Argonne NATIONAL LABORATORY
... for a brighter future

PVDIS Experiments with Baseline Equipment in Halls A & C at JLab
E08-011 and E-12-07-102

Paul E. Reimer

3 June 2008

- *Historical review*
- *What can we learn by repeating our past?*
  - QCD Physics
  - ElectroWeak Physics
  - Questions in Interpretation
- *6 GeV JLab E08-011*
- *12 GeV JLab E12-07-102*

PV-DIS in 1977

PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING☆

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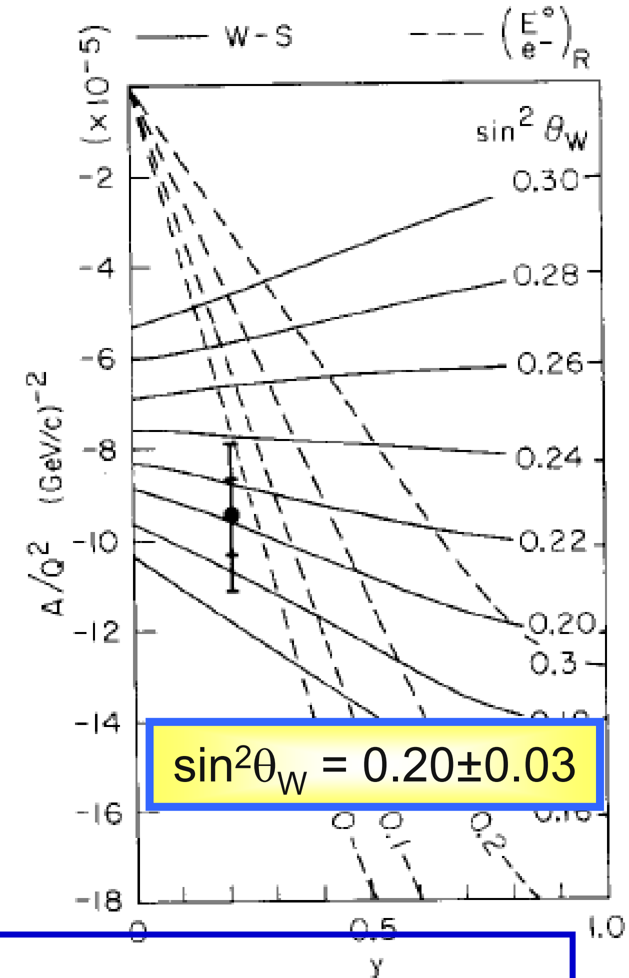
Phys. Lett. 77B, 347 (1979)

Received 14 July 1978



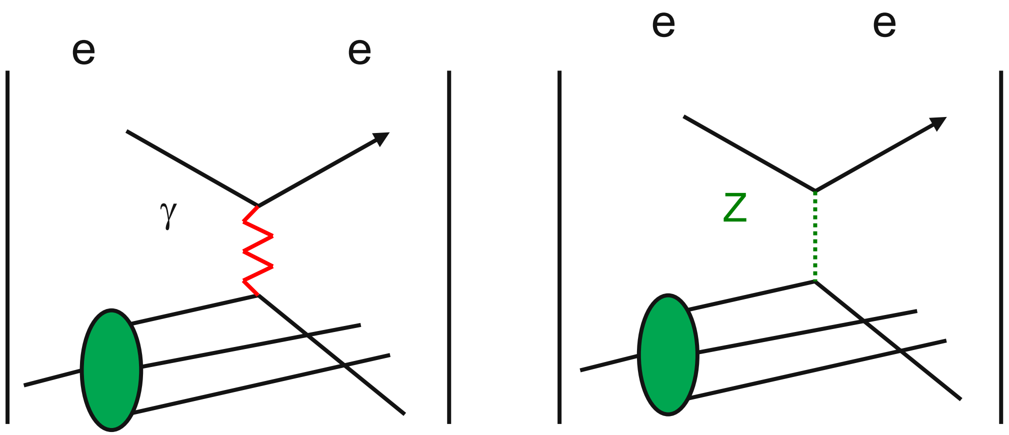
Abstract

We have measured parity violating asymmetries in the inelastic scattering of longitudinally polarized electrons from deuterium and hydrogen. For deuterium near $Q^2 = 1.6$ $(GeV/c)^2$ the asymmetry is $(-9.5\times10^{-5})Q^2$ with statistical and systematic **uncertainties each about 10%**

PV-DIS in 1977

- Prescott *et al.* were measuring the interference between γ and Z^0 exchange in Deep Inelastic Scattering (DIS)

A_{PV} ~



- Tour de **Force** experiment which established the Standard Model and the value of $\sin^2\theta_W$.

