Deep Inelastic Scattering *in the Valence Regime*

Thia Keppel

ICNFP 2019

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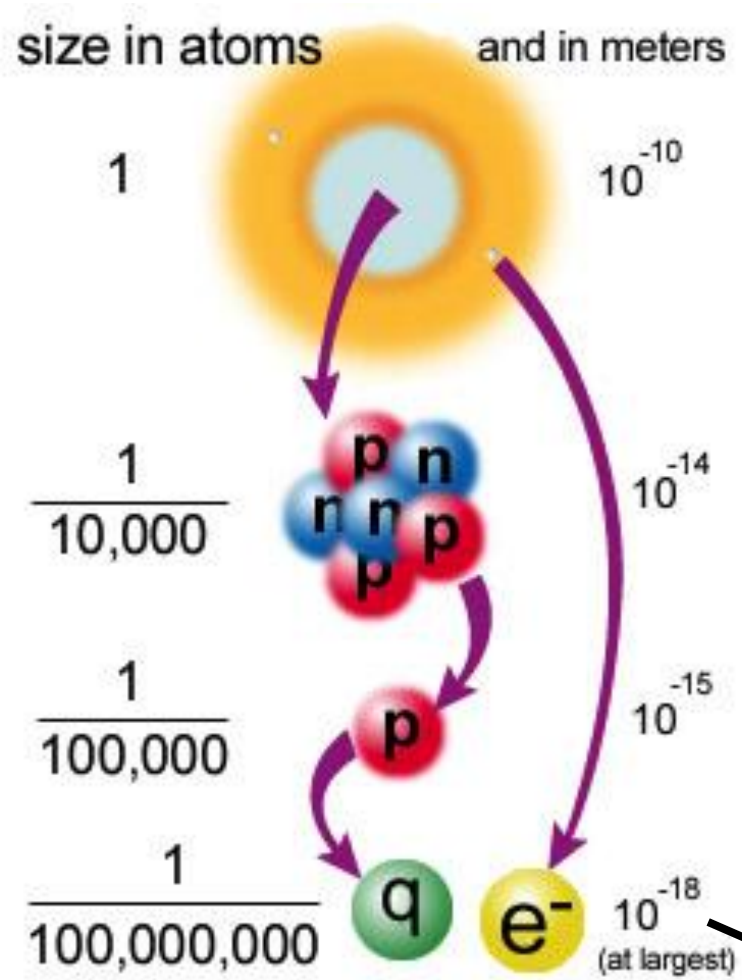
Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

How to probe the nucleon structure?



- Electron scattering experiments employ high momentum point-like leptons, + electromagnetic interactions, which are well understood, to probe hadronic structure (which isn't).

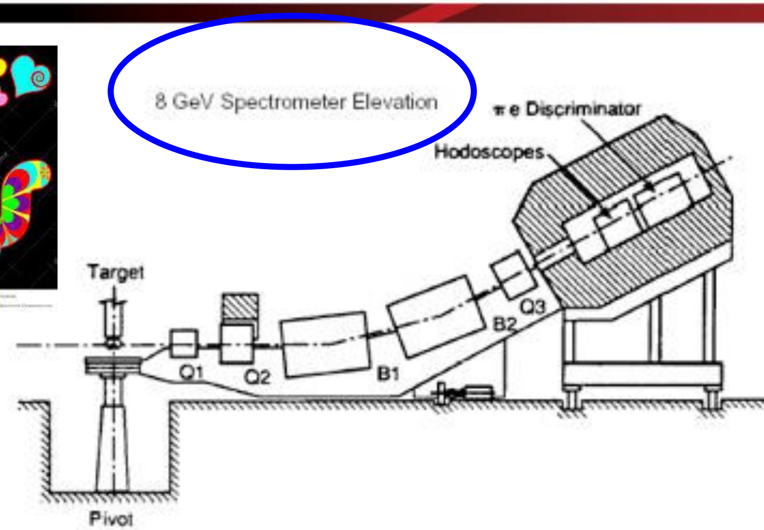
High energy electrons are a great tool for the job!

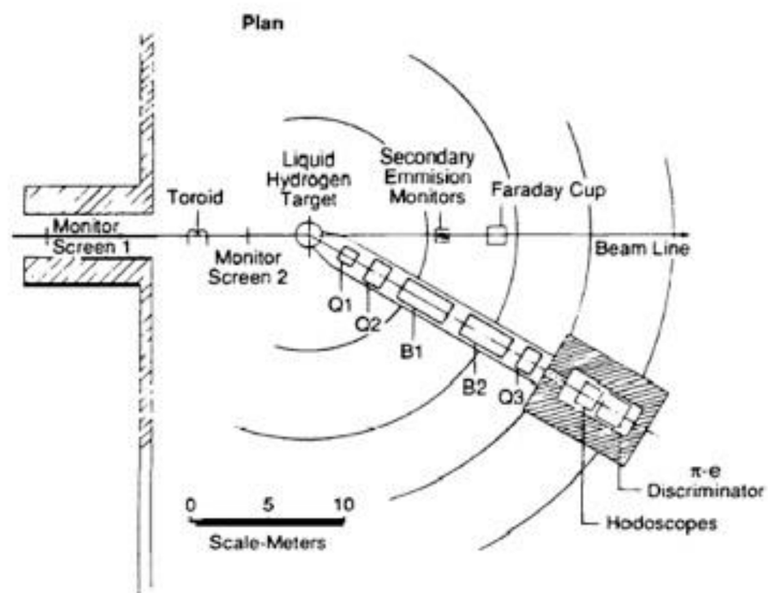
short distance -> large momentum

$$d_{probed} \propto \lambda\!\!\!^{-} = \frac{\hbar}{p} \approx 10^{-18}\ \mathrm{m}$$

Deep Inelastic Electron Scattering Beginnings: e-p and e-d at SLAC

J. Friedman, H.Kendall, R.Taylor
Nobel Prize 1990

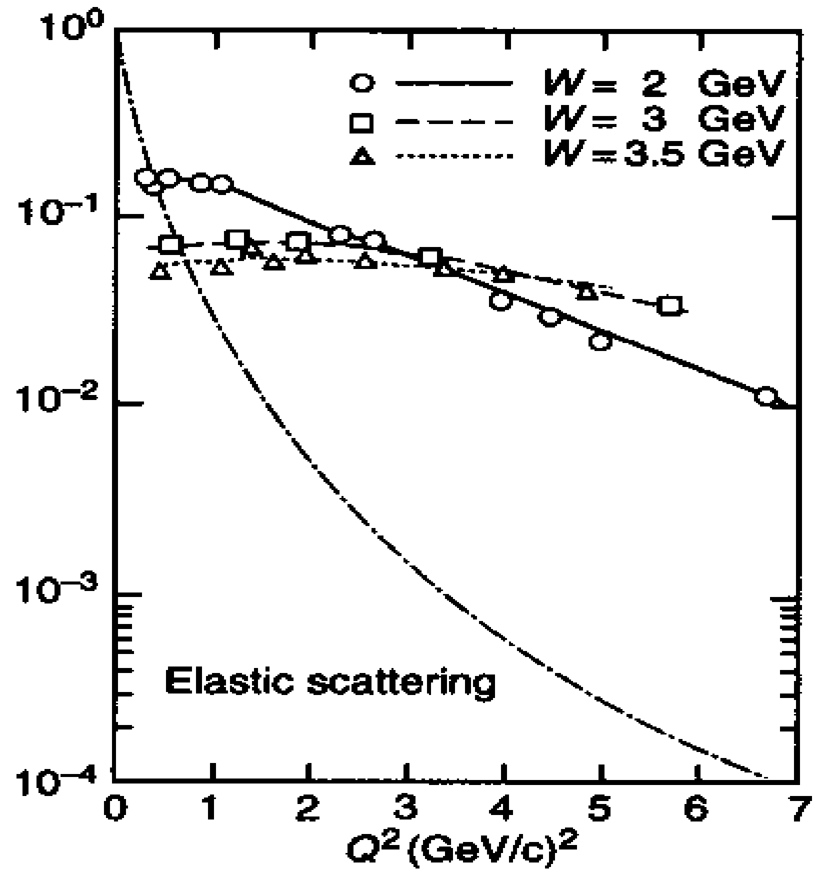




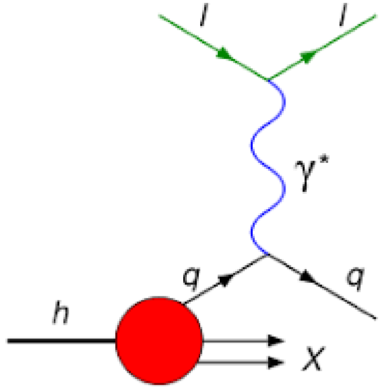
- Q^2 = four-momentum transfer in electron scattering process
- First SLAC experiment (‘69):
  - expected from proton form factor:

$$\frac{d\sigma / dE' d\Omega}{(d\sigma / d\Omega)_{\mathrm{Mott}}} = \left(\frac{1}{(1+Q^2/0.71)^2} \right)^2 \propto Q^{-8}$$

- First data show big surprise:
  - very weak Q^2-dependence
  - scattering off point-like objects?
  - *quark structure of the proton!*



Structure Functions in Deep Inelastic Electron-Nucleon Scattering



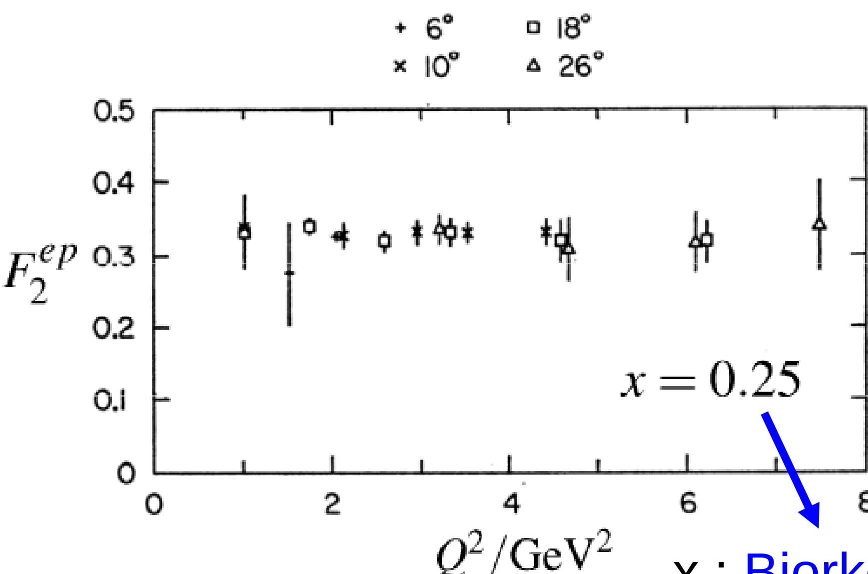
Probability of inelastic interaction:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E_0^2 \sin^4\frac{\theta}{2}} \cos^2\frac{\theta}{2}\left[\frac{1}{\nu} F_2(x,Q^2) + \frac{2}{M} F_1(x,Q^2)\tan^2\frac{\theta}{2}\right]$$

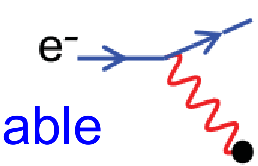
Unpolarized *"Structure Functions"* $F_1(x,Q^2)$ and $F_2(x,Q^2)$:

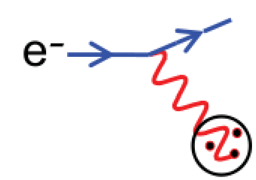
- Account for the sub-structure of the protons and neutrons
- Give access to *partonic structure* of the nucleon, i.e.

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



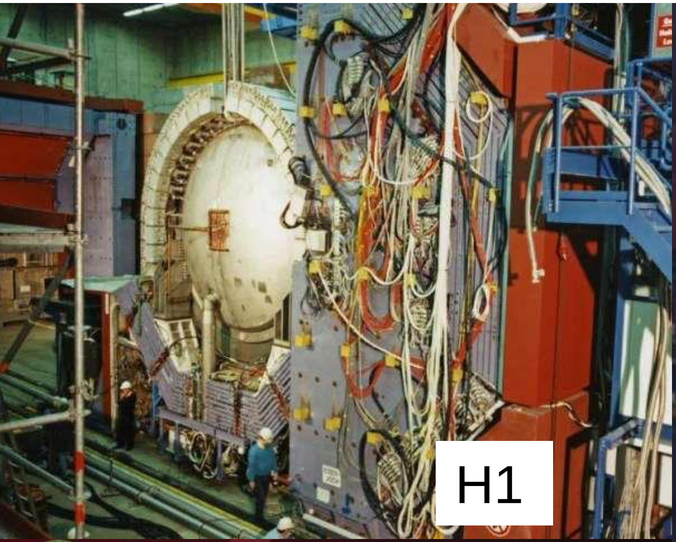
x : Bjorken "scaling" variable ($= Q^2/2M\nu$), *momentum fraction of struck quark*



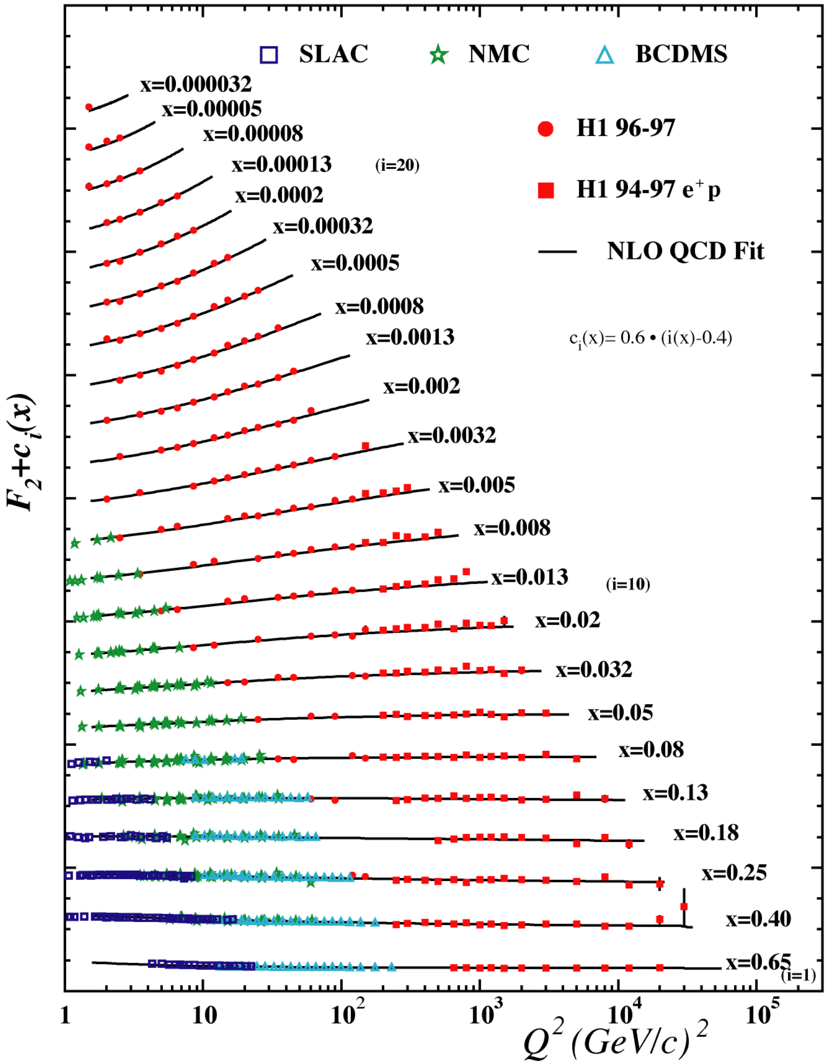


Fast forward….

50 years of charged lepton Deep Inelastic Scattering at *multiple* laboratories including SLAC (to ~2000), CERN 80-90s EMC, NMC, BCDMS..), DESY (90s – 21st century H1, ZEUS,...), and ***more!***

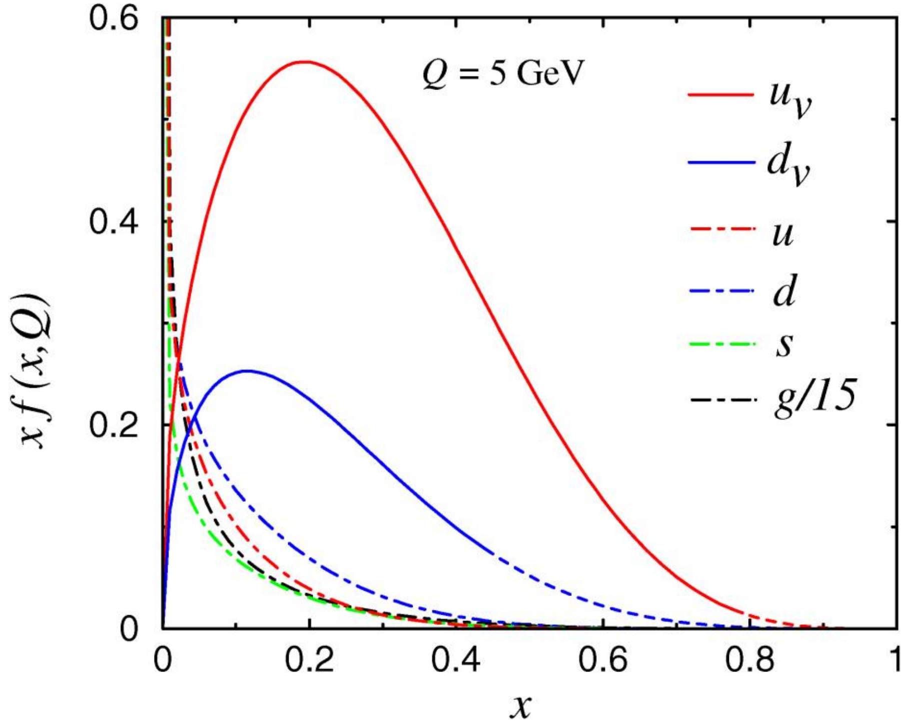


World data on F_2^p



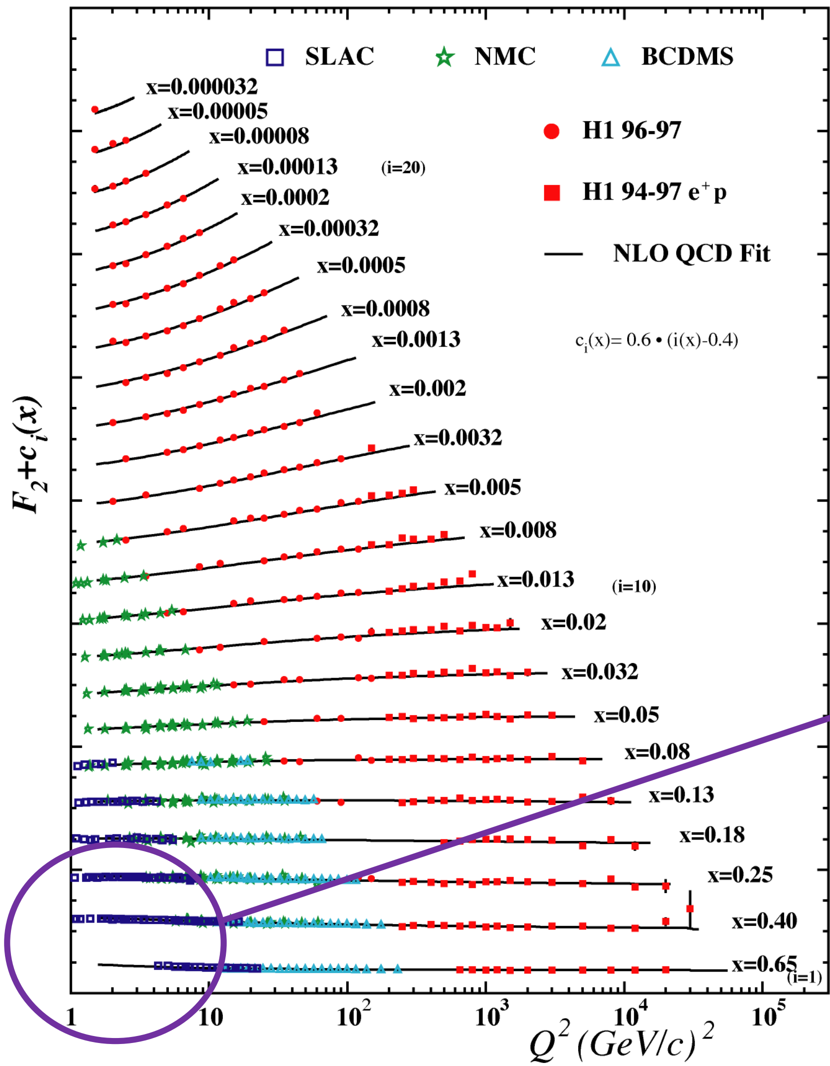
Some things we now know really well….

Q² Evolution of the F_2 *Proton* Structure Function



Allows extraction of "Parton Distribution Functions" $f(x,Q^2)$ - think momentum distribution of quarks

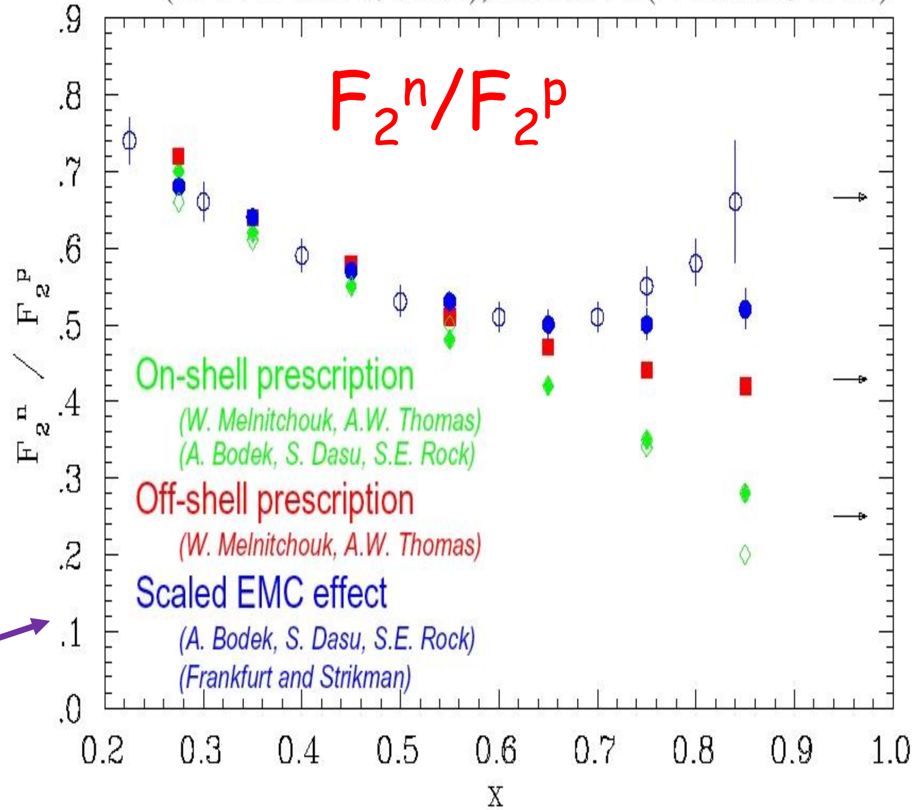
World data on F_2^p



Some things we now know really well….

…and some things we don't.

Proton and deuterium data from SLAC E139 (*L. W. Whitlow, et al.*), and E140 (*J. Gomez, et al.*)



- The neutron structure function is not well known at large x
- Large x is the valence regime of nucleon structure

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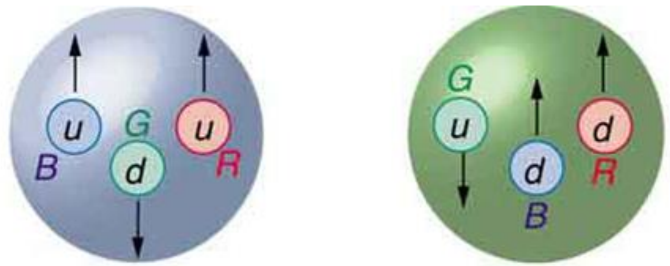
Why is the valence regime interesting?



	Proton	Neutron
Spin	$\frac{1}{2}+\frac{1}{2}-\frac{1}{2}=\frac{1}{2}$	$-\frac{1}{2}+\frac{1}{2}+\frac{1}{2}=\frac{1}{2}$
Charge	$+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=1$	$+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$

- Partonic structure in the valence region ***defines*** a hadron
    - Baryon number, charge, flavor content, total spin, …
- "Valence regime" at large x, low Q^2 evolves to low x, high Q^2
    - Intersection of nuclear and particle physics
- Keen discriminator of nucleon structure models
- New generation of experiments at JLab focused on high x

Neutron Structure Function

Parton model:

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

$$u_p(x) = d_n(x) \equiv u(x)$$

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

$$\frac{F_2^n}{F_2^p} = \frac{u+\bar{u}+4(d+\bar{d})+s+\bar{s}}{4(u+\bar{u})+d+\bar{d}+s+\bar{s}}$$

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

200 Partons

sea quark dominance $F_2^n/F_2^p \to 1$

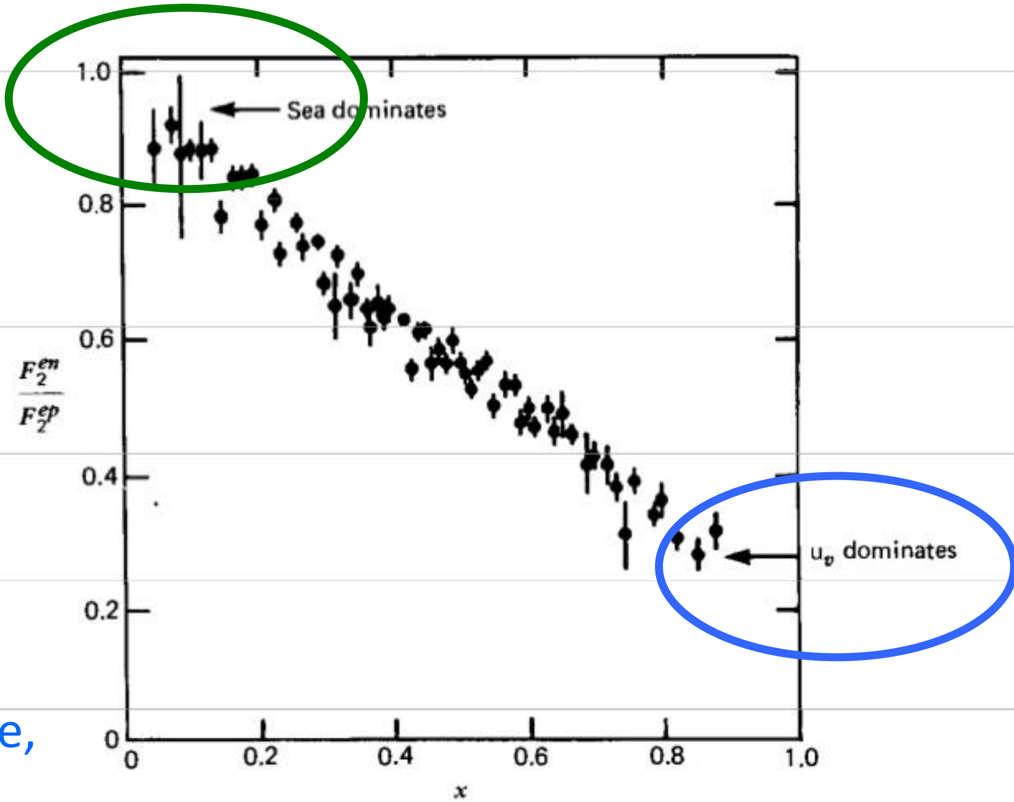


Fig. 9.6 The ratio F_2^{en}/F_2^{ep} as a function of x, measured in deep inelastic scattering. Data are from the Stanford Linear Accelerator.

u quark dominance,

d/u –> 0

$F_2^n/F_2^p \to 1/4$

Neutron Structure Function

Parton model:

~~200 Partons~~

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

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$$\frac{F_2^n}{F_2^p} = \frac{u+\bar{u}+4(d+\bar{d})+s+\bar{s}}{4(u+\bar{u})+d+\bar{d}+s+\bar{s}}$$

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

u quark dominance,

d/u –> 0

F_2^n/F_2^p –> 1/4

sea quark dominance F_2^n/F_2^p –> 1

$\frac{F_2^{en}}{F_2^{ep}}$

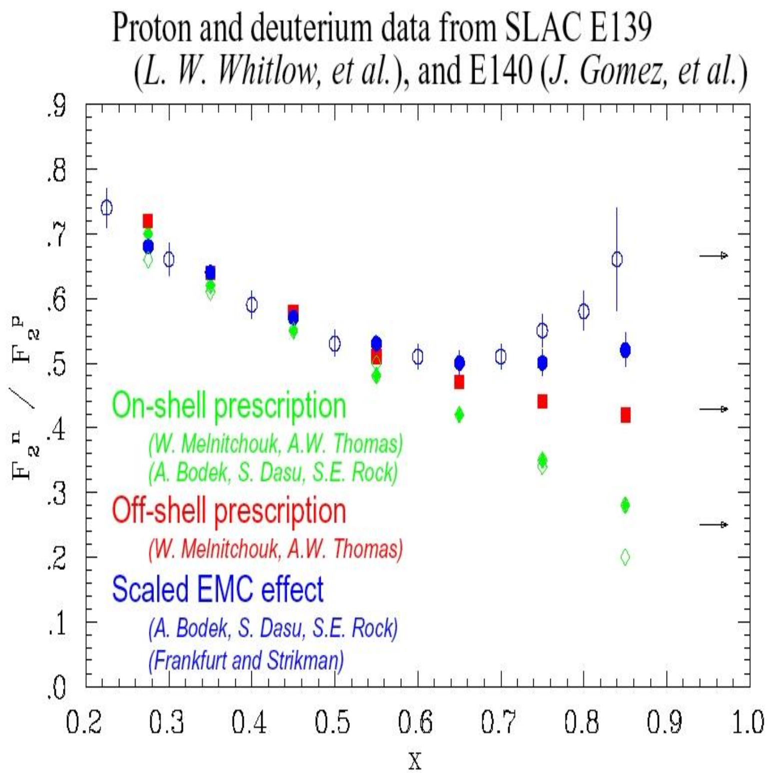


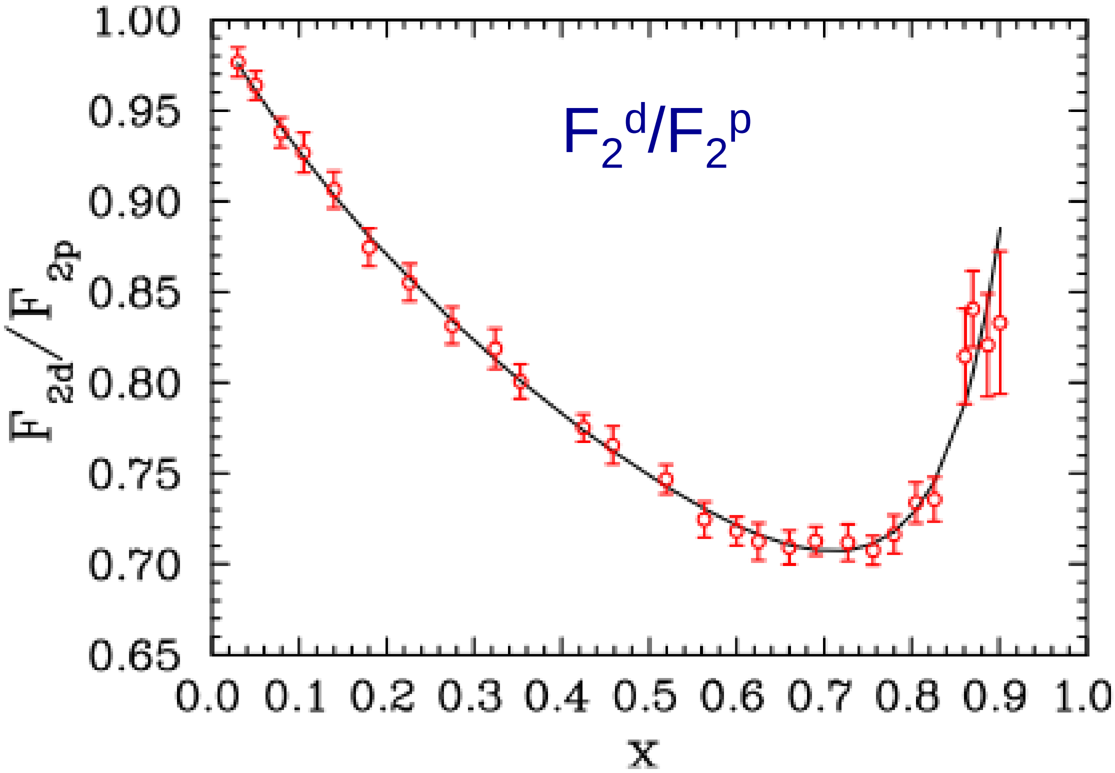
Fig. 9.6 The ratio F_2^{en}/F_2^{ep} as a function of x, measured in deep inelastic scattering. Data are from the Stanford Linear Accelerator.

The deuteron is a nucleus!

Neutron structure is typically derived from deuterium target data by subtracting proton data

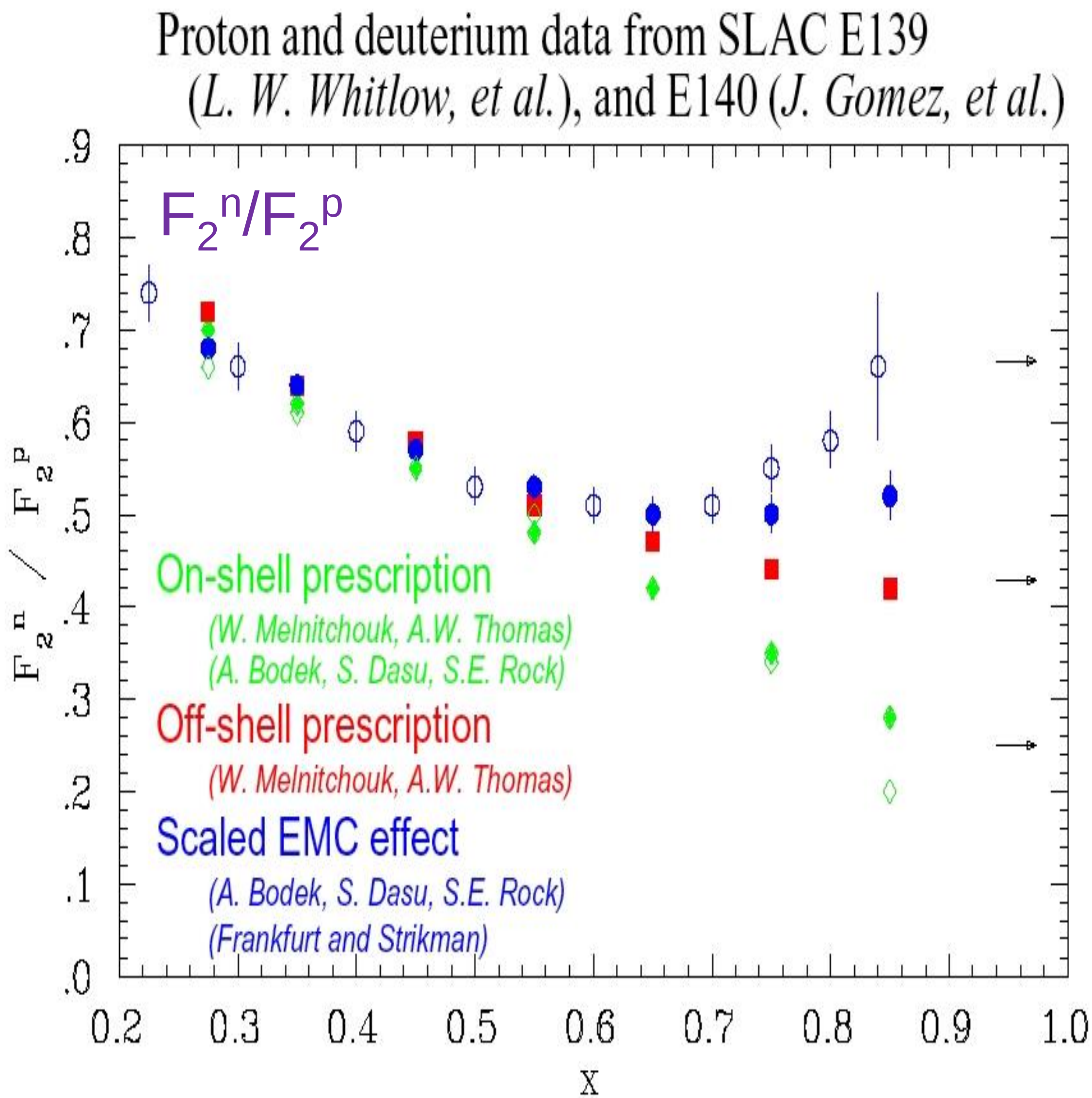
…..but…..

Large uncertainty in unfolding nuclear effects (Fermi motion, off-shell effects, deuteron wave function, coherent scattering, final state interactions, nucleon structure modification ("EMC"-effect),……….



The moon at nuclear density

Deuteron nuclear effects are an obstacle to extracting F_2^n



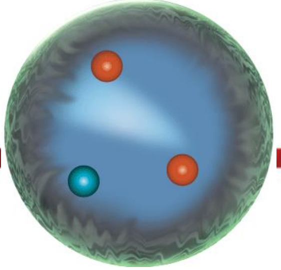
No free neutrons, so use the deuteron

SAME data set

Different deuteron nuclear effect analyses

$0.2 < F_2^n/F_2^p < 0.8$?!?!

Predictions for F_2^n/F_2^p (neutron/proton) ratio at Large x



- SU(6)-symmetric wave function of the proton in the quark model:

$$|p\uparrow\rangle = \frac{1}{\sqrt{18}}\left(3u\uparrow[ud]_{S=0} + u\uparrow[ud]_{S=1} - \sqrt{2}u\downarrow[ud]_{S=1} - \sqrt{2}d\uparrow[uu]_{S=1} - 2d\downarrow[uu]_{S=1}\right)$$

  – SU(6) spin/flavor symmetry in u,d
    In this model: d/u = 1/2, F_2^n/F_2^p = 2/3 for *x* -> 1
  – But, N and Δ would be degenerate in mass….

- SU(6) symmetry is broken: N-Δ Mass Splitting
  – Mechanism produces mass splitting between S=1 and S=0 diquark spectator.
  – symmetric states are raised, antisymmetric states are lowered (~300 MeV).
  – S=1 suppressed => d/u = 0, F_2^n/F_2^p = 1/4, for *x* -> 1

- pQCD: helicity conservation (q↑↑p) => d/u =2/(9+1) = 1/5, F_2^n/F_2^p = 3/7 for *x* -> 1

- Dyson-Schwinger Eq.: Contains finite size S=0 and S=1 diquarks
  – d/u = 0.28, F_2^n/F_2^p = 0.49 for *x* -> 1

There are more!

Multiple predictions for large x

$$|p\uparrow\rangle = \frac{1}{\sqrt{2}}|u\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|u\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|u\downarrow(ud)_{S=1}\rangle$$
$$-\frac{1}{3}|d\uparrow(uu)_{S=1}\rangle - \frac{\sqrt{2}}{3}|d\downarrow(uu)_{S=1}\rangle$$

Nucleon Model	F_2^n/F_2^p	d/u
SU(6)	2/3	1/2
Valence Quark	1/4	0
DSE contact interaction	0.41	0.18
DSE realistic interaction	0.49	0.28
pQCD	3/7	1/5

A Longstanding Problem!

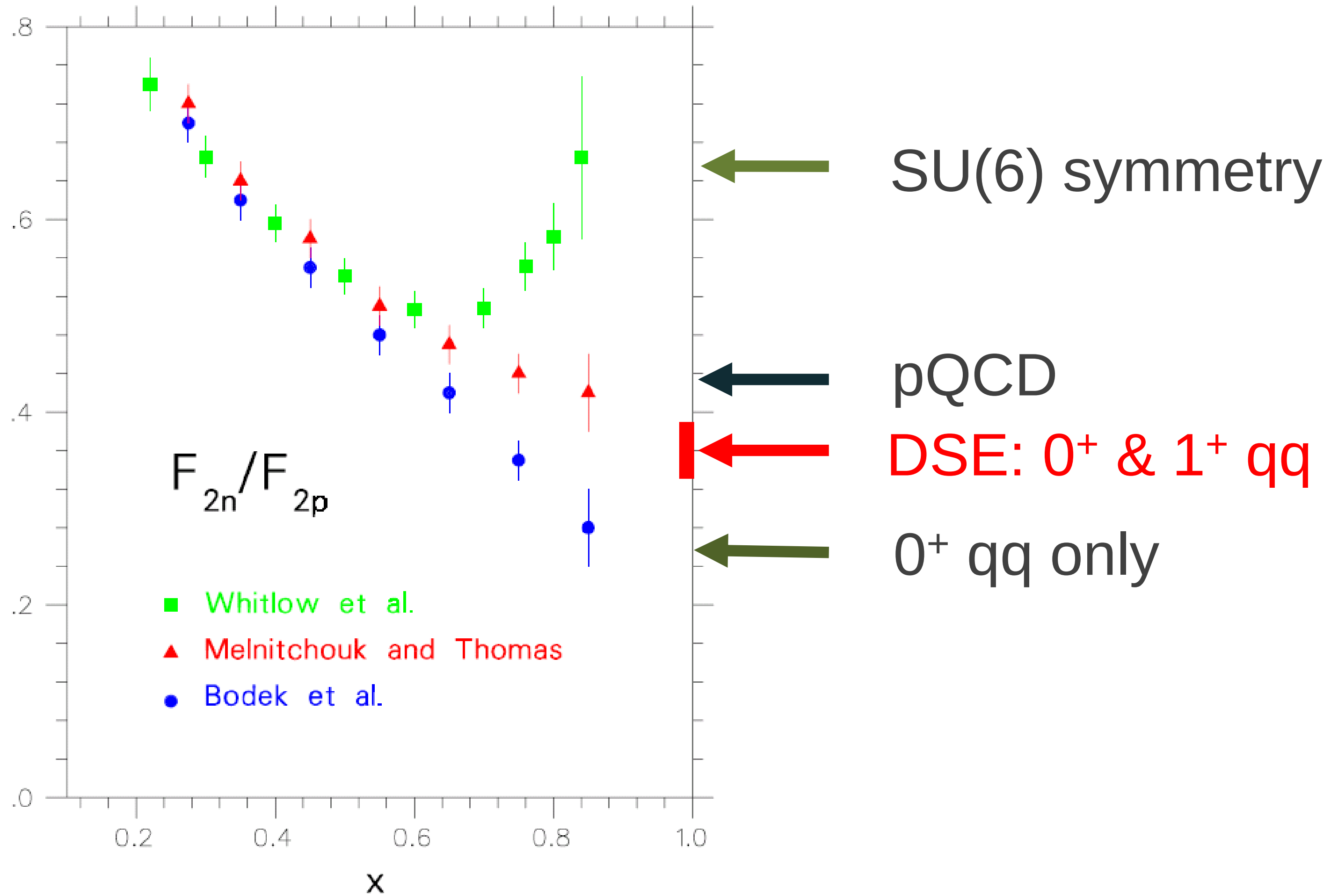
Numerous Review Articles:

- N. Isgur, PR**D 59** (1999)
- S Brodsky et al NP **B441** (1995)
- W. Melnitchouk and A. Thomas PL **B377** (1996)
- R.J. Holt and C. D. Roberts, Rev. Mod. Phys. 82 (2010)
- I. Cloet et al, Few Body Syst. **46** (2009) 1.

