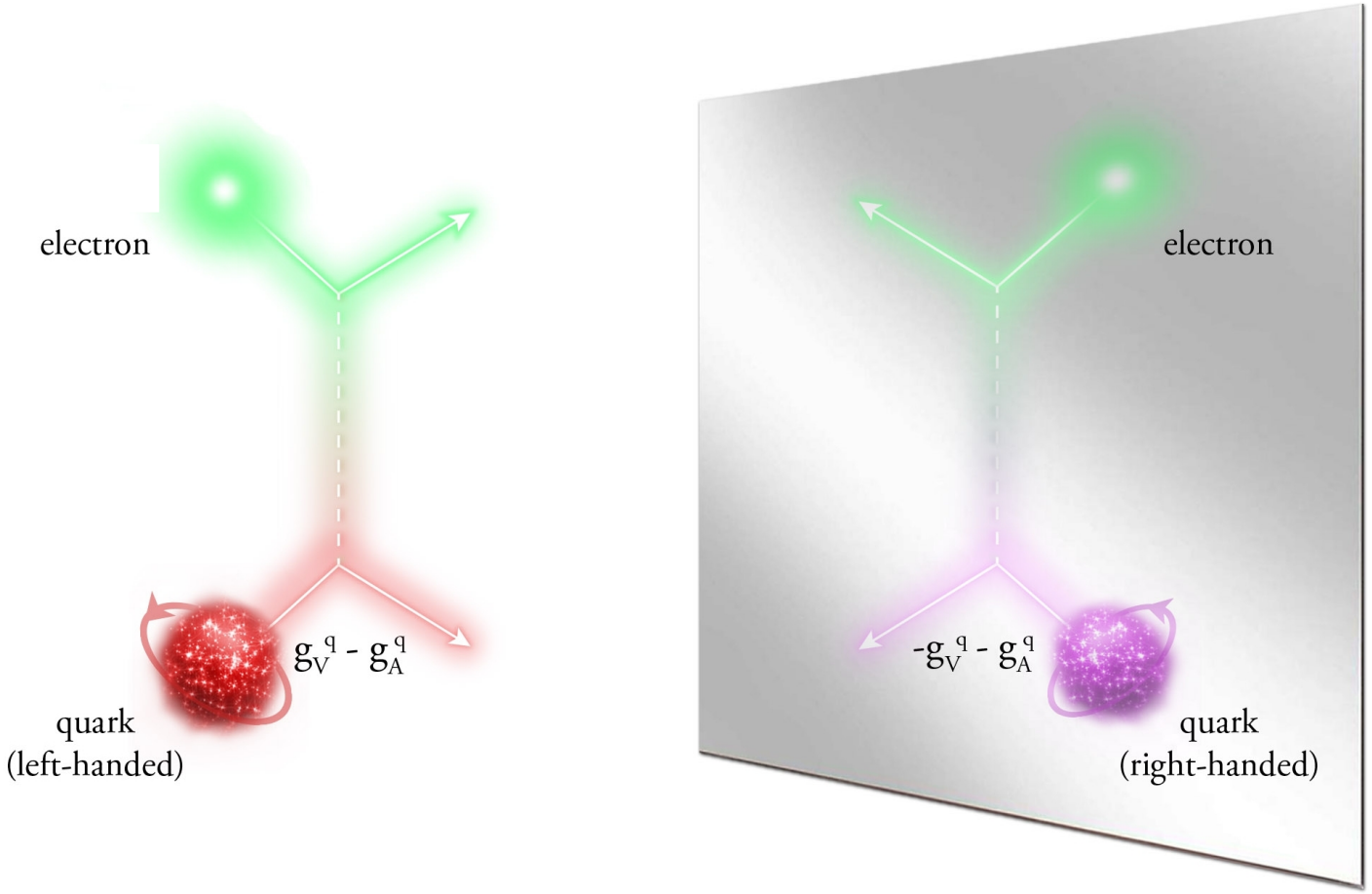
Previous PVDIS Experiments



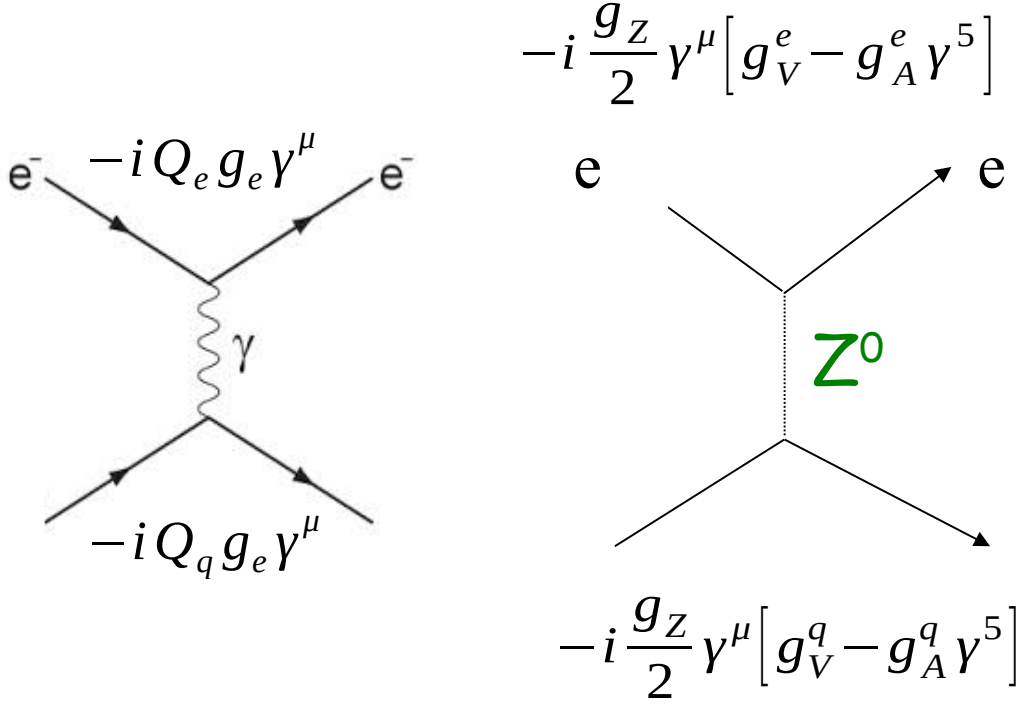
Precision Physics with MOLLER Workshop

November 5-6, 2026

Xiaochao Zheng

University of Virginia

Parity Violation in Deep Inelastic Scattering



At $Q^2 \ll M_Z^2$

$$A_{PV} \approx \frac{Q^2}{M_Z^2} \approx 90 \text{ ppm/GeV}^2 \times Q^2$$

fermion	Q_f	c_A^f	c_V^f
ν_e, ν_μ, ν_τ	0	$\frac{1}{2}$	$\frac{1}{2}$
e^-, μ^-, τ^-	-1	$-\frac{1}{2}$	$-\frac{1}{2} + 2\sin^2\theta_W \approx -0.03$
u, c, t	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W \approx 0.19$
d, s, b	$-\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W \approx -0.34$

PVDIS on the deuteron

Full expression:

$$A_{RL}^{e^-} = \frac{|P_b|\eta_{\gamma Z}\left[g_A^e 2yF_1^{\gamma Z} + g_A^e F_2^{\gamma Z}\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right) + g_V^e(2-y)F_3^{\gamma Z}\right]}{2yF_1^{\gamma} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right)F_2^{\gamma} - \eta_{\gamma Z}\left[g_V^e 2yF_1^{\gamma Z} + g_V^e\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right)F_2^{\gamma Z} + g_A^e(2-y)F_3^{\gamma Z}\right]}$$

To a good approximation:

$$A_{RL,d}^{e^-,\mathrm{PVDIS}} \approx |\lambda|\frac{3G_F Q^2}{10\sqrt{2}\pi\alpha}\left[(2C_{1u} - C_{1d}) + R_V Y(2C_{2u} - C_{2d})\right]$$

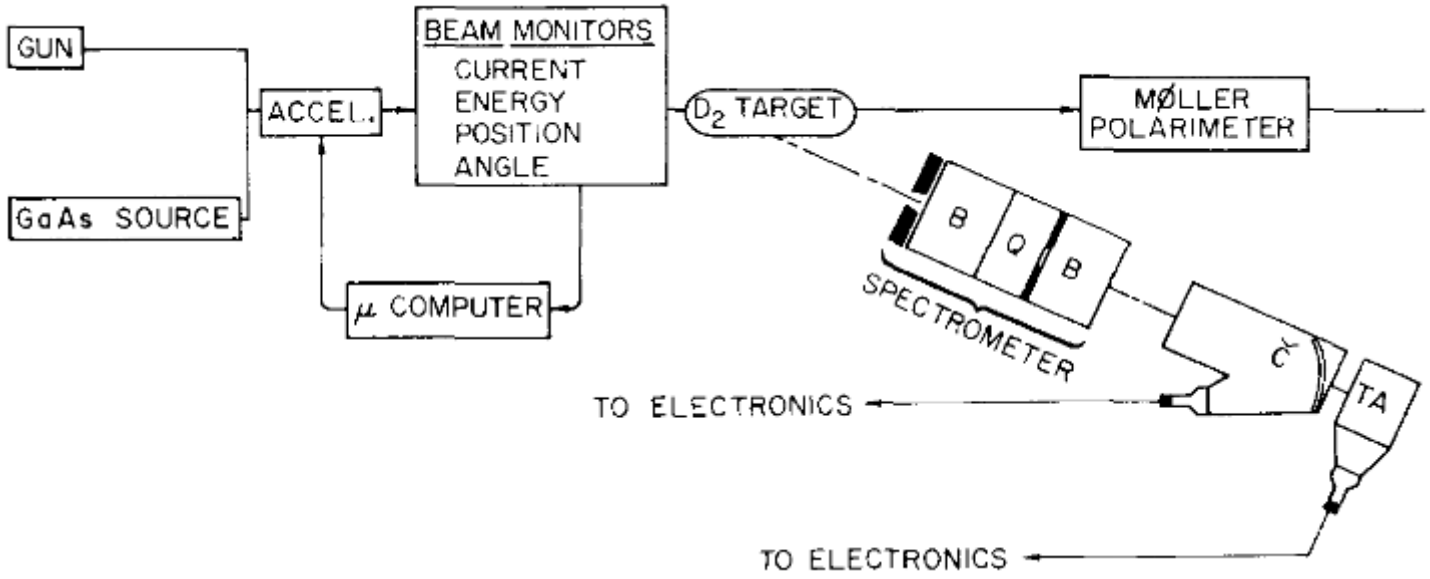
$$g_{AV}^{eu} = C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W;\quad g_{AV}^{ed} = C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W$$

$$g_{VA}^{eu} = C_{2u} = -\frac{1}{2} + 2\sin^2\theta_W;\quad g_{VA}^{ed} = C_{2d} = \frac{1}{2} - 2\sin^2\theta_W.$$

SLAC E122

- 16.2, 17.8, 19.4 and 22.2 GeV electron beam, 37% polarization
- 30-cm proton and deuteron targets
- Spectrometer: 4 deg
- Counts were integrated in Cherenkov and Shower detectors

Prescott et al, Phys. Lett. 77B, 347 (1978)



- Data from the two higher energies were published in the 1978 paper:

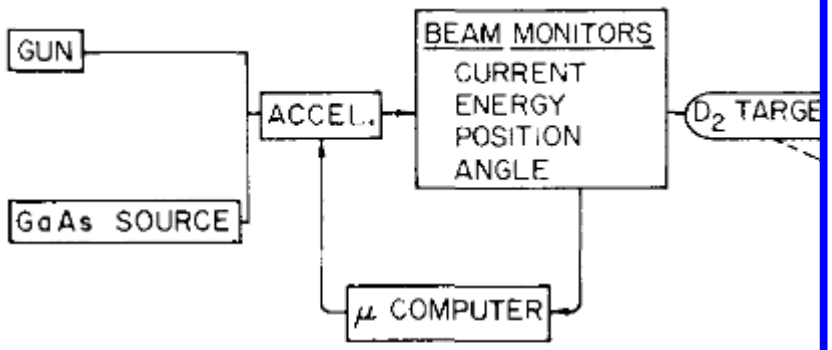
$$A/Q^2 = (-9.5 \pm 1.6) \times 10^{-5}\ (\mathrm{GeV}/c)^{-2}\ \text{(deuterium)}.$$

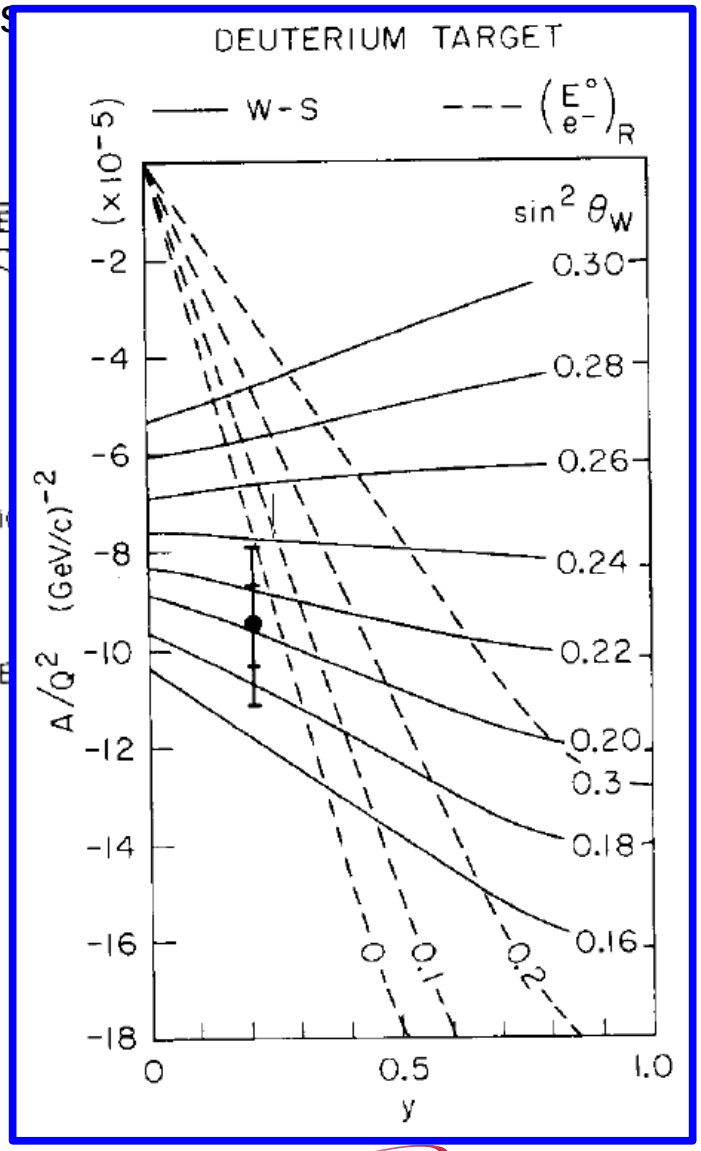
$$A/Q^2 = (-9.7 \pm 2.7) \times 10^{-5}\ (\mathrm{GeV}/c)^{-2}\ \text{(hydrogen)}.$$