> for two SU(2) × U(1) models. The simplest model (W–S) is in good agreement with our measurement for $\sin^2\theta_W = 0.20 \pm 0.03$ which is consistent with the values obtained in neutrino experiments. The hybrid mod-

From 1[st] PRL ±15%

PVDIS variables

Cahn and Gilman, PRD **17** 1313 (1978) polarized electrons on deuterium

$$A_{\mathrm{iso}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_L}$$

$$= -\left[\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right]\frac{2C_{1u} - C_{1d} + Y\left(2C_{2u} - C_{2d}\right)}{5}$$

$$Y = \frac{1-(1-y)^2}{1+(1-y)^2 - y^2}$$

ElectroWeak Standard Model

C_{1q} ⇒ NC **vector** coupling to q

× NC **axial** coupling to e

C_{2q} ⇒ NC **axial** coupling to q

× NC **vector** coupling to e

$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \approx -0.19$$
$$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \approx 0.35,$$

$$C_{2u} = -\frac{1}{2} + 2\sin^2(\theta_W) \approx -0.04$$
$$C_{2d} = \frac{1}{2} - 2\sin^2(\theta_W) \approx 0.04.$$

with $\sin^2(\theta_W) \approx 0.23$

PVDIS variables

$$A_{\text{iso}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_L}$$

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$$Y = \frac{1 - (1-y)^2}{1 + (1-y)^2 - y^2 R/(1+R)}$$

$$R(x, Q^2) = \sigma_L/\sigma_R \approx 0.2$$

ElectroWeak Standard Model

C_{1q} ⇒ NC **vector** coupling to *q* × NC **axial** coupling to *e*

C_{2q} ⇒ NC **axial** coupling to *q* × NC **vector** coupling to *e*

R^γ is well measured, but does $\mathbf{R^\gamma = R^{\gamma Z}}$?

See Hobbs & Melnitchouk, PRD **77**, 114023 (2008)

PVDIS variables

$$A_{\mathrm{iso}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_L}$$

Cahn and Gilman, PRD **17** 1313 (1978) polarized electrons on deuterium

$$R_s(x) = \frac{2S(x)}{U(x)+D(x)} \xrightarrow{\text{large x}} 0$$

$$R_v(x) = \frac{u_v(x)+d_v(x)}{U(x)+D(x)} \xrightarrow{\text{large x}} 1$$

$$= -\left[\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right]\frac{2C_{1u} - C_{1d}\left[1+R_s\right] + Y\left(2C_{2u} - C_{2d}\right)R_v}{5+R_s}$$

$$Y = \frac{1-(1-y)^2}{1+(1-y)^2 - y^2 R/(1+R)}$$

$$R(x,Q^2) = \sigma_L/\sigma_R \approx 0.2$$

QCD
- Parton distributions
  - (u, d, s, c)
- Nuclear Effects (EMC)
- Charge Symmerty
  - (CSV)
- Higher Twist (HT)

ElectroWeak Standard Model

C_{1q} ⇒ NC **vector** coupling to q
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C_{2q} ⇒ NC **axial** coupling to q
× NC **vector** coupling to e

R^{γ} vs $R^{\gamma Z}$
See Hobbs & Melnitchouk, PRD **77**, 114023 (2008)

Charge Symmetry Violation

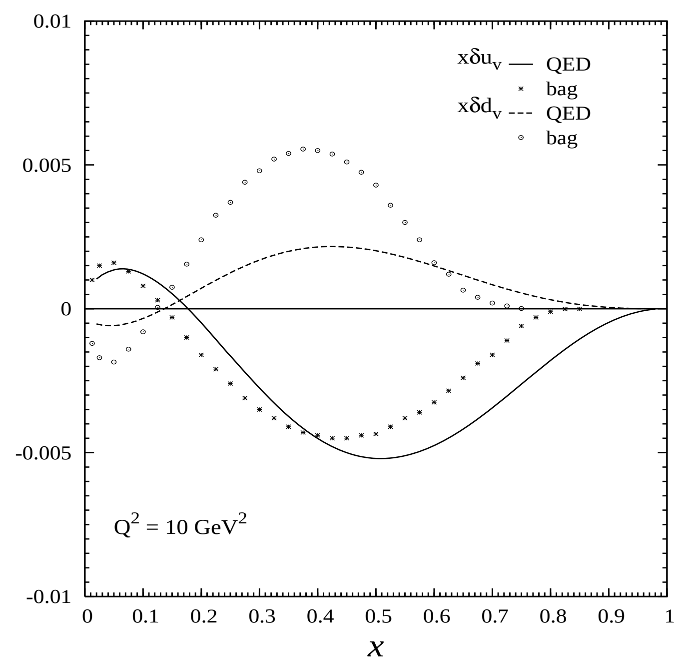
Figures from T. Londergan

Charge symmetry	Charge Symmetry Violation
$u^p(x) = d^n(x)$	$\delta u(x) = u^p(x) - d^n(x)$
$d^p(x) = u^n(x)$	$\delta d(x) = d^p(x) - u^n(x)$

quark mass difference: $\delta m \equiv m_d - m_u \sim 4$ MeV
n-p mass difference: $\delta M \equiv M_n - M_p = 1.3$ MeV

Sather: Analytic Quark Model Approximation for Valence Parton CSV.

Leads to analytic results (model-dependent)



"QED Splitting"

- Contributes even if $m_u = m_d$ and $M_n = M_p$
- **add to** quark model CSV term (almost)
- MRST incorporate QED splitting with PDFs in global fit to high energy data

Londergan,Murdock,Thomas Phys. Rev. **D**73, 076004 (2006)
MRST, Eur.Phys.J. **39**, 155 (05);
Glueck, Jimenez-Delgado, Reya, PRL**95**, 022002 (05)

Does data already constrain partonic CSV?

MRST PDF global fit [Eur Phys J C35, 325 (04)]: contains both QED and QCD splitting)

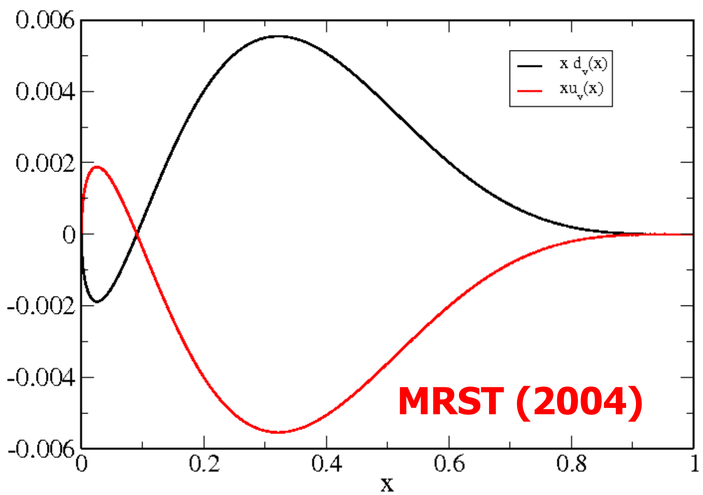
$$\pm d_{\mathrm{v}}(x) = -\kappa f(x) = -\pm u_{\mathrm{v}}(x)$$

$$f(x) = x^{-0.5}(1-x)^4(x-.0909)$$

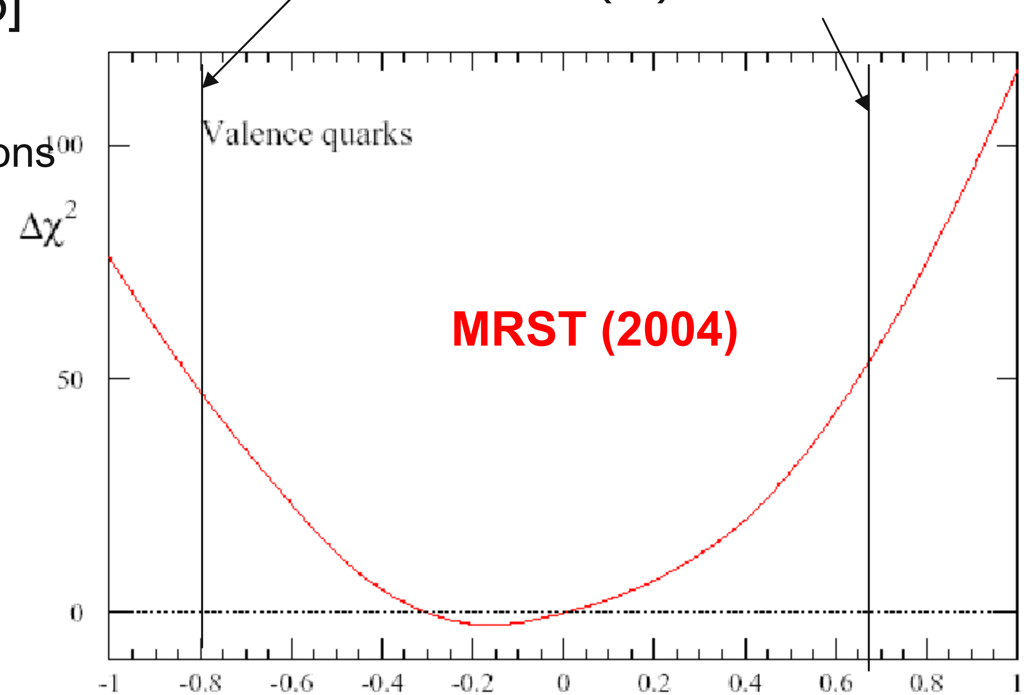
Best fit: **κ = -0.2**, but κ ∈ [-0.8, 0.65]

large uncertainty !

Remarkably similar to model CSV calculations



90% conf limit (κ)



Figures from T. Londergan

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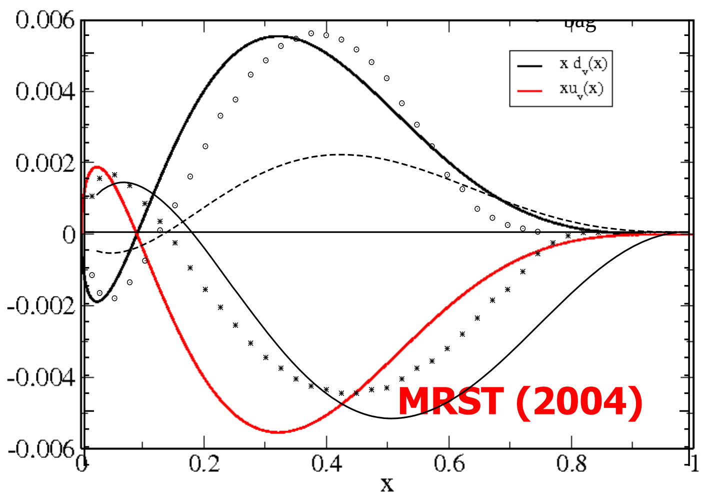

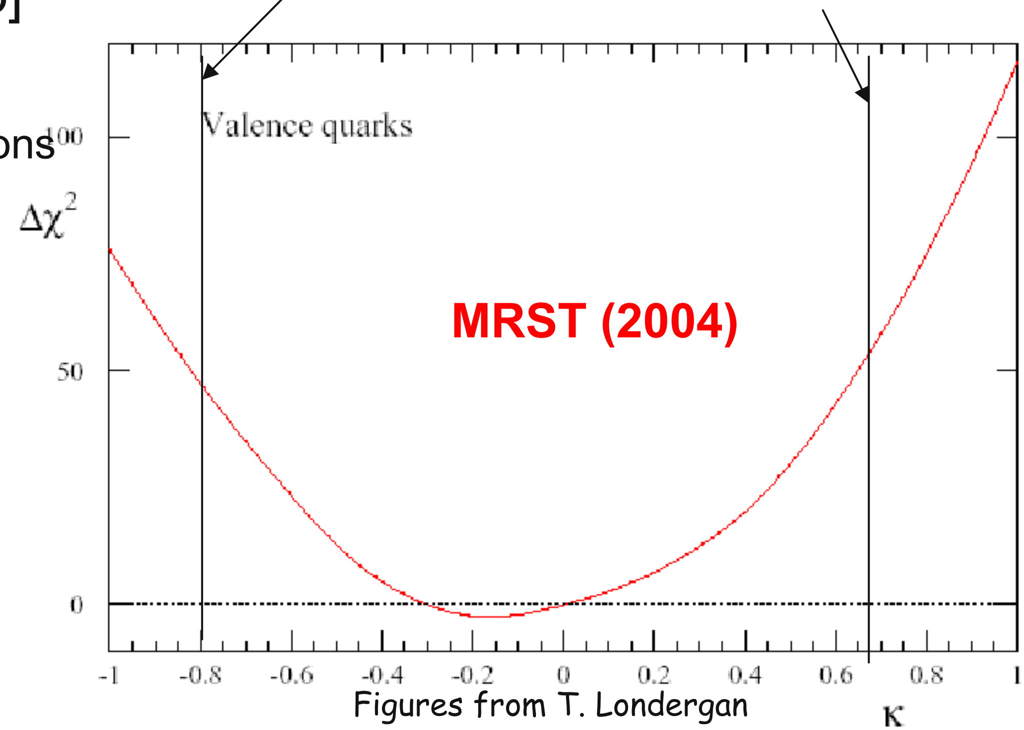

Figures from T. Londergan

Higher Twist Effects

- From Non-PV DIS Data
  - MRST: HT on $F_{1,2}$ < 0.1% for 0.1<x<0.3 in NNLO and NNNLO; EPJC35, 325 (2004)
  - LSS: HT on g_{1d} and A_{1d} consistent with zero for 0.1<x<0.3 in NLO analysis; hep-ph/0309048, hep-ph/0411323, priv. comm.
  - Moments of g_1 show negligible HT; hep-ph/0404066 (n); hep-ph/0404195 (p)
- In PV DIS:
  - Bag model: ~0.3%/Q^2 correction to A_d Phys. Rev. D 31, 2760 (1985)
  - QCD NLO, NNLO calculations: ~1%/Q^2 correction to A_d for 0.1 < x < 0.3 W. L. van Neerven (Jlab LOI 03-106)
  - Quick calculation from 3 MIT Bag Models show (0.2-0.4)% HT effect on A_d for Q^2 = 1-2 GeV^2, smaller for higher Q^2. (G. Sacco and M. Ramsey-Musolf)
- Overall:
  - Most theories predict <1%/Q^2 HT correction to A_d

Bottom Line:

Some limits, but we need to understand the physics and need to measure Q^2 and x dependence

Other QCD Effects

- EMC effect—see talk by I. Cloet
  - Very interesting and could be significant for non-isoscalar targets
  - Possibly could be addressed by with additional running time either 6 or 12 GeV experiments
  - Could address NuTeV Anomoly

- d/u ratio at high-x
  - Essentially unknown due to nuclear corrections in data
  - Kinematics not within range 6 or 12 GeV proposal “baseline” equipment proposals

Can these be constrained more with existing (or standard 12 GeV) equipment?

- Quark Scattering
  - DIS region ⇒ $Q^2 > 1.0$ GeV^2
    ⇒ $W^2 > 2.0$ GeV^2
- Better sensitivity to $2C_{2u}$-C_{2d} ⇒ Large Y
- Hadronic Physics
  - Sea quark uncertainties ⇒ x >~ 0.3
  - d(x)/u(x) uncertainties ⇒ deuterium target
  - Minimize higher twist ⇒ Large Q^2
    ⇒ $x < 0.7$
  - Reduce CSV contribution ⇒ Low x
- Minimize π backgrounds ⇒ $E'/E>0.3$ ($y<0.7$)
- Reasonable rates ⇒ determine PID event by event
  ⇒ realistic run time

6 GeV E08-011

- Hall A Both HRS
- Low Q^2, but constrain HT via 2 meas.

12GeV E12-07-102

- Hall C SHMS and HMS

Can these be constrained more with existing (or standard 12 GeV) equipment?

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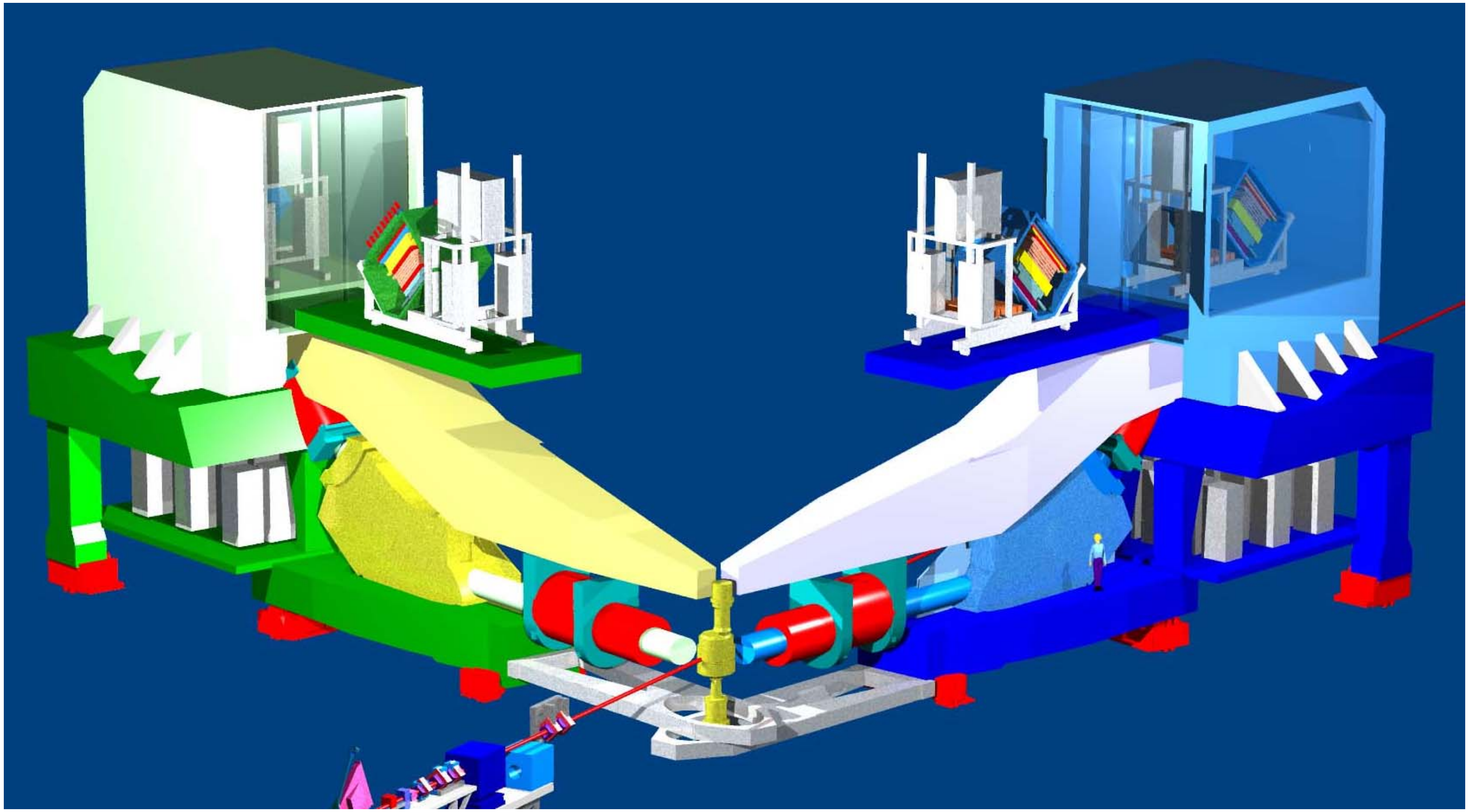
  ⇒ realistic run time

Or, can we constrain higher twist with these measurements?

6 GeV E08-011
- Hall A Both HRS
- Low Q^2, but constrain HT via 2 meas.

12GeV E12-07-102
- Hall C SHMS and HMS

6 GeV PVDIS E08-011Hall A



JLab E08-011 6 GeV PVDIS Collaboration

A. Afanasev, D.S. Armstrong, J. Arrington, T.D. Averett, E.J. Beise, W. Bertozzi, P.E. Bosted, H. Breuer, J.R. Calarco, A. Camsonne, G.D. Cates, J.-P. Chen, E. Chudakov, P. Decowski, X.-Y. Deng, A. Deur, J. Erler, J.M. Finn, S. Gilad, K.A. Griffioen, K. Grimm, K. Hafidi, J.-O. Hansen, D.W. Higinbotham, R. Holmes, T. Holmstrom, R.J. Holt, J. Huang, P.M. King, W. Korsch, S. Kowalski, K. Kumar, N. Liyanage, A. Lukhanin, D.J. Mack, D.J. Margoziotis, P. Markowitz, D. McNulty, R. Michaels (co-spokesperson), B. Moffit, P. Monaghan, N. Muangma, V. Nelyubin, B.E. Norum, K. Paschke, C. Perdrisat, A.J. Puckett, Y. Qiang, P.E. Reimer (co-spokesperson), J. Roche, A. Saha, B. Sawatