Parity-Violating Duality, and More

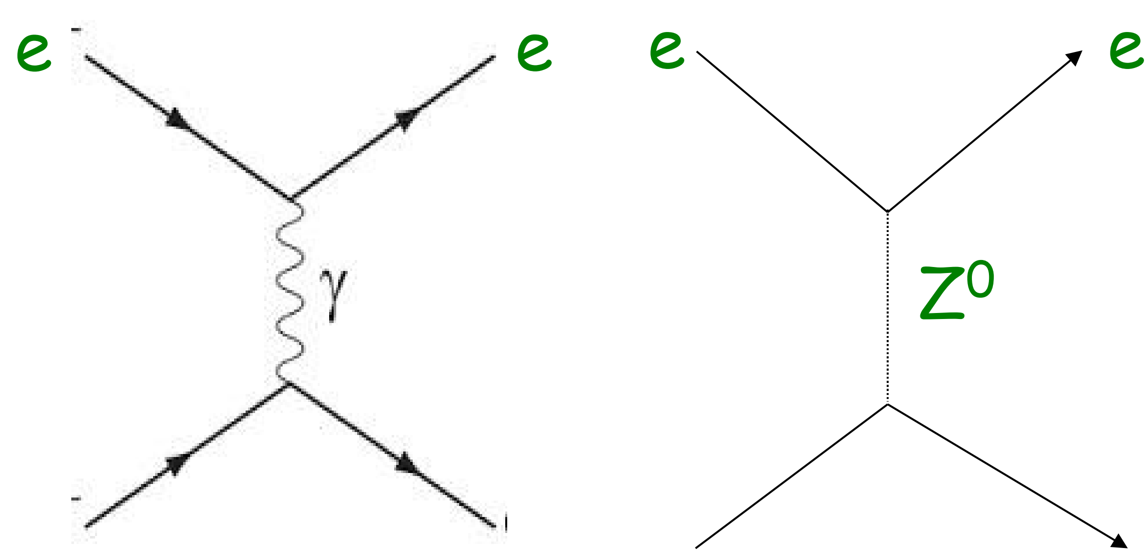
Xiaochao Zheng (Univ. of Virginia)

September 25th, 2018

- Parity Violating DIS and electron-quark effective couplings
- The 6 GeV PVDIS experiment and resonance results – duality in EW sector?
- Resonance coverage by SoLID
- Duality in Spin Asymmetry A_1^n

Parity-Violating Electron Scattering

- To study nucleon structure not accessible in electromagnetic interaction:
  - elastic PVES: nucleon strange form factors; "neutron skin" in heavy nucleus
- To test the electroweak Standard Model:
  - Moller – E158
  - Qweak
  - PVDIS

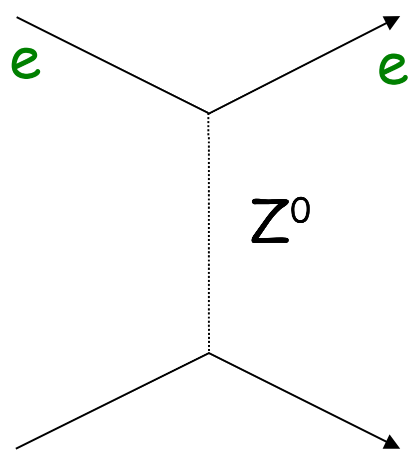


Parity Violation in the Standard Model

- Unlike electric charge, need two charges (couplings) for weak interaction: g_L, g_R

  or "vector" and "axial" weak charges:
  - $g_V \sim (g_L + g_R)$ $g_A \sim (g_L - g_R)$

$$-i\frac{g_Z}{2}\gamma^\mu[g_V^e - g_A^e\gamma^5]$$



fermions	$g_A^f = I_3$	$g_V^f = I_3 - 2Q\sin^2\theta_W$
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
e-, μ-	$-\frac{1}{2}$	$-\frac{1}{2} + 2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W$

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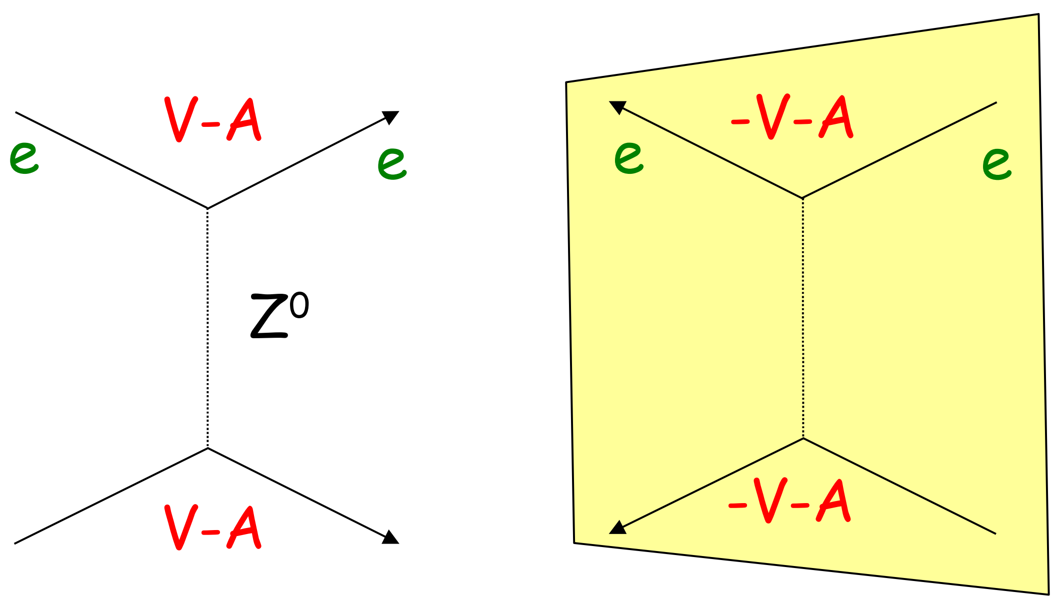
- PVES asymmetry comes from V(e)xA(targ) and A(e)xV(targ)



Effective Couplings in the Standard Model

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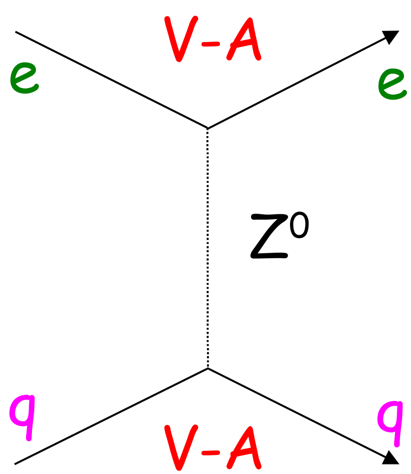
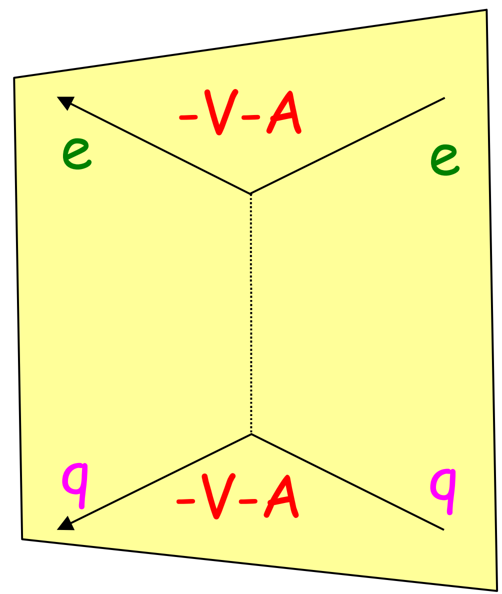
- PVDIS asymmetry comes from:

$$\boxed{C_{1q} \equiv 2 g_A^e g_V^q, \quad C_{2q} \equiv 2 g_V^e g_A^q}$$





"electron-quark effective couplings"

Effective Couplings and New Contact Interactions

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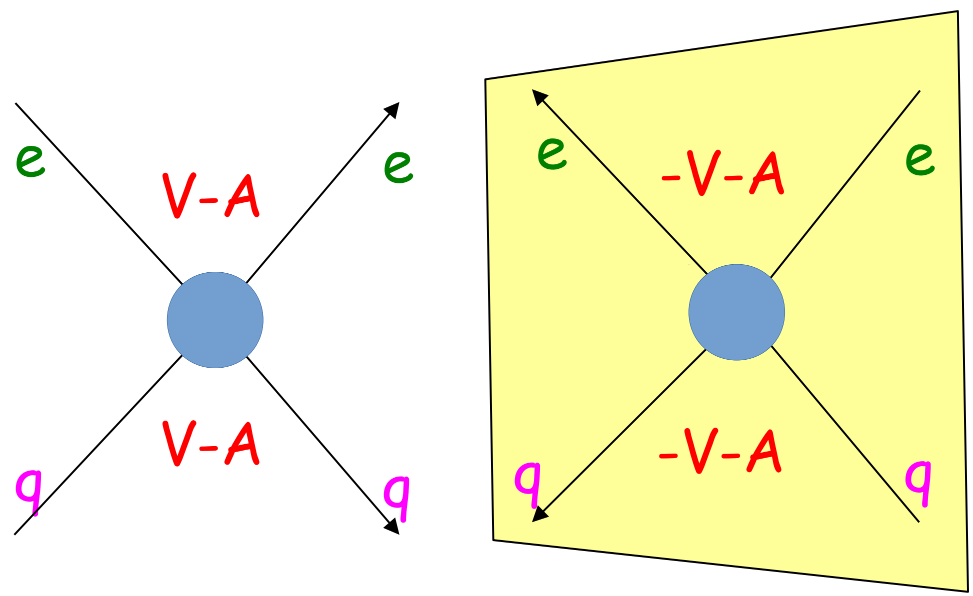

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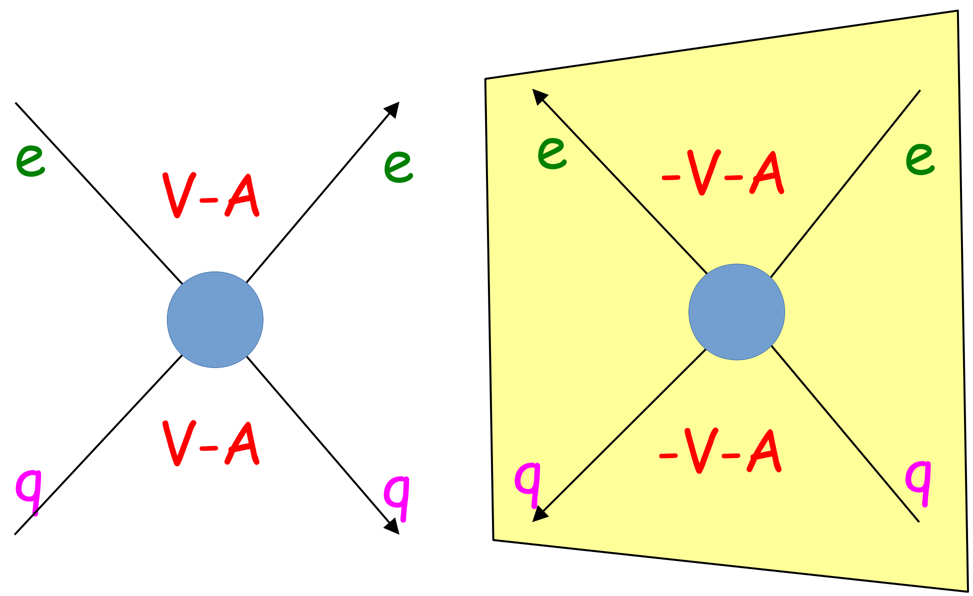

"electron-quark effective couplings"

$$\boxed{C_{1q} = g_{AV}^{eq},\ C_{2q} = g_{VA}^{eq}}$$

Erler&Su, Prog. Part. Nucl. Phys. 71, 119 (2013)

Formalism for Parity Violation in DIS

$$A_{PV}=\frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x)+Y(y)b(x)\right]$$

$$x\equiv x_{Bjorken} \qquad y\equiv 1-E'/E$$

$$q_i^+(x)\equiv q_i(x)+\bar{q}_i(x)$$

$$q_i^-(x)=q_i^V(x)\equiv q_i(x)-\bar{q}_i(x)$$

$$a(x)=\frac{1}{2}g_A^e\frac{F_1^{\gamma Z}}{F_1^{\gamma}}=\frac{1}{2}\frac{\sum_i C_{1i}Q_i q_i^+(x)}{\sum_i Q_i^2 q_i^+(x)}$$

$$b(x)=g_V^e\frac{F_3^{\gamma Z}}{F_1^{\gamma}}=\frac{1}{2}\frac{\sum_i C_{2i}Q_i q_i^-(x)}{\sum_i Q_i^2 q_i^+(x)}$$

For an isoscalar target (^{2}H), structure functions largely simplifies:

$$a(x)=\frac{3}{10}\left(2C_{1u}-C_{1d}\right)\left(1+\frac{0.6\,s^+}{u^+ +d^+}\right)$$

$$b(x)=\frac{3}{10}\left(2C_{2u}-C_{2d}\right)\left(\frac{u_V+d_V}{u^+ +d^+}\right)$$

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0

$$b(x) = \frac{3}{10}\left(2C_{2u} - C_{2d}\right)\left(\frac{u_V + d_V}{u^+ + d^+}\right)$$

1

If neglecting sea quarks, asymmetry is no longer sensitive to PDFs → "static limit"

PVDIS at 6 GeV (JLab E08-011)

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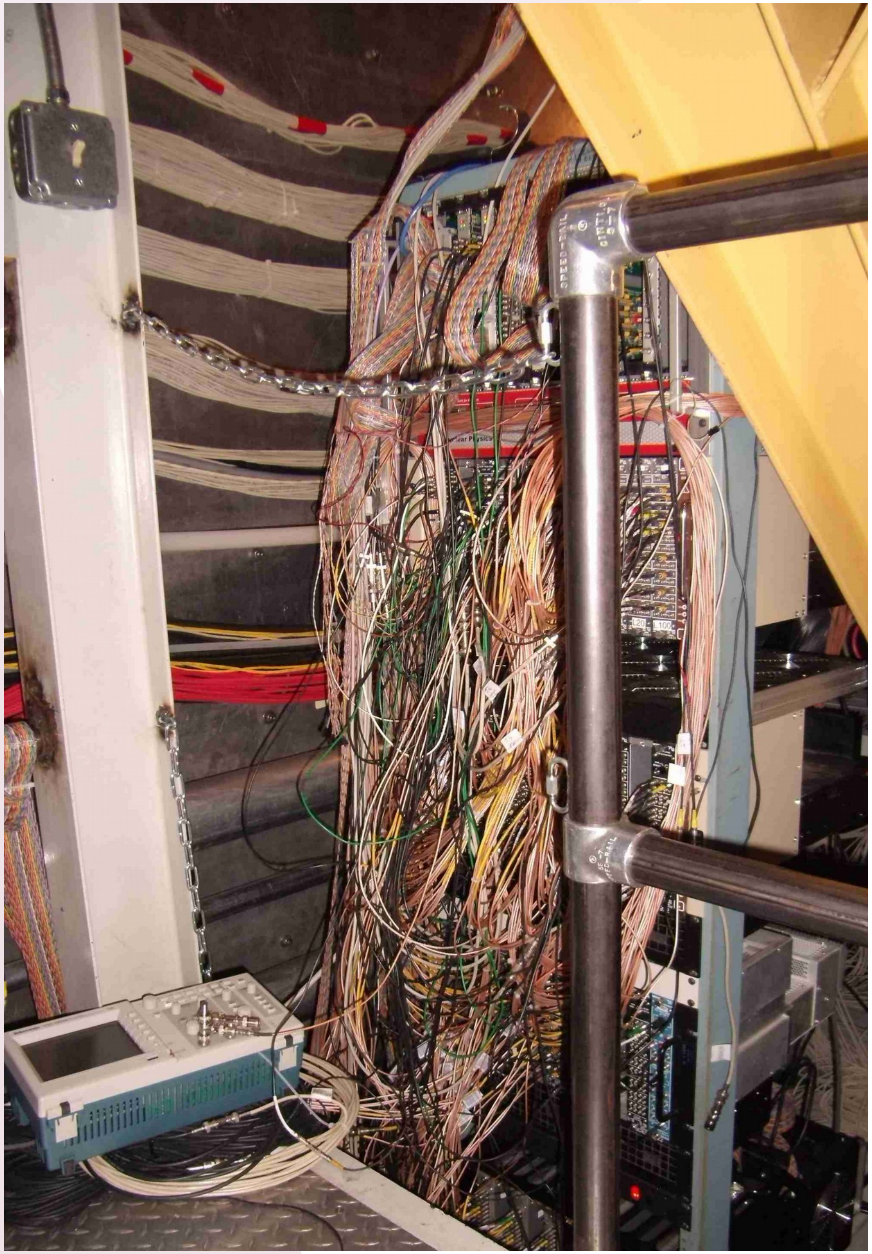