SLAC E122

- 16.2, 17.8, 19.4 and 22.2 GeV electron beam, 37% polarization
- 30-cm proton and deuteron targets
- Spectrometer: 4 deg
- Counts were integrated in Cherenkov and Shower detectors

Prescott et al, Phys. Lett. 77B, 347 (1978)





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$$A/Q^2 = (-9.7 \pm 2.7) \times 10^{-5}\ (\mathrm{GeV}/c)^{-2}\ \text{(hydrogen)}.$$

SLAC E122

- The 1979 paper contained asymmetries from 11 individual kinematic points:

Prescott et al, Phys. Lett. B 84, 524 (1979)

Table 1
Asymmetries and kinematic parameters. $x \equiv Q^2/2M(E_0 - E')$ and $y \equiv (E_0 - E')/E_0$. An overall error of ±5% in scale, due to uncertainty in P_e, is not included in these errors.

E_0 (GeV)	Q^2 (GeV/c)^2	x	y	π/e fraction (%)	$10^5\ A/Q^2$		
					asymmetry (GeV/c)$^{-2}$	total error (GeV/c)$^{-2}$	statistical error only (GeV/c)$^{-2}$
16.2	0.92	0.14	0.22	2.1	−11.8	±4.5	±3.4
19.4	1.53	0.28	0.15	0.8	− 8.9	±1.3	±1.1
19.4	1.52	0.26	0.16	0.9	− 9.2	±1.7	±1.2
19.4	1.33	0.16	0.23	2.1	− 6.3	±1.7	±1.4
19.4	1.28	0.14	0.25	2.8	−13.4	±2.8	±1.6
19.4	1.25	0.13	0.26	3.3	− 8.6	±2.0	±1.6
19.4	1.16	0.11	0.29	6.0	−10.4	±1.8	±1.4
19.4	1.07	0.09	0.32	10.8	− 4.6	±2.9	±2.2
19.4	0.93	0.07	0.36	25.0	− 5.3	±3.0	±2.0
22.2	1.96	0.28	0.17	1.0	− 7.0	±2.1	±1.9
22.2	1.66	0.15	0.26	2.9	− 8.9	±2.8	±2.2

SLAC E122

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Prescott et al, Phys. Lett. B 84, 524 (1979)

Table 1
Asymmetries and kinematic parameters. $x \equiv Q^2/2M(E_0 - E')$ and $y \equiv (E_0 - E')/E_0$. An overall error of ±5% in scale, due to uncertainty in P_e, is not included in these errors.

E_0 (GeV)	Q^2 (GeV/c)^2	x	y	π/e fraction (%)	$10^5\ A/Q^2$ asymmetry (GeV/c)$^{-2}$	total error (GeV/c)$^{-2}$	statistical error only (GeV/c)$^{-2}$
16.2	0.92	0.14	0.22	0.19	−11.8	±4.5	±3.4
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19.4	1.52	0.26	0.16	0.16	− 9.2	±1.7	±1.2
19.4	1.33	0.16	0.23	0.21	− 6.3	±1.7	±1.4
19.4	1.28	0.14	0.25	0.23	−13.4	±2.8	±1.6
19.4	1.25	0.13	0.26	0.24	− 8.6	±2.0	±1.6
19.4	1.16	0.11	0.29	0.26	−10.4	±1.8	±1.4
19.4	1.07	0.09	0.32	0.29	− 4.6	±2.9	±2.2
19.4	0.93	0.07	0.36	0.33	− 5.3	±3.0	±2.0
22.2	1.96	0.28	0.17	0.17	− 7.0	±2.1	±1.9
22.2	1.66	0.15	0.26	0.24	− 8.9	±2.8	±2.2

E_b (GeV)	Q^2 (GeV/c)^2	x	y	Y_3	R_S	R_V	$Y_3 R_V$
16.2	0.92	0.14	0.22	0.19	0.071 ± 0.014	0.623 ± 0.014	0.12
19.4	1.53	0.28	0.15	0.15	0.022 ± 0.005	0.859 ± 0.012	0.13
19.4	1.52	0.26	0.16	0.16	0.027 ± 0.006	0.836 ± 0.012	0.13
19.4	1.33	0.16	0.23	0.21	0.068 ± 0.012	0.671 ± 0.014	0.14
19.4	1.28	0.14	0.25	0.23	0.082 ± 0.013	0.630 ± 0.014	0.14
19.4	1.25	0.13	0.26	0.24	0.090 ± 0.013	0.608 ± 0.013	0.14
19.4	1.16	0.11	0.29	0.26	0.107 ± 0.013	0.563 ± 0.013	0.15
19.4	1.07	0.09	0.32	0.29	0.127 ± 0.014	0.518 ± 0.012	0.15
19.4	0.93	0.07	0.36	0.33	0.148 ± 0.017	0.471 ± 0.011	0.15
22.2	1.96	0.28	0.17	0.17	0.027 ± 0.005	0.860 ± 0.011	0.14
22.2	1.66	0.15	0.26	0.24	0.081 ± 0.012	0.654 ± 0.014	0.16

Updated PDF from MSTW2008 (A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C 63, 189 (2009).)

D. Wang et al. Phys.Rev.C 91 (2015) 4, 045506

SLAC E122

- The 1979 paper contained asymmetries from 11 individual kinematic points:

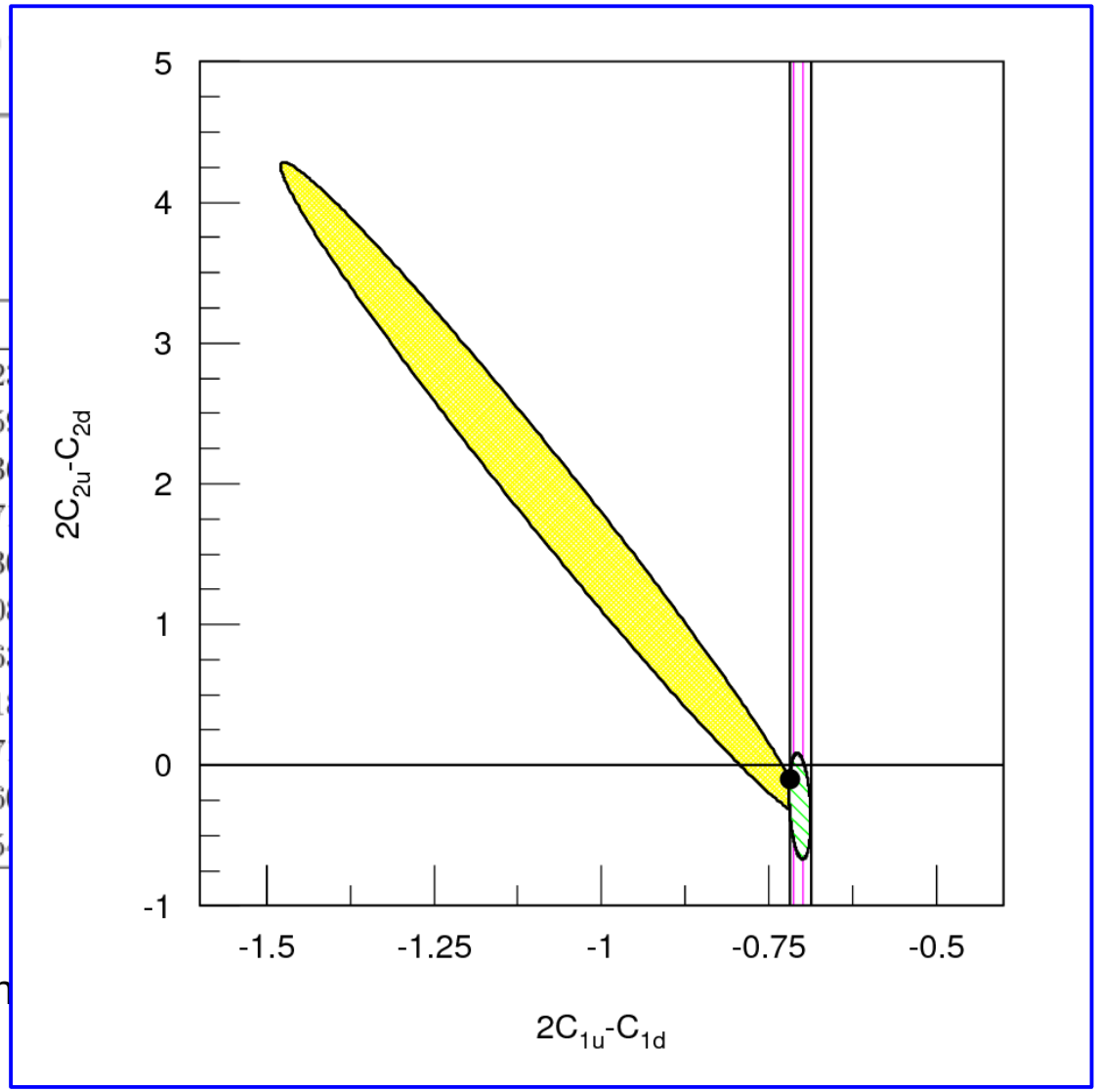
Prescott et al, Phys. Lett. B 84, 524 (1979)

Table 1
Asymmetries and kinematic parameters. $x \equiv Q^2/2M(E_0$ certainty in P_e, is not included in these errors.

E_0 (GeV)	Q^2 (GeV/c)^2	x	y

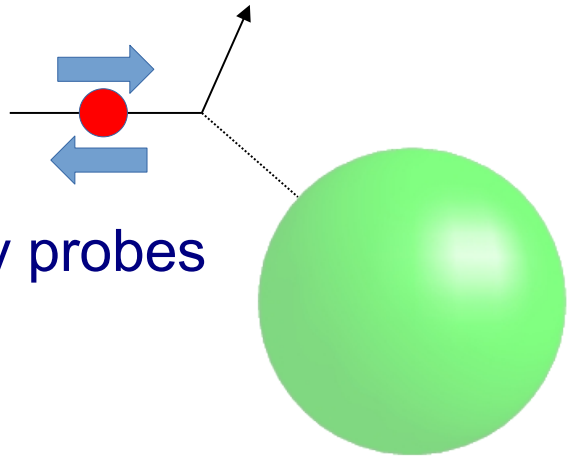
E_b (GeV)	Q^2 (GeV/c)^2	x	y	Y_3	R_S	
16.2	0.92	0.14	0.22	0.19	0.071 ± 0.014	0.62
19.4	1.53	0.28	0.15	0.15	0.022 ± 0.005	0.85
19.4	1.52	0.26	0.16	0.16	0.027 ± 0.006	0.83
19.4	1.33	0.16	0.23	0.21	0.068 ± 0.012	0.67
19.4	1.28	0.14	0.25	0.23	0.082 ± 0.013	0.63
19.4	1.25	0.13	0.26	0.24	0.090 ± 0.013	0.60
19.4	1.16	0.11	0.29	0.26	0.107 ± 0.013	0.56
19.4	1.07	0.09	0.32	0.29	0.127 ± 0.014	0.51
19.4	0.93	0.07	0.36	0.33	0.148 ± 0.017	0.47
22.2	1.96	0.28	0.17	0.17	0.027 ± 0.005	0.86
22.2	1.66	0.15	0.26	0.24	0.081 ± 0.012	0.65

Updated PDF from MSTW2008 (A. D. Martin
C 63, 189 (2009).)



D. Wang et al. Phys.Rev.C 91 (2015) 4, 045506

Accessing C_{1q} in Elastic PVES



- Elastic PVES:
  - Hadronic effects suppressed at $Q^2=0$, directly probes C_{1q} as the proton weak charge

$$A_{PV}^{elastic} \propto -Q^2\left[Q_W^p + F\left(\theta, Q^2\right)\right]$$

$$Q_W^p = -2\left(2C_{1u} + C_{1d}\right)$$
$$\text{or} = -2\left(2g_{AV}^{eu} + g_{AV}^{ed}\right) = 1 - 4\sin^2\theta_W$$

shouldn't it be $2c_V^u + c_V^d = \frac{1}{2} - 2\sin^2\theta_W$?

