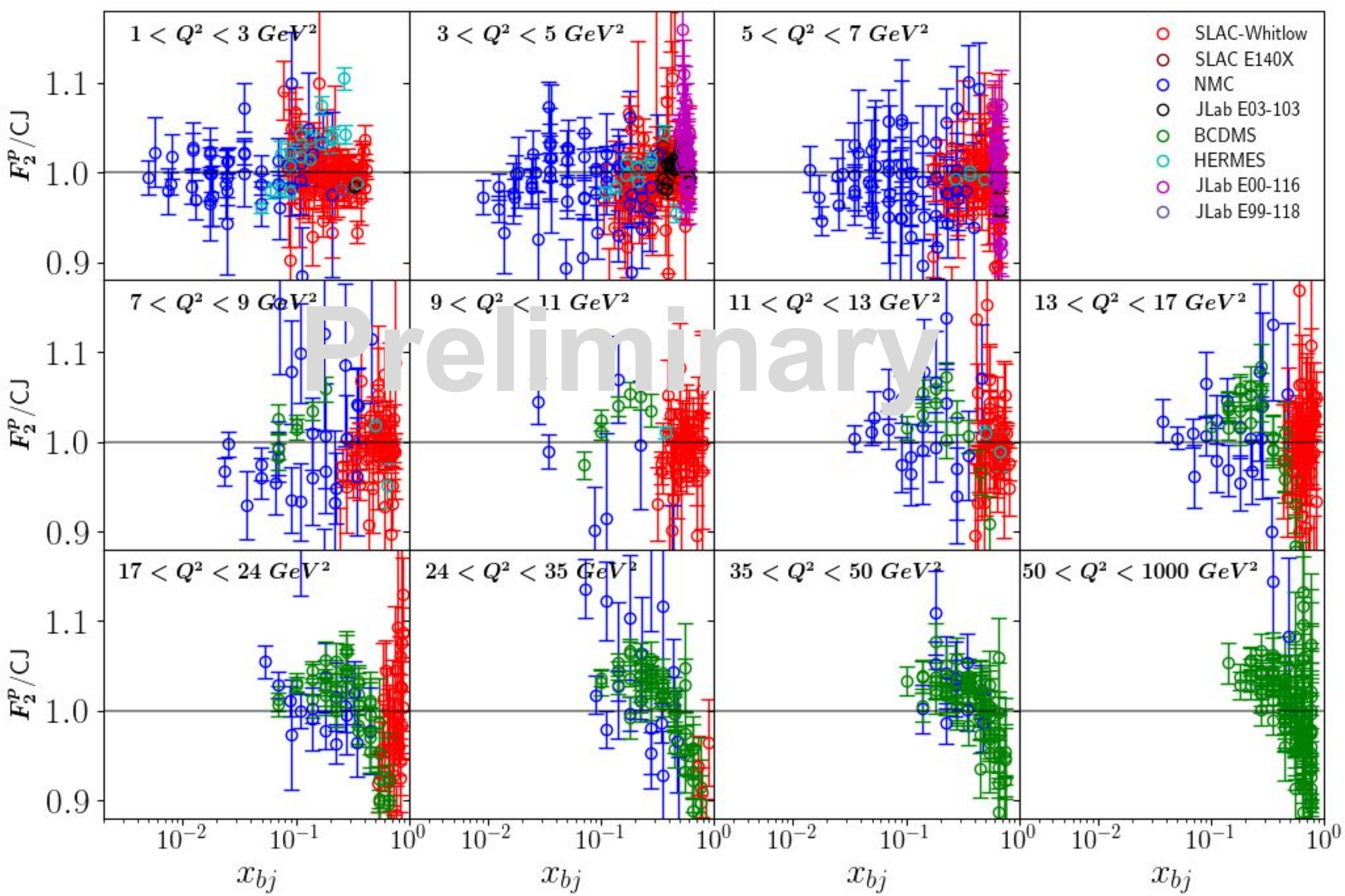
Then The F_2 neutron are constructed as:

$$n_{data} = (p+n)^*_{data} - p^*_{data} = d^*_{data} * (p+n)_{cj}/d_{cj} - p^*_{data}$$

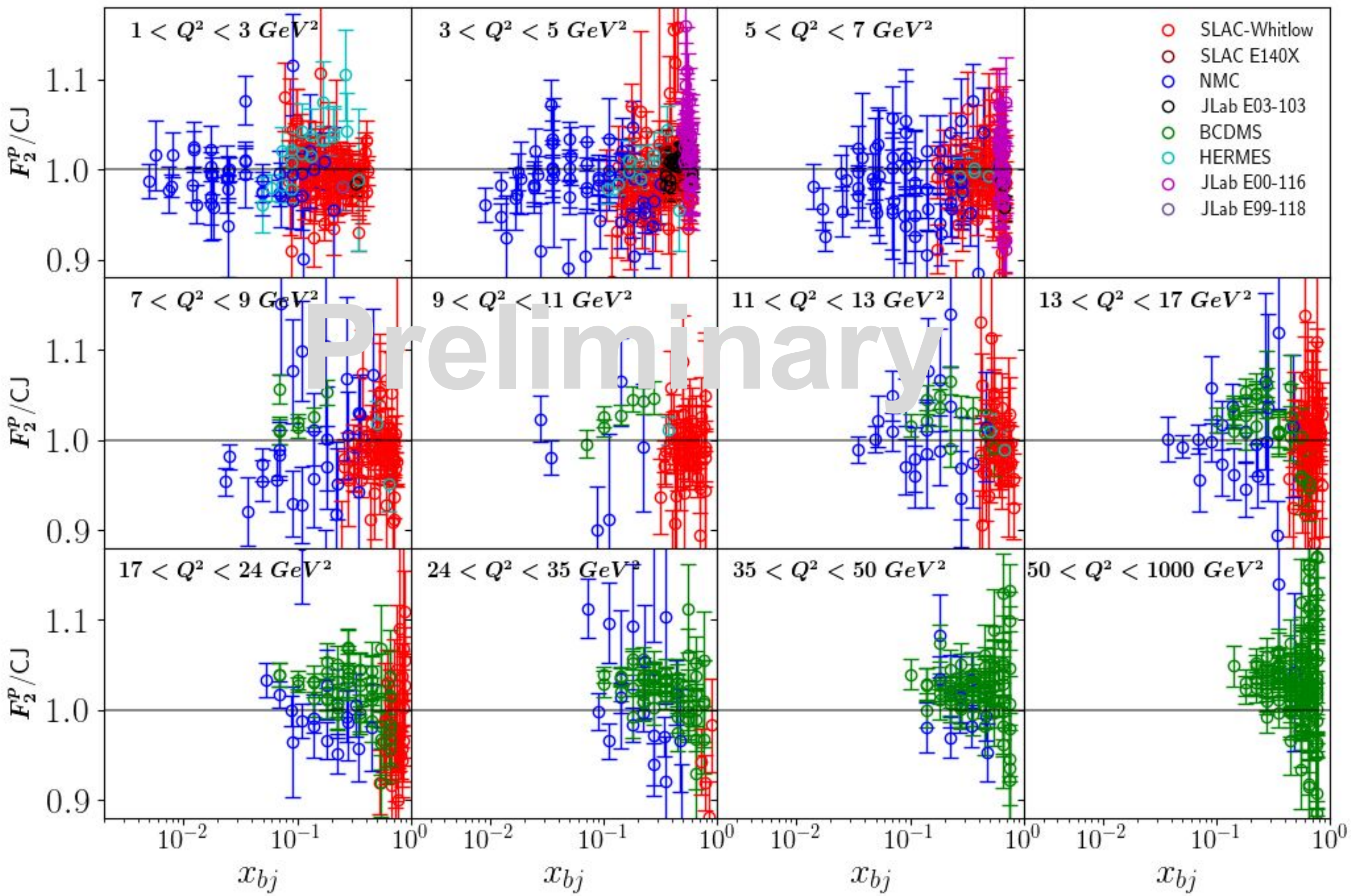
Where d^*_{data} is the original F2 data being shifted within their correlated and normalization uncertainties (decided by CJ15 fit) so that it's cross-normalized and ready for use.

Similar approach also for d/p experiments (HERMES, NMC...) and BONuS n/d!