- Ran in Oct-Dec 2009, 100uA, 90% polarized electron beam, 20-cm liquid deuterium target
- Two High Resolution Spectrometers (HRS pair) detected electrons in the inclusive mode at DIS Q^2=1.1 and 1.9 GeV^2, and five resonance kinematics.
- Scaler-based fast counting DAQ specifically built for the 500kHz DIS rates w/ 10^4 pion rejection.
- Spokespeople: R. Michaels, P. Reimer, X. Z.
- Students:Xiaoyan Deng, Kai Pan Diancheng Wang.
- postdoc: Ramesh Subedi

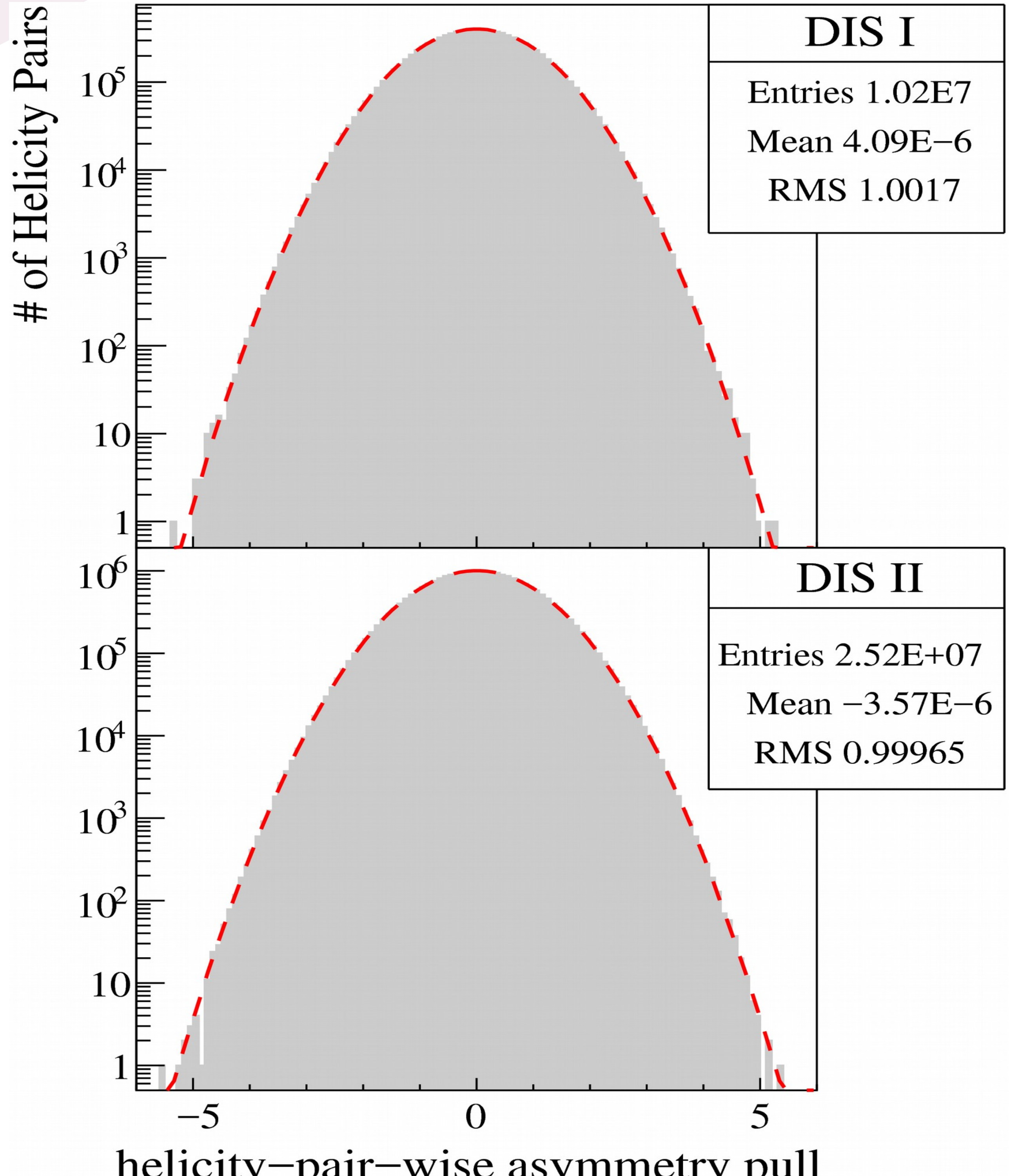
E08-011 Kinematics

Kine#	HRS	E_b (GeV)	θ_0(deg)	E'_0 (GeV)	R_e(kHz)	R_{π^-}/R_e
DIS#1	Left	6.067	12.9	3.66	$\approx$210	$\approx$0.5
DIS#2	Left & Right	6.067	20.0	2.63	$\approx$18	$\approx$3.3
RES I	Left	4.867	12.9	4.0	$\approx$300	$< \approx 0.25$
RES II	Left	4.867	12.9	3.55	$\approx$600	$< \approx 0.25$
RES III	Right	4.867	12.9	3.1	$\approx$400	$< \approx 0.4$
RES IV	Left	6.067	15	3.66	$\approx$80	$< \approx 0.6$
RES V	Left	6.067	14	3.66	$\approx$130	$< \approx 0.7$

Data Quality

(pair-wise asymmetry pull plots):

$$pull = \frac{A_i - \langle A \rangle}{\Delta A_i}$$



DIS Asymmetry Results and Compare to SM

$$A^{phys}_{Q^2=1.085,\,x=0.241} = -91.10 \pm 3.11 \pm 2.97\ ppm$$

$$A^{SM} = (1.156 \times 10^{-4})\left[(2C_{1u} - C_{1d}) + 0.348(2C_{2u} - C_{2d})\right] = -87.7\ ppm$$

uncertainty due to PDF: 0.5% 5%

- uncertainty due to HT: 0.5%/Q^2, 0.7ppm

$$A^{phys}_{Q^2=1.901,\,x=0.295} = -160.80 \pm 6.39 \pm 3.12\ ppm$$

$$A^{SM} = (2.022 \times 10^{-4})\left[(2C_{1u} - C_{1d}) + 0.594(2C_{2u} - C_{2d})\right] = -158.9\ ppm$$

uncertainty due to PDF: 0.5% 5%

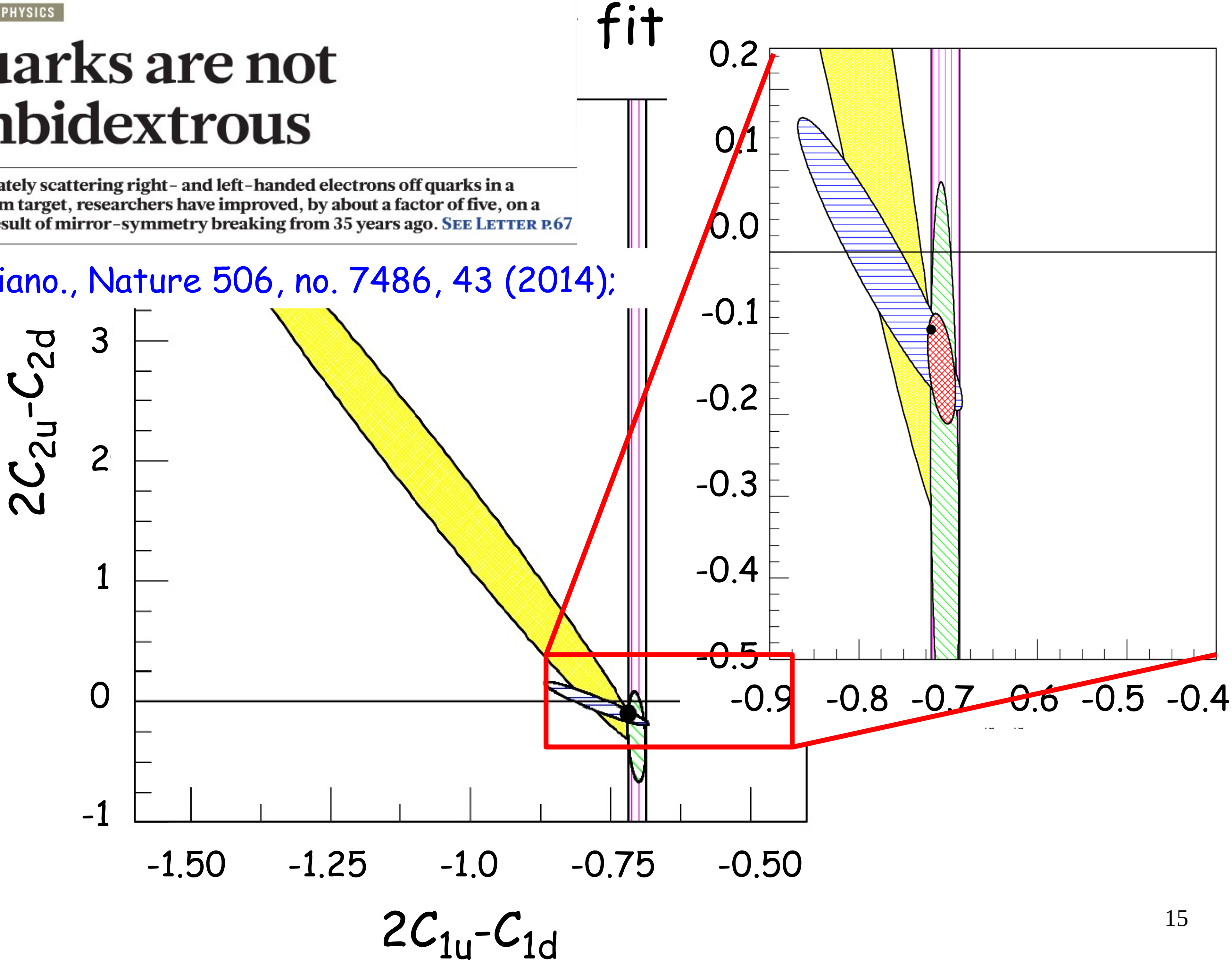
- uncertainty due to HT: 0.5%/Q^2, 1.2ppm

PARTICLE PHYSICS

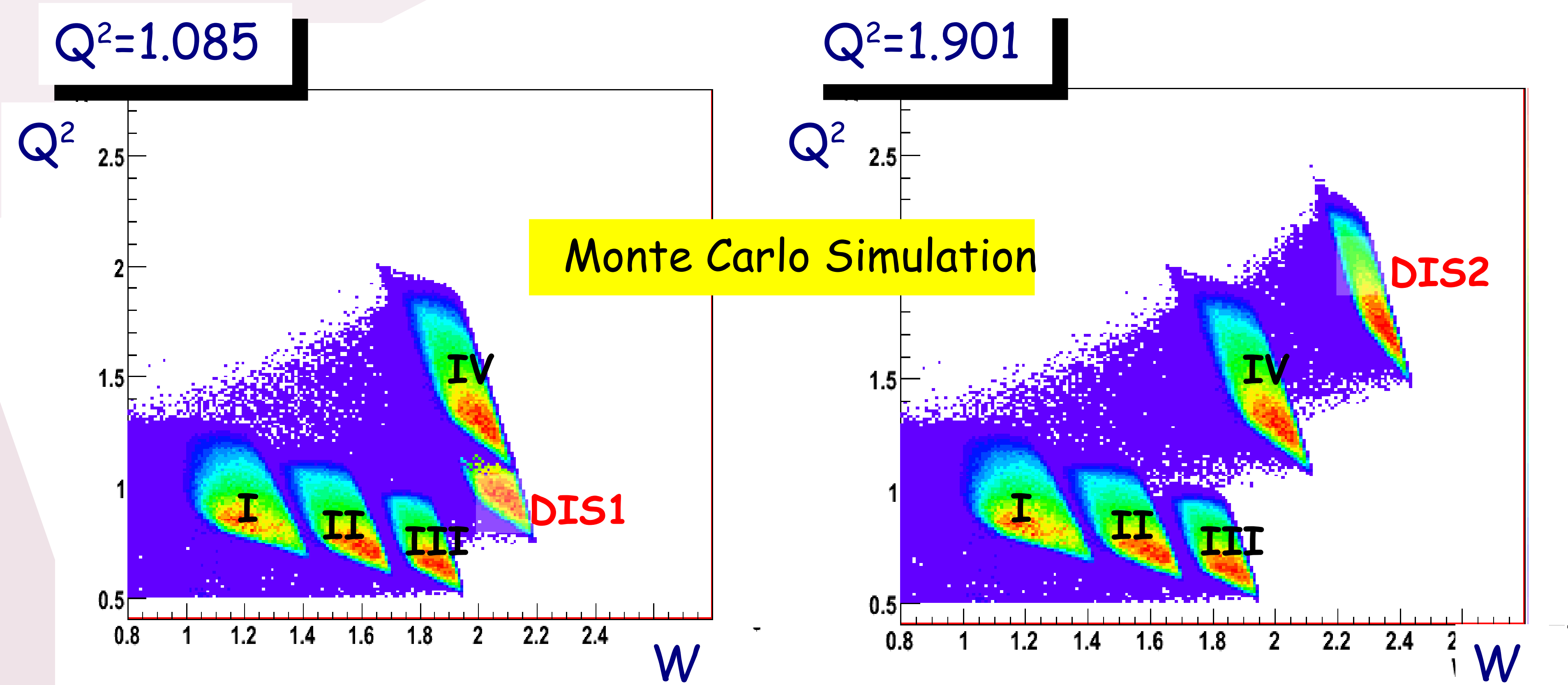
Quarks are not ambidextrous

By separately scattering right- and left-handed electrons off quarks in a deuterium target, researchers have improved, by about a factor of five, on a classic result of mirror-symmetry breaking from 35 years ago. SEE LETTER P.67

Marciano., Nature 506, no. 7486, 43 (2014);



Resonance Background Data Coverage



- Four setting covered the full resonance region;
- "Grouping" of lead glass blocks allowed a reasonable study of the W-dependence;

Resonance PV Asymmetry Results

Kinematics

	RES I	RES II	RES III	RES IV	RES V
E_b (GeV)	4.867	4.867	4.867	6.067	6.067
θ_0	12.9°	12.9°	12.9°	15.0°	14.0°
E'_0 (GeV)	4.00	3.66	3.10	3.66	3.66
$\langle Q^2\rangle_{\mathtt{data}}$ [(GeV/c)^2]	0.950	0.831	0.757	1.472	1.278
$\langle x\rangle_{\mathtt{data}}$	0.571	0.335	0.228	0.326	0.283
$\langle W\rangle_{\mathtt{data}}$ (GeV)	1.263	1.591	1.857	1.981	2.030

Asymmetry Results

$A^{\rm phys}$ (ppm)	-68.62	-73.75	-61.49	-118.97	-77.50
(stat.)	± 8.43	± 6.84	± 5.05	± 17.45	± 24.27
(syst.)	± 3.26	± 2.78	± 2.06	± 5.54	± 3.84
(total)	± 9.04	± 7.38	± 5.46	± 18.31	± 24.57

Wang et al., PRL 111, 082501 (2013);

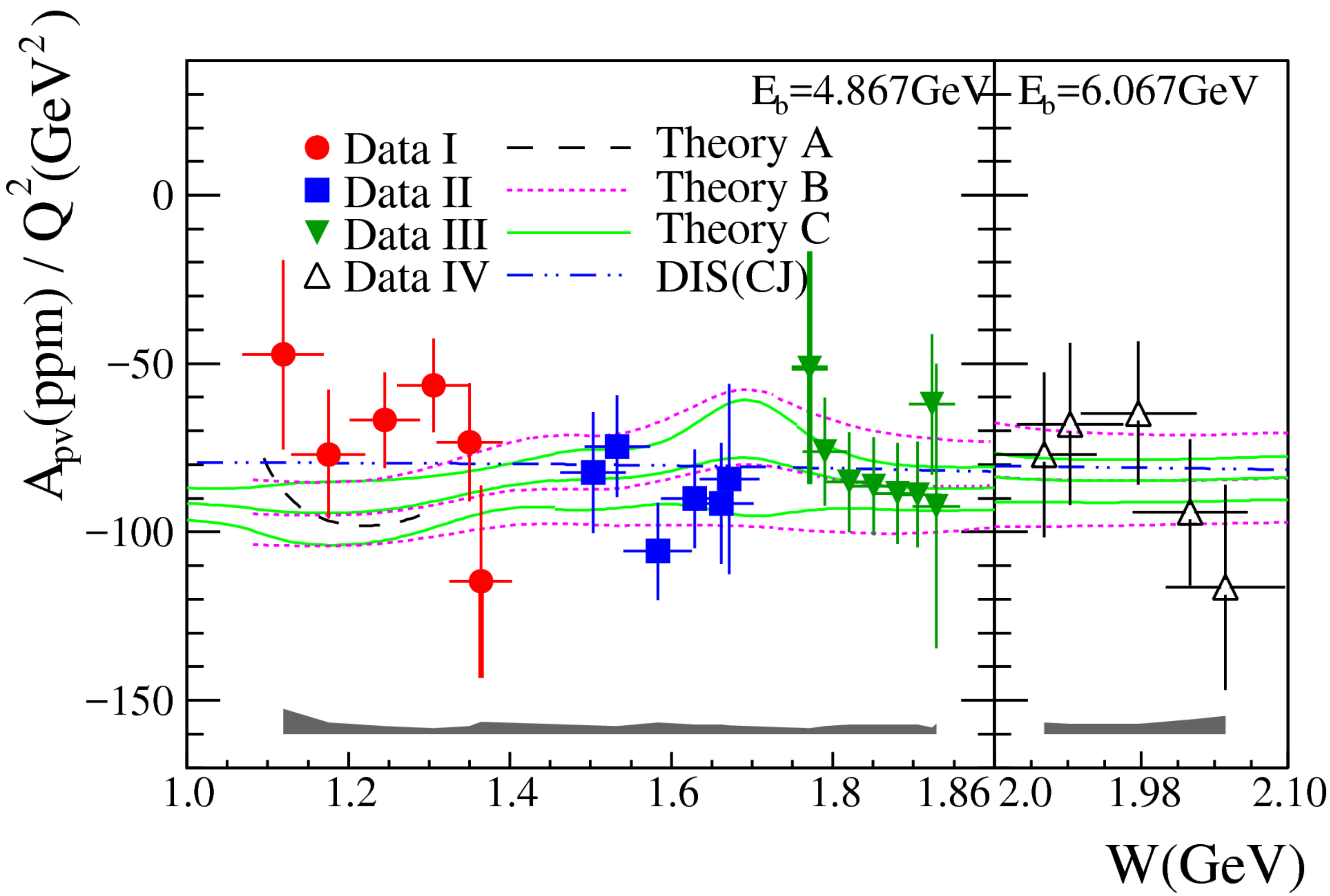
Resonance PV Asymmetry Results

Theory A: Matsui, Sato, Lee, PRC72,025204(2005)

Theory B: Gorchtein, Horowitz, Ramsey-Musolf, PRC84,015502(2011)

Theory C: Hall, Blunden, Melnitchouk, Thomas, Young, PRD88, 013011 (2013)

DIS (CJ): using DIS PDFs (and ignored the W and Q2 limits of the code)



Wang et al., PRL 111, 082501 (2013);

Do we expect "duality" in the parity-violating asymmetry?

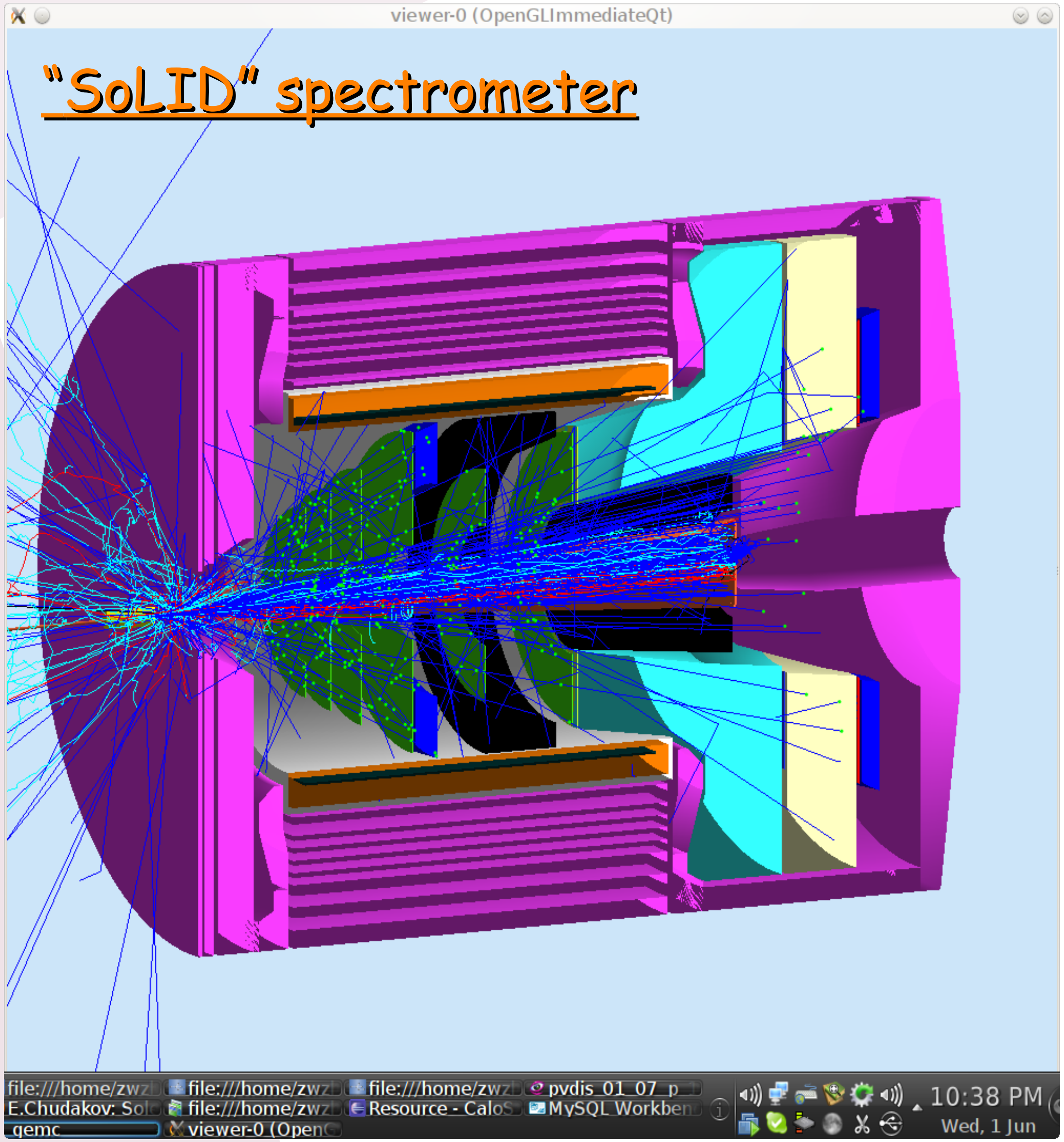
(1) In some sense we do expect the asymmetry to not vary with W, because of

(a) the "static" limit, that the asymmetry is not sensitive to structure functions, to start with
(b) cancellation of the resonance structure between gamma-Z and gamma structure functions

It also means:
(c) We will not see the same charming "resonance structure at low Q2 reduces to smooth curves at high Q2" as for unpolarized and polarized structure functions
(d) DIS calculation is probably good enough if resonance PV is a background or only needed for radiative corrections.

(Note: the RES-parity proposal was proposed and declined twice.)

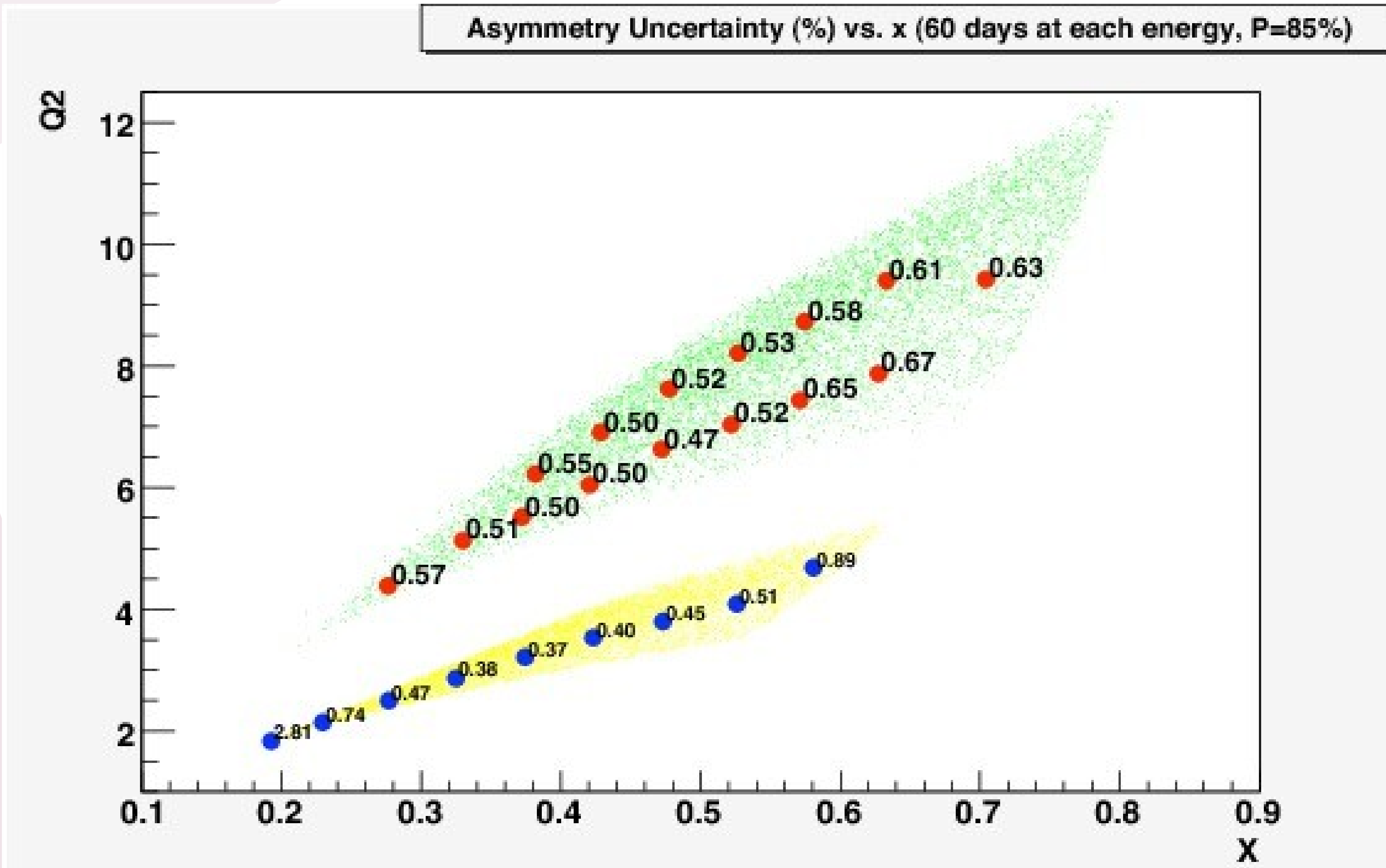
Coherent PVDIS Program with SoLID @ 11 GeV



SoLID Physics topics:

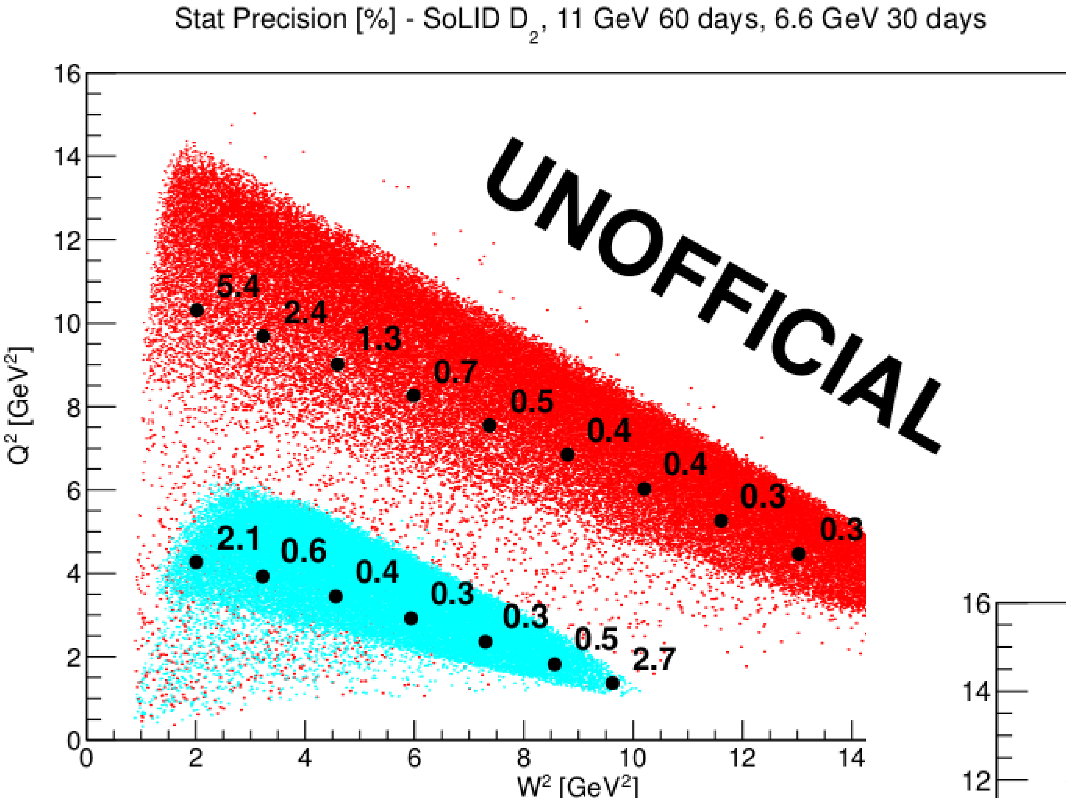
- PVDIS deuteron (180 days) – C_2, $\sin^2\theta_W$, CSV, diquarks,
- PVDIS proton (90 days) – d/u
- PV with polarized ^{3}He (LOI)
- SIDIS
- J/ψ

Coherent PVDIS Program with SoLID @ 11 GeV



Goal on C_{2q}: one order of magnitude improvement over 6 GeV

Data in the resonance region (W<2) with no addition beam time



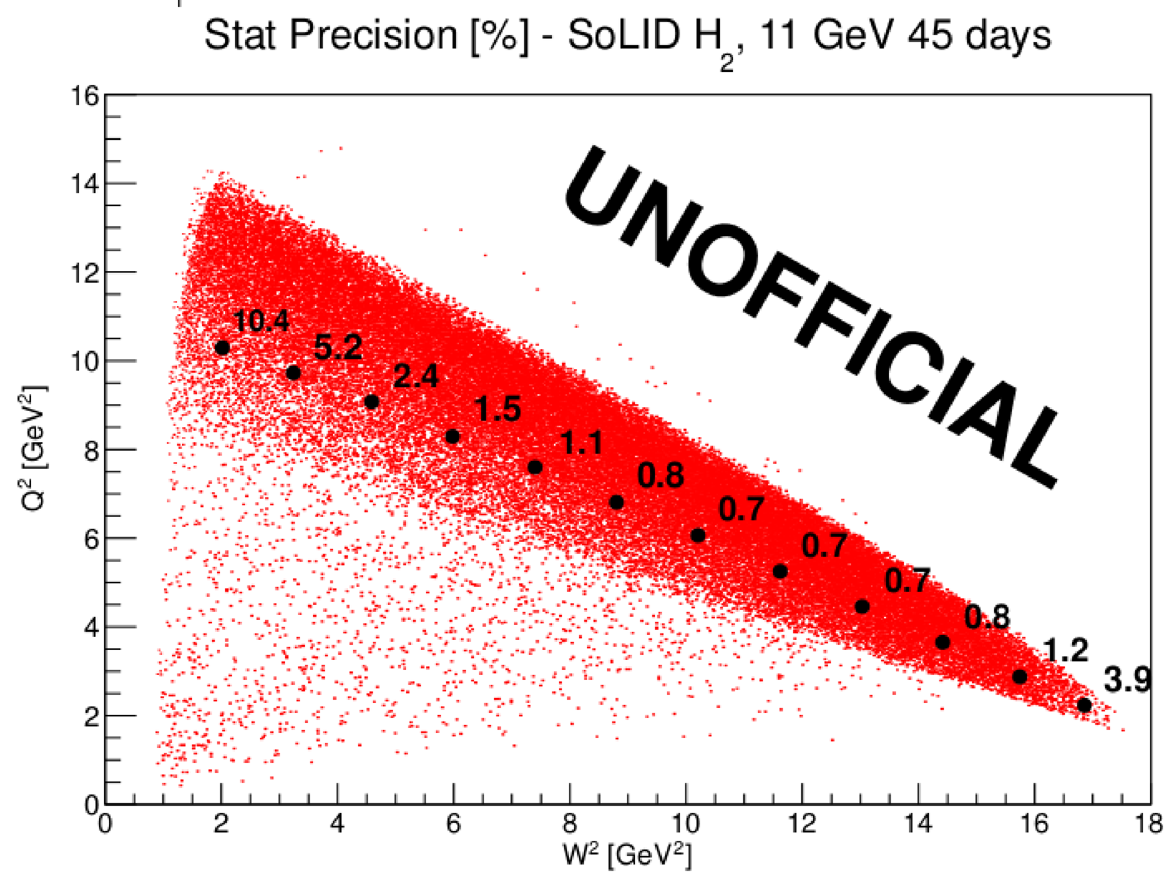
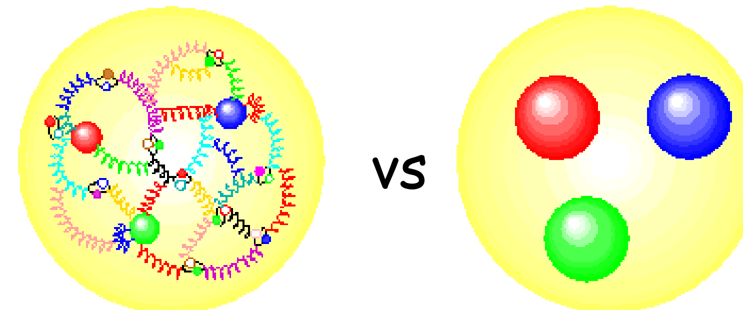


Figure credit: S. Riordan

Nucleon (spin) Structure at High x_{Bj}

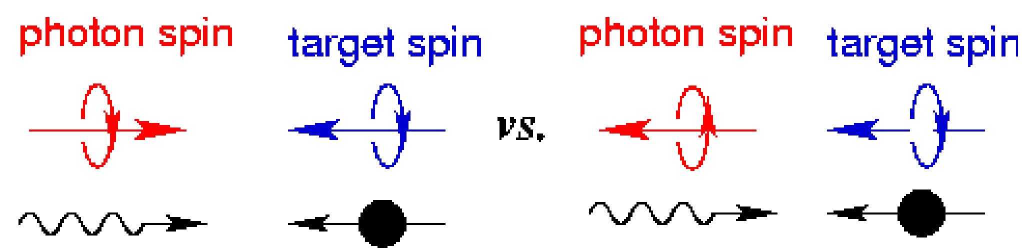
- We need structure function measurements for which QCD can make absolute predictions!



The far valence domain (x>0.5)

- is a clean place to make predictions for the nucleon structure functions (or their ratios)

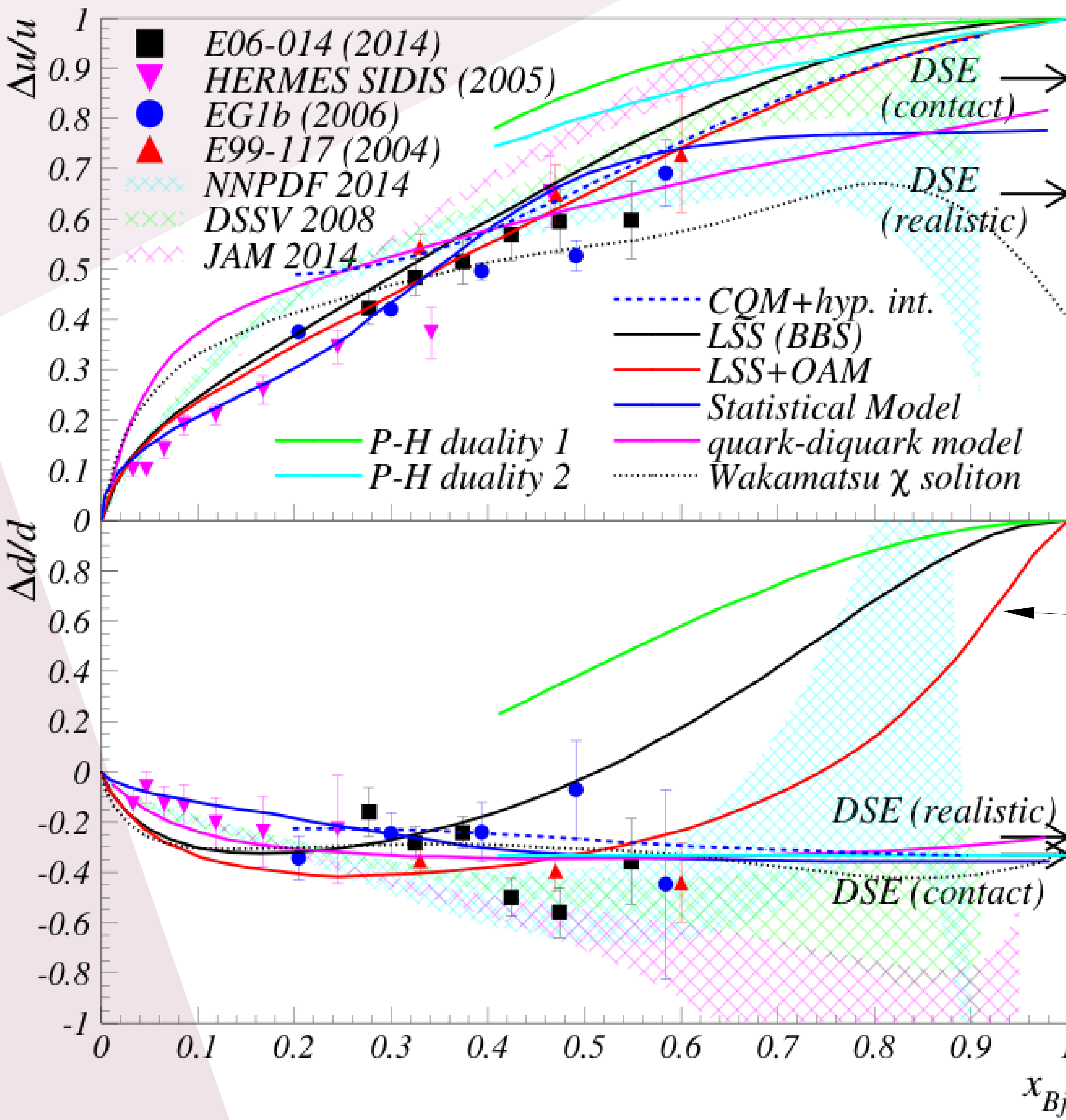
- F_2^p/F_2^n and d/u
- A_1^p, A_1^n, or $\Delta u/u$ and $\Delta d/d$



$$A_1 = \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}}$$

$$A_1 = \frac{g_1-\gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1}$$ at large Q^2

$$\gamma^2 = \frac{Q^2}{\nu^2} = \frac{4M^2x^2}{Q^2}$$



A non-perturbative, (low-energy) effective theory. Non-pointlike diquark correlations as a result of dynamical chiral symmetry breaking. Predictions used diquark probabilities extracted from nucleon elastic form factors

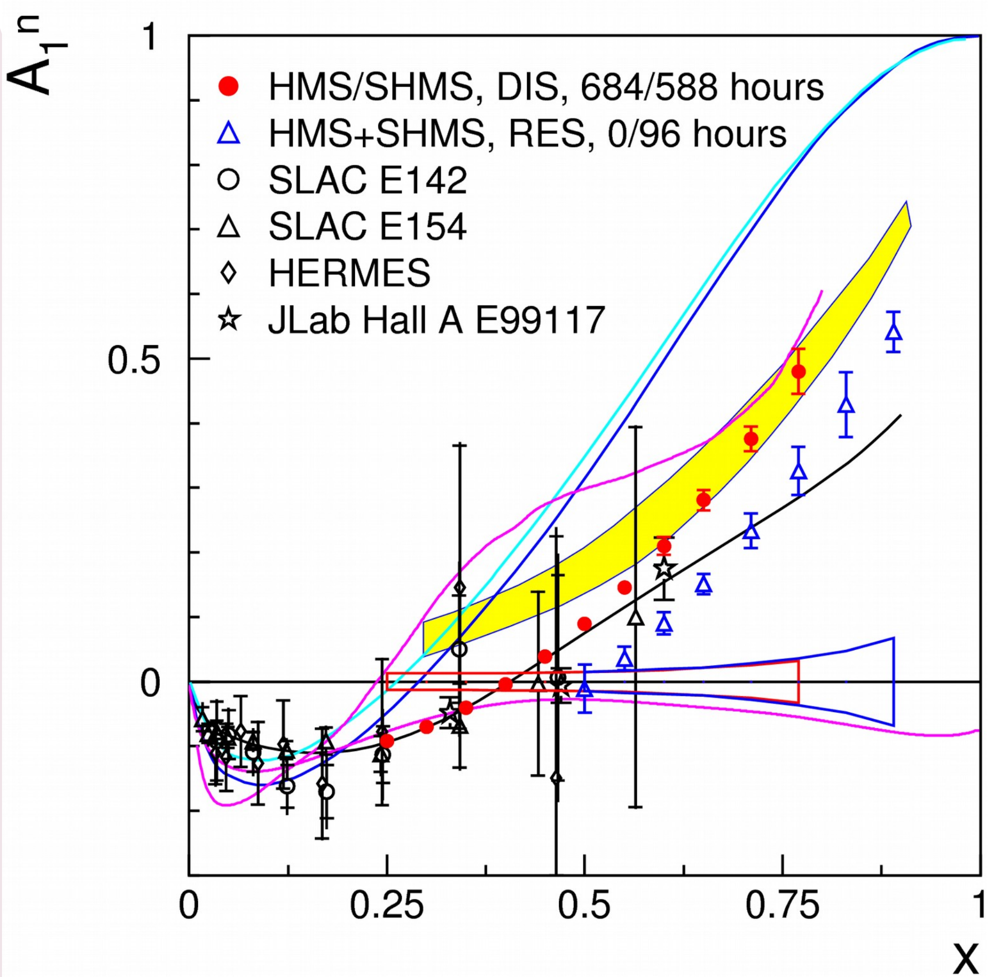
pQCD: the struck quark is free + constraint on the gluon exchange within the diquark → the struck quark must carry nucleon's helicity at x→1

applies to SU(6) wavefunction

now added quark OAM, but Δd/d still must be 1 at x=1

Expected Results on Spin Asymmetries:

Hall A with 36 days



CLAS12 with 80 days

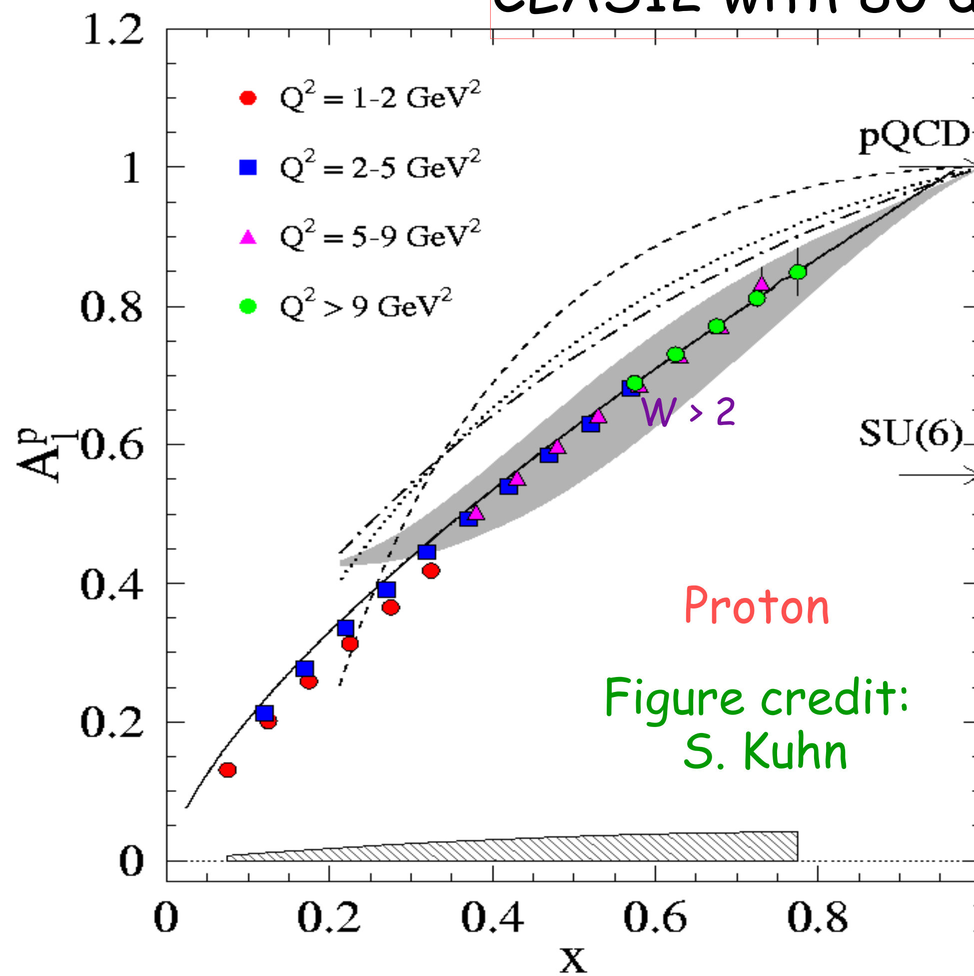
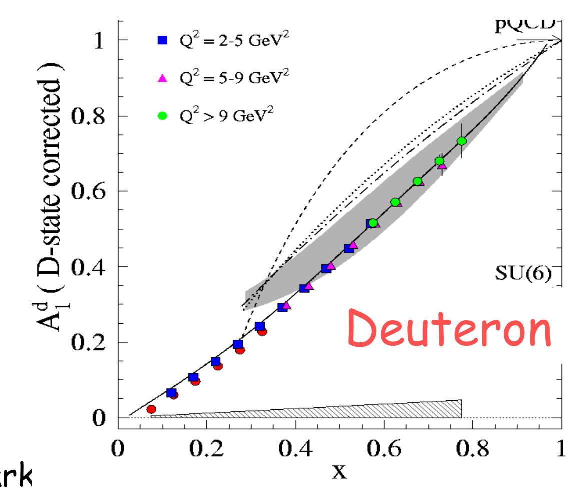
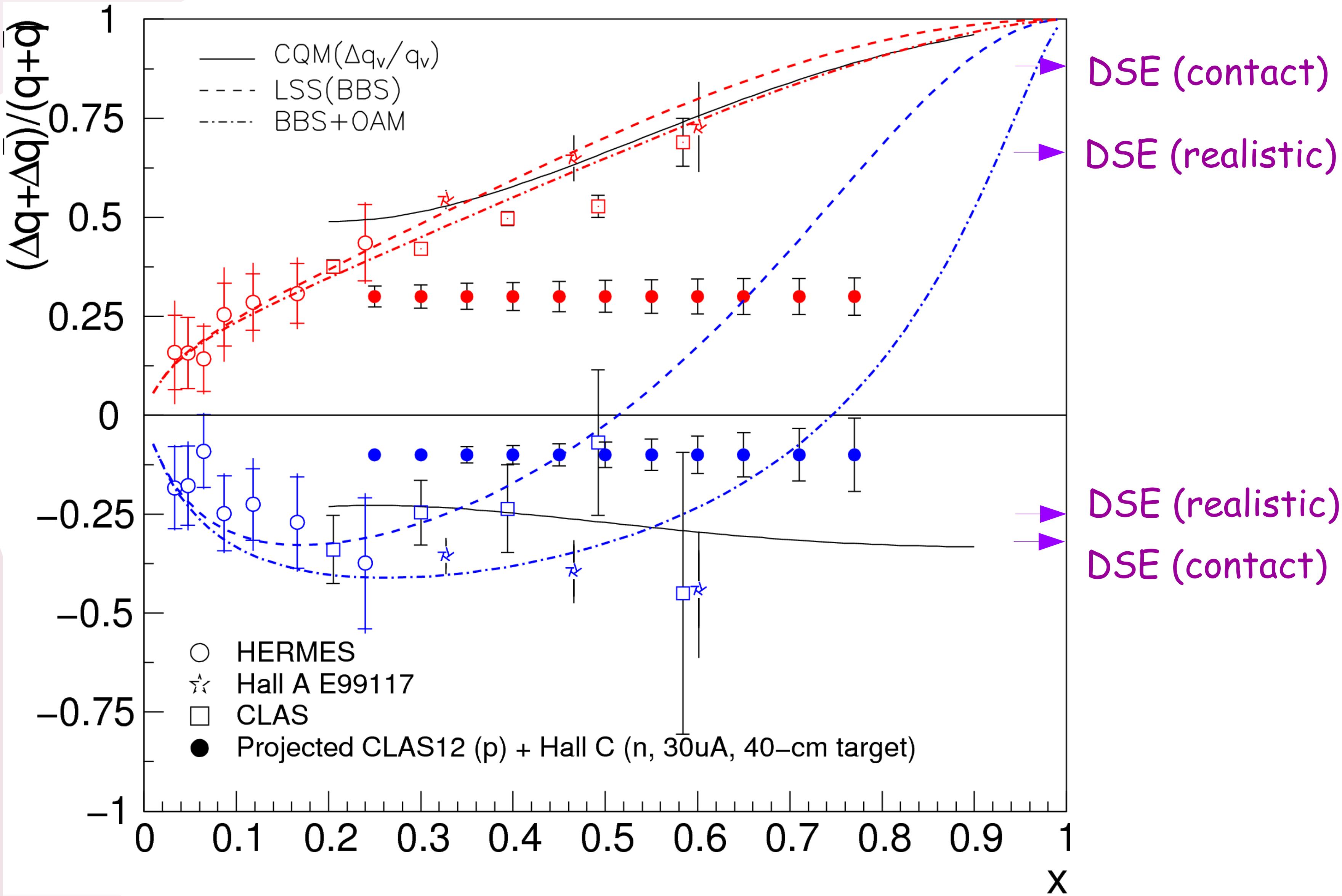


Figure credit:
S. Kuhn



Extracting Δq/q from both proton and neutron (^{3}He) data



We all love the $x \rightarrow 1$ limit. However, it is a limit that we cannot attain, both theoretically and experimentally.

- If duality works, can we reach the limit using duality?
- $x=1$ is elastic scattering, does it mean we can extract $\Delta u/u$ and $\Delta d/d$ using elastic data? And how?

Summary and Perspectives

The 6 GeV PVDIS experiment from JLab:

- Improved world data on the eq VA effective coupling term $2C_{2u}-C_{2d}$ by factor of five;
- Resonance PV asymmetries seem to indicate duality in the electroweak observables, but see slide for possible detailed reasoning.

"New construction" experiments at JLab 12 GeV:

- PVDIS @ 11 GeV (SoLID) will improve C_{2q} by another order of magnitude, and will provide reasonable data in the resonance region (both proton and deuteron)

Can we use duality to reach the x=1 limit?