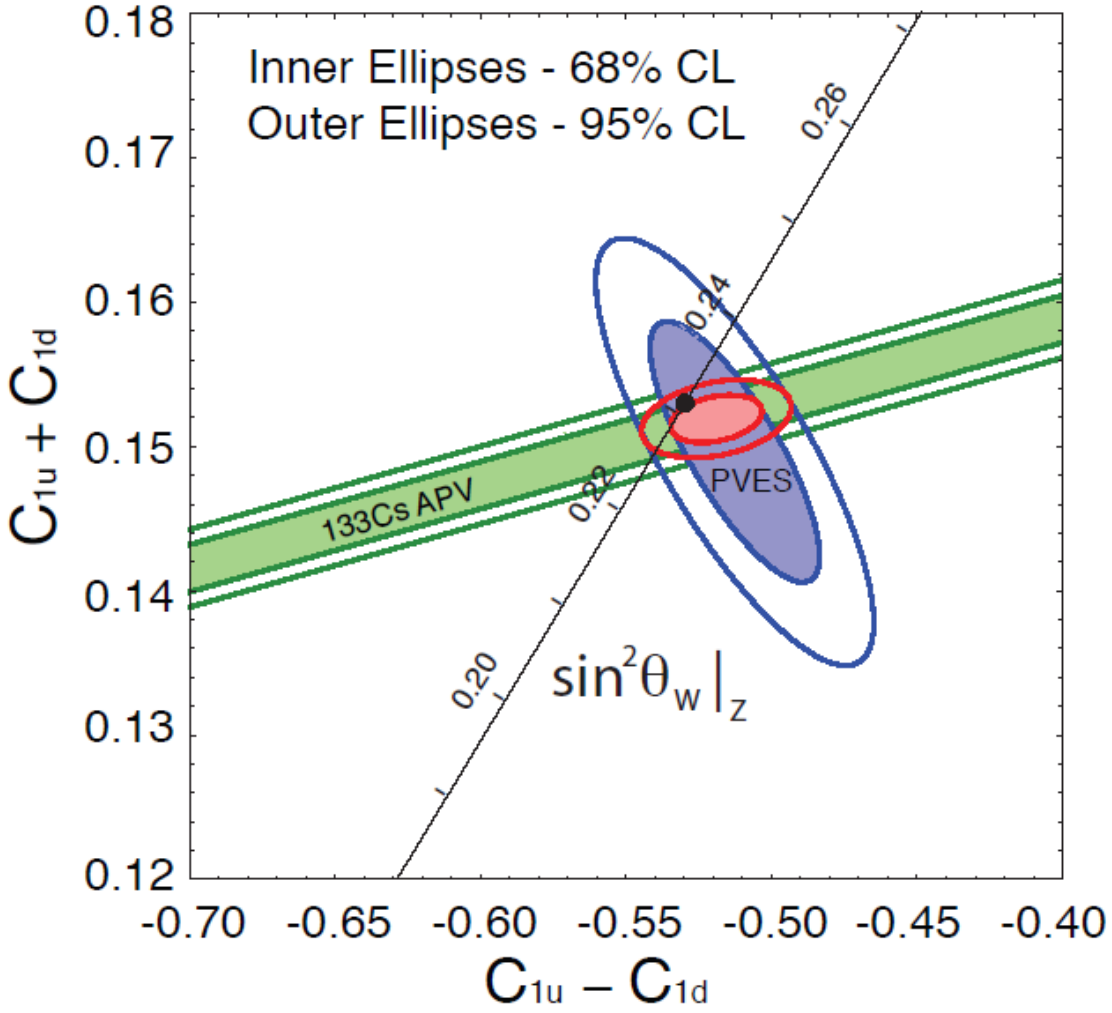
Electron axial weak charge (L-R)

x by

Quark vector weak charge (L+R)

$$G_E^p\left(Q^2=0\right) = 1 = 2\left(Q_u\right) + 1\left(Q_d\right)$$

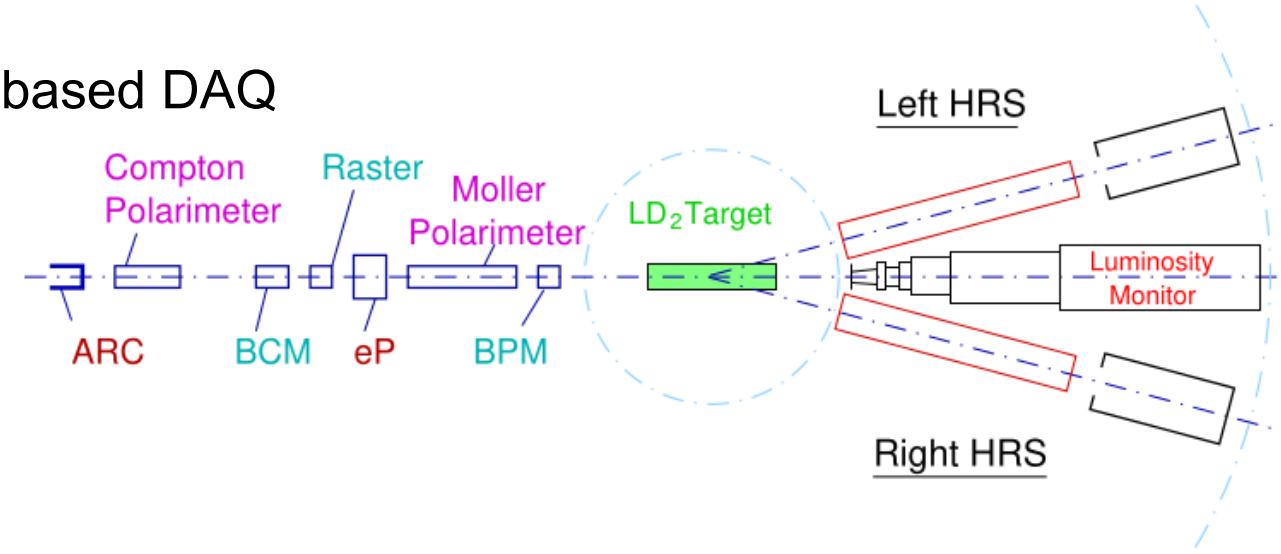
2013 Best Data on C_{1q} (eq AV couplings) from PVES+APV



Androic et al., PRL 111, 141803 (2013);

Hall A 6 GeV PVDIS (E05-007/E08-011)

- 6.0 GeV, 100uA beam, 89.45% (Compton), 88.74% (Moller) polarization
- 20 cm LD2 target
- Two HRSs, DC off, scaler-based DAQ
- 30 PAC days



The Jefferson Lab PVDIS Collaboration

D. Wang, K. Pan, R. Subedi, X. Deng, Z. Ahmed, K. Allada, K. A. Aniol, D. S. Armstrong, J. Arrington, V. Bellini, R.Beminiwattha, J. Benesch, F. Benmokhtar, W. Bertozzi, A. Camsonne, M. Canan, G. D. Cates, J.-P. Chen, E.Chudakov, E. Cisbani, M. M. Dalton, C. W. de Jager, R. De Leo, W. Deconinck, A. Deur, C. Dutta, L. El Fassi, J.Erler, D. Flay, G. B. Franklin, M. Friend, S. Frullani, F. Garibaldi, S. Gilad, A. Giusa, A. Glamazdin, S. Golge, K.Grimm, K. Hafidi, J.-O. Hansen, D. W. Higinbotham, R. Holmes, T. Holmstrom, R. J. Holt, J. Huang, C. E. Hyde, C.M.Jen, D. Jones, Hoyoung Kang, P. M. King, S. Kowalski, K. S. Kumar, J. H. Lee, J. J. LeRose, N. Liyanage, E.Long, D. McNulty, D. J. Margaziotis, F. Meddi, D. G. Meekins, L. Mercado, Z.-E. Meziani, R. Michaels, M.Mihovilovic, N. Muangma, K. E. Myers, S. Nanda, A. Narayan, V. Nelyubin, Nuruzzaman, Y. Oh, D. Parno, K. D. Paschke, S.K.Phillips, X. Qian, Y. Qiang, B. Quinn, A. Rakhman, P. E. Reimer, K. Rider, S. Riordan, J. Roche, J. Rubin, G.Russo, K. Saenboonruang, A. Saha, B. Sawatzky, A. Shahinyan, R. Silwal, S. Sirca, P. A. Souder, R. Suleiman, V.Sulkosky, C. M. Sutera, W. A. Tobias, G. M. Urciuoli, B. Waidyawansa, B. Wojtsekhowski, L. Ye, B. Zhao & X. Zheng

Hall A 6 GeV PVDIS (E05-007/E08-011)

Main results:

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

compare to

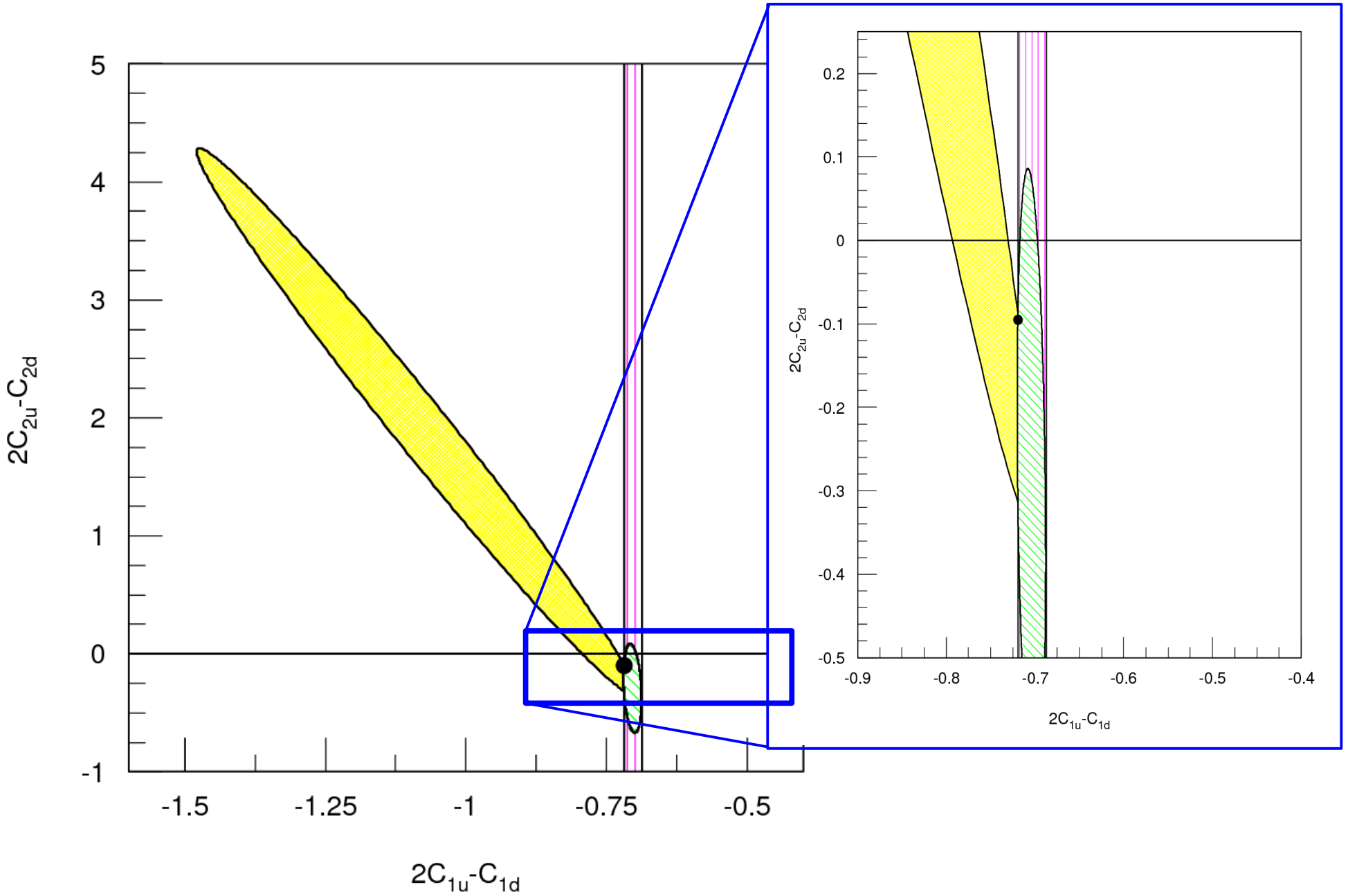
$$A^{SM} = \left(1.156\times10^{-4}\right)\left[\left(2C_{1u}-C_{1d}\right)+0.348\left(2C_{2u}-C_{2d}\right)\right]$$

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

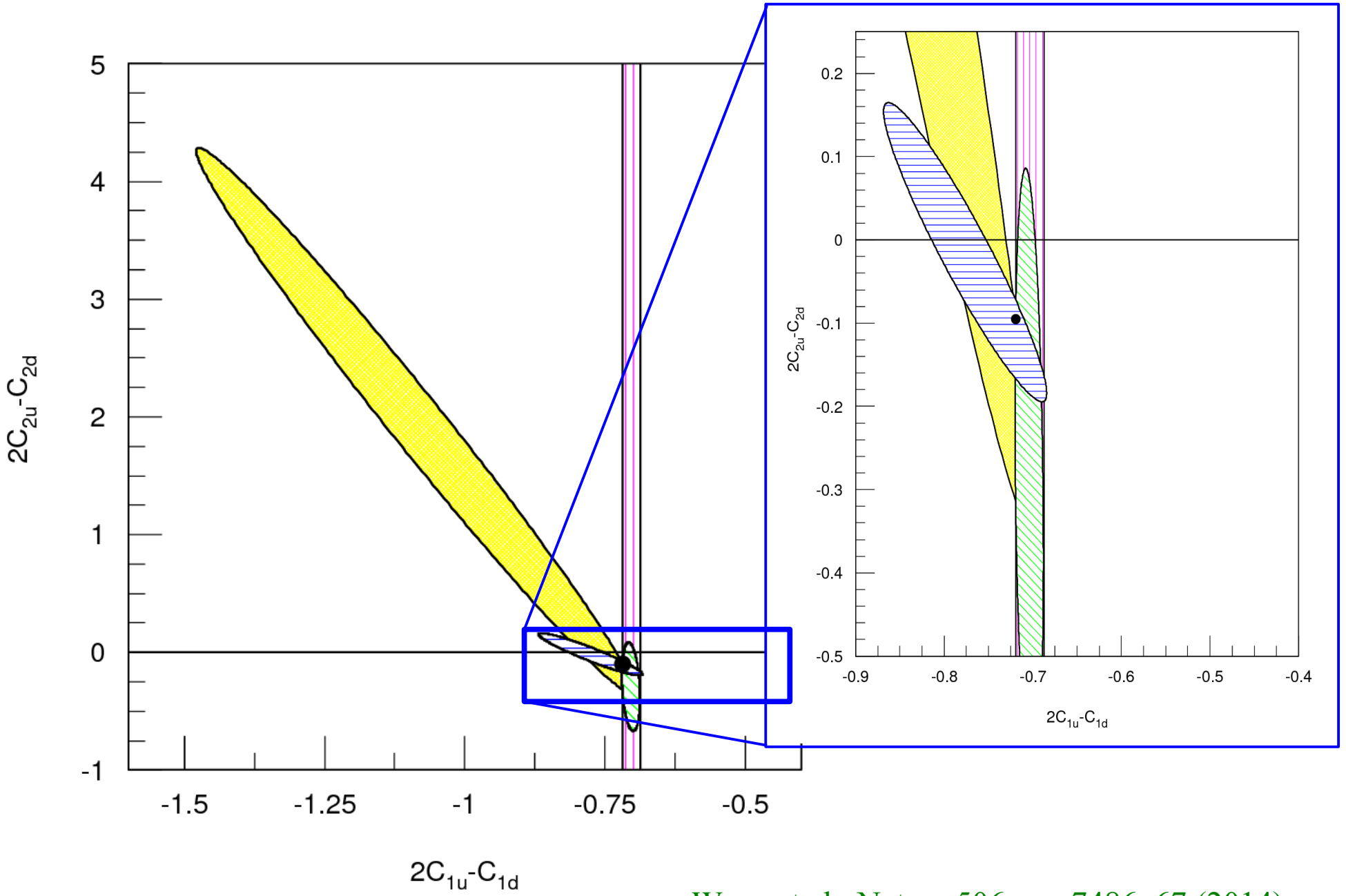
compare to

$$A^{SM} = \left(2.022\times10^{-4}\right)\left[\left(2C_{1u}-C_{1d}\right)+0.594\left(2C_{2u}-C_{2d}\right)\right]$$