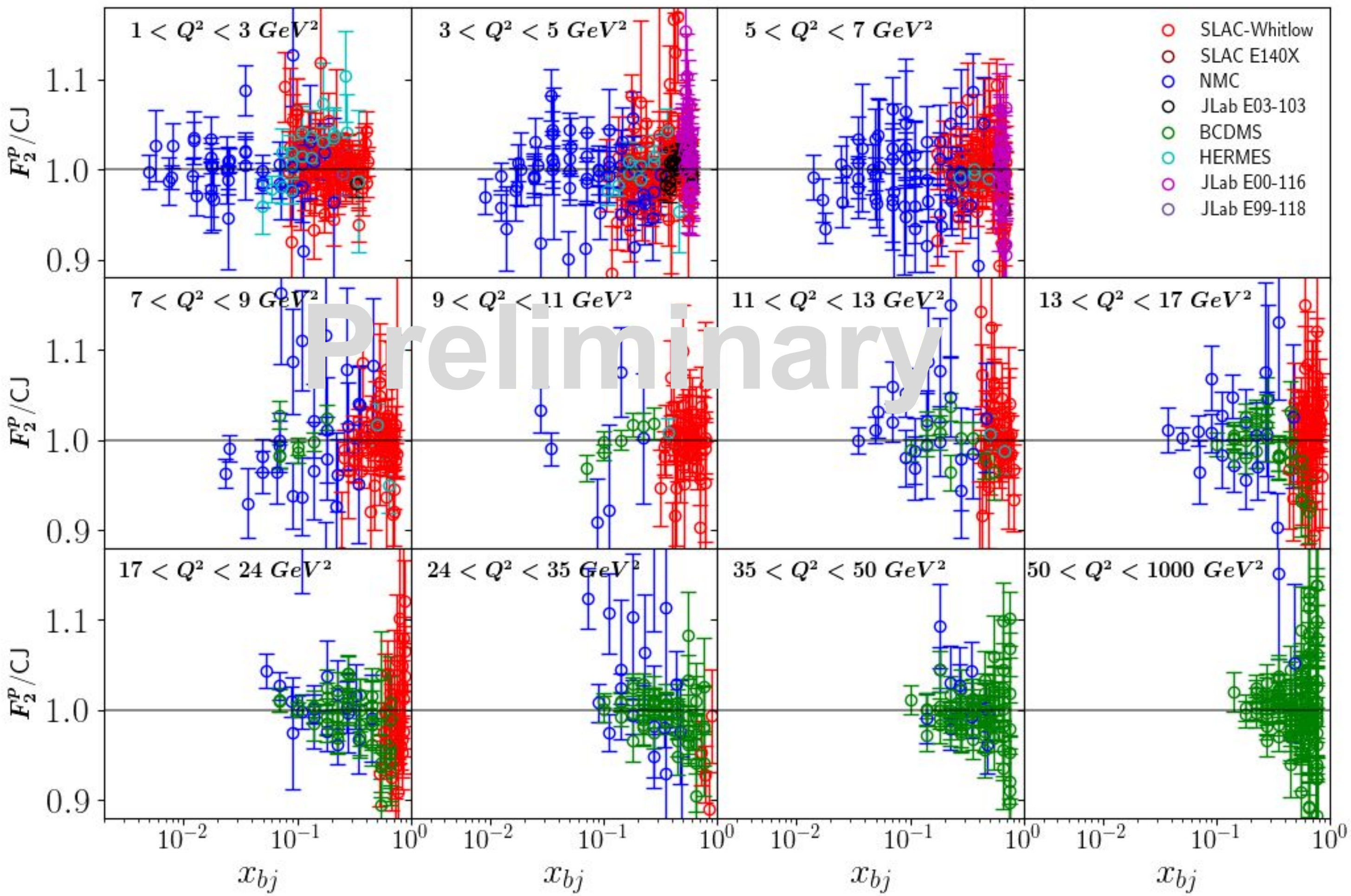
raw F_2^p Data/CJ



modified F_2^p Data/CJ



modified+normed F_2^p Data/CJ



Uncertainties

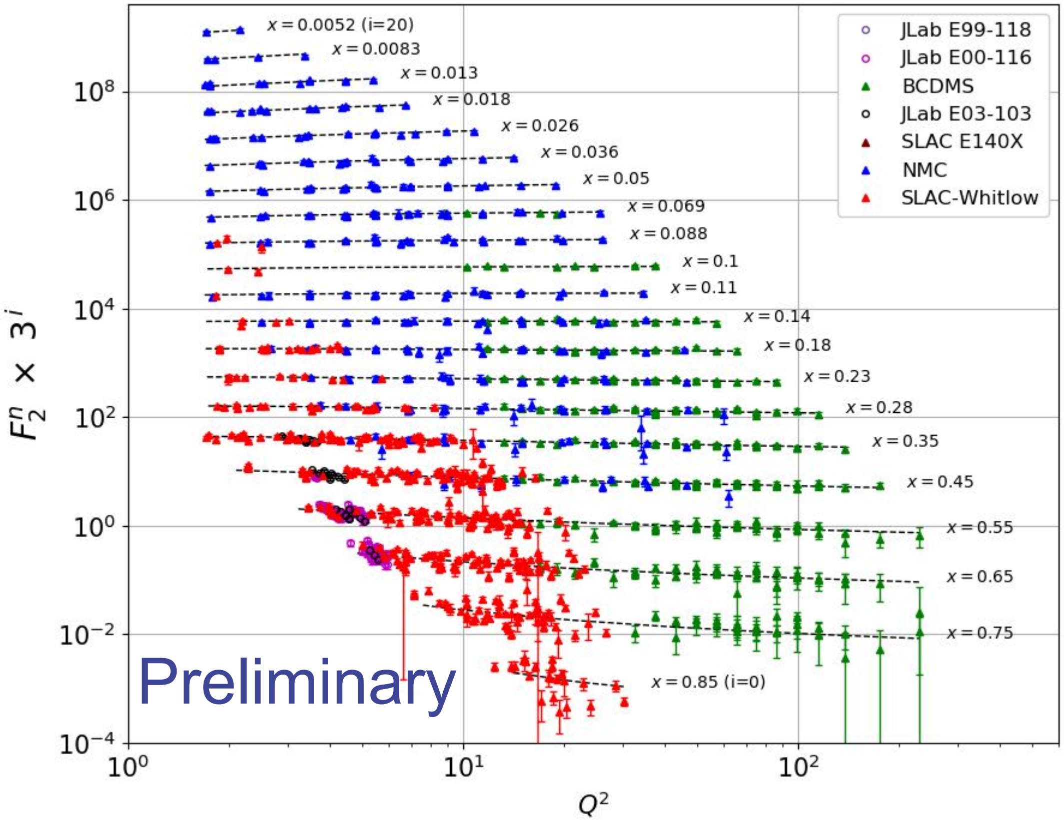
- Experimental uncertainties
  - Statistical
  - uncorrelated systematics

- theoretical systematics (PDF uncertainties) using 2* 24 (=19 PDF + 2 off-shell + 3 higher-twist parameters) eigen-PDF sets:
    - Normalization + correlated shifts uncertainties
    - Nuclear correction (d/(p+n)) uncertainties

F2 Neutron Results!

Markers: DIS data after rebinned in x_bj.

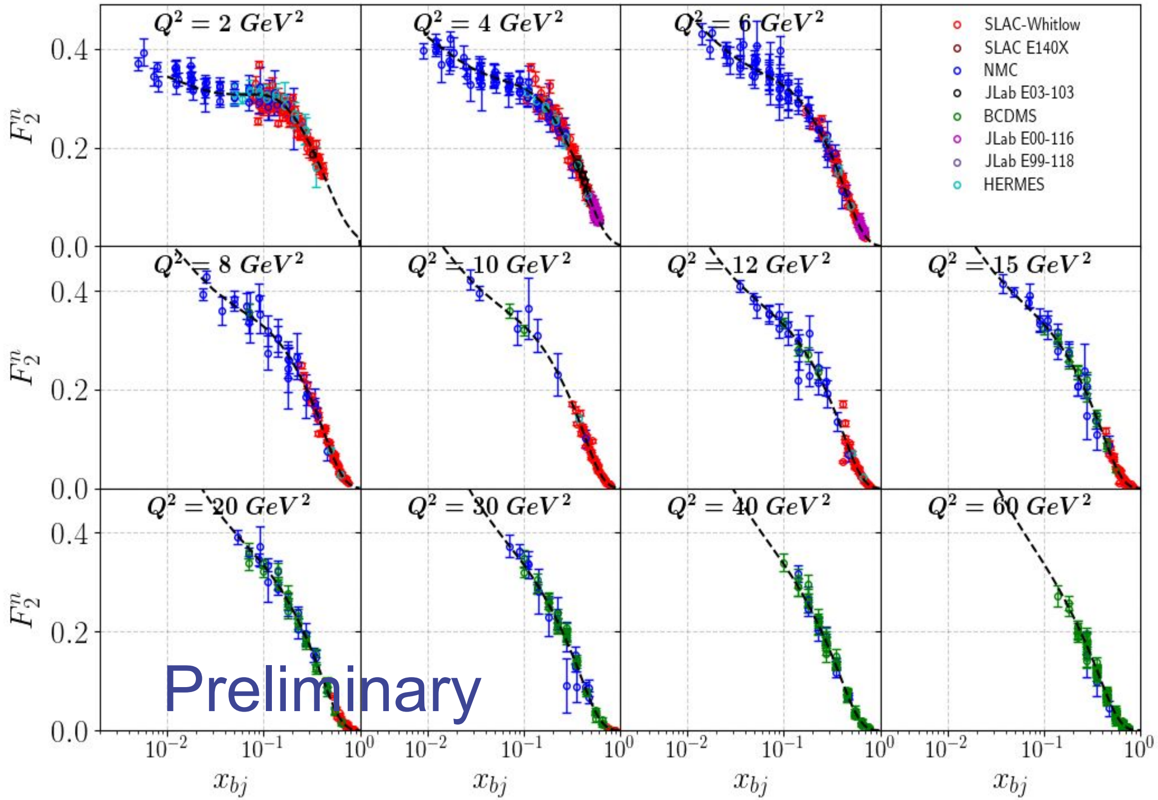
Dashed line: CJ15 calculation



F2 Neutron Results!

F_2^n v.s. x_{bj}

Markers: data after rebinned in x_{bj} and Q^2. Dashed line: CJ15 calculation



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Can compare free and bound nucleons (*both* proton and neutron) in nuclei

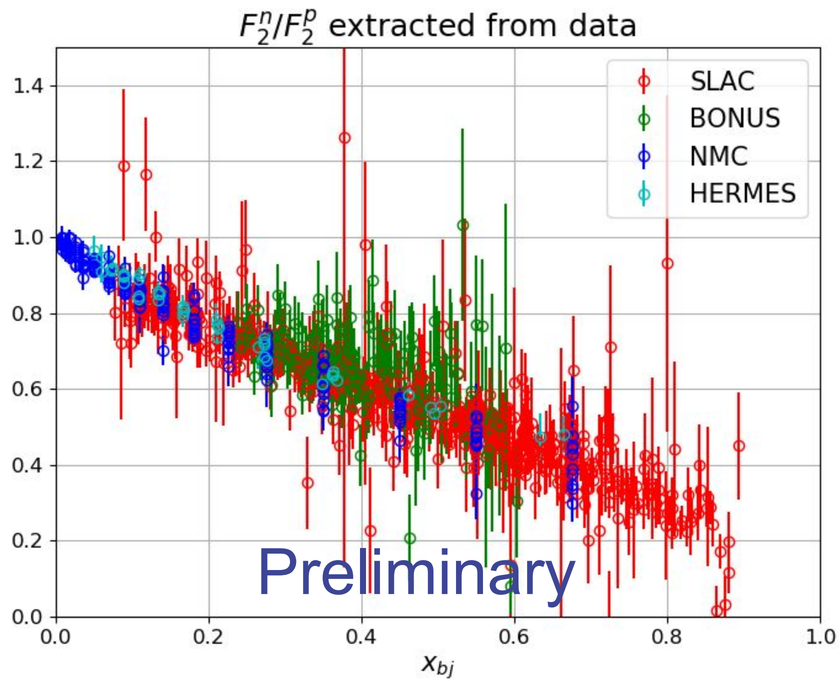
New window on the EMC effect

F2 n/p from Data

$n/p = (d/p)_{data} - (d/(n+p))_{CJ}$

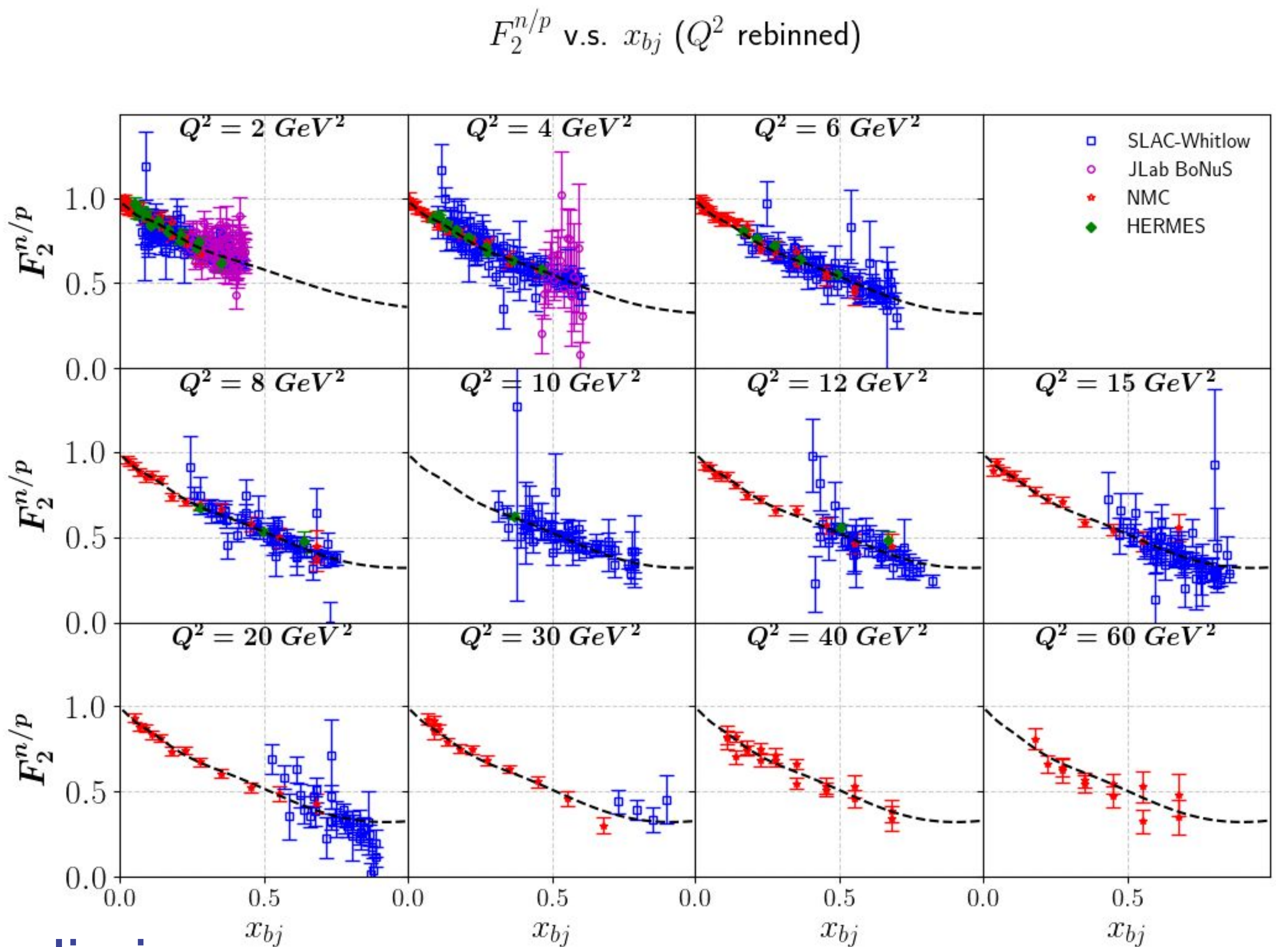
$n/p = 1/\{1/[(n/d)_{data}\,(d/(n+p))_{CJ}] - 1\}$

Leverages precisions d/p data (NMC, HERMES, SLAC) and spectator tagged n/d (BoNuS)



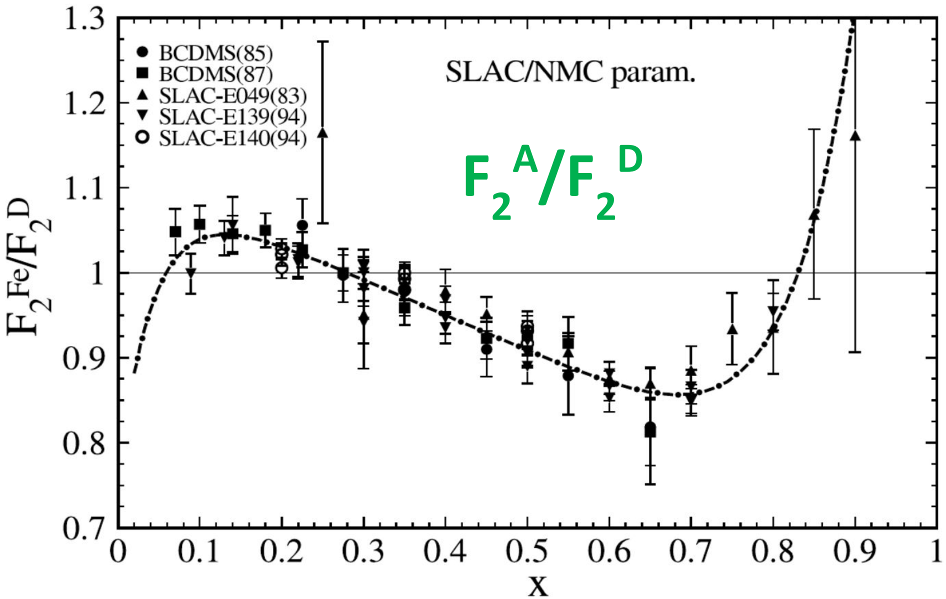
Spread in data in part from few large uncertainty data points, the Q2-dependence

Also BONuS



Preliminary

Isoscalar Corrections and the EMC Effect



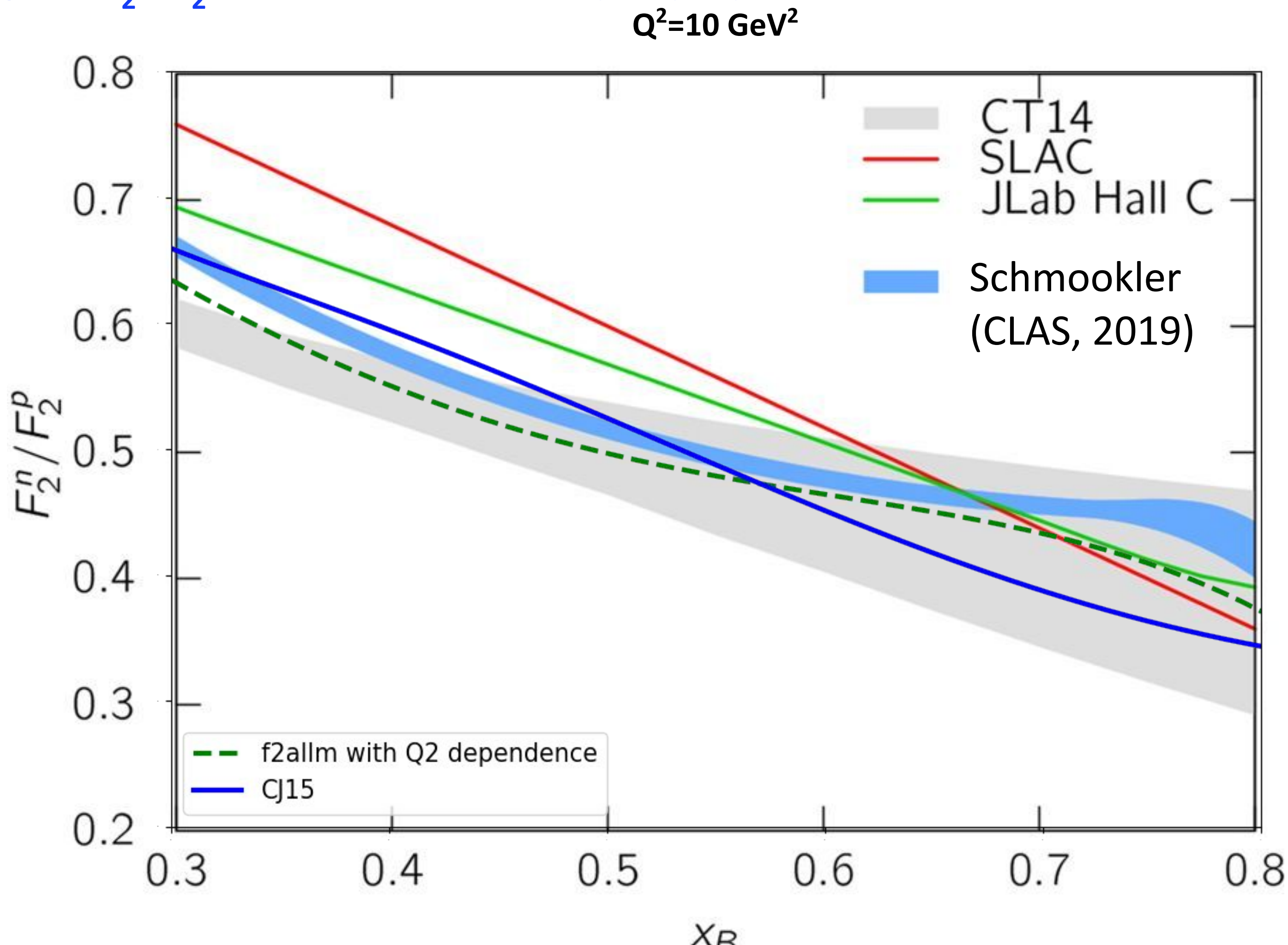
Will make user-friendly parameterization **with uncertainties!** available for neutron excess corrections *(soon - publication in progress)*

$$f_{iso}^{A} = \frac{\frac{1}{2}\left(1 + F_2^n/F_2^p\right)}{\frac{1}{A}\left(Z + (A - Z)F_2^n/F_2^p\right)}.$$

May be important to precision studies of the EMC effect

- Can be a large data correction
- Possible flavor dependence

A range of F_2^n/F_2^p models are currently deployed…



Probing the Valence Regime at JLab12

New generation of experiments at JLab at 12 GeV will access the regime where valence quarks dominate

First experiments *COMPLETED!*

✔ Hall C $F_2^{p,d}$

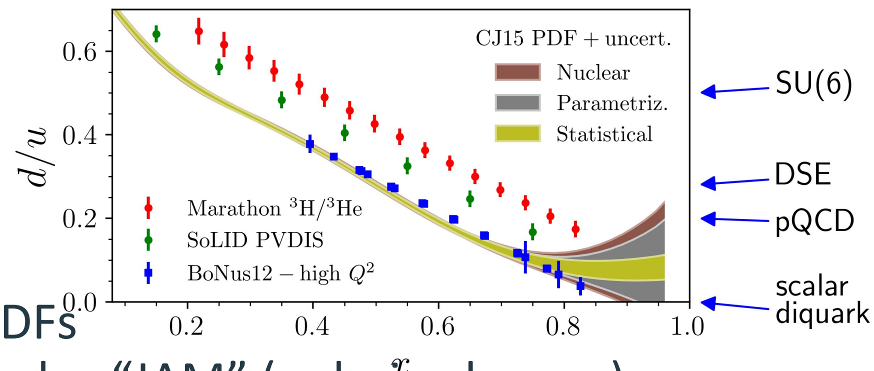
✔ Hall A $^3H/^3He$

BONUS12 to run this Fall

PVDIS (further future) on p target

Dedicated effort to extract valence PDFs

"CJ", (CTEQ-Jefferson Lab) – and also "JAM" (polarized PDF, SIDIS) collaborations



Also SeaQuest Drell-Yan experiment E906 at FNAL focused on high x sea

References

[1]A. Accardi, L.T. Brady, W. Melnitchouk, J.F. Owens, N. Sato, Phys. Rev. D **93** 114017 (2016)
[2] http://www.slac.stanford.edu/exp/e140/
[3] BCDMS Collaboration, Physics Letters B, Volume 223, Issues 3–4, 1989, Pages 485-489
[4] BCDMS Collaboration, Physics Letters B, Volume 237, Issues 3–4, 22 March 1990, Pages 592-598
[5] The HERMES Collaboraton, Journal of High Energy Physics, 2011, Volume 2011, Number 5, Page 1
[6] S. P. Malace et al, Phys. Rev. C 80, 035207
[7] New Muon Collaboration, Nucl.Phys. B483 (1997) 3-43
[8] L. Tao, Ph.D. Thesis, The American University, 1994
[9] J. Seely et al.Phys. Rev. Lett. 103, 202301
[10] M. Osipenko et al. (CLAS Collaboration)Phys. Rev. C 73, 045205
[11] M. Osipenko et al. (CLAS Collaboration)Phys. Rev. C 73, 045205
[12] The Jefferson Lab Hall C E94-110 Collaboration, arXiv:nucl-ex/0410027
[13] Ibrahim Albayrak, JLAB-PHY-11-1417, Ph.D. Thesis, Hampton University, 2011
[14] V. Tvaskis et al.Phys. Rev. C 81, 055207

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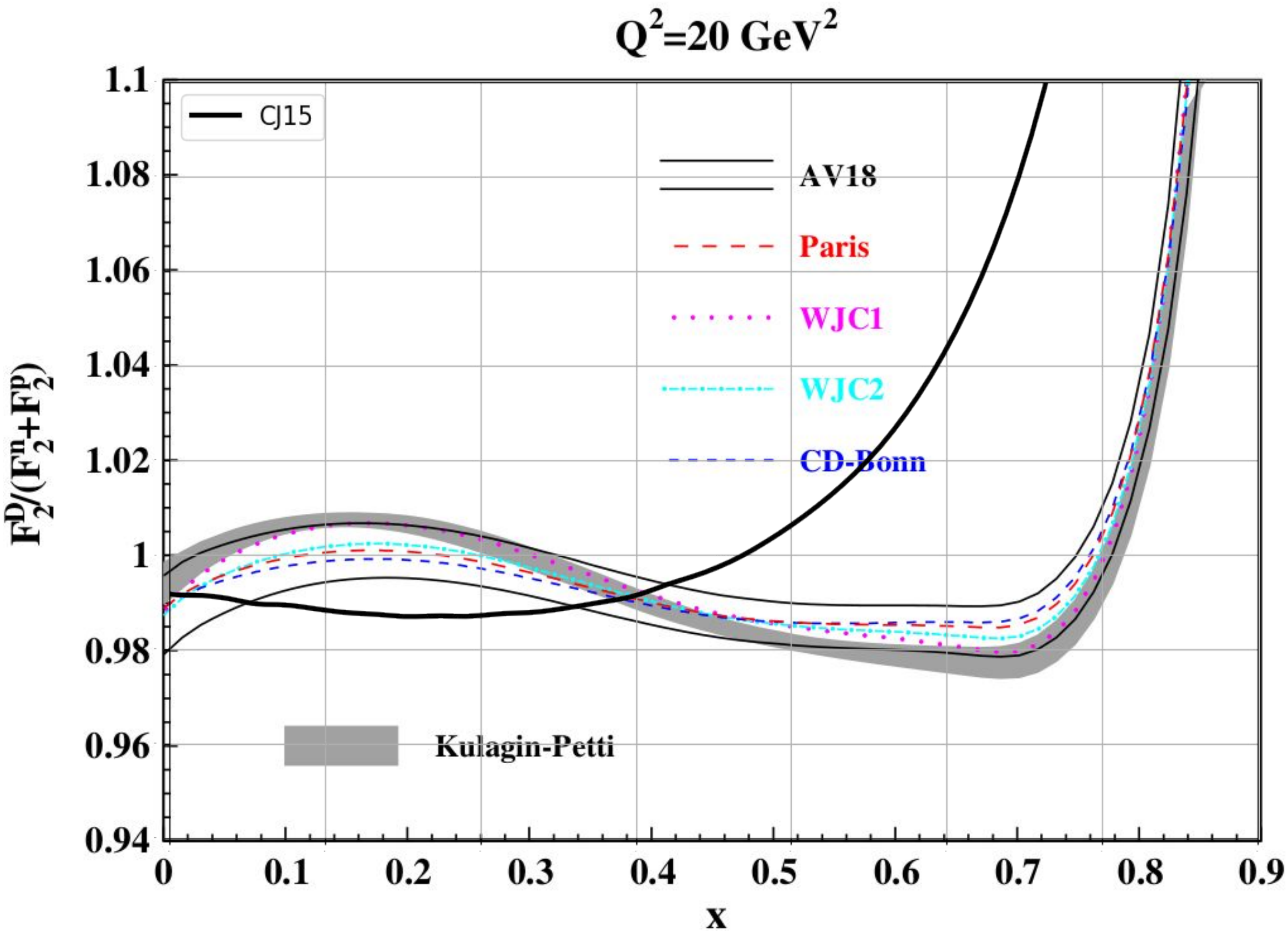
backups


Q^2=20 GeV^2
CJ15
AV18
Paris
WJC1
WJC2
CD-Bonn
Kulagin-Petti
$F_2^D/(F_2^n+F_2^p)$
x
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

F2 n/p Models

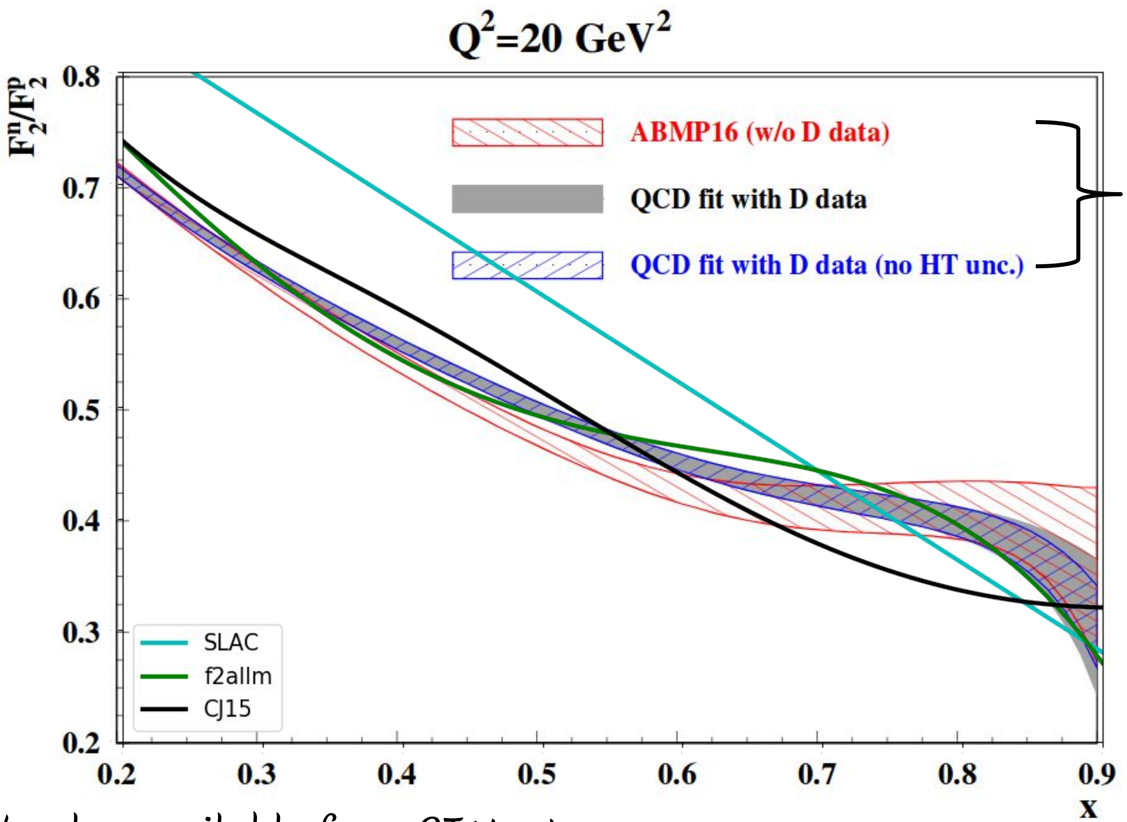


Fig 10 from S. I. Alekhin, S. A. Kulagin, and R. Petti

Phys. Rev. D 96, 054005(2017)

n/p also available from CT14, etc …