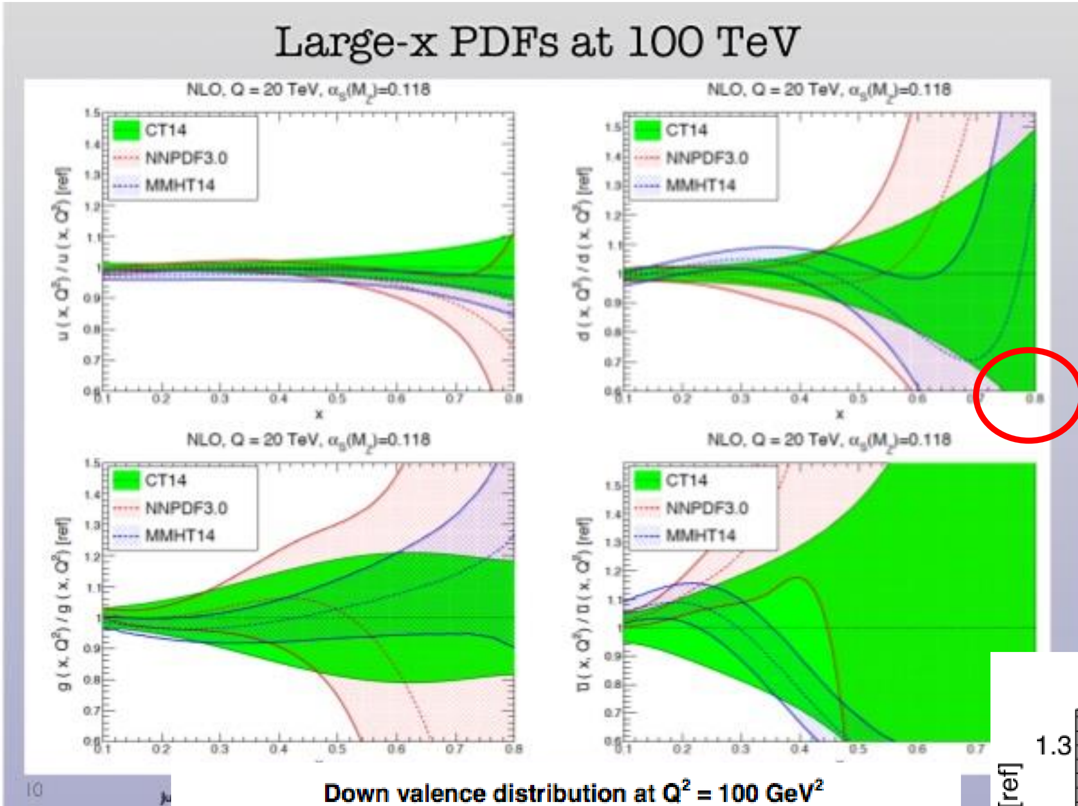
A measurement is needed…

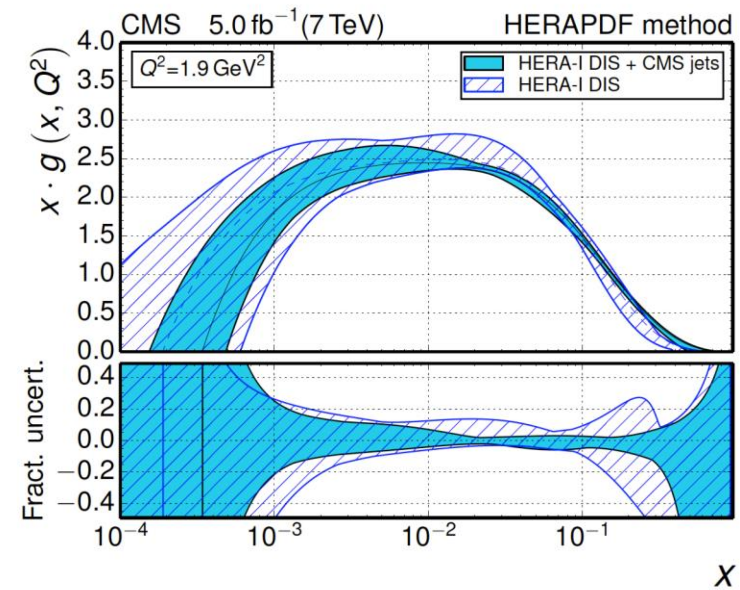
F_2^n/F_2^p (and, hence, d/u) essentially unknown at large x:

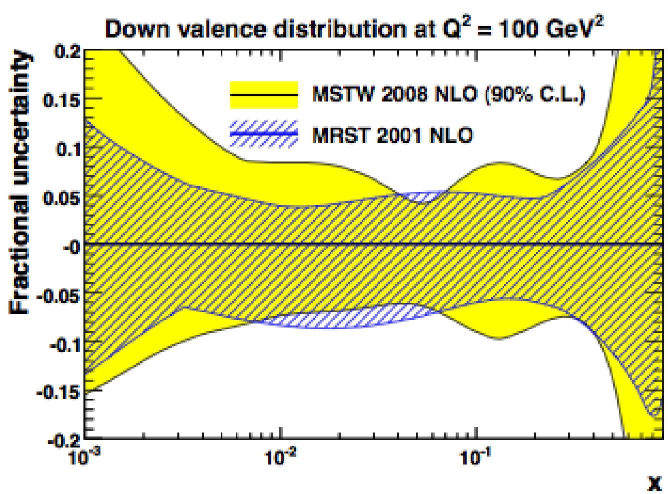
- Conflicting fundamental theory pictures
- F_2^n data inconclusive due to uncertainties in deuterium nuclear corrections
- *Translates directly to large uncertainties on d(x), g(x) parton distribution functions*

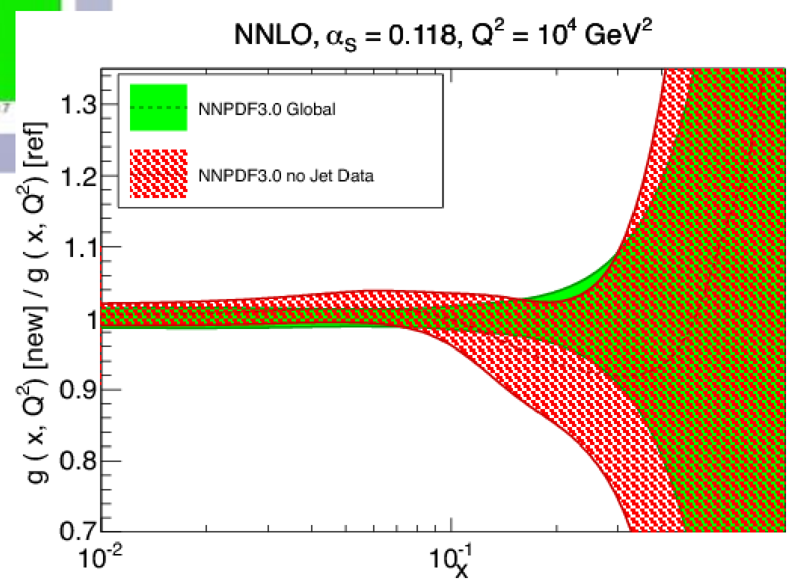


Present status: large uncertainties on PDFs at large x

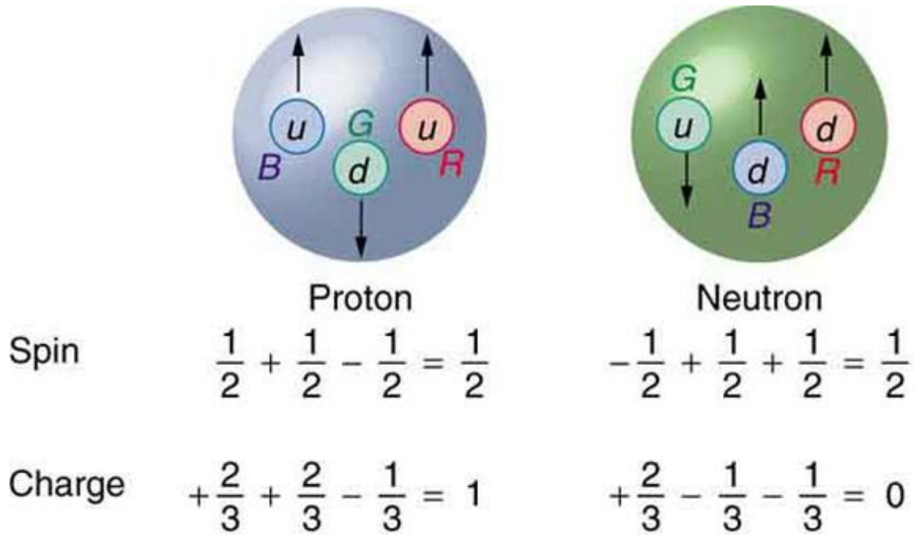








Why is the valence regime interesting?



- Partonic structure in the valence region ***<u>defines</u>*** a hadron
  - Baryon number, charge, flavor content, total spin, …
- "Valence regime" at large x, low Q^2 evolves to low x, high Q^2
  - Intersection of nuclear and particle physics
- Keen discriminator of nucleon structure models
- New generation of experiments at JLab focused on high x

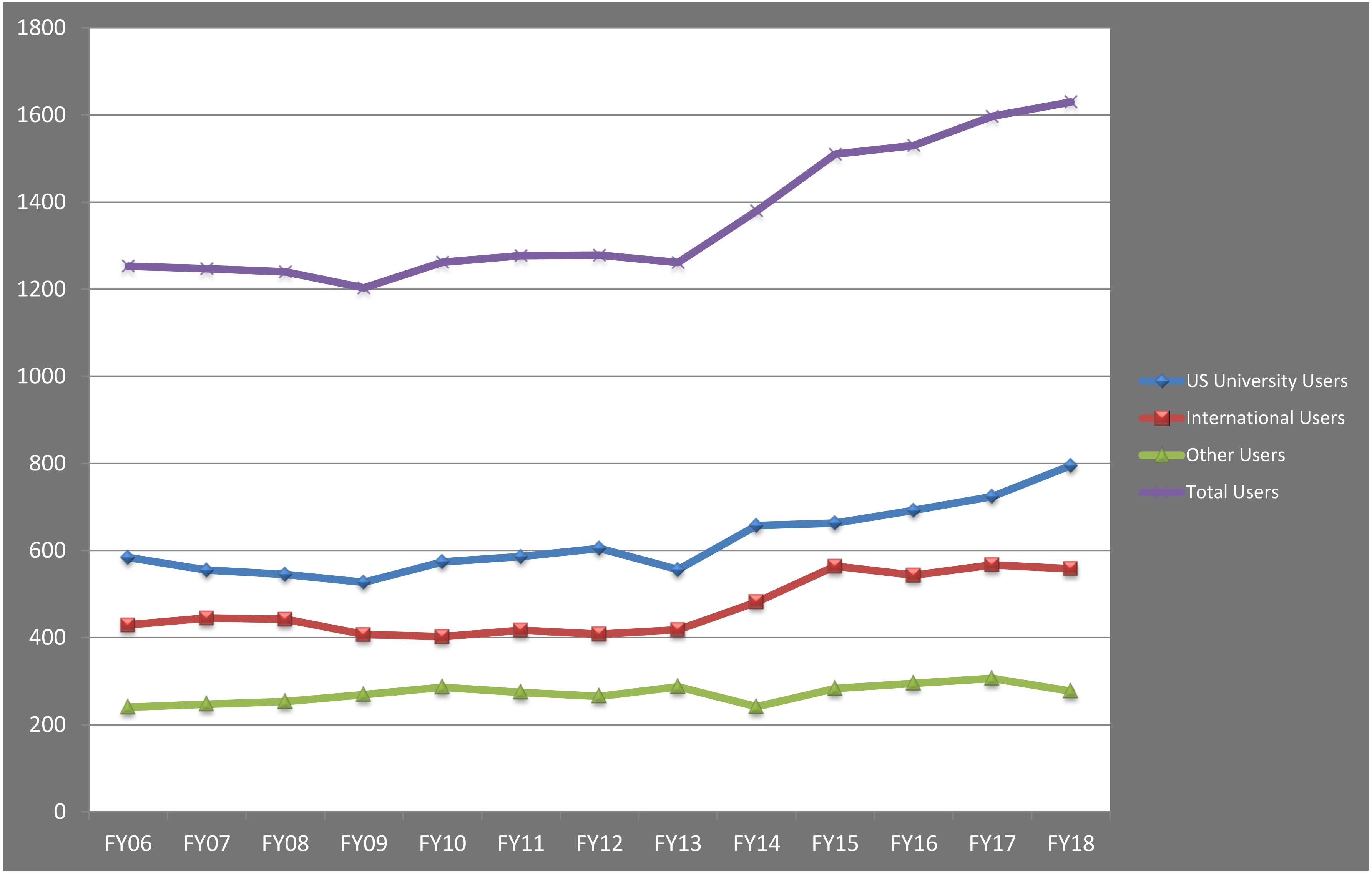
Jefferson Lab Overview

- DOE Office of Science Laboratory with a single program focused on Nuclear Physics.
  - In operation since 1995
- Created to build and operate the Continuous Electron Beam Accelerator Facility (CEBAF), unique user facility for Nuclear Physics.
- Mission is to gain a deeper understanding of the structure of matter:
  - Through advances in fundamental research in nuclear physics
  - Through advances in accelerator and nuclear science and technology

Jefferson Lab by the numbers:

- 700 employees, 27 Joint faculty
- 169 acre site
- 1,630 Active Users
- 630 PhDs granted to-date (212 in progress)
- K-12 programs serve more than 12,000 students and 950 teachers annually
- Scientific users from 39 countries, 278 institutes (124 institutions in 34 states)

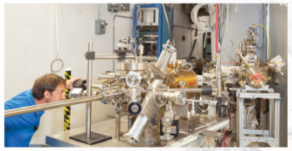
Jefferson Lab's user community continues to grow



Jefferson Lab

CEBAF AT JEFFERSON LAB

Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) enables world-class fundamental research of the atom's nucleus. Like a giant microscope, it allows scientists to "see" things a million times smaller than an atom.



1 INJECTOR

The injector produces electron beams for experiments.

2 LINEAR ACCELERATOR

The straight portions of CEBAF, the linacs, each have 25 sections of accelerator called cryomodules. Electrons travel up to 5.5 passes through the linacs to reach 12 GeV.

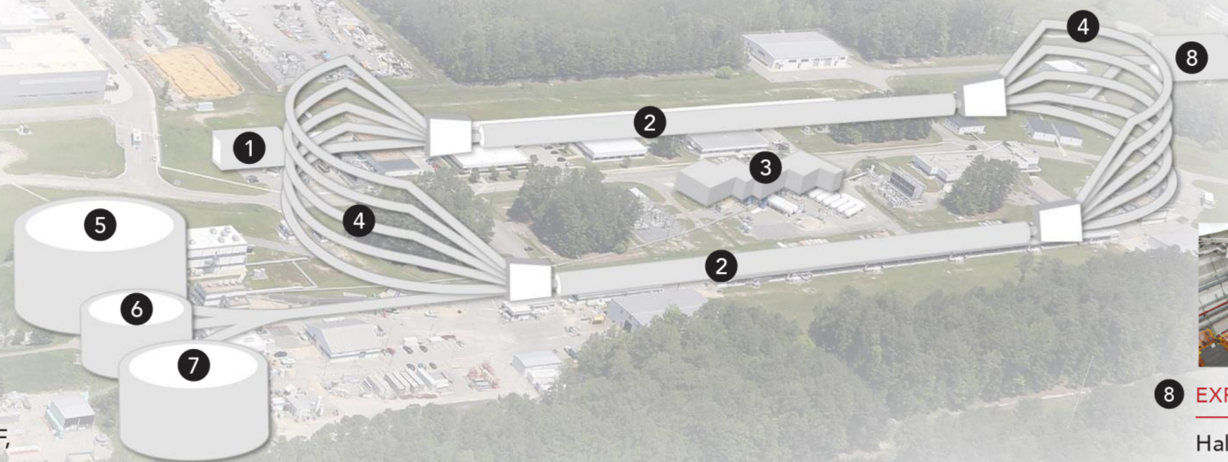


Diagram representational of below ground structure

8 EXPERIMENTAL HALL D

Hall D is configured with a superconducting solenoid magnet and associated detector systems that are used to study the strong force that binds quarks together.

3 CENTRAL HELIUM LIQUEFIER

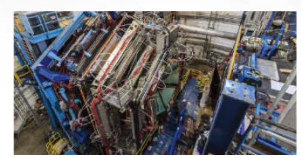
The Central Helium Liquefier keeps the accelerator cavities at -456 degrees Fahrenheit.

4 RECIRCULATION MAGNETS

Quadrupole and dipole magnets in the tunnel focus and steer the beam as it passes through each arc.

5 EXPERIMENTAL HALL A

Hall A is configured with two High Resolution Spectrometers for precise measurements of the inner structure of nuclei. The hall is also used for one-of-a-kind, large-installation experiments.



6 EXPERIMENTAL HALL B

The CEBAF Large Acceptance Spectrometer surrounds the target, permitting researchers to measure simultaneously many different reactions over a broad range of angles.

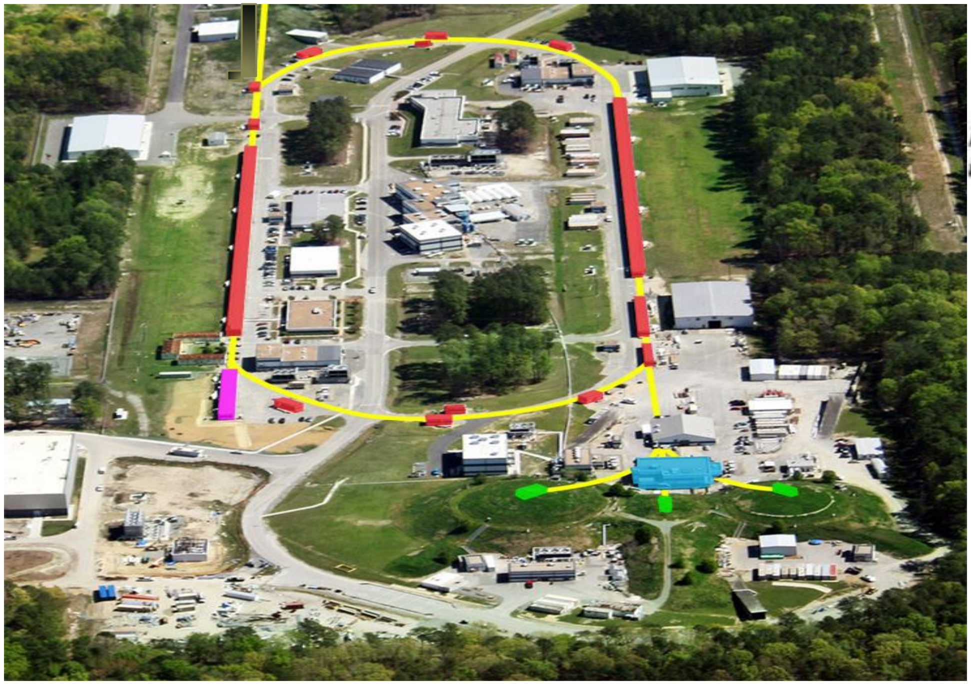
7 EXPERIMENTAL HALL C

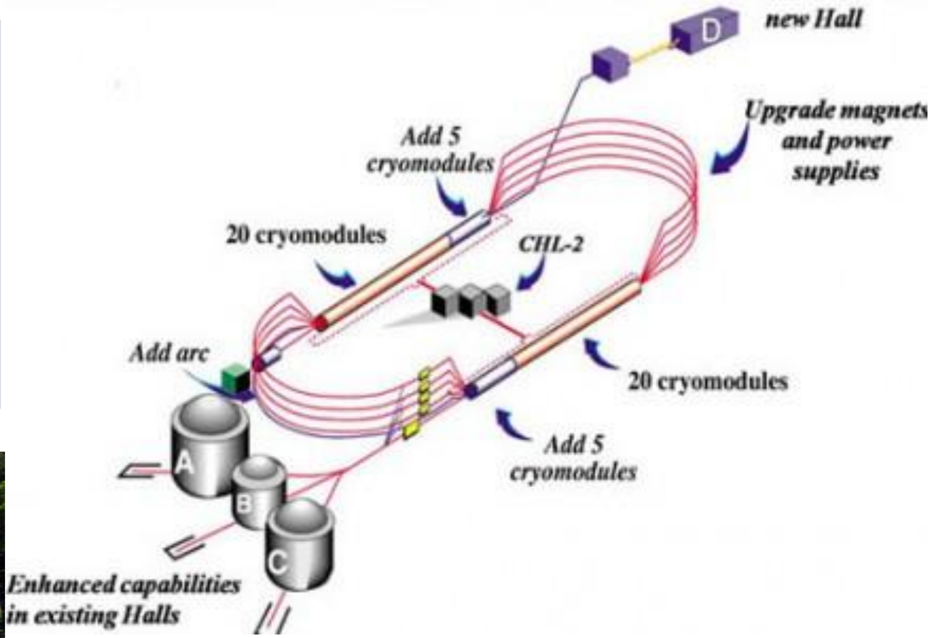
The Super High Momentum Spectrometer and the High Momentum Spectrometer make precise measurements of the inner structure of protons and nuclei at high beam energy and current.

RECENTLY COMPLETED UPGRADE AT JEFFERSON LAB

(as of September 27, 2017)

- **12 GeV Upgrade Project Complete:**
  - Total Project Cost of $338M
  - Double maximum accelerator energy to 12 GeV
  - Add 4th experimental Hall D
  - New experimental equipment in Halls B, C, D
- **In full operation now with simultaneously beam deliver to all 4 experimental halls**

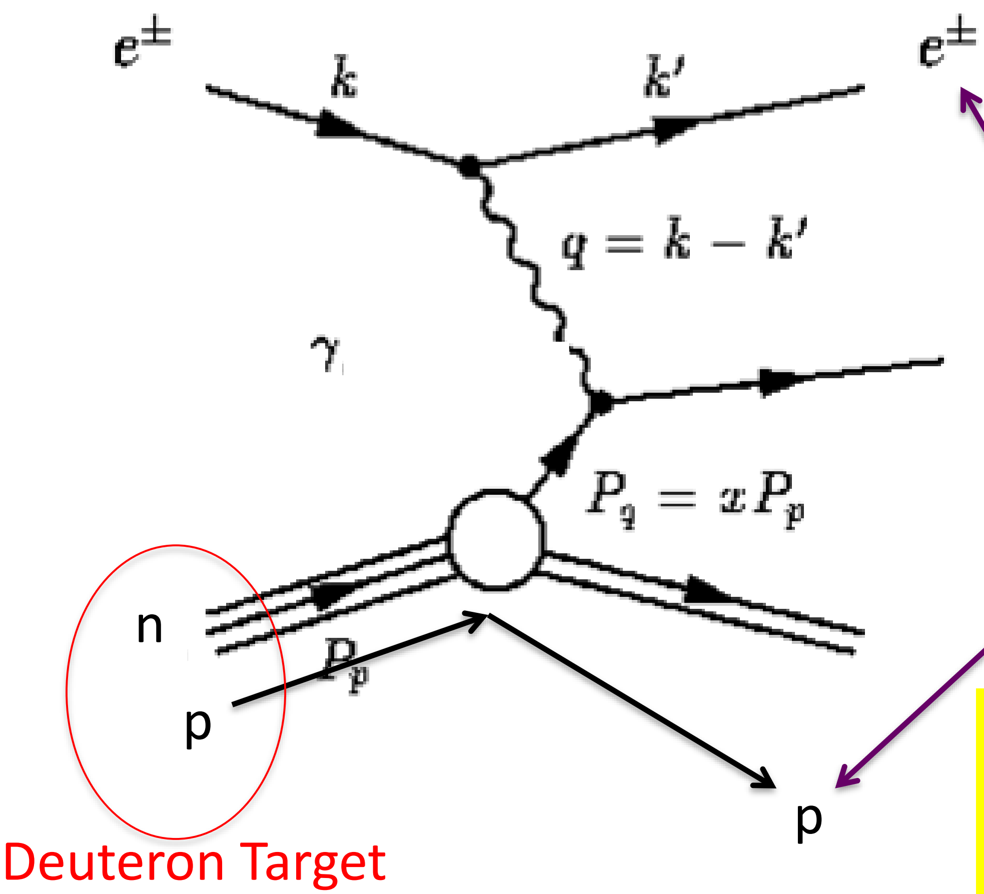


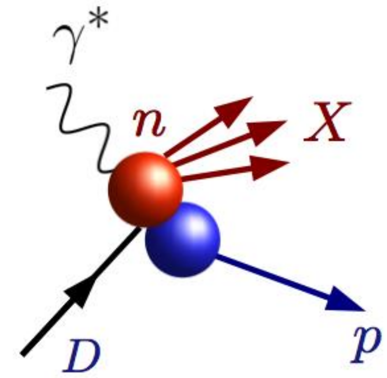


Secures a forefront scientific program for the next 10 or more years

TDIS to access nucleon valence structure

"BONuS" Experiment at Jefferson Lab – use fixed target Tagged DIS to create an effective ***free neutron*** target



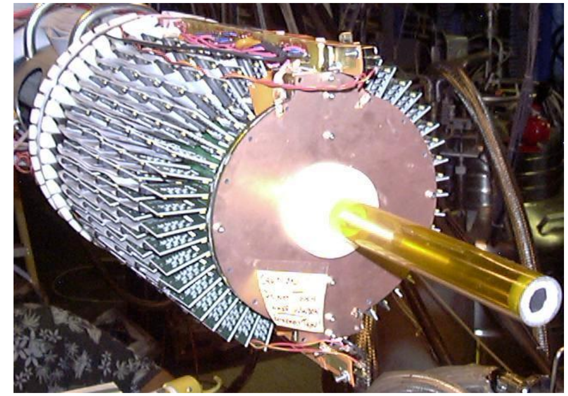


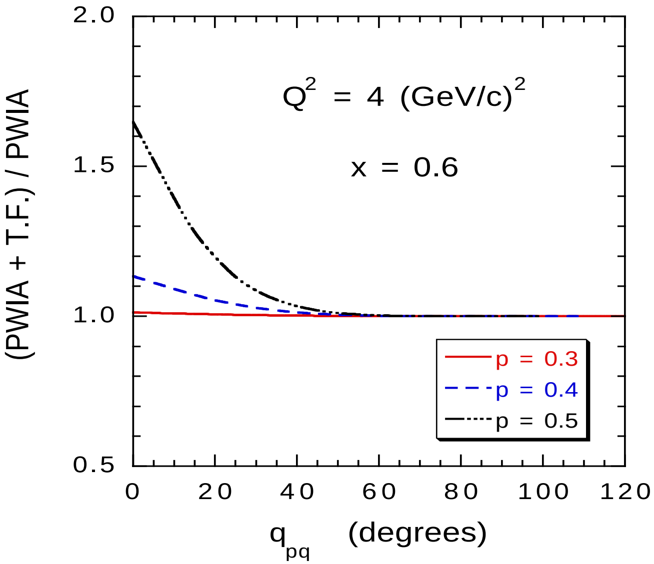
Measure DIS electron in coincidence with proton tag

- "Hard" scattering inelastic event (high Q, W)
- Proton remains intact
- Low momentum proton = nucleons barely off shell
- ✓ Neutron target!

The BONuS approach:

use low mass radial TPC detector / target in magnetic field to TAG “spectator” proton at (very) low momenta (~65 MeV/c) and large angles (> 90º in lab) ***….difficult but doable***



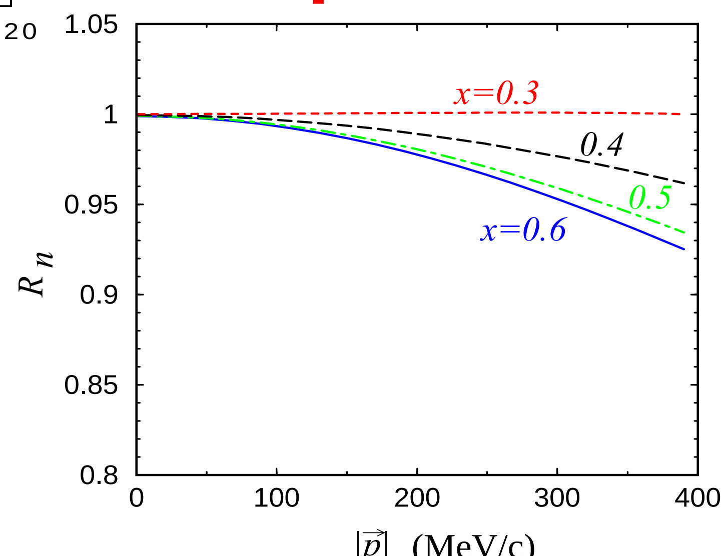


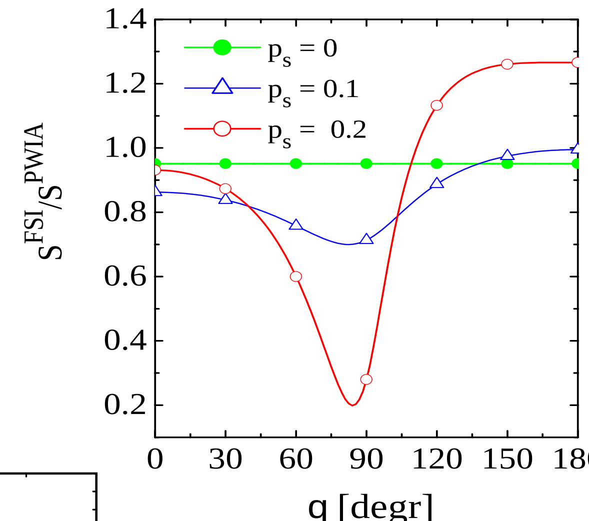
Target fragmentation

negligible

Bound / free neutron structure

***O* (1%)**





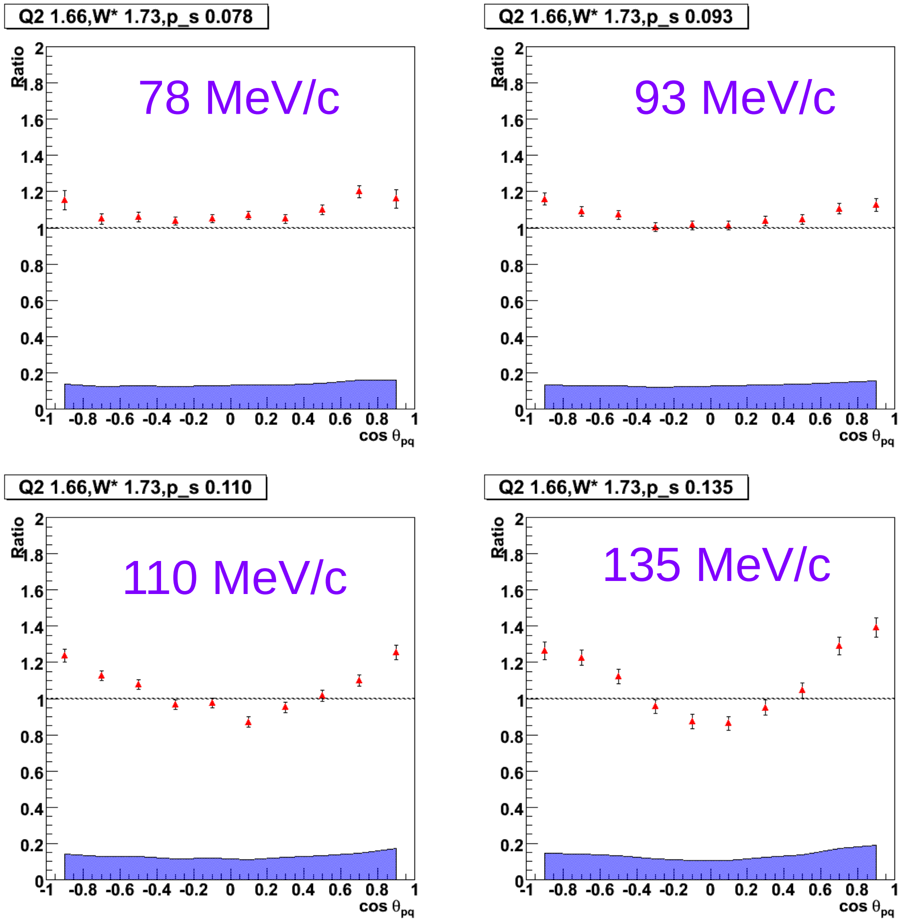
Final state interactions

***O* (5%)**

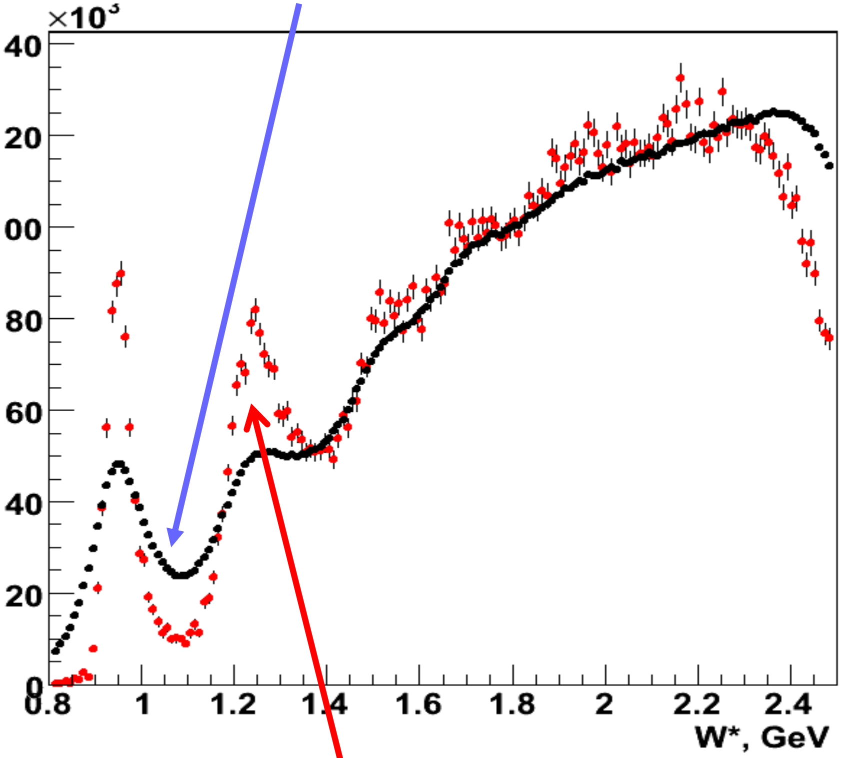
The technique works!

angle - momentum dependence

$$W^2 = M^2 + 2Mn - Q^2$$



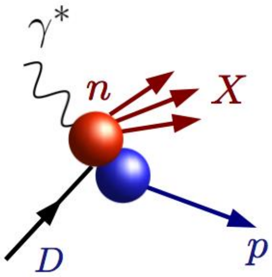
cosθ_{pq}



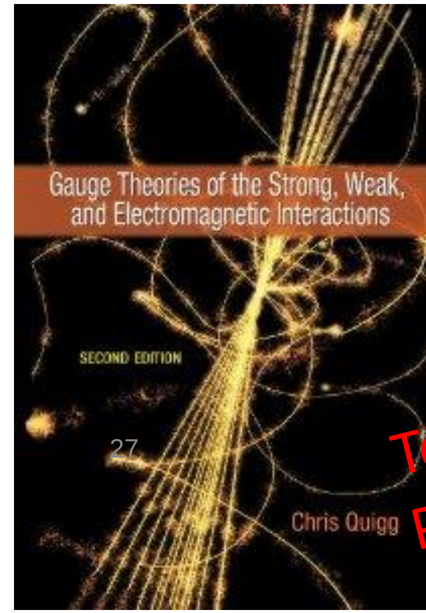
$$W^{*2} = (p_n + q)^2 = p_n^{\mu} p_{n\mu} + 2\left((M_D - E_s)\nu - \vec{p}_n \cdot \vec{q}\right) - Q^2$$

$$\approx M^{*2} + 2M\nu(2 - \alpha_S) - Q^2$$

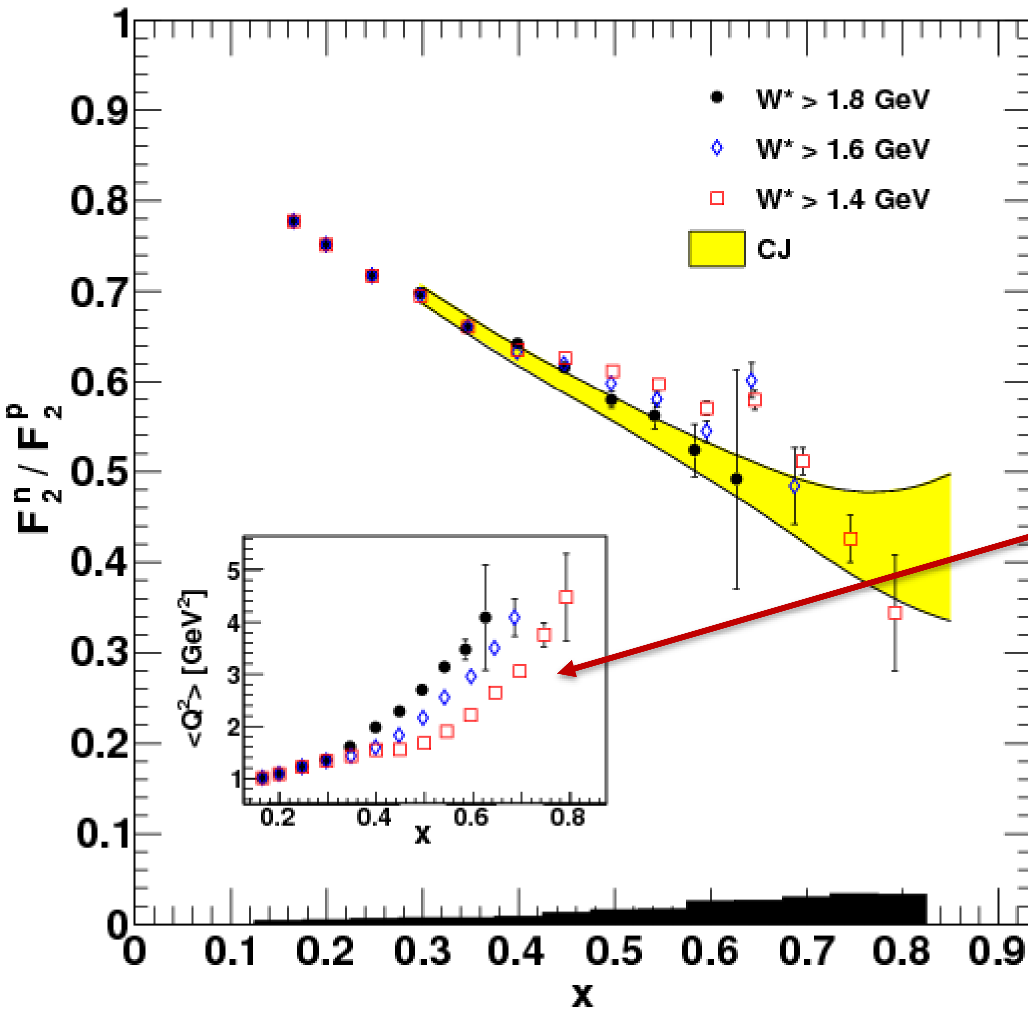
BONUS effective neutron target via TDIS *achieved!*



Phys.Rev. C92 (2015) no.1, 015211
Phys.Rev. C91 (2015) no.5, 055206
Phys. Rev. C89 (2014) 045206 – editor's suggestion
Phys. Rev. Lett. 108 (2012) 199902
Nucl. Instrum. Meth. A592 (2008) 273-286



Textbook Physics!

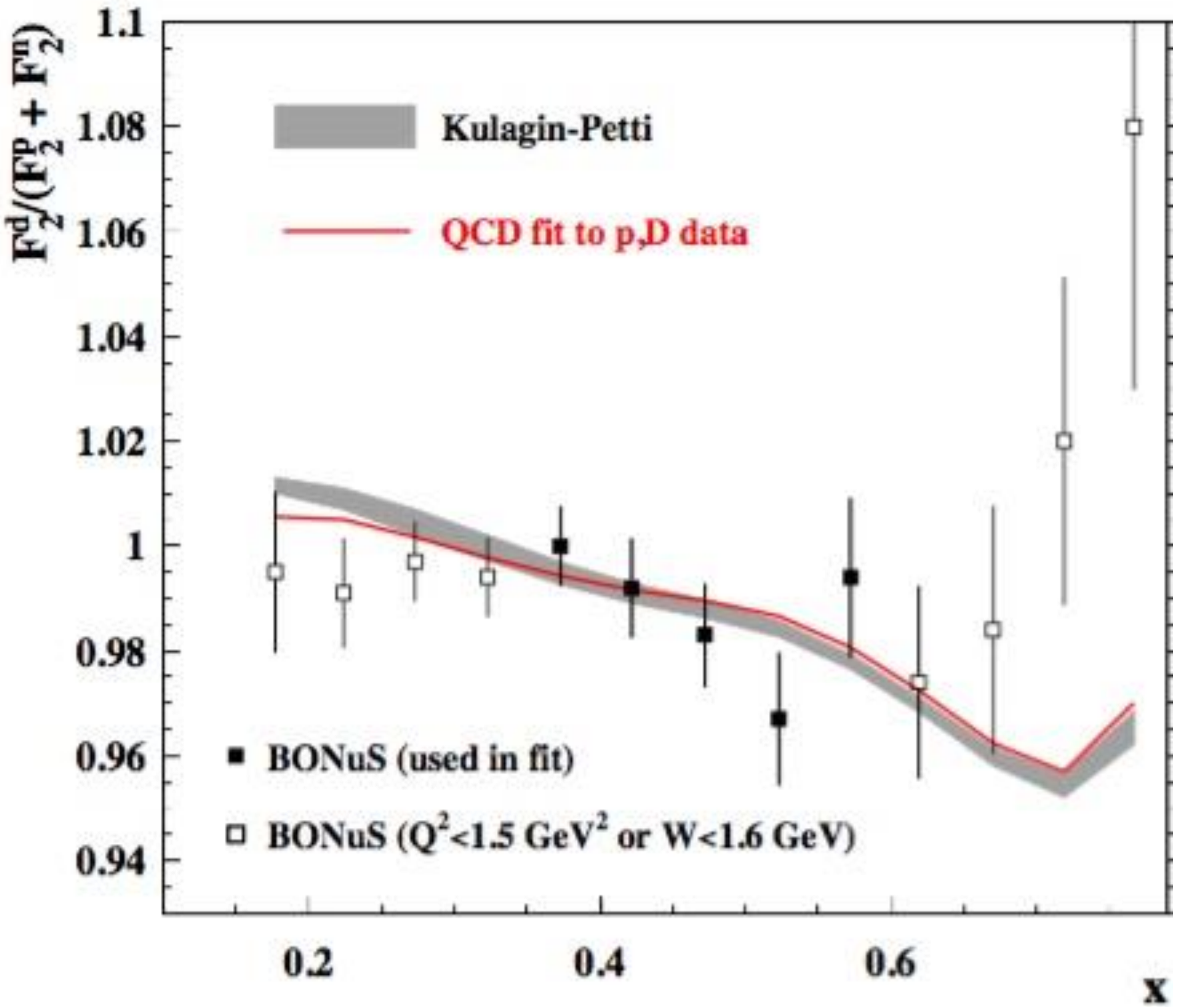


> 400 ***neutron*** data points!

- Lower W, Q^2 than desirable….
- Still powerful input for global PDF fits
- Provides deuteron nuclear correction

EMC effect in deuterium – correction for (nuclear) PDFs

$F_2^D/(F_2^n + F_2^p)$ with F_2^n from BONUS

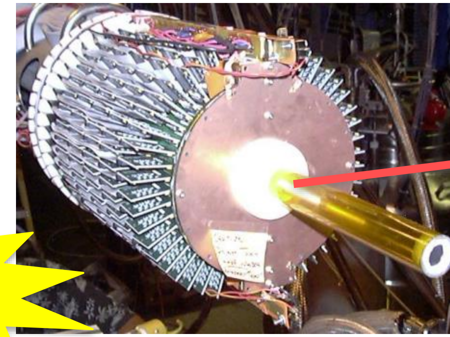


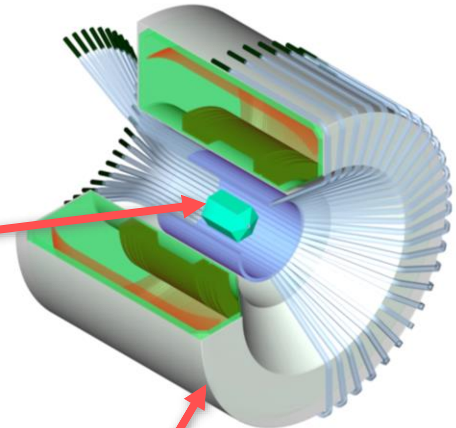
S.I. Alekhin, S.A. Kulagin, R. Petti Phys. Rev. D 96, 054005 (2017)

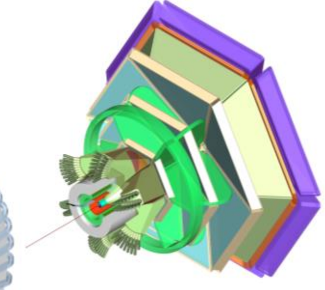
"The recent direct measurement of the deuteron nuclear correction by the BONuS experiment substantially reduces this uncertainty by constraining the normalization of the overall nuclear corrections."

E12-06-113 "BONUS12": Larger x and higher Q^2

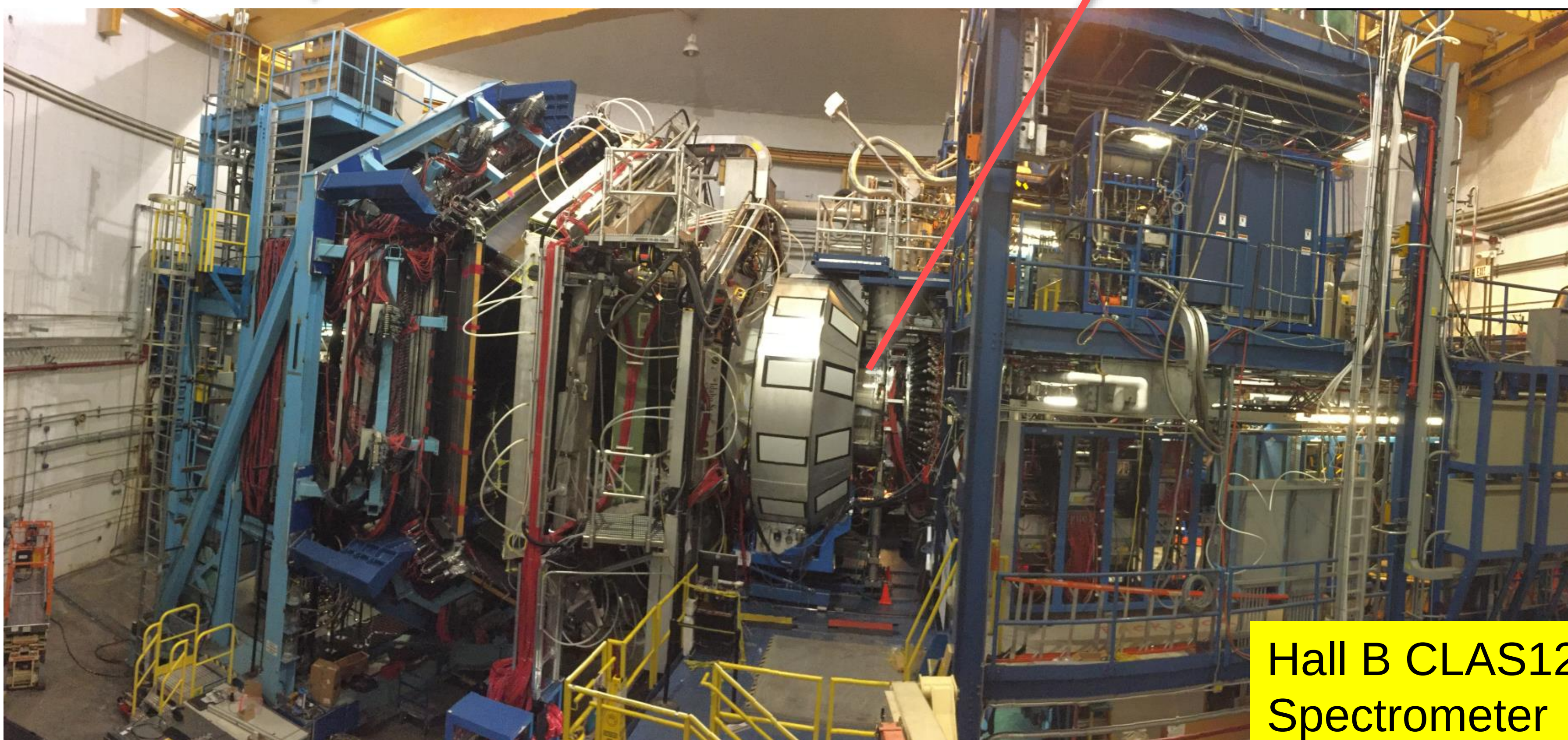
High Impact





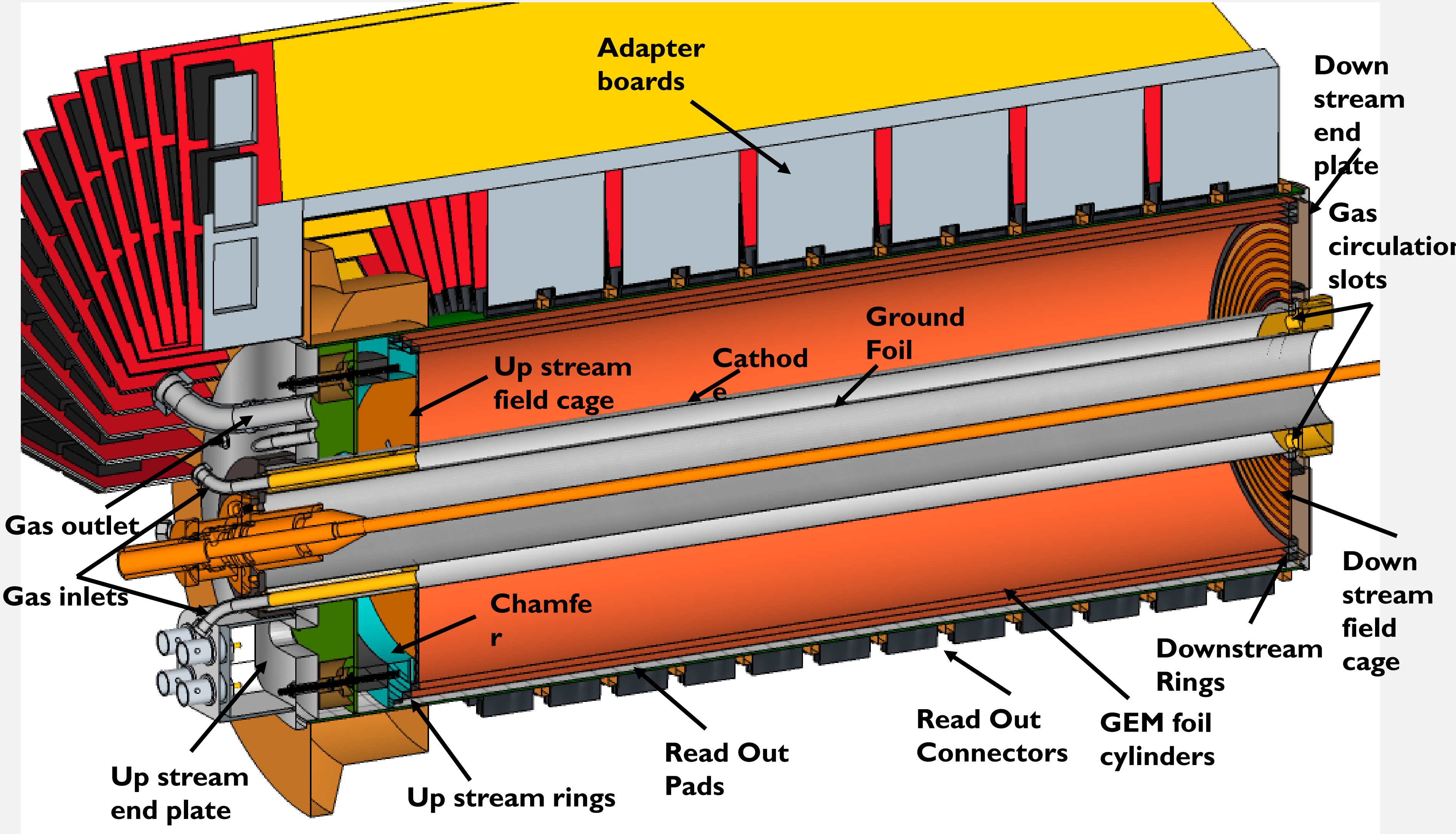


CLAS12 Central Detector



Hall B CLAS12 Spectrometer

BONUS12 RTPC



RTPC UNDER CONSTRUCTION

Preparing for 2020 run!

Removal of glued capton cylinder using puller mechanism

Self aligning puller assembly

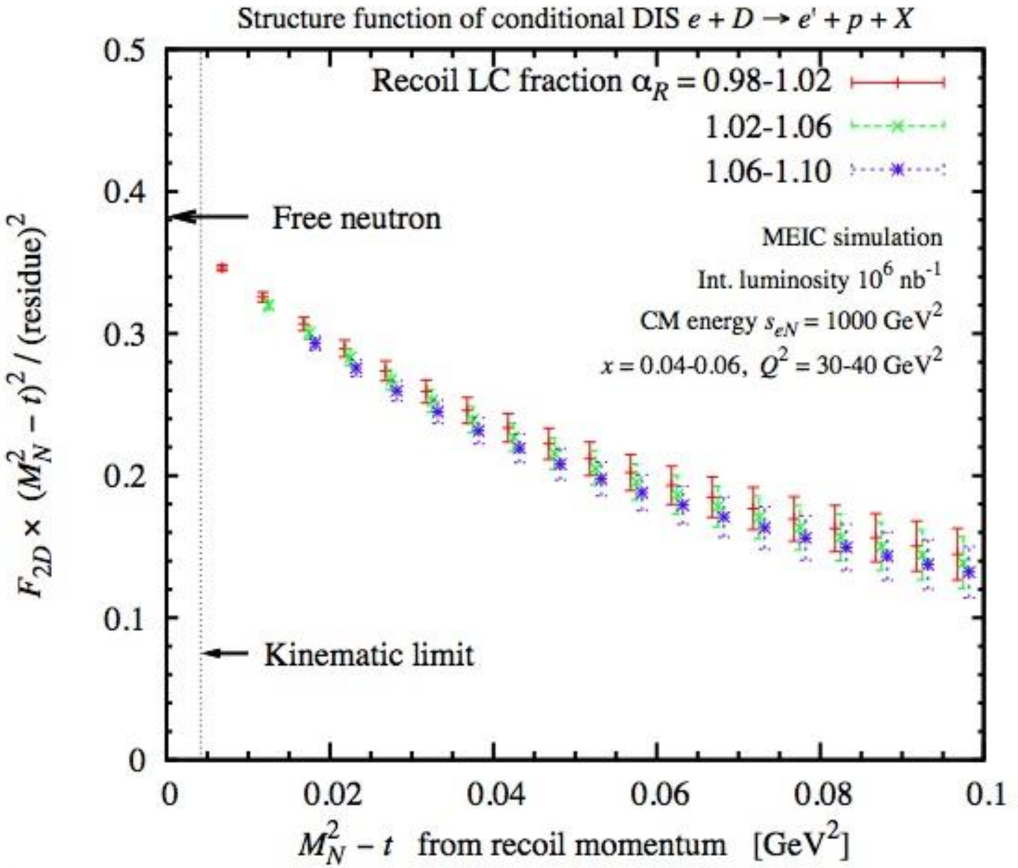
Tagged Neutron Structure at an Electron Ion Collider

The TDIS technique is better suited to colliders: no target material absorbing low-momentum nucleons, forward acceptance only! Need:

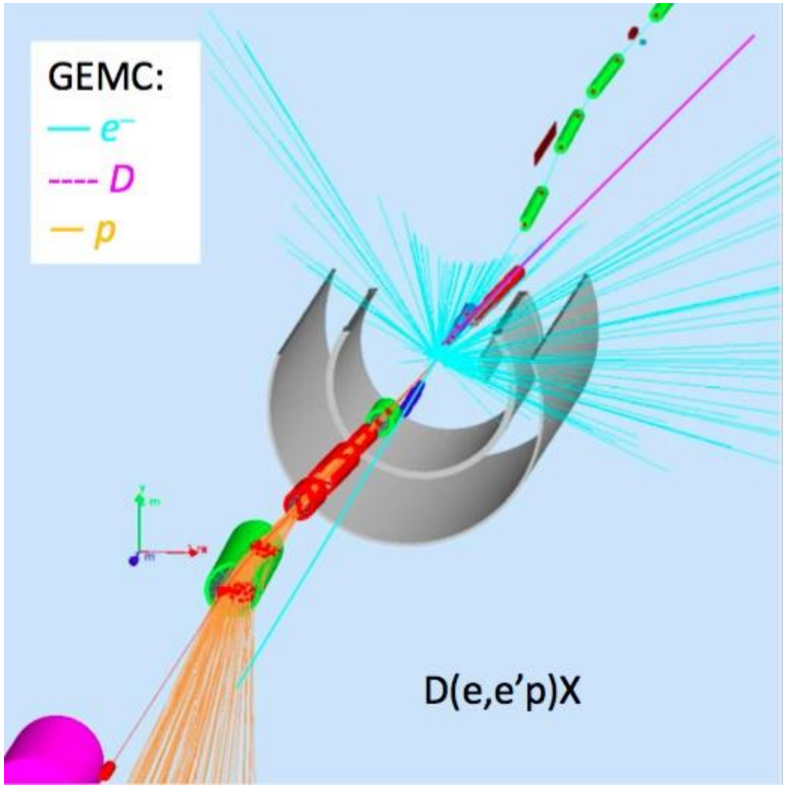
- good momentum resolution (ΔpT ~20 MeV, < Fermi momentum)
- small intrinsic momentum spread in the ion beam for accurate reconstruction

EIC being designed with this physics in mind – neutron structure functions up to Q^2 ~ 40 GeV^2

e + D → e′ + p + X *a la BONUS*



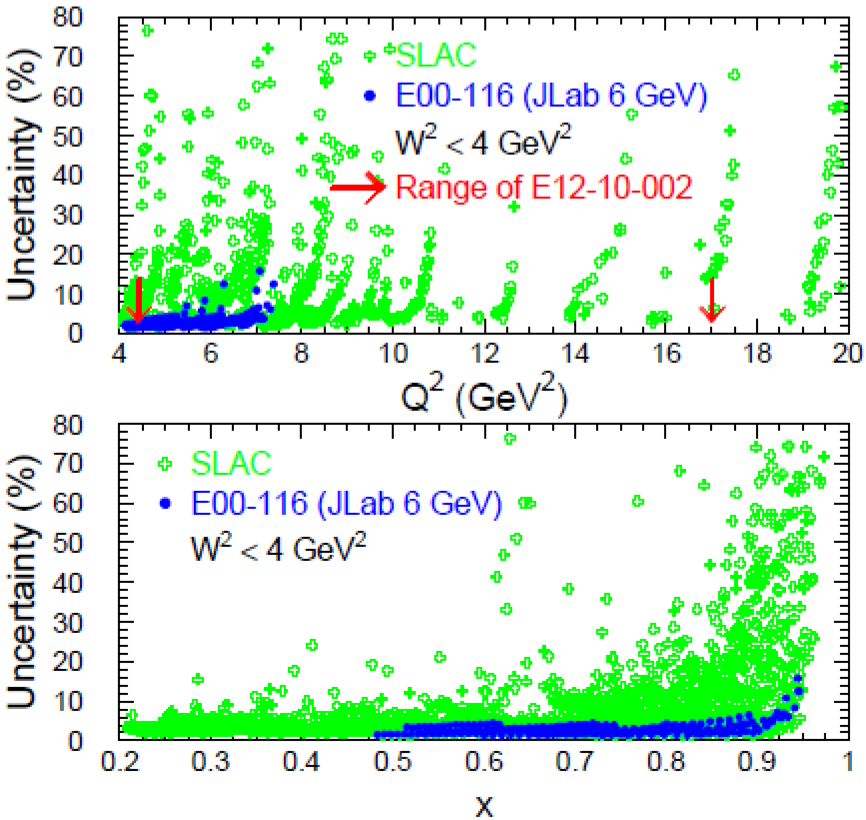
JLEIC

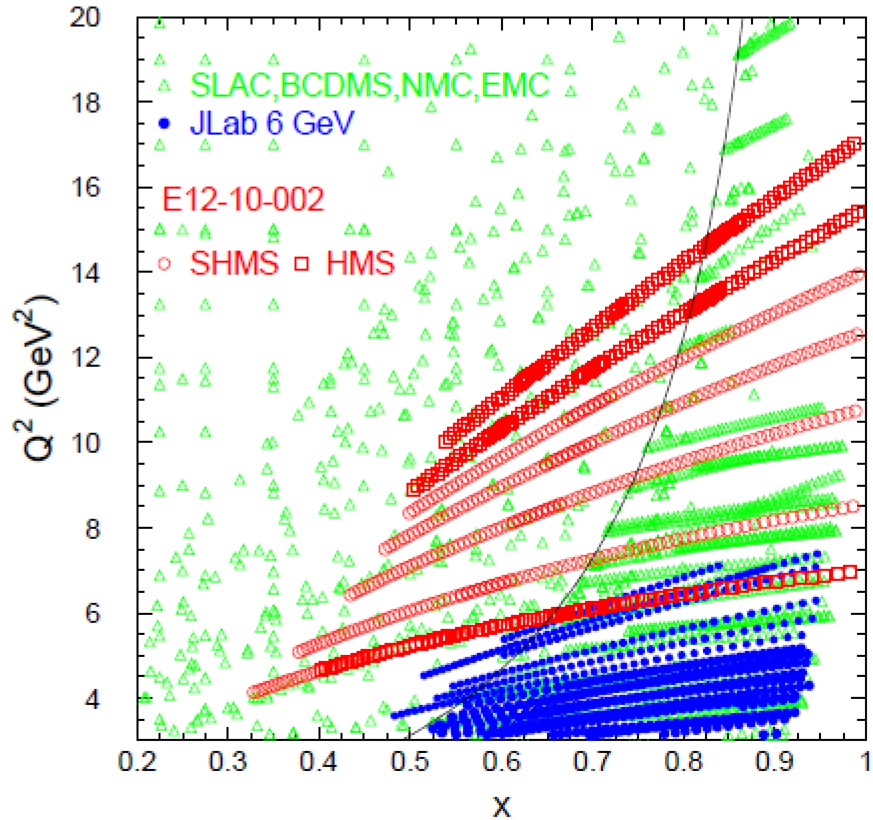


See Spectator Tagging Project at https://www.jlab.org/theory/tag/

F_2^p & F_2^d Structure Functions in Hall C

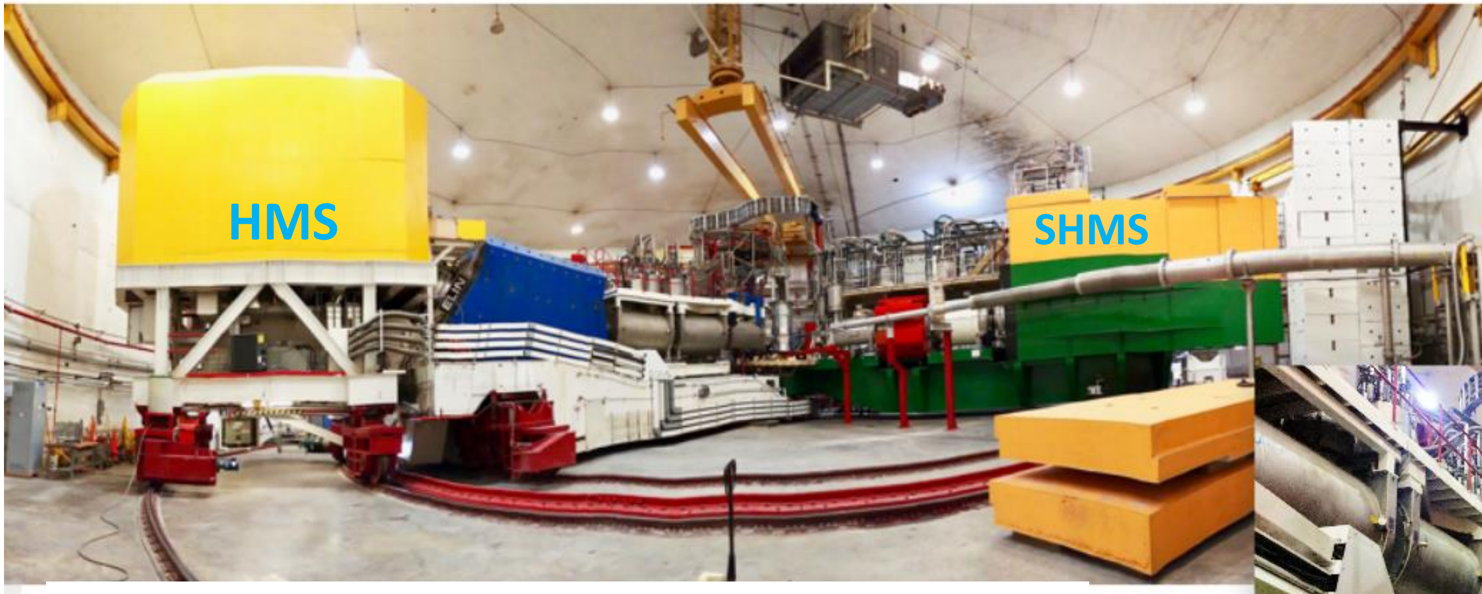
JLab12 Hall C commissioning experiment aims to reduce uncertainties in F_2^p and F_2^d structure functions at large x and high Q



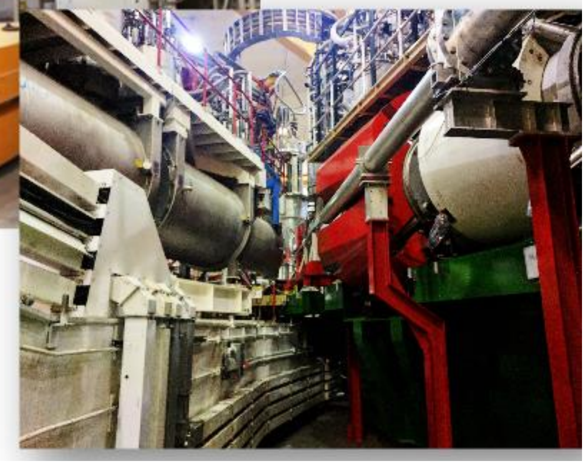


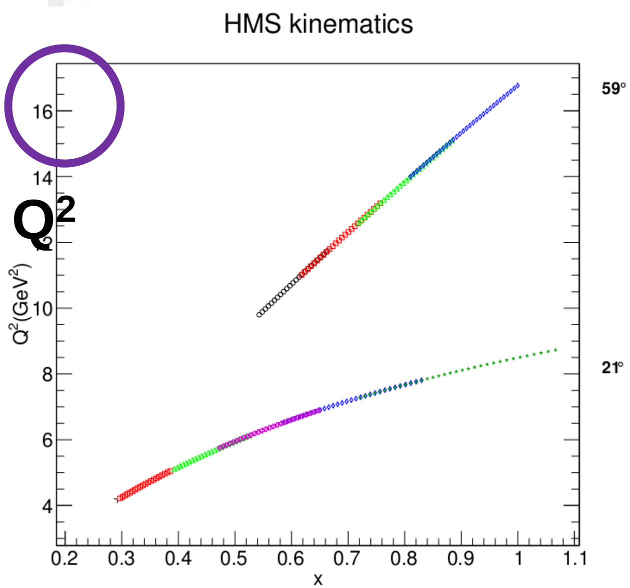
Goal @ 12 GeV: <2% total precision cross sections, (as achieved by E00-116 @ 6 GeV)

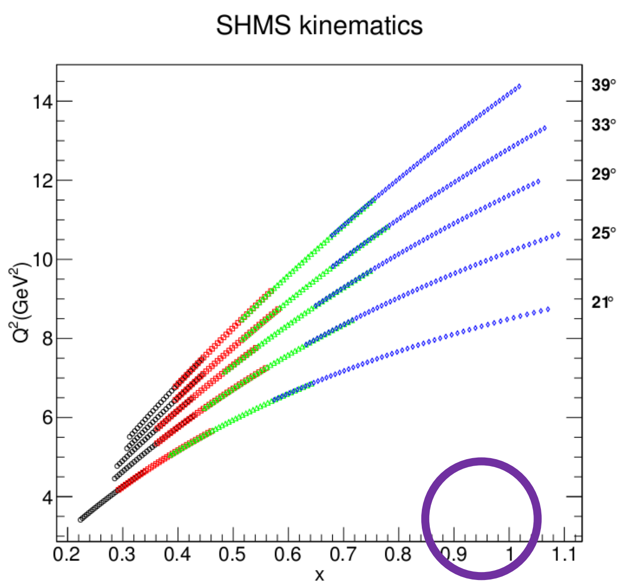
E12-10-002: High Precision Measurement of the F_2 Structure Function on p,D



- 10.6 GeV beam
- Targets: LH2, LD2, Al





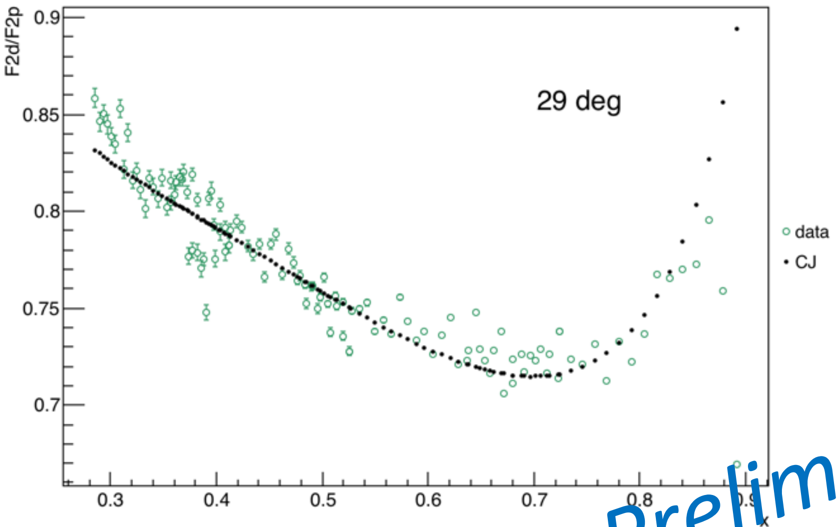


x

- Fix energy and angle
- Scan in momentum
- Effective scan in x
- Stringent check on spectrometer acceptance

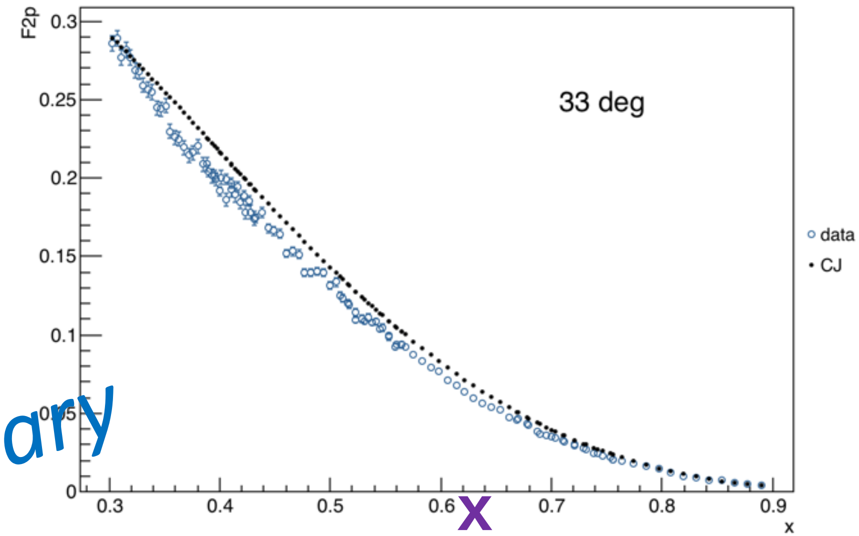
Preliminary Results: Structure Functions (and CJ fit)

F_2^d/F_2^p



x

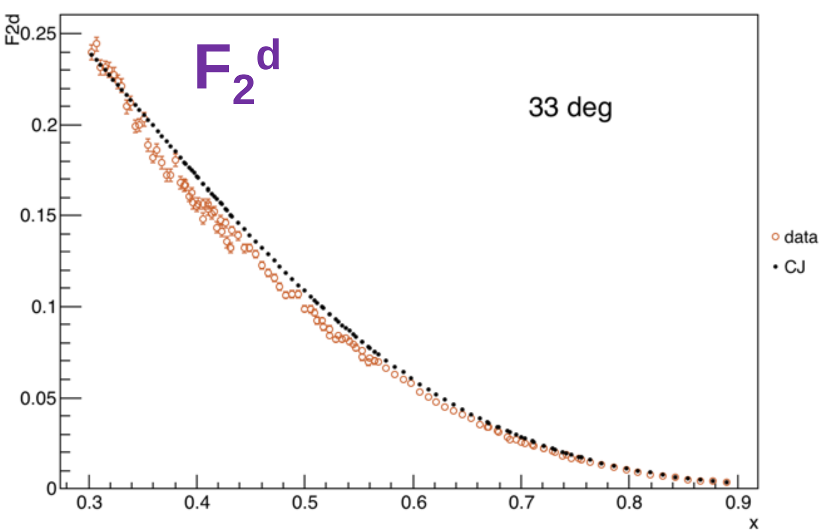
F_2^p



x

Preliminary

F_2^d

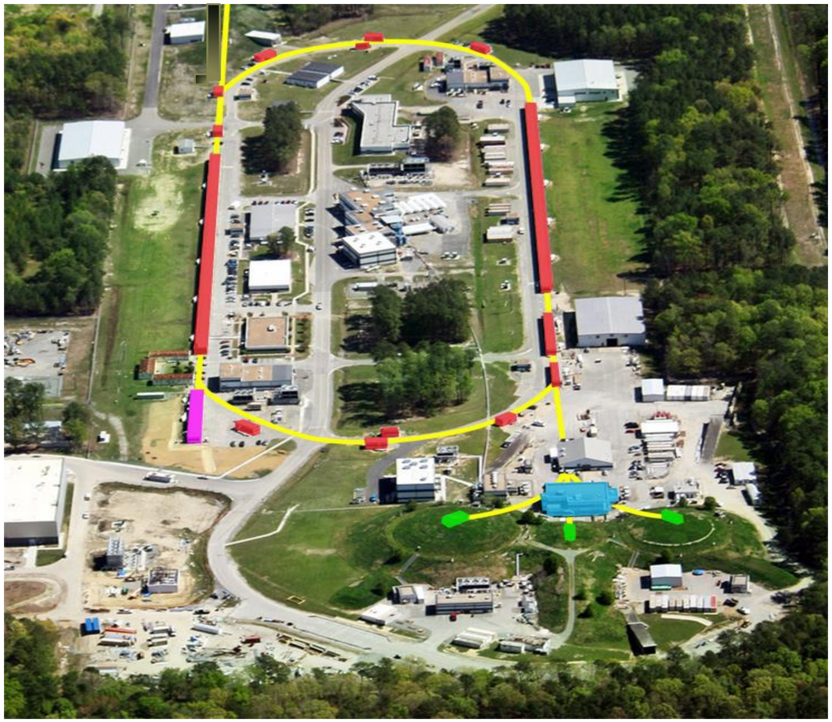


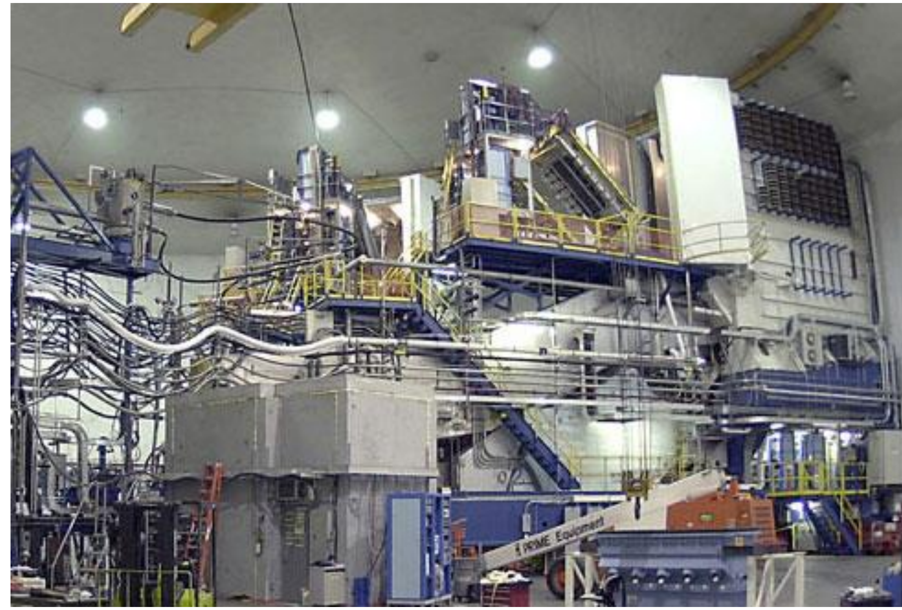
Still working on:

- Some background subtractions
- Systematic uncertainties
- Looking towards F_2d/F_2p paper submission ***this Fall***

Jefferson Lab

Or, a nuclear physicists approach to the problem….





JLab Hall A HRS Spectrometer

- Problem:
  - The deuteron experiments present free nucleon extraction complications.
- *Solution:* Add another nucleon!
- $^{3}H/^{3}He$ ratio: minimizes nuclear physics uncertainties

Deep Inelastic Scattering from A=3 Nuclei

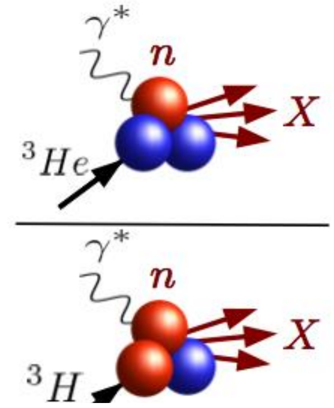
$$R(^3\mathrm{He}) = \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n}, \qquad R(^3\mathrm{H}) = \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n}$$

- Mirror symmetry of A=3 nuclei
  - Extract F_2^n/F_2^p from ratio of measured ^{3}He/^{3}H structure functions

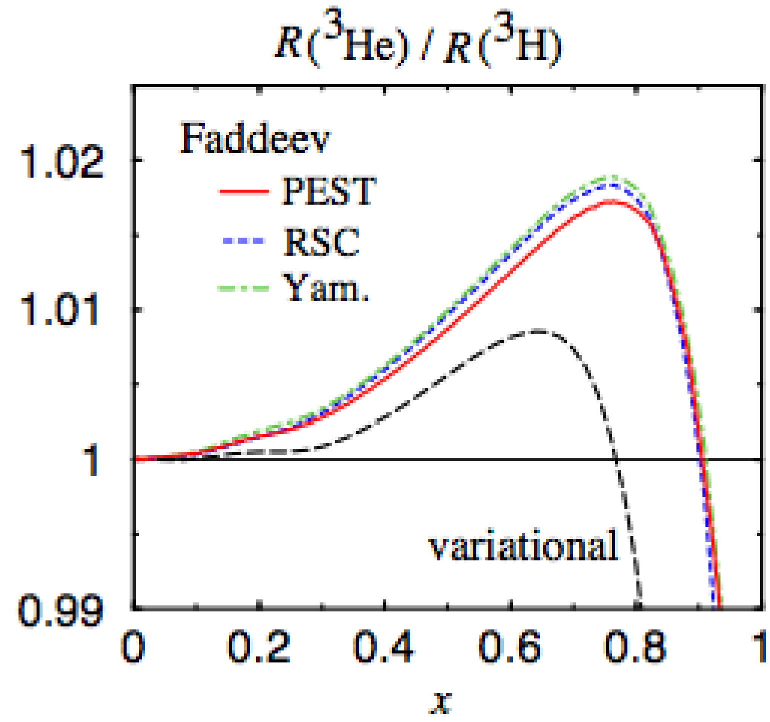
$$\frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - \mathcal{R}}$$

$\mathcal{R}$ = SUPER ratio of ”EMC ratios” for ^{3}He and ^{3}H

- Relies only on *difference* in nuclear effects in ^{3}H, ^{3}He
- Calculated to within 1%
- Most systematic and theoretical uncertainties cancel



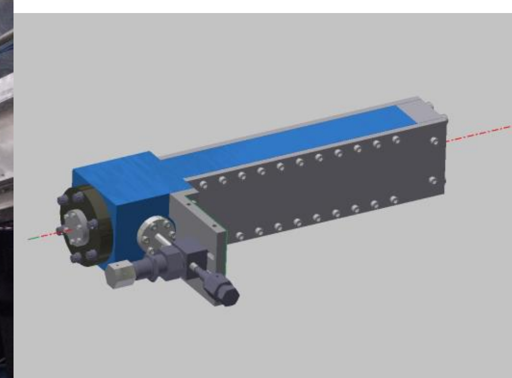
I. Afnan et al, PRC 68 (2003)



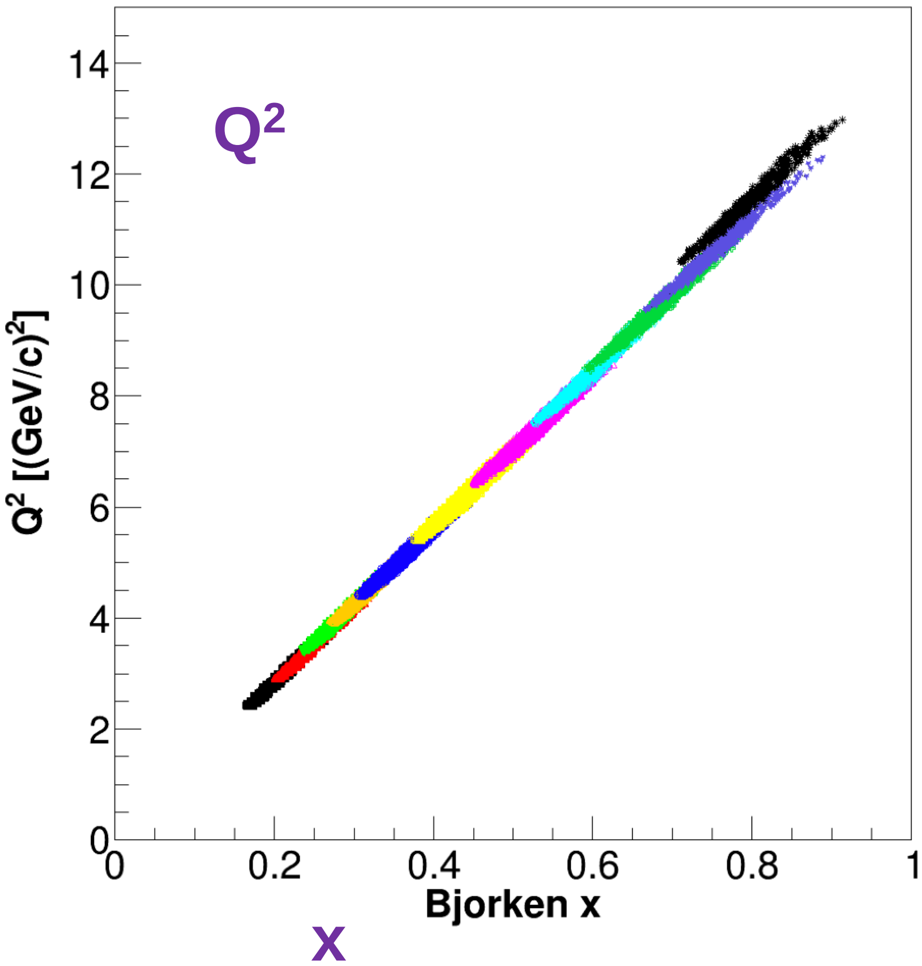
Hall A Tritium Target first in over 3 decades!!

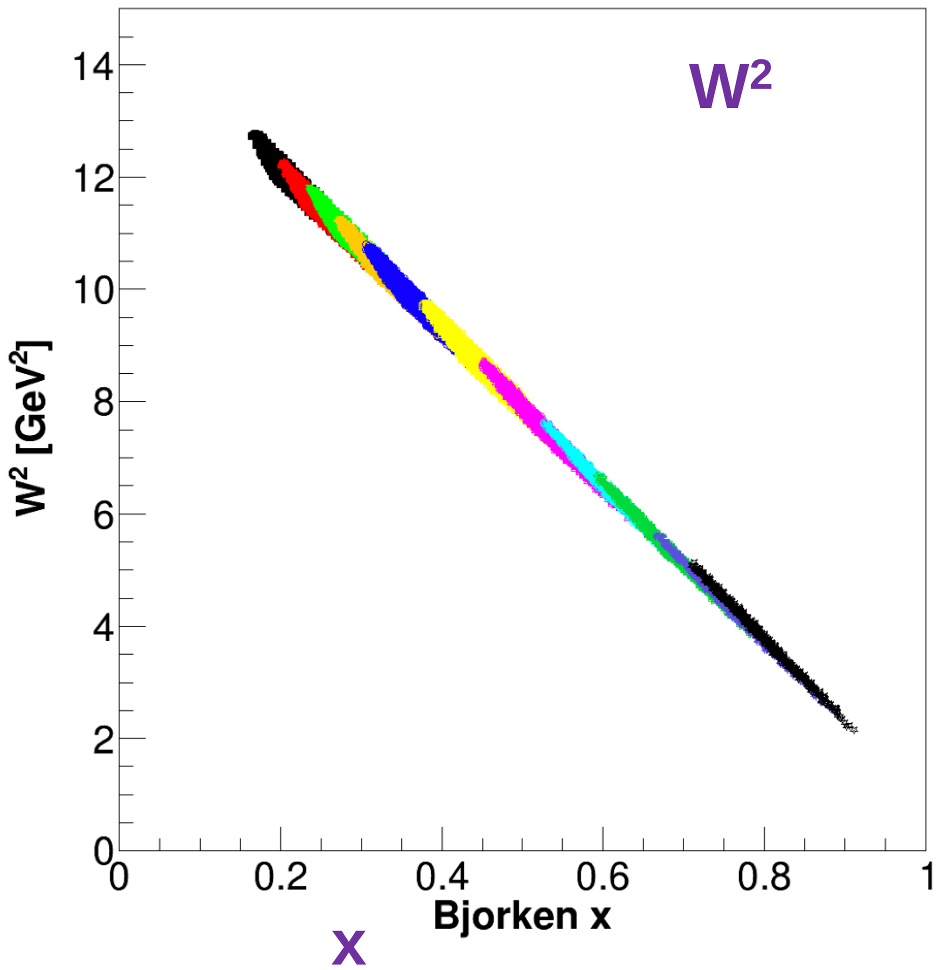
Lab	Year	Quantity (kCi)	Thickness (g/cm²)	Current (μA)	Current *x* thickness (μA-g/cm²)
Stanford	1963	25	0.8	0.5	0.4
MIT-Bates	1982	180	0.3	20	6.0
Saskatoon	1985	3	0.02	30	0.6
JLab	**2017**	**1**	**0.08**	**20**	**1.6**

JLab Luminosity ~ 2.0 x 10^{36} tritons/cm^2/s



Kinematic Coverage of MARATHON





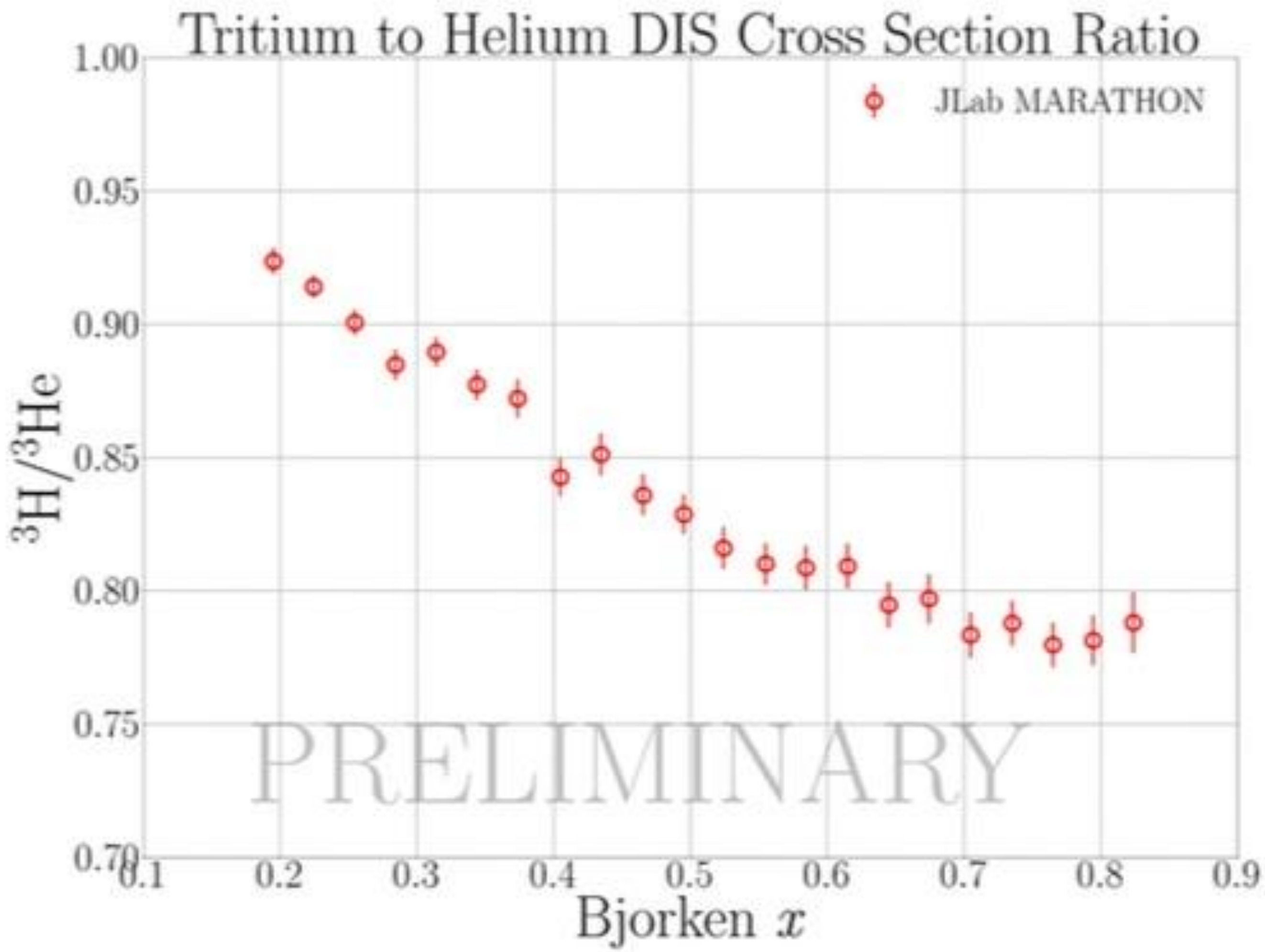
* DIS with 10.6 GeV electron beam on ^{3}H, ^{3}He and ^{2}H targets. The electron scattering angle ranged between 17 and 36 deg.

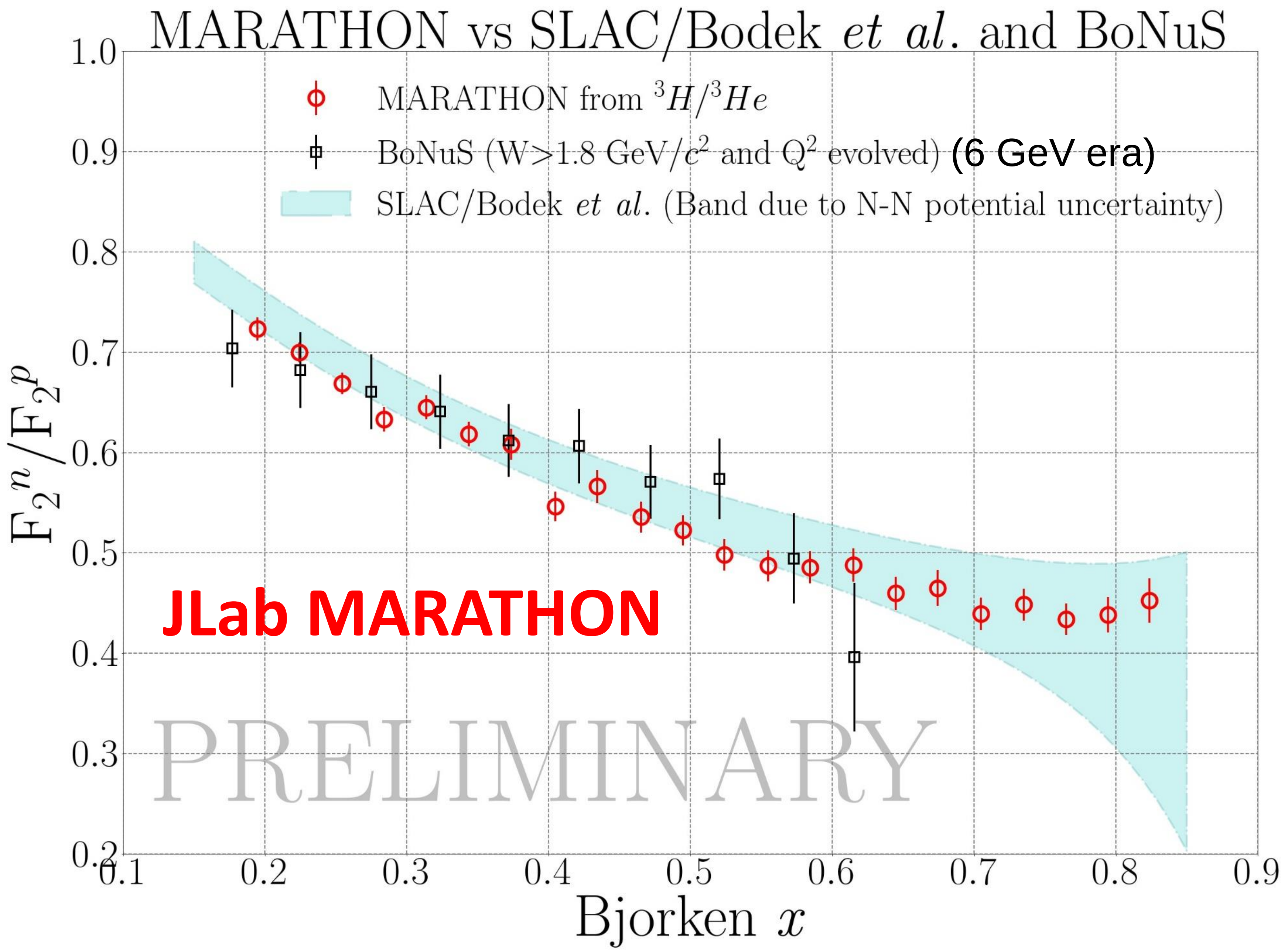
JLab MARATHON preliminary results

This is the actual (preliminary) data!

Still working on systematic uncertainties

Use ratio of nuclear effects in ^3H, ^3He to get....





MARATHON vs SLAC/Bodek et al. and BoNuS
MARATHON from $^3H/^3He$
BoNuS (W>1.8 GeV/c^2 and Q^2 evolved) (6 GeV era)
SLAC/Bodek et al. (Band due to N-N potential uncertainty)
JLab MARATHON
PRELIMINARY
F_2^n/F_2^p
Bjorken x
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Polarized predictions for d/u structure at large x

Proton Wavefunction (Spin and Flavor Symmetric)

$$|p\uparrow\rangle = \frac{1}{\sqrt{2}}|u\uparrow (ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|u\uparrow (ud)_{S=1}\rangle - \frac{1}{3}|u\downarrow (ud)_{S=1}\rangle$$

$$-\frac{1}{3}|d\uparrow (uu)_{S=1}\rangle - \frac{\sqrt{2}}{3}|d\downarrow (uu)_{S=1}\rangle$$

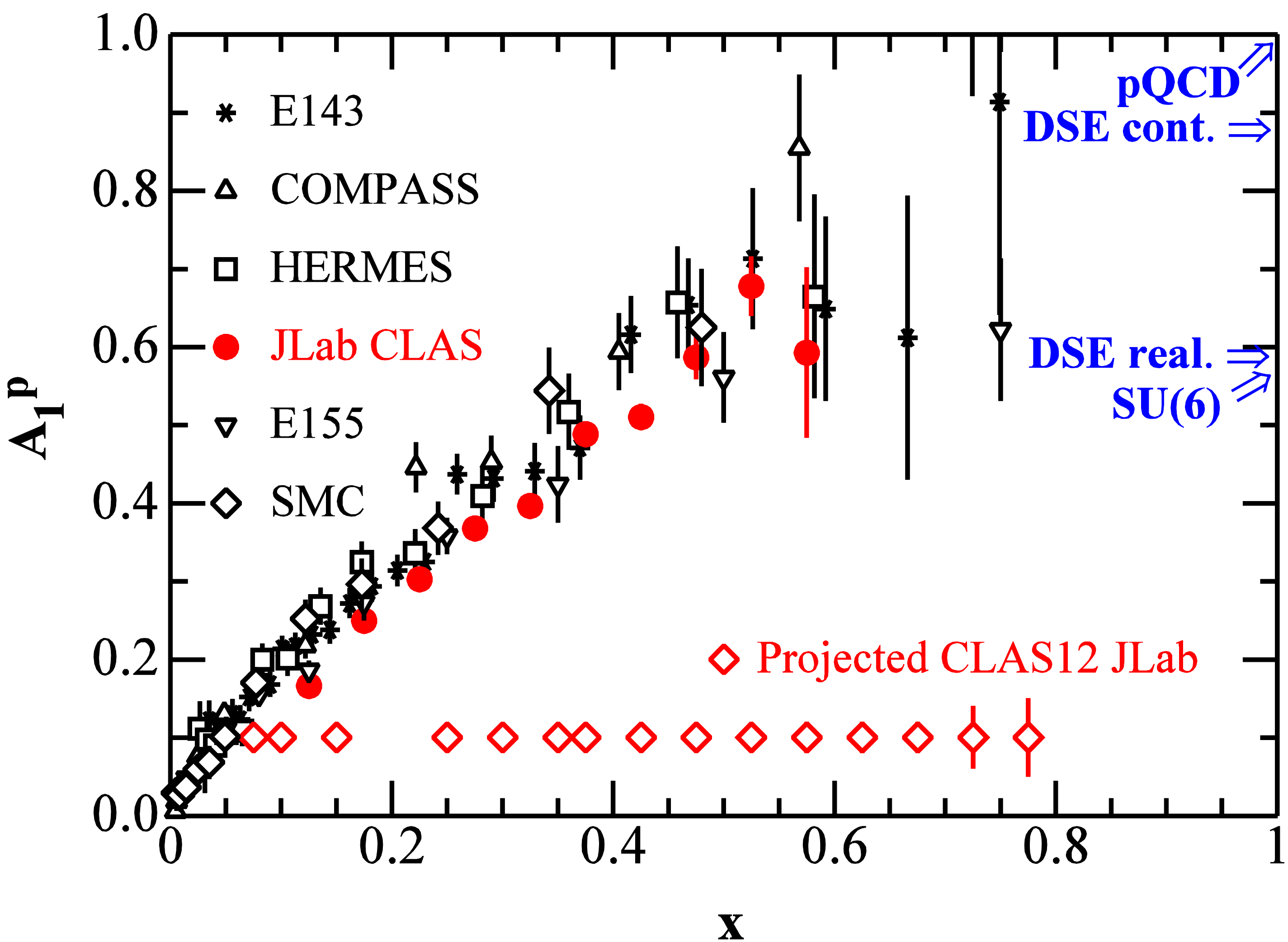
Model	F_2^n/F_2^p	d/u	Δ u/u	Δ d/d	A_1^n	A_1^p
SU(6) = SU3 flavor + SU2 spin	2/3	1/2	2/3	-1/3	0	5/9
Valence Quark + Hyperfine	1/4	0	1	-1/3	1	1
pQCD + HHC	3/7	1/5	1	1	1	1
DSE-1 (realistic)	0.49	0.28	0.65	-0.26	0.17	0.59
DSE-2 (contact)	0.41	0.18	0.88	-0.33	0.34	0.88

Lepton scattering spin structure experiments (mostly inclusive):

JLab's focus is high precision large x and low to intermediate Q^2 values

Experiment	Ref.	Target	Analysis	W (GeV)	x_{Bj}	Q^2 (GeV^2)
E80 (SLAC)	[101]	p	A_1	2.1 to 2.6	0.2 to 0.33	1.4 to 2.7
E130 (SLAC)	[102]	p	A_1	2.1 to 4.0	0.1 to 0.5	1.0 to 4.1
EMC (CERN)	[103]	p	A_1	5.9 to 15.2	1.5×10^{-2} to 0.47	3.5 to 29.5
SMC (CERN)	[250]	p, d	A_1	7.7 to 16.1	10^{-4} to 0.482	0.02 to 57
E142 (SLAC)	[244]	^{3}He	A_1, A_2	2.7 to 5.5	3.6×10^{-2} to 0.47	1.1 to 5.5
E143 (SLAC)	[245]	p, d	A_1, A_2	1.1 to 6.4	3.1×10^{-2} to 0.75	0.45 to 9.5
E154 (SLAC)	[246, 247]	^{3}He	A_1, A_2	3.5 to 8.4	1.7×10^{-2} to 0.57	1.2 to 15.0
E155/x (SLAC)	[248, 249]	p, d	A_1, A_2	3.5 to 9.0	1.5×10^{-2} to 0.75	1.2 to 34.7
HERMES (DESY)	[253, 254]	p, ^{3}He	A_1	2.1 to 6.2	2.1×10^{-2} to 0.85	0.8 to 20
E94010 (JLab)	[256]	^{3}He	g_1, g_2	1.0 to 2.4	1.9×10^{-2} to 1.0	0.019 to 1.2
EG1a (JLab)	[257]	p, d	A_1	1.0 to 2.1	5.9×10^{-2} to 1.0	0.15 to 1.8
RSS (JLab)	[258, 259]	p, d	A_1, A_2	1.0 to 1.9	0.3 to 1.0	0.8 to 1.4
COMPASS (CERN) DIS	[251]	p, d	A_1	7.0 to 15.5	4.6×10^{-3} to 0.6	1.1 to 62.1
COMPASS (CERN) low-Q^2	[280]	p, d	A_1	5.2 to 19.1	4×10^{-5} to 4×10^{-2}	0.001 to 1.
EG1b (JLab)	[260, 261, 262, 263]	p, d	A_1	1.0 to 3.1	2.5×10^{-2} to 1.0	0.05 to 4.2
E99-117 (JLab)	[264]	^{3}He	A_1, A_2	2.0 to 2.5	0.33 to 0.60	2.7 to 4.8
E99-107 (JLab)	[265]	^{3}He	g_1, g_2	2.0 to 2.5	0.16 to 0.20	0.57 to 1.34
E01-012 (JLab)	[266, 267]	^{3}He	g_1, g_2	1.0 to 1.8	0.33 to 1.0	1.2 to 3.3
E97-110 (JLab)	[268]	^{3}He	g_1, g_2	1.0 to 2.6	2.8×10^{-3} to 1.0	0.006 to 0.3
EG4 (JLab)	[269]	p, n	g_1	1.0 to 2.4	7.0×10^{-3} to 1.0	0.003 to 0.84
SANE (JLab)	[271]	p	A_1, A_2	1.4 to 2.8	0.3 to 0.85	2.5 to 6.5
EG1dvcs (JLab)	[270]	p	A_1	1.0 to 3.1	6.9×10^{-2} to 0.63	0.61 to 5.8
E06-014 (JLab)	[272, 273]	^{3}He	g_1, g_2	1.0 to 2.9	0.25 to 1.0	1.9 to 6.9
E06-010/011 (JLab)	[278]	^{3}He	single spin asy.	2.4 to 2.9	0.16 to 0.35	1.4 to 2.7
E07-013 (JLab)	[72]	^{3}He	single spin asy.	1.7 to 2.9	0.16 to 0.65	1.1 to 4.0
E08-027 (JLab)	[309]	p	g_1, g_2	1. to 2.1	3.0×10^{-3} to 1.0	0.02 to 0.4

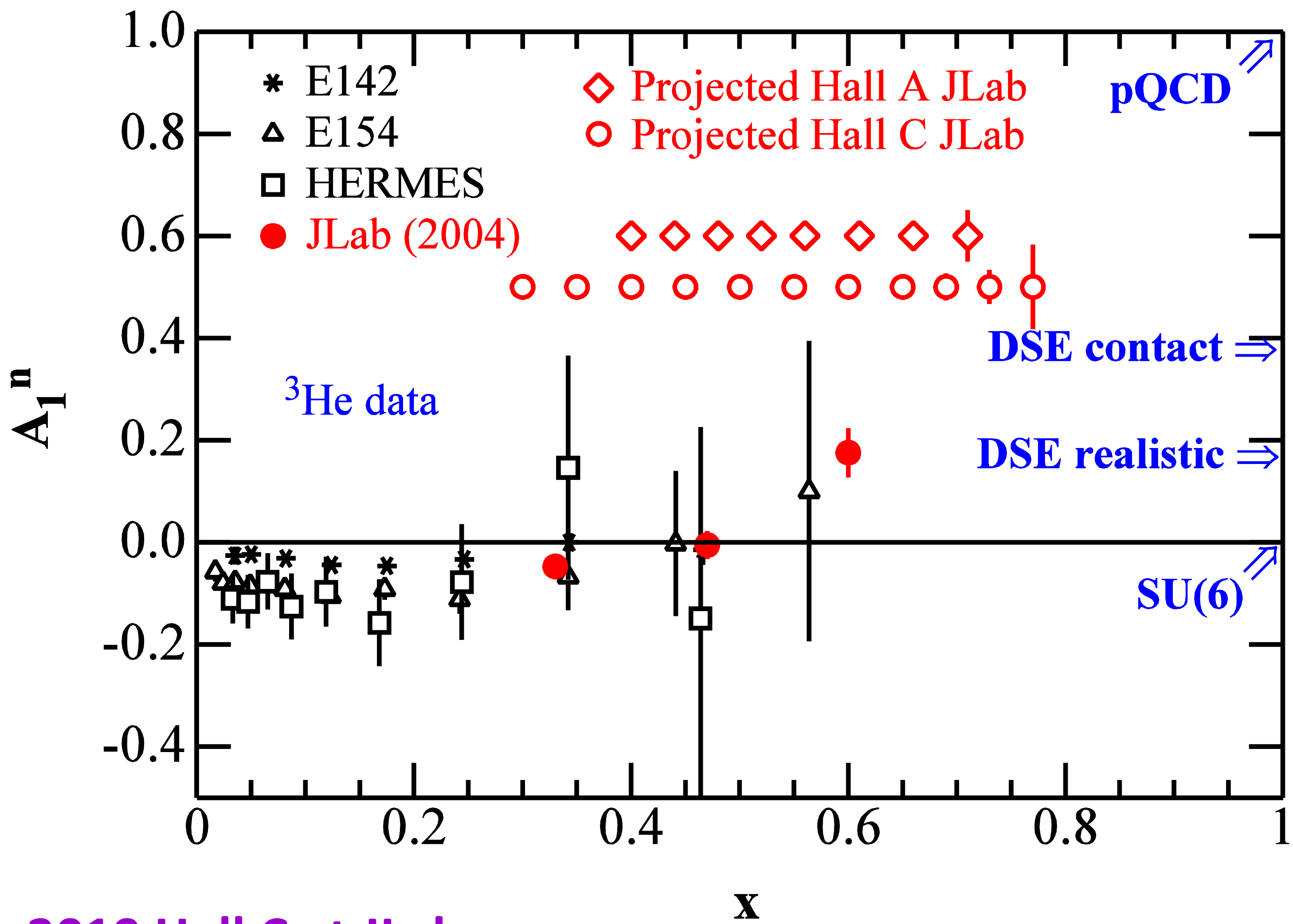
Measurements and Projections for A_1^p



JLab E12-06-109, S. Kuhn, D. Crabb, A. Deur, V. Dharmawardane, T. Forest, K. Griffioen, M. Holtrop, Y. Prok, et al.

C. D. Roberts, R. Holt, S. Schmidt, Phys. Lett. B **727** (2013) pp. 249–254

Measurements and Projections for A_1^n

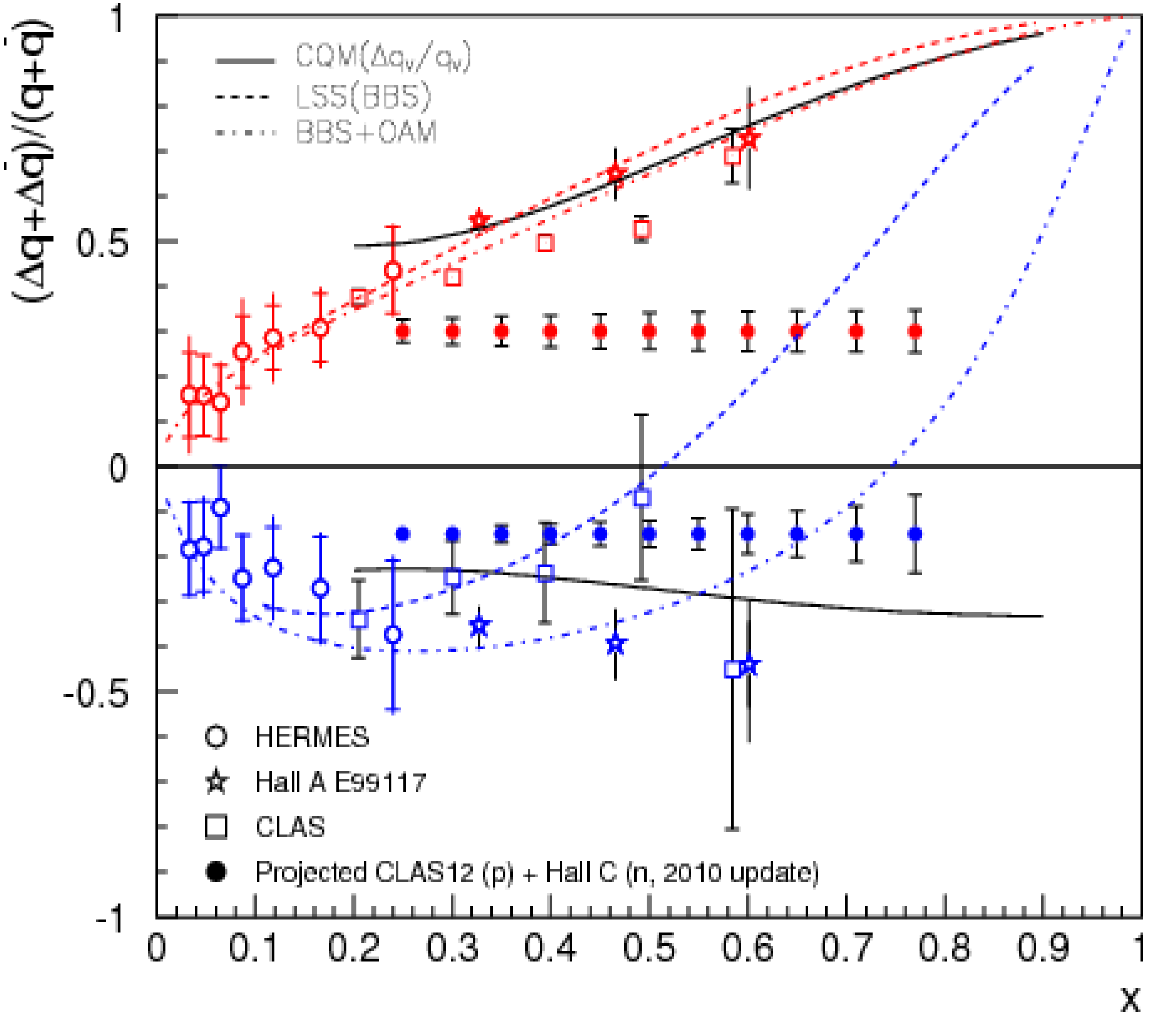


2019 Hall C at JLab

JLab E12-06-110, X. Zheng, J.-P. Chen, Z.-E. Meziani, G. Cates et al.

JLab E12-06-122, B. Wojtsekhowski, G. Cates, N. Liyanage, Z.-E. Meziani, G. Rosner, X. Zheng, et al.

Measurements and Projections for A_1^n



Combined results from Hall C (neutron) and Hall B (proton): polarized pdfs

2019 Hall C at JLab

JLab E12-06-110, X. Zheng, J.-P. Chen, Z.-E. Meziani, G. Cates et al.

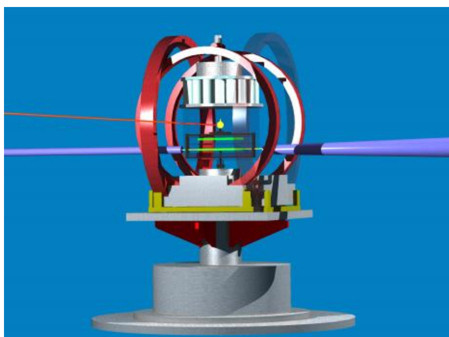
JLab E12-06-122, B. Wojtsekhowski, G. Cates, N. Liyanage, Z.-E. Meziani, G. Rosner, X. Zheng, et al.

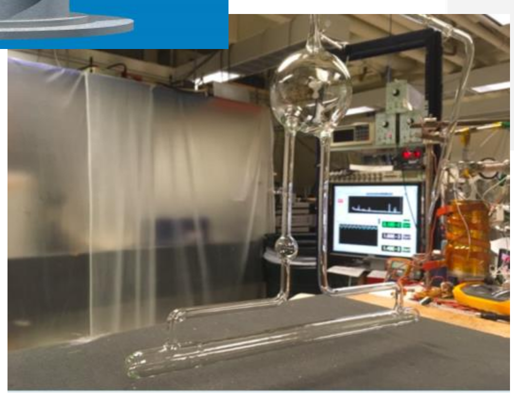
Measuring polarized structure functions: A_1^n

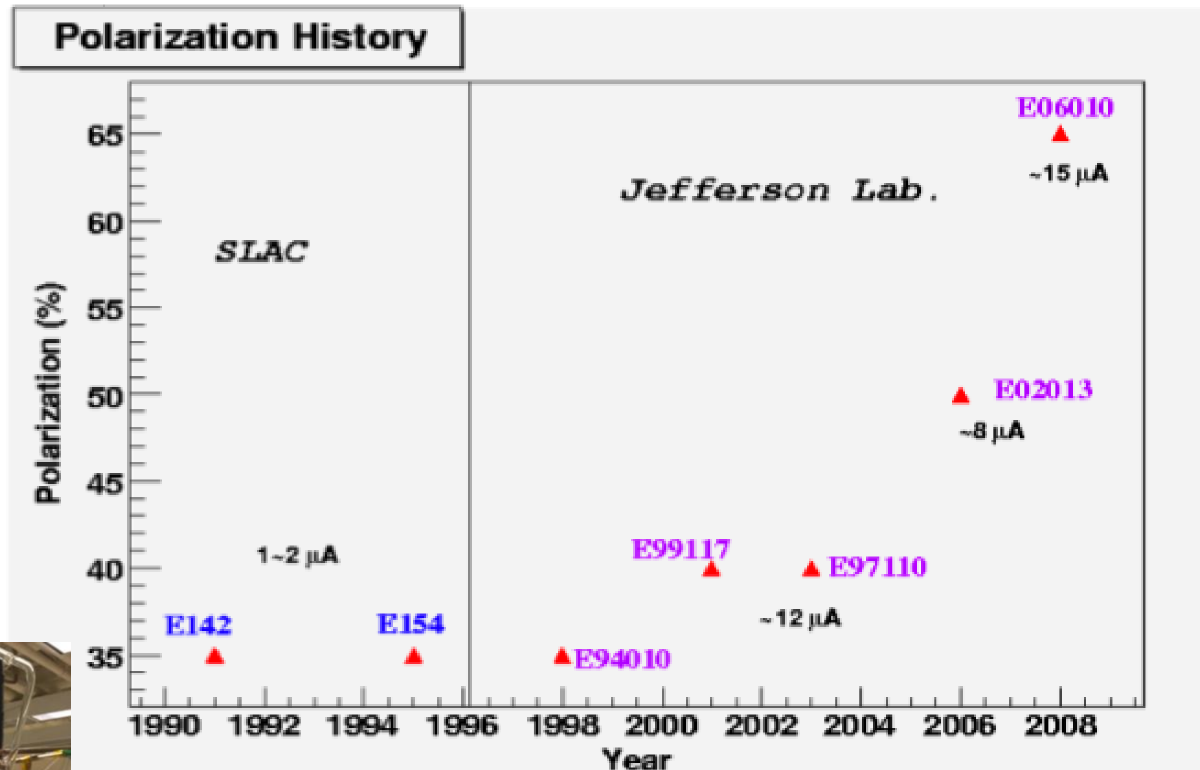
REQUIRES:

- High beam polarization
- High target polarization
- High electron current
- Part of a broad JLab12 program!

^{3}He target





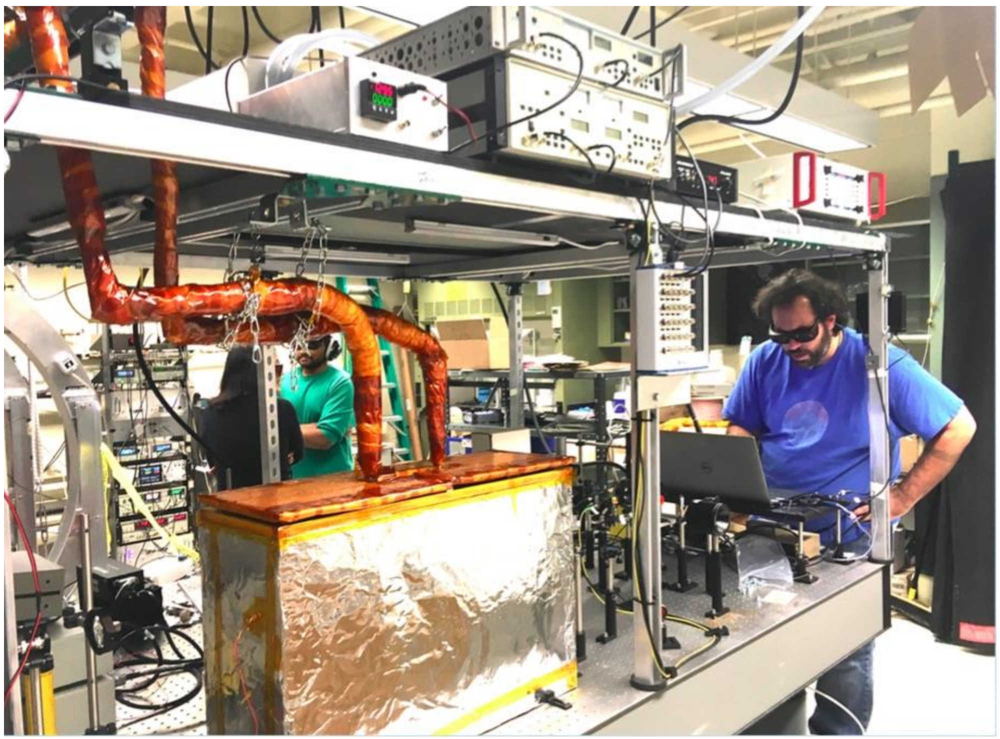


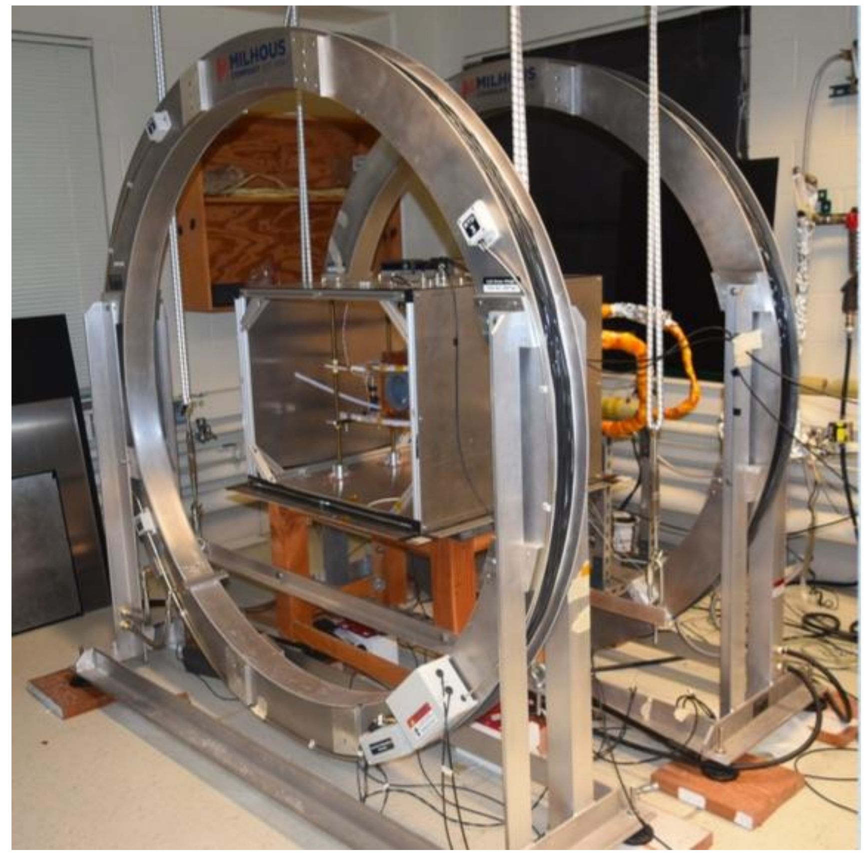
Measuring polarized structure functions: A_1^n

Current status:

- Target cell filling and characterization ongoing
- ***Hall C installation started!***

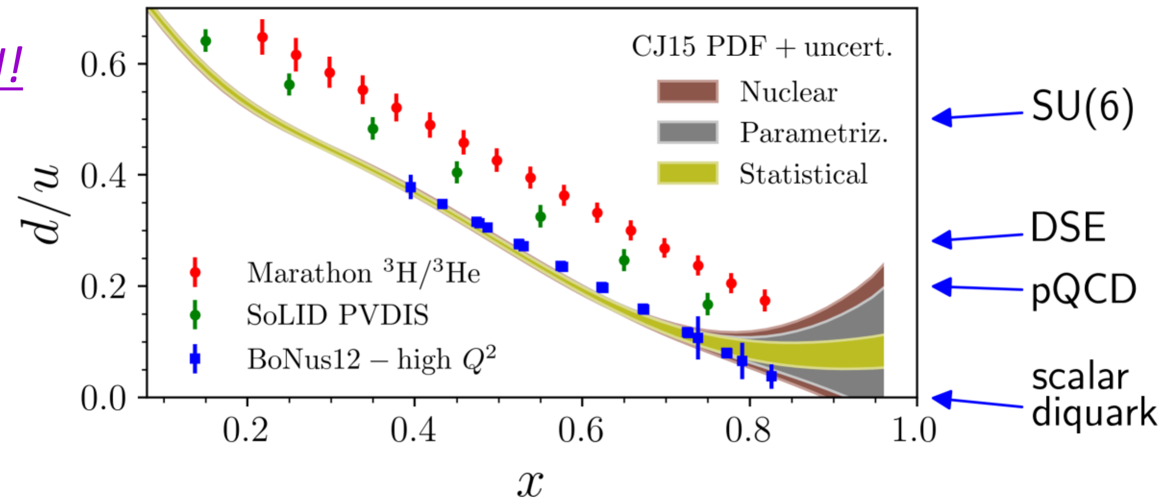
Photos courtesy of
G. Cates, UVA





Probing the Valence Regime: Summary

- New generation of experiments at JLab at 12 GeV will access the regime where valence quarks dominate
- First experiments *HAVE RUN!*
  - Hall C F2p,d
  - Hall A $^3H/^3He$
- More experiments
  - Hall C A1n *FALL 2019*
  - Hall B BONuS *2020*



- More to follow (PVDIS, A1p, g2n….)
- Dedicated theory efforts also underway (CJ, JAM,..)
- Also SeaQuest Drell-Yan experiment E906 at FNAL focused on high x sea
- Also also W-asymmetry data from RHIC

Expect large improvements in our understanding of the valence regime in the next 1-2 years!

- Mesonic Structure (pi,k PDFs)
- Semi-Inclusive DIS
  - 3D Nucleon Structure
  - Generalized PDFs
  - Transvers Momentum Dependent Parton Distributions
- JLab12 **broad** program… dark matter searches (4 and counting), glueballs/exotic searches (Hall D), parity violation to study neutron skin, standard model tests, short range correlations, superfast quarks (x>1), EMC effect, proton radius,……***more!***…
- Proposed Electron Ion Collider

Thank You!