C1, C2 from E122 and Elastic + APV

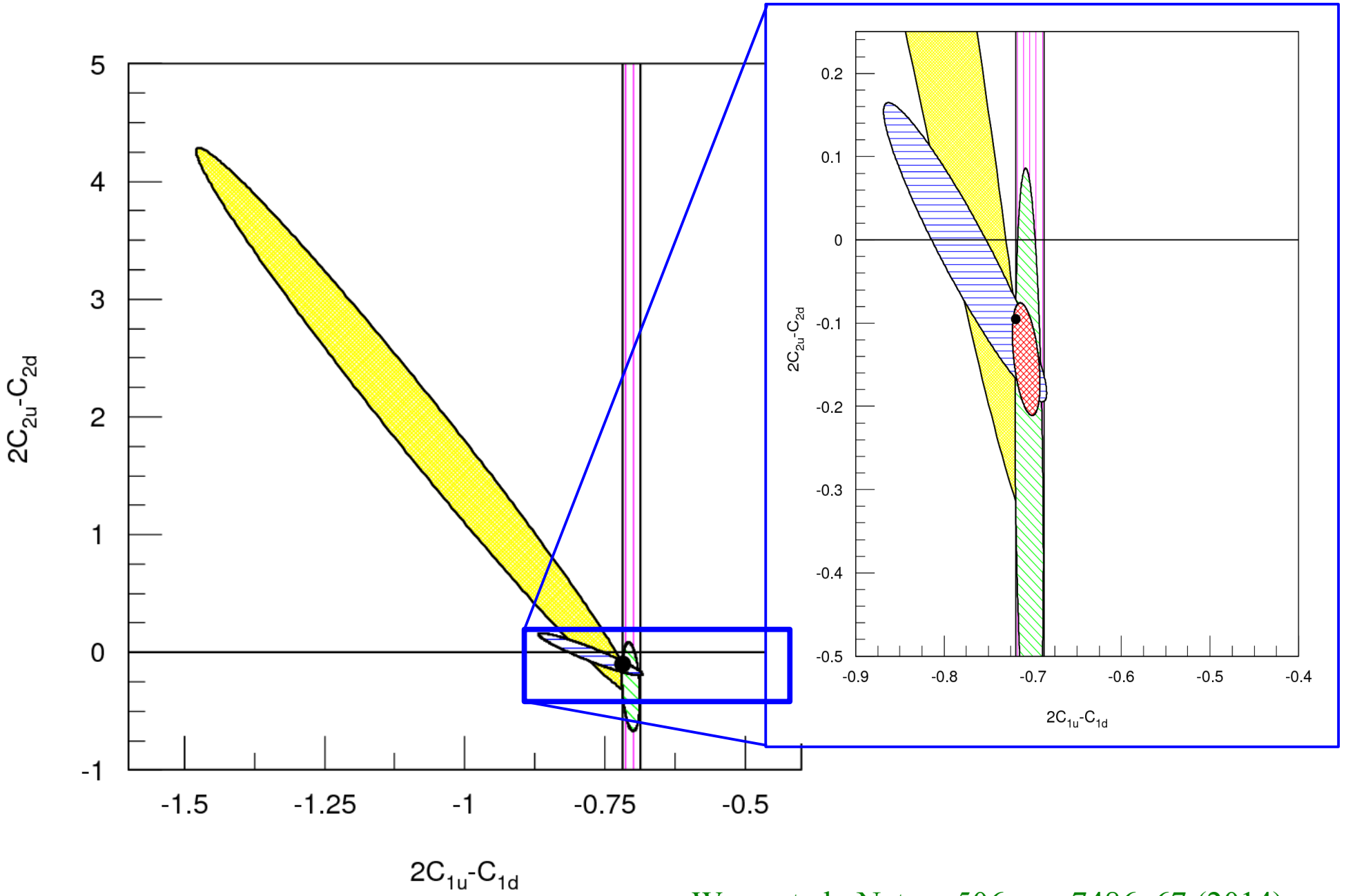


C1, C2 from Hall A 6 GeV PVDIS



Wang et al., Nature 506, no. 7486, 67 (2014);

C1, C2 from Hall A 6 GeV PVDIS



Wang et al., Nature 506, no. 7486, 67 (2014);

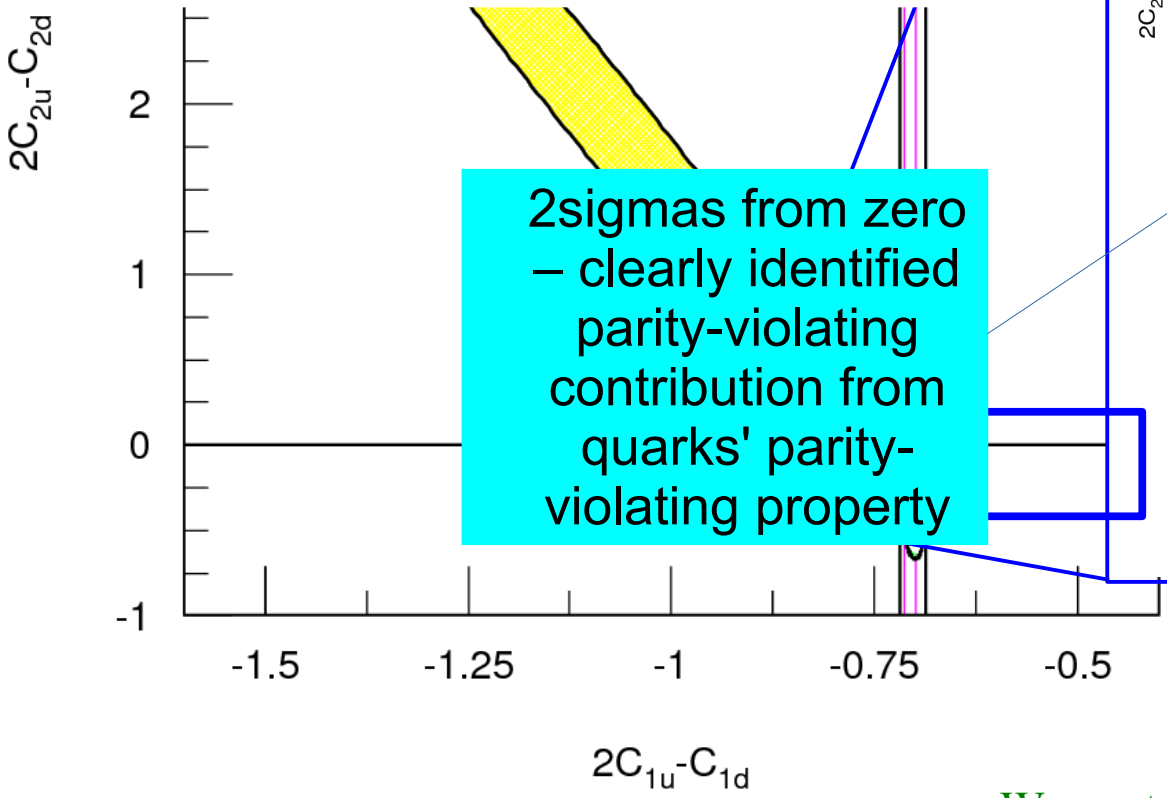
C1, C2 from Hall A 6 GeV PVDIS

PARTICLE PHYSICS

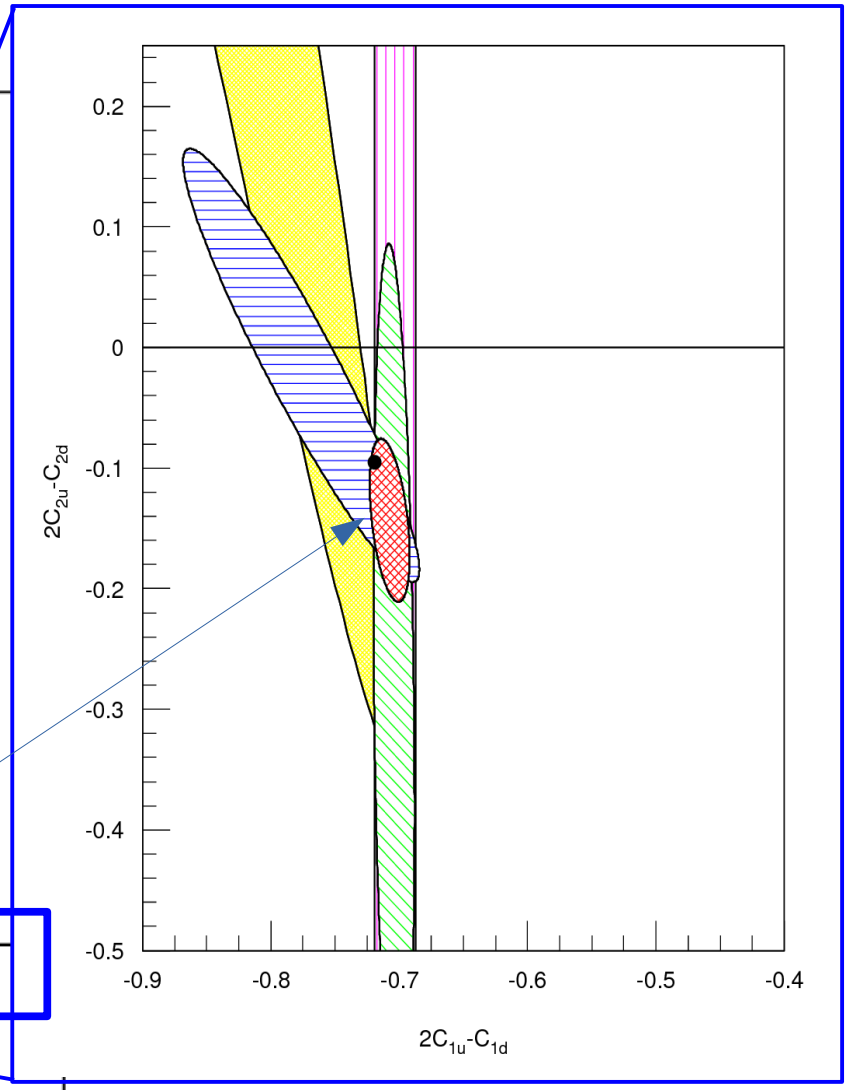
Quarks are not ambidextrous

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);



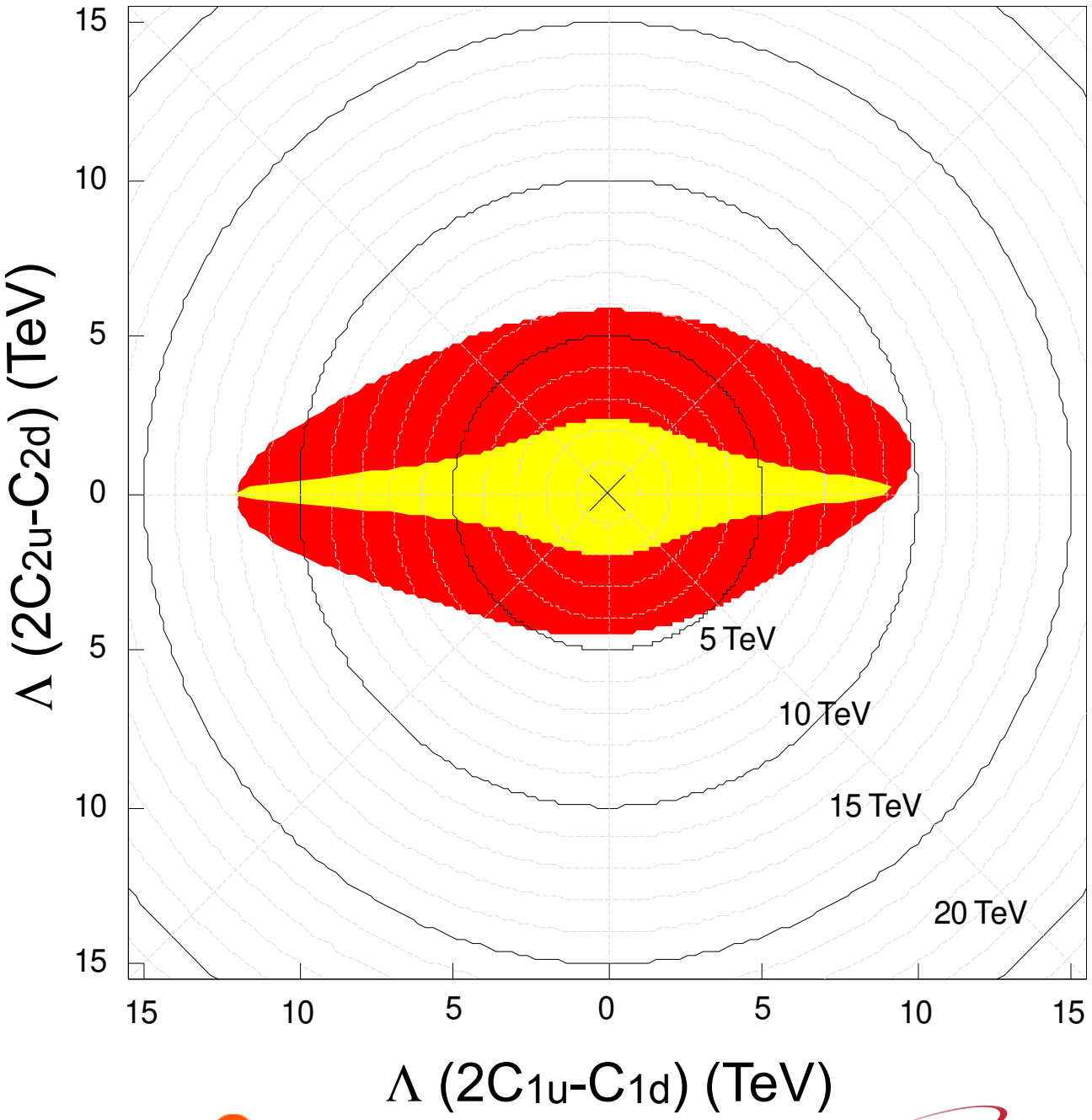
2sigmas from zero – clearly identified parity-violating contribution from quarks' parity-violating property



Wang et al., Nature 506, no. 7486, 67 (2014);

BSM Mass Limit on eq VA contact interaction

Complementary to LHC results on the mass limit of electron-quark contact interactions



In 2023, I finally understood how the mass limits are calculated from C1,2's.

Resonance Apv from Hall A 6 GeV PVDIS

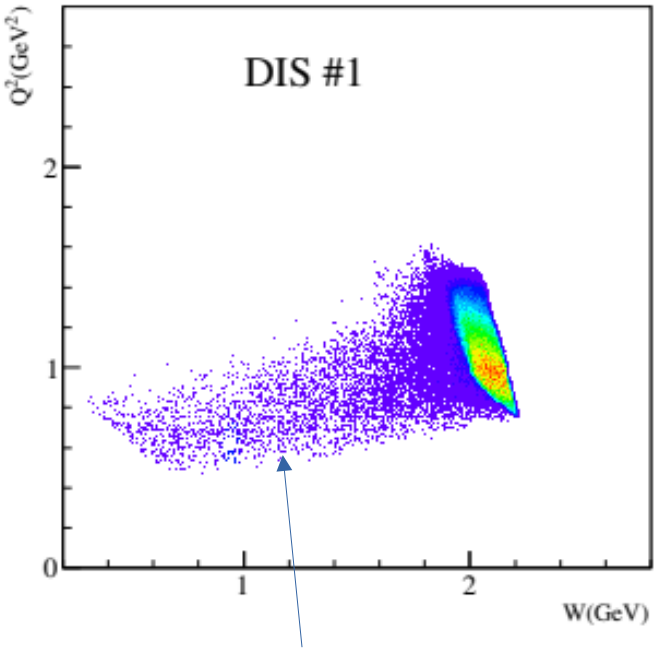
Kine#	HRS	E_b (GeV)	θ_0(deg)	E'_0 (GeV)	R_e(kHz)	R_{π^-}/R_e
DIS#1	Left	6.067	12.9	3.66	≈210	≈0.5
DIS#2	Left & Right	6.067	20.0	2.63	≈18	≈3.3
RES I	Left	4.867	12.9	4.0	≈300	$<$ ≈0.25
RES II	Left	4.867	12.9	3.55	≈600	$<$ ≈0.25
RES III	Right	4.867	12.9	3.1	≈400	$<$ ≈0.4
RES IV	Left	6.067	15	3.66	≈80	$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

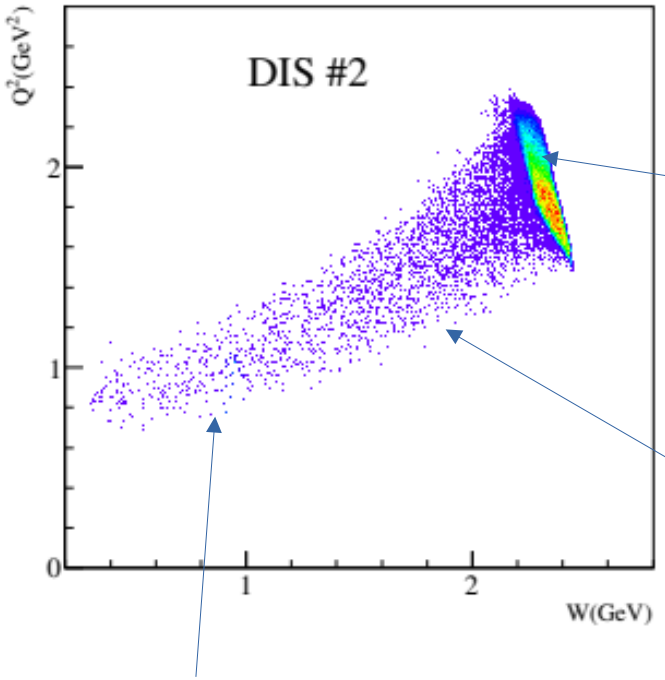
D. Wang et al. Phys.Rev.C 91 (2015) 4, 045506

Radiative Correction for 6 GeV PVDIS

Q2_vertex vs. W_vertex for 6 GeV that includes both internal and external radiations

internal use Mo&Tsai's effective radiator formula: (see HAMC manual)



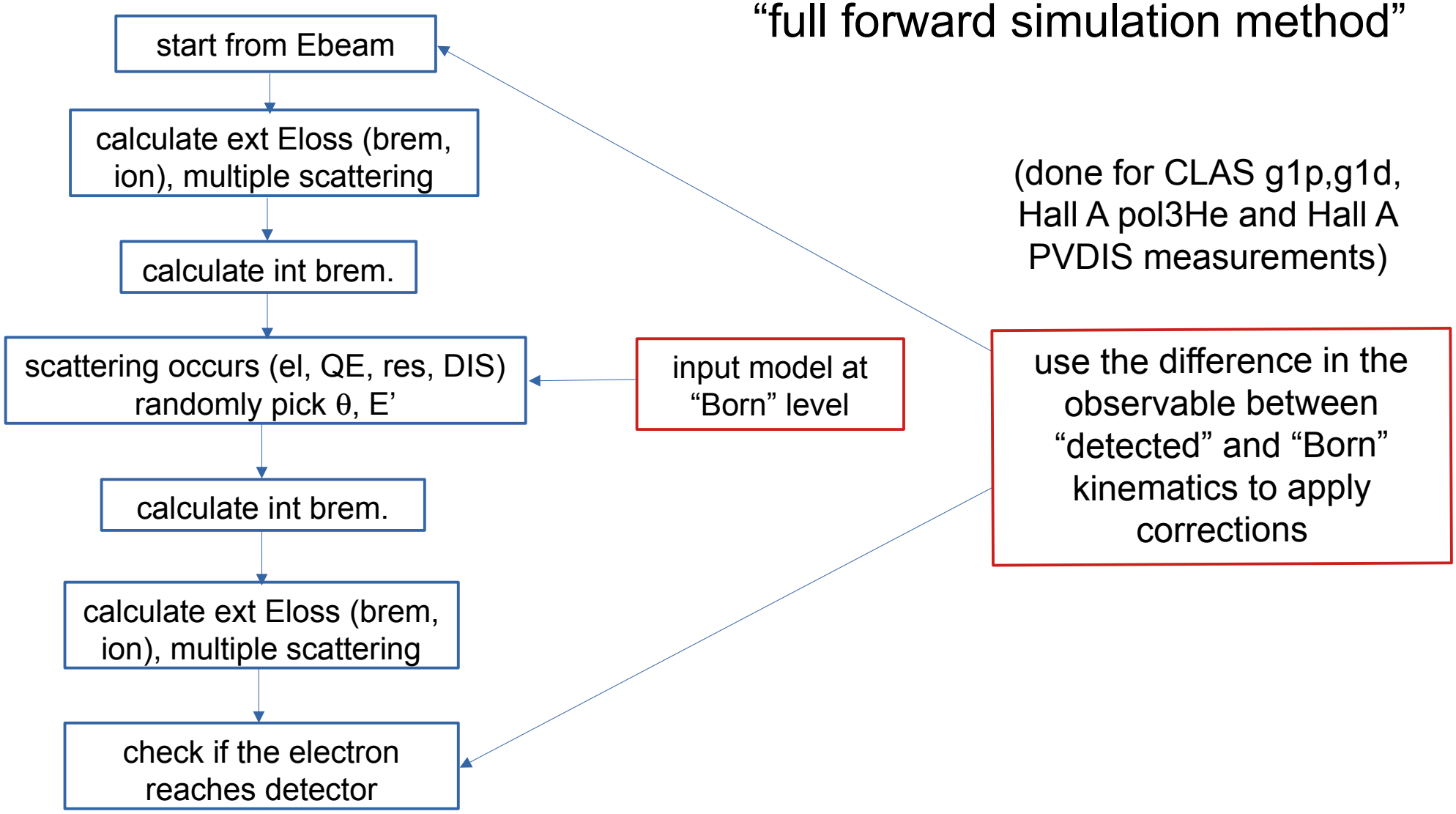


spectrometer sits here (and where we think DIS events occurs)

where scattering actually occurs

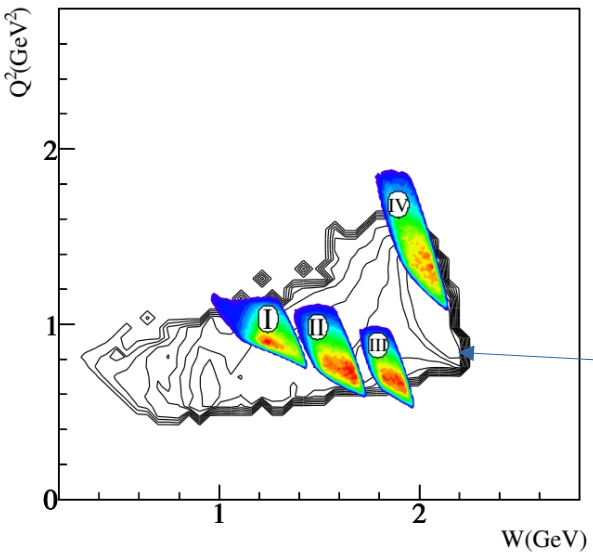
resonance Apv: used model, checked with data (next slide)

Radiative Correction for 6 GeV PVDIS

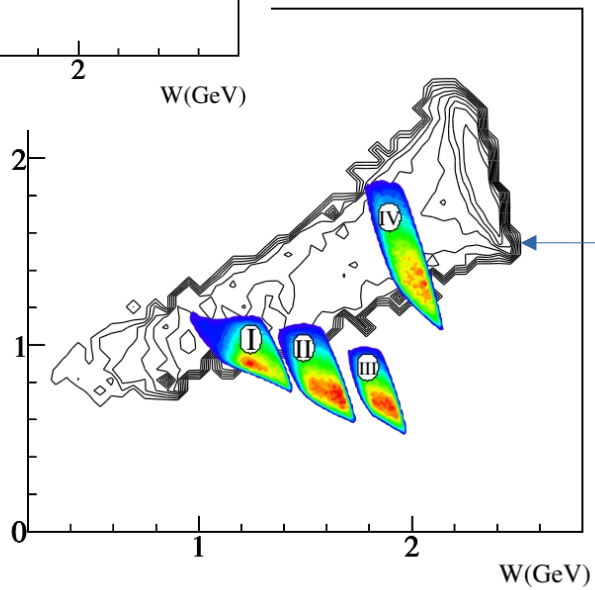


Resonance Apv from 6 GeV PVDIS

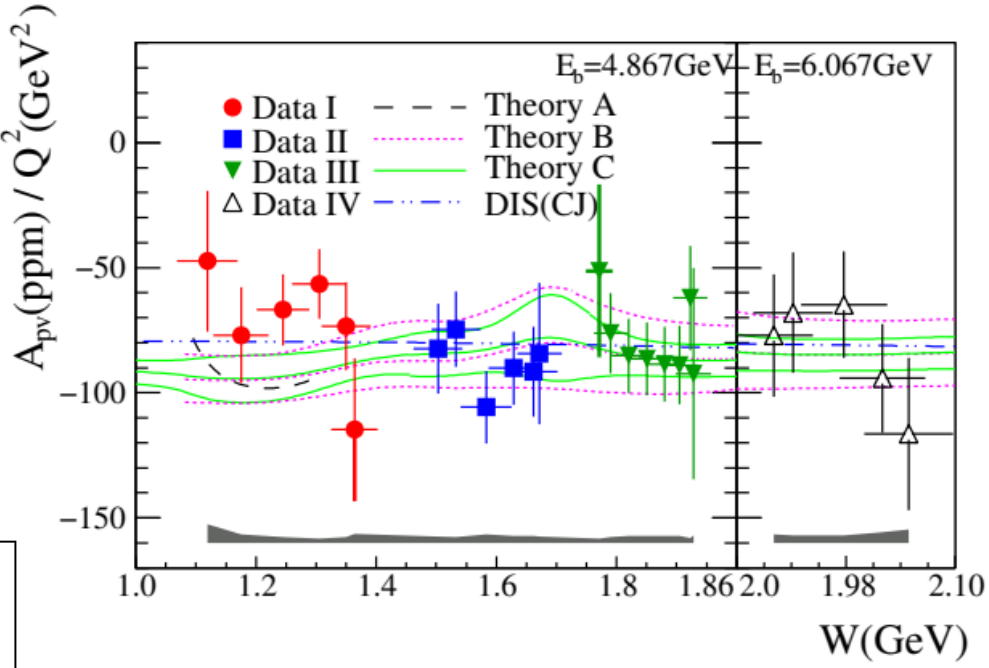
Resonance data taken during 6 GeV



"DIS#1"



"DIS#2"



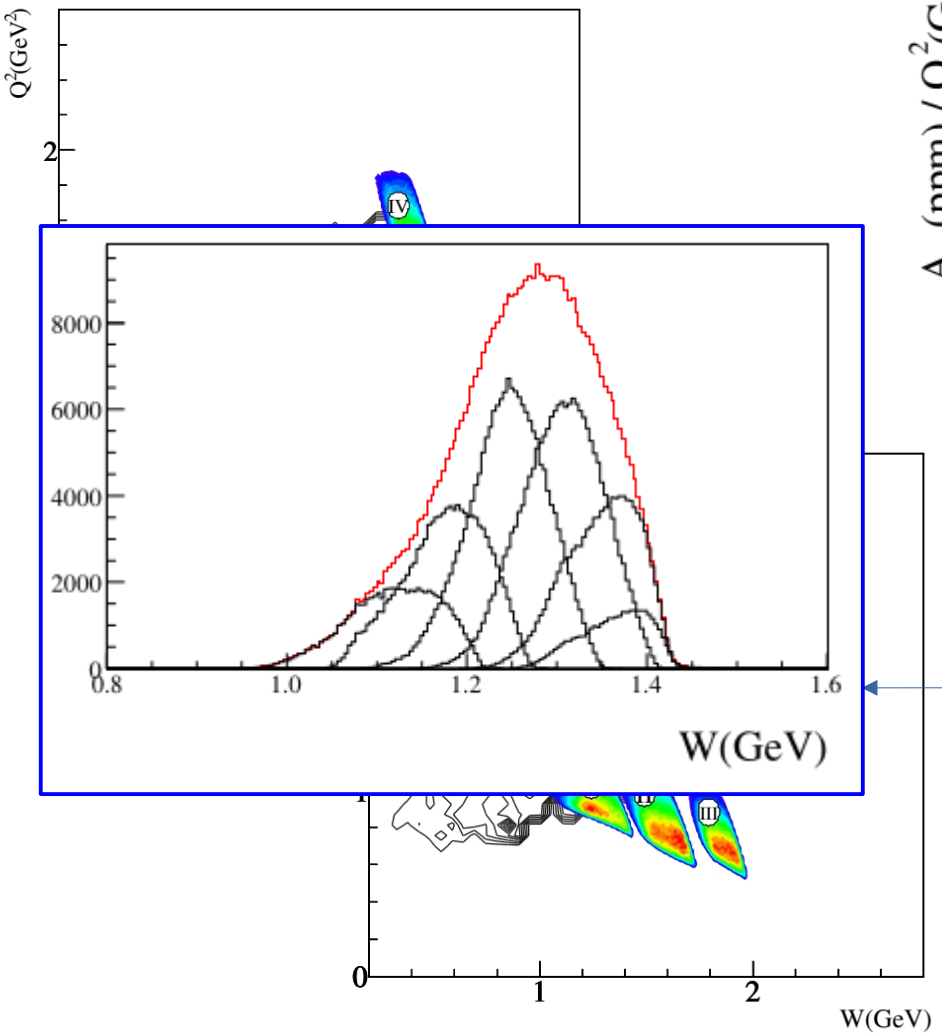
Elastic and QE calculated separately;

Uncertainty in resonance Apv as input to radiative corrections:
- W<1.4 GeV: 25%
- 1.4<W<1.7 GeV: 10%
- 1.7<W<2.0 GeV: 7.7%

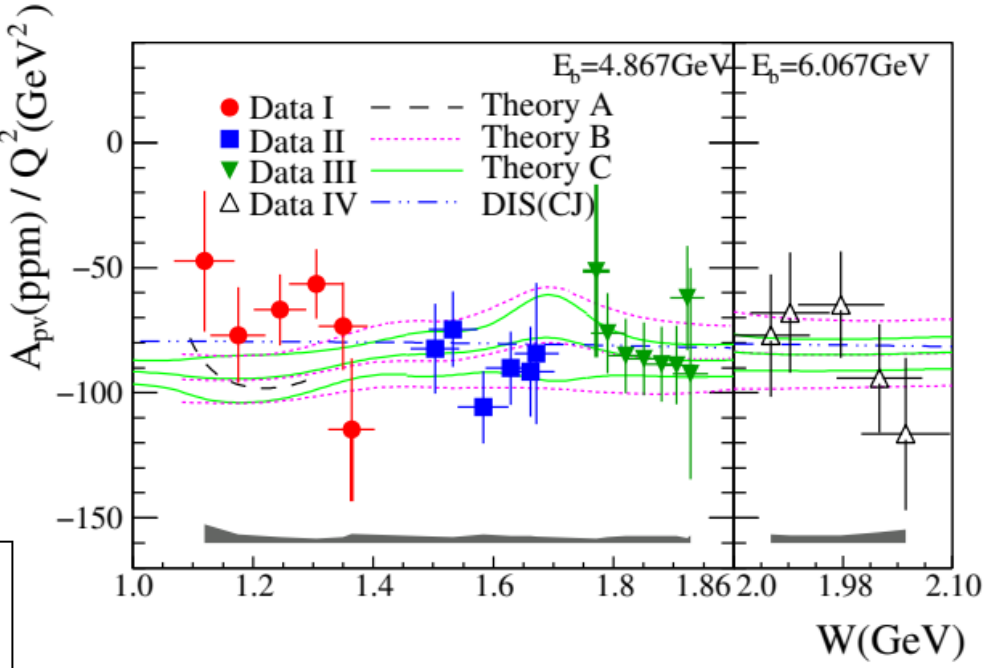
D. Wang et al. Phys. Rev. Lett. 111, 082501 (2013).

Resonance Apv from 6 GeV PVDIS

Resonance data taken during 6 GeV



"DIS#2"



Caveat:
– We didn't really have so many (small) W bins and these points overlap (are correlated)
– HAMC implementation of t_{equiv} was "off"

D. Wang et al. Phys. Rev. Lett. 111, 082501 (2013).

Toy Model for Resonance Apv

Flavor decomposition using F1F221 fits and naive parton model:

$$F_1^p = \frac{1}{2}\left[\left(\frac{2}{3}\right)^2(u+c) + \left(-\frac{1}{3}\right)^2(d+s)\right]$$
$$F_1^n = \frac{1}{2}\left[-\left(\frac{1}{3}\right)^2(u+c) + \left(\frac{2}{3}\right)^2(d+s)\right]$$

$$u+c = \frac{6}{5}(4F_1^p - F_1^n)$$
$$d+s = \frac{6}{5}(4F_1^n - F_1^p)$$

Construct γZ structure functions:

$$F_1^{\gamma Z} = \frac{1}{2}\left[\left(\frac{2}{3}\right)g_V^u(u+c) + \left(-\frac{1}{3}\right)g_V^d(d+s)\right]$$
$$F_3^{\gamma Z} = \frac{1}{2}\left[\left(\frac{2}{3}\right)g_A^u(u+c) + \left(-\frac{1}{3}\right)g_A^d(d+s)\right]$$

Construct Apv:

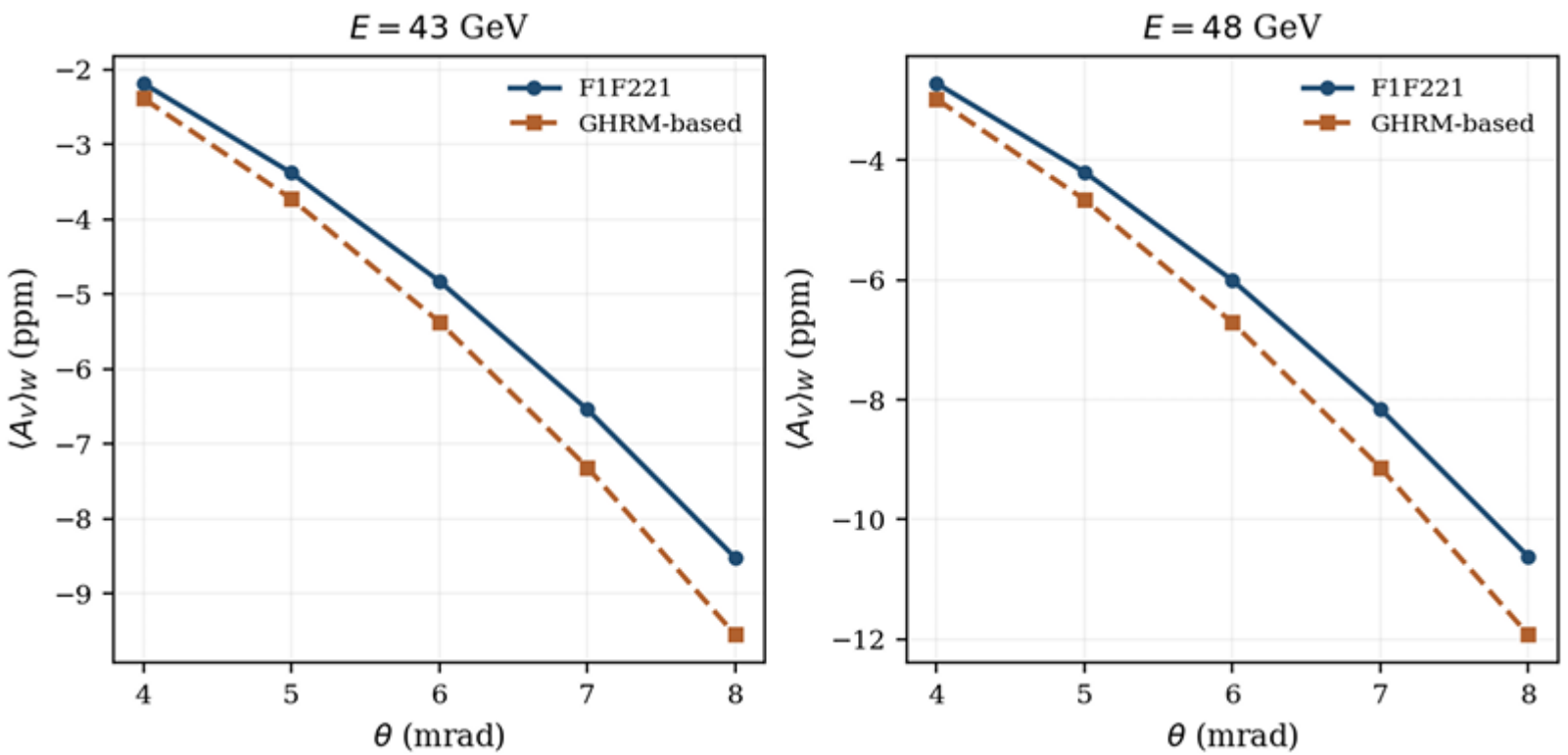
with $r^2 = 1 + \frac{Q^2}{\nu^2}$. The asymmetry can now be written as:

$$A_{PV} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A^e \frac{F_1^{\gamma Z}}{F_1^\gamma} Y_1 + \frac{g_V^e}{2}\frac{F_3^{\gamma Z}}{F_1^\gamma} Y_3\right]$$

$$Y_1 = \left[\frac{1+R^{\gamma Z}}{1+R^\gamma}\right]\frac{1+(1-y)^2 - y^2\left[1-\frac{r^2}{1+R^{\gamma Z}}\right] - \frac{2M^2x^2y}{Q^2}}{1+(1-y)^2 - y^2\left[1-\frac{r^2}{1+R^\gamma}\right] - \frac{2M^2x^2y}{Q^2}}$$

$$Y_3 = \left[\frac{r^2}{1+R^\gamma}\right]\frac{1-(1-y)^2}{1+(1-y)^2 - y^2\left[1-\frac{r^2}{1+R^\gamma}\right] - \frac{2M^2x^2y}{Q^2}}.$$

Toy Model for Resonance Apv (E158 Kinematics)



Work done by Richard Trotta

Model and contribution	$E = 43$ GeV	$E = 48$ GeV
F1F221: $\langle A_V \rangle$	−4.4540	−5.5066
F1F221: $\langle A_A \rangle$ (valence approximation)	−0.0151	−0.0174
F1F221: $\langle A_{PV} \rangle$ (valence approximation)	**−4.4691**	**−5.5239**
GHRM Model II-based: $\langle A_V \rangle$	−4.9334	−6.1197

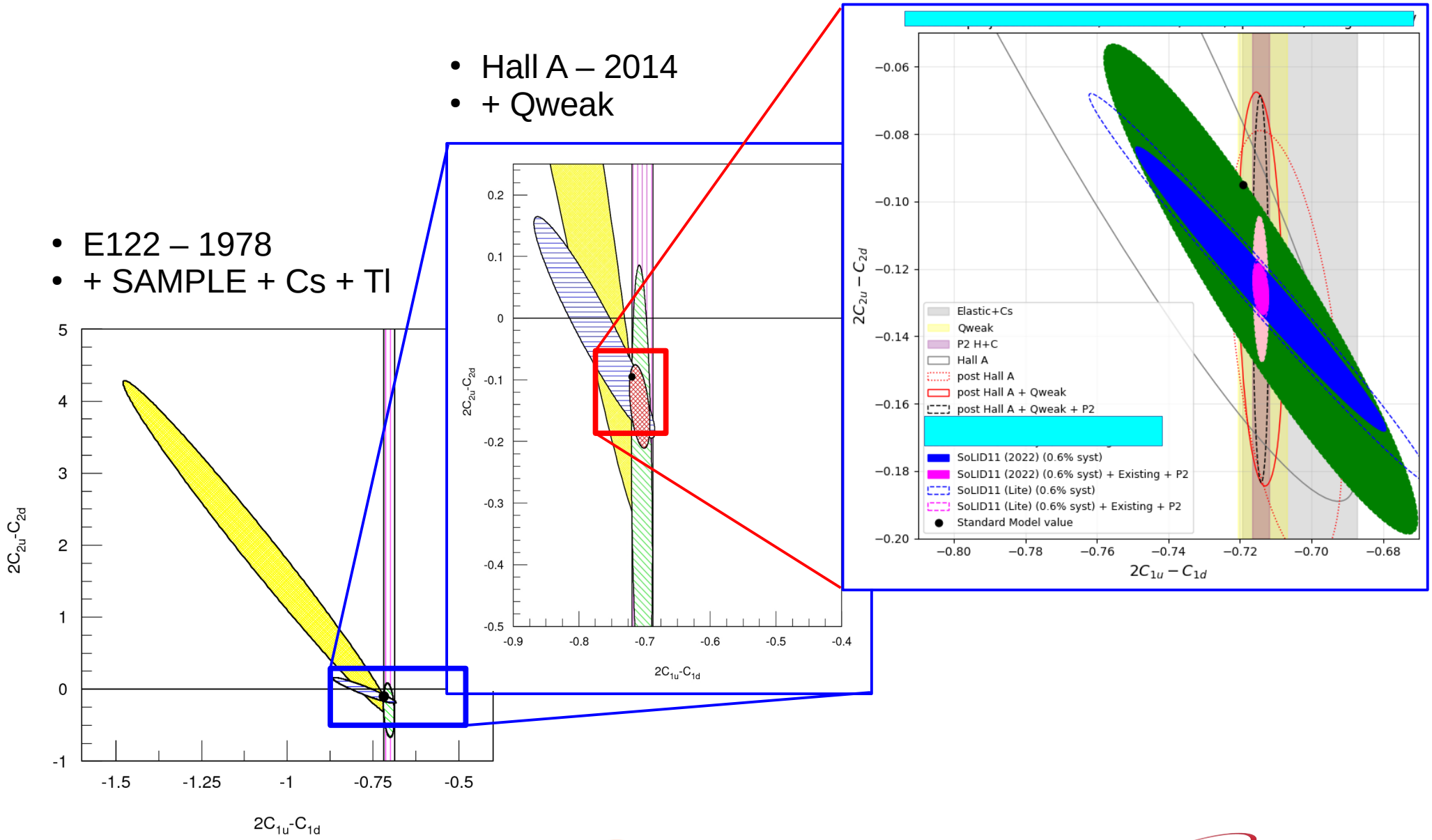
$$\overline{A}_V = \frac{\int_{4\,\mathrm{mrad}}^{8\,\mathrm{mrad}} d\Omega \int_{1.1}^{3.1} dW\, A_V(W,\theta)\, \frac{d^2\sigma_\gamma}{d\Omega\, dW}}{\int_{4\,\mathrm{mrad}}^{8\,\mathrm{mrad}} d\Omega \int_{1.1}^{3.1} dW\, \frac{d^2\sigma_\gamma}{d\Omega\, dW}}.$$

Pioneer → Exploratory → Some Future?

- E122 – 1978
- + SAMPLE + Cs + Tl

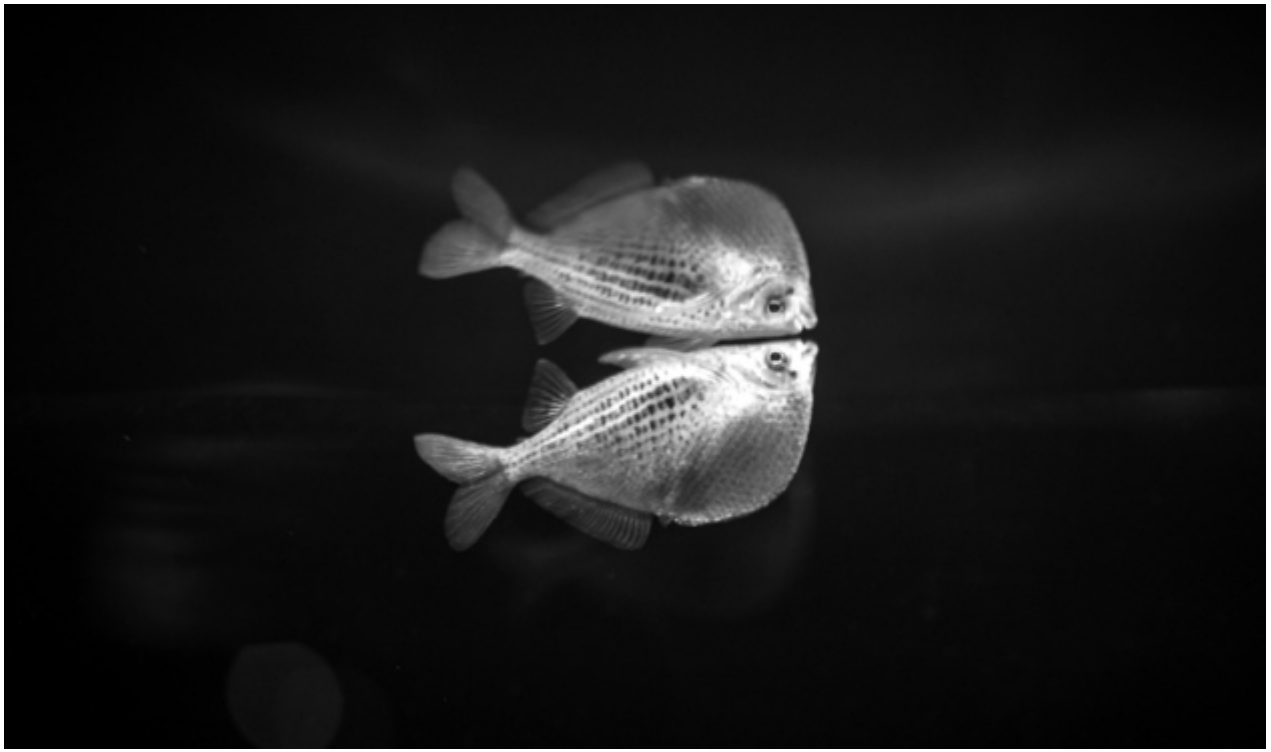
- Hall A – 2014
- + Qweak

- some future?
- + P2



Summary

What can I (we) do for MOLLER?



Backup Slides

More Physics!

$$A_{RL}^{e^\pm} = \frac{\sigma_R^{e^\pm} - \sigma_L^{e^\pm}}{\sigma_R^{e^\pm} + \sigma_L^{e^\pm}}$$

$$\left(A_{RL}^{e^\pm} = -A_{LR}^{e^\pm}\right)$$

$$A_d = |\lambda|(108\ ppm)Q^2[(2C_{1u} - C_{1d}) + Y(y)(2C_{2u} - C_{2d})R_V(x)]$$

beam polarization

$$Y(y) = \frac{1-(1-y)^2}{1+(1-y)^2} \qquad R_V(x) = \frac{u_V(x)+d_V(x)}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

(indicates spin flip of quarks)

$$A_{RL}^{e^+e^-} = \frac{\sigma_R^{e^+} - \sigma_L^{e^-}}{\sigma_R^{e^+} + \sigma_L^{e^-}}$$

$$\left(A_{RL}^{e^+e^-} \neq -A_{LR}^{e^+e^-}\right)$$

$$A_{RL,d}^{e^+e^-} = (108\ ppm)Q^2 Y(y) R_V(x)[|\lambda|(2C_{2u} - C_{2d}) - (2C_{3u} - C_{3d})]$$

(flip |λ| for LR)

"B" in CERN measurement

$$A_{RR}^{e^+e^-} = \frac{\sigma_R^{e^+} - \sigma_R^{e^-}}{\sigma_R^{e^+} + \sigma_R^{e^-}}$$

$$\left(A_{RR}^{e^+e^-} \neq -A_{LL}^{e^+e^-}\right)$$

$$A_{RR,d}^{e^+e^-} = (108\ ppm)Q^2[|\lambda|(2C_{1u} - C_{1d}) - Y(y)R_V(x)(2C_{3u} - C_{3d})]$$

(flip |λ| for LL)

not "charge conjugation" asymmetry

$$A_{unpol}^{e^+e^-} = \frac{\sigma^{e^+} - \sigma^{e^-}}{\sigma^{e^+} + \sigma^{e^-}}$$

$$A_d^{e^+e^-} = -(108\ ppm)Q^2 Y(y) R_V(x)(2C_{3u} - C_{3d})$$

(no polarization needed!)

(done) The general case

based on
Anselmino et al. [arXiv:hep-ph/9401264]
also in
Hobb et al. arXiv:0801.4791;
Brady et al.[arXiv:1108.4734 [hep-ph]].

For PVDIS:

$$A_{RL}^{e^-} = \frac{|\lambda|\,\eta_{\gamma Z}\left[g_A^e\, 2y\, F_1^{\gamma Z} + g_A^e\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma Z} + g_V^e (2-y) F_3^{\gamma Z}\right]}{2y\, F_1^{\gamma} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma} - \eta_{\gamma Z}\left[g_V^e\, 2y\, F_1^{\gamma Z} + g_V^e\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma Z} + g_A^e (2-y) F_3^{\gamma Z}\right]}$$

For A^{e+e-}:

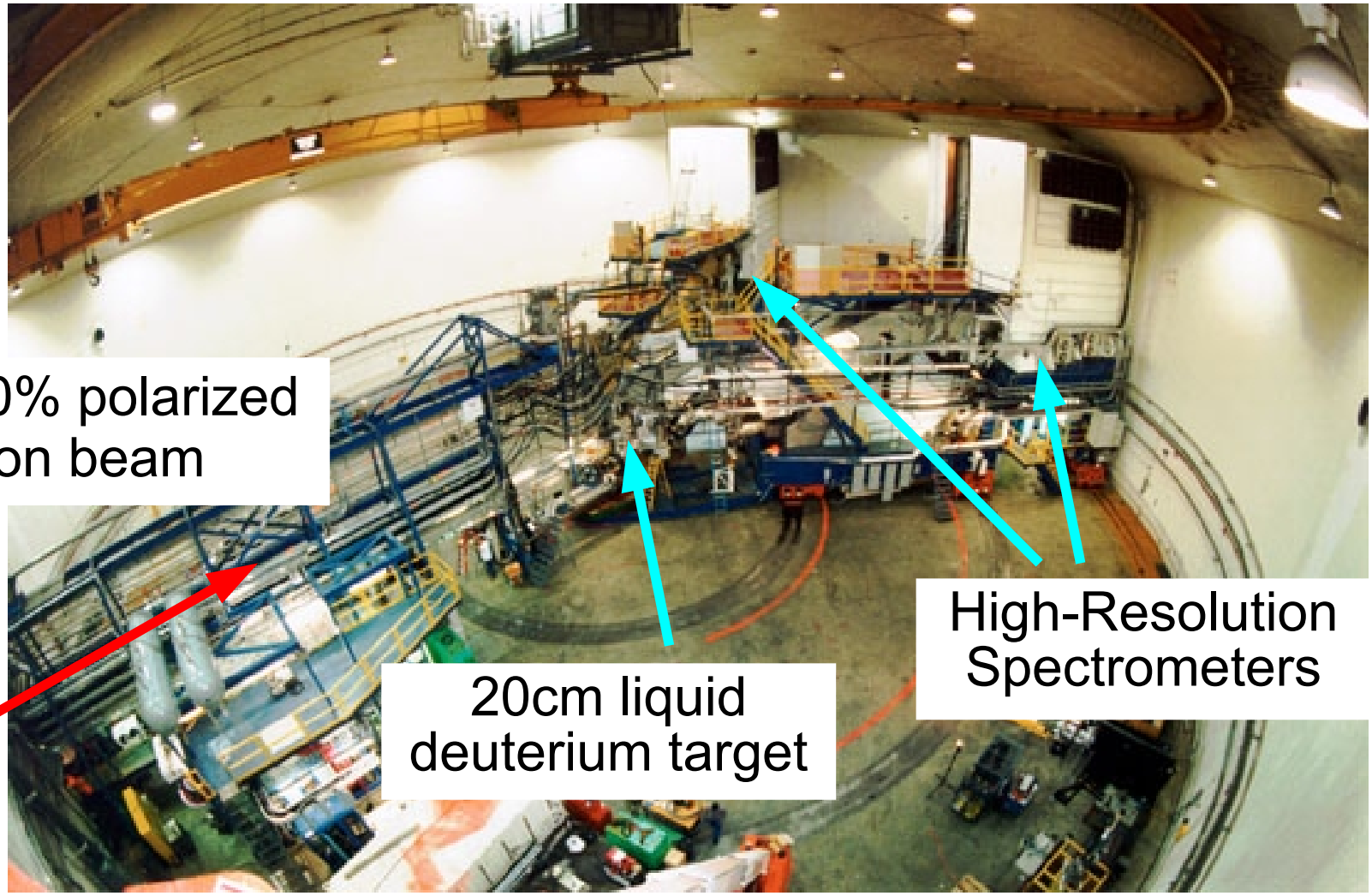
$$\eta_{\gamma Z} = \frac{G_F Q^2}{2\sqrt{2}\,\pi\alpha} \frac{M_Z^2}{M_Z^2 + Q^2}$$

$$A_{RL}^{e^+ e^-} = \frac{\eta_{\gamma Z}\left(|\lambda|\, g_V^e + g_A^e\right)(2-y) F_3^{\gamma Z}}{2y\, F_1^{\gamma} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma} - \eta_{\gamma Z}\left(g_V^e + g_A^e\right)\left[2y\, F_1^{\gamma Z} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma Z}\right]}$$

$$A_{RR}^{e^-} = \frac{\eta_{\gamma Z}\, g_A^e\left[-|\lambda| 2y\, F_1^{\gamma Z} - |\lambda|\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma Z} + (2-y) F_3^{\gamma Z}\right]}{2y\, F_1^{\gamma} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma} - \eta_{\gamma Z}\, g_V^e\left[2y\, F_1^{\gamma Z} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2 xy}{Q^2}\right) F_2^{\gamma Z} + (2-y) F_3^{\gamma Z}\right]}$$

PVDIS at 6 GeV (JLab Hall A)

- Measured two DIS points: Q^2=1.085 and 1.901 $(GeV/c)^2$



- Ran from Oct-Dec 2009
- Dedicated DAQ system counted 170 billion (E9) electrons in total

γ–Z box

Electroweak radiative corrections were applied to all couplings used in the calculation of the asymmetry. The electromagnetic fine structure constant α was evolved to the measured Q^2-values from $\alpha_{EM}|_{Q^2=0} = 1/137.036$ [52]. The evaluation takes into account purely electromagnetic vacuum polarization. The Fermi constant is $G_F = 1.1663787(6) \times 10^{-5}$ GeV^{-2} [52]. The $C_{1q,2q}$ were evaluated using Table 7 and Eq. (114-115) of Ref. [91] at our measured Q^2-values in the modified minimal subtraction ($\overline{\text{MS}}$) scheme using a fixed Higgs mass $M_H = 125.5$ GeV:

$$C_{1u}^{\text{SM}} = -0.1887 - 0.0011 \times \frac{2}{3} \ln(\langle Q^2 \rangle / 0.14\text{GeV}^2) \quad (86)$$

$$C_{1d}^{\text{SM}} = 0.3419 - 0.0011 \times \frac{-1}{3} \ln(\langle Q^2 \rangle / 0.14\text{GeV}^2) \quad (87)$$

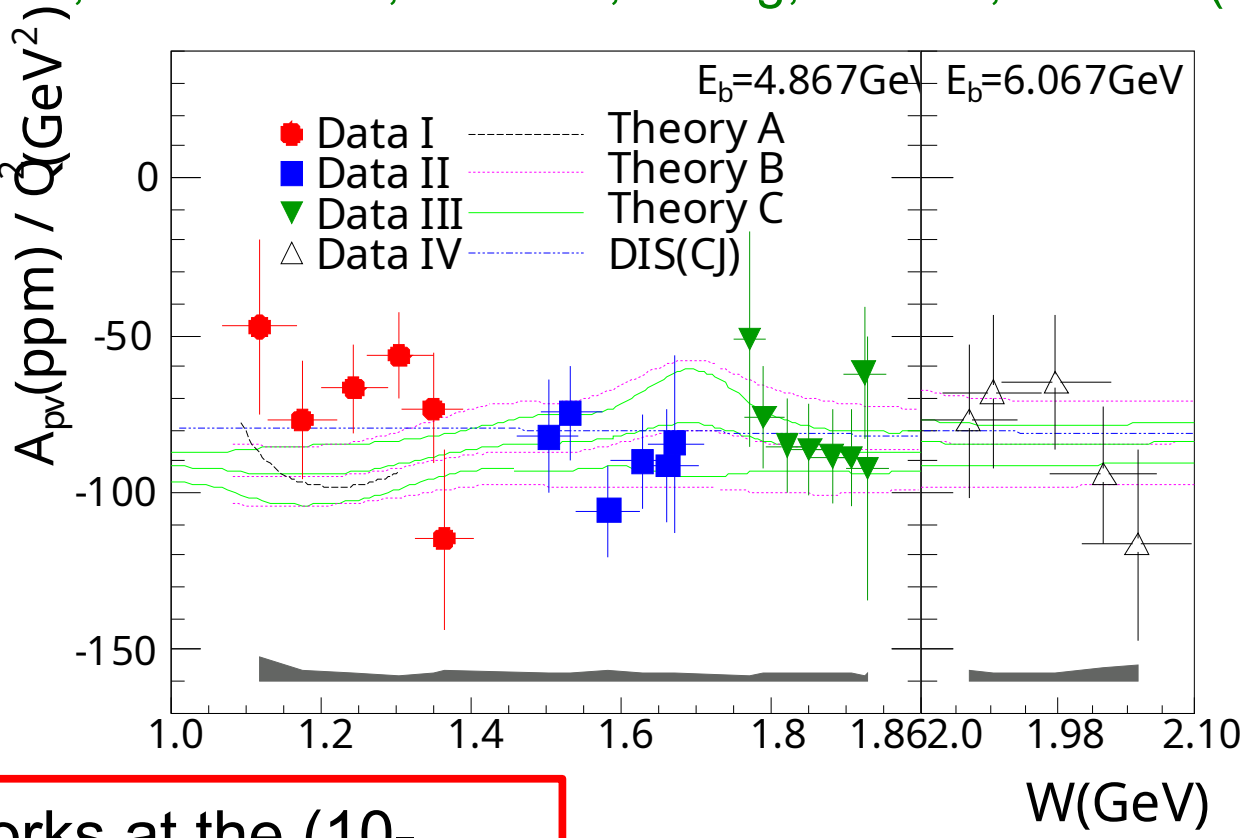
$$C_{2u}^{\text{SM}} = -0.0351 - 0.0009 \ln(\langle Q^2 \rangle / 0.078\ \text{GeV}^2) \quad (88)$$

$$C_{2d}^{\text{SM}} = 0.0248 + 0.0007 \ln(\langle Q^2 \rangle / 0.021\ \text{GeV}^2) \quad (89)$$

and it is expected that the uncertainty is negligible. Equations (86-89) include the "charge radius effect" and an estimate of the interference between γ-exchange and the γZ box, but not the effect from the $\gamma\gamma$ box. The effect from the $\gamma\gamma$ box was applied as a correction to the measured asymmetry as described in previous sections.

Resonance PV Asymmetry Results

A: Matsui, Sato, Lee, PRC72,025204(2005)
B: Gorchtein, Horowitz, Ramsey-Musolf, PRC84,015502(2011)
C: Hall, Blunden, Melnitchouk, Thomas, Young, PRD88, 013011 (2013)



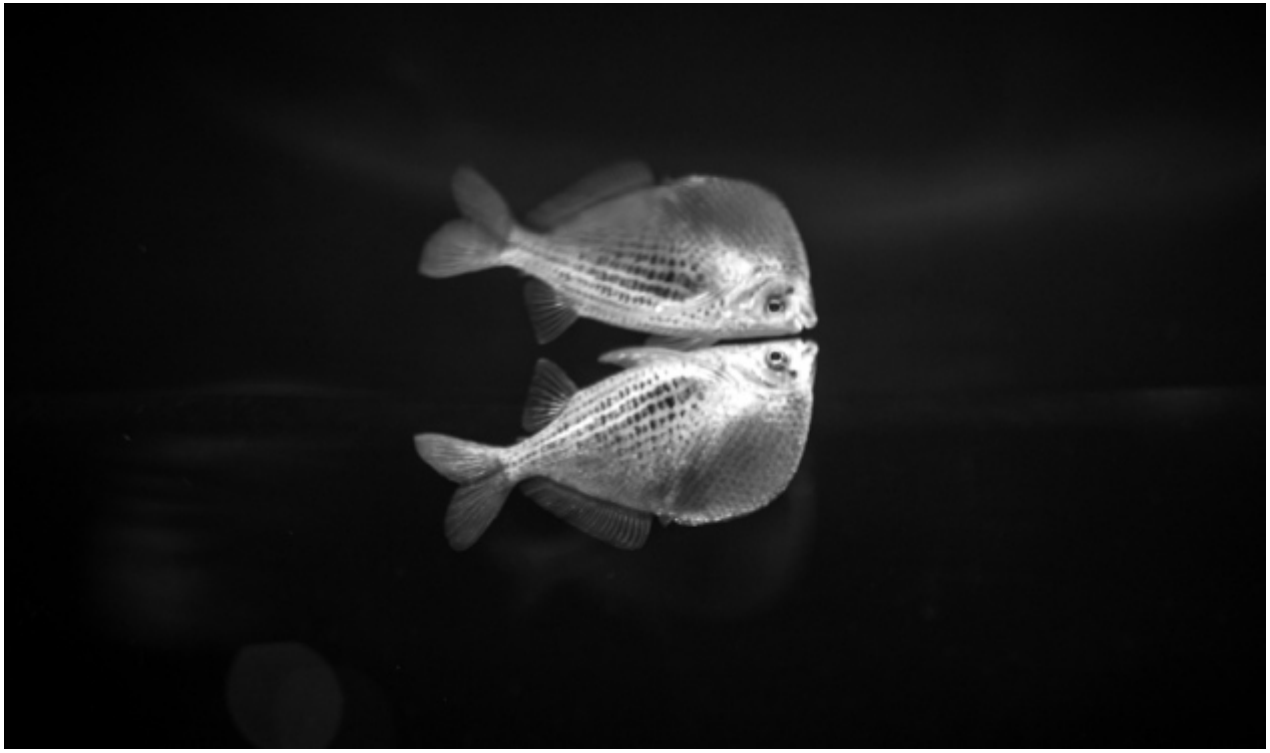
- "duality works at the (10-15)% level"
- helps to constraint gamma-Z box diagram correction for PVES experiments

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

Will a better measurement of res-parity help to constrain γ-Z models?

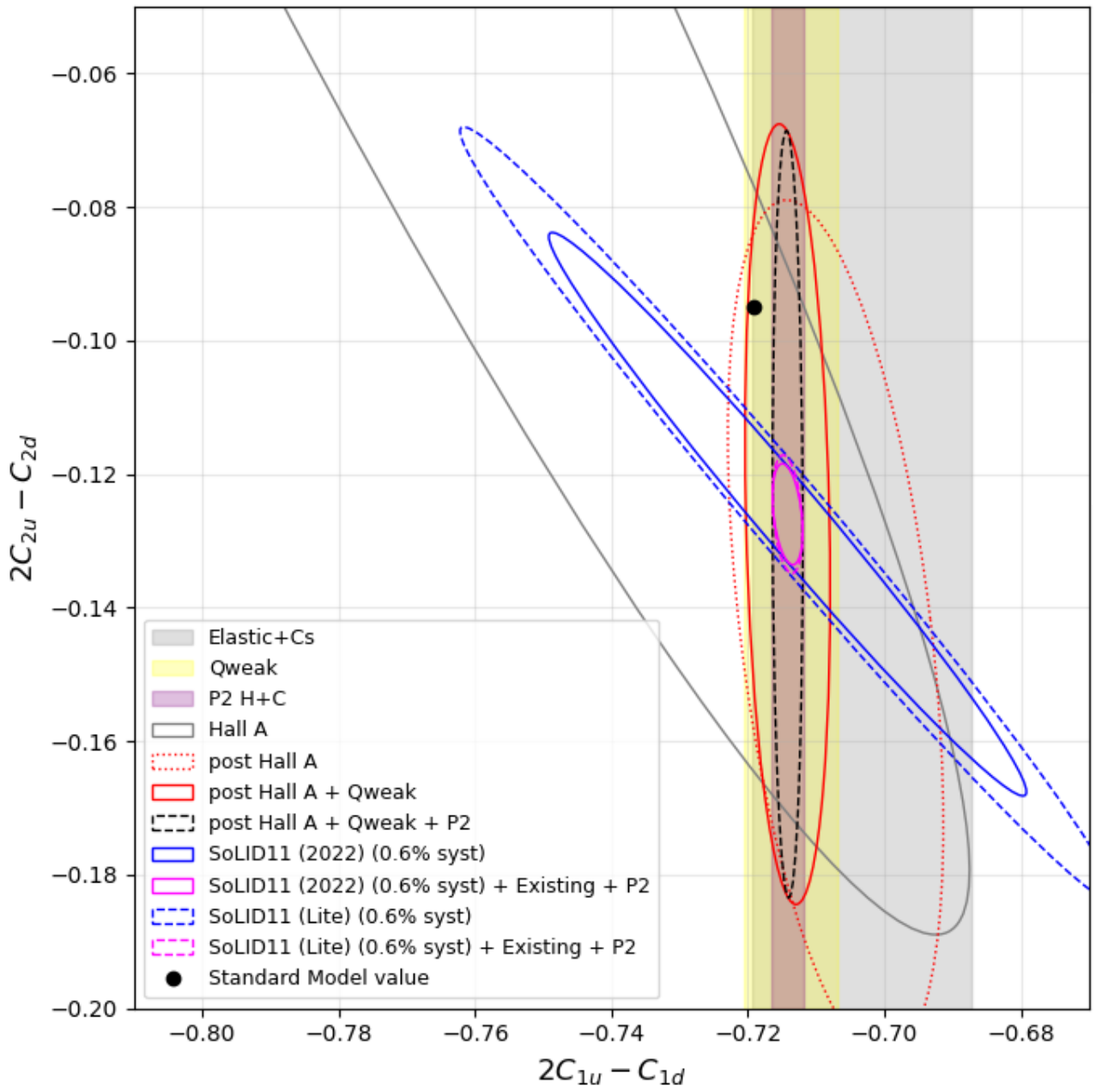
Nature | News **Force of nature gave life its asymmetry**

Dreiling, Gay, PRL 113, 118103 (2014).



Physicists have found hints that the asymmetry of life — the fact that most biochemical molecules are ‘left-handed’ or ‘right-handed’ — could have been caused by electrons from nuclear decay in the early days of evolution. In an experiment that took 13 years to perfect1, the researchers have found that these electrons tend to destroy certain organic molecules slightly more often than they destroy their mirror images.

PVDIS with High Luminosity – 2026 "Lite"



Polarimetry	0.4
Q^2	0.2
Radiative Corrections	0.2 ←$\times\sqrt{2}$
Event reconstruction	0.2
Statistics	0.3 ←$\times\sqrt{2}$
PDF uncertainty	0.2
Total systematic	0.57
Total statistic and systematic	0.64

- "SoLID lite" ellipse "grew" by 40%, but the combined uncertainty on C2 only increased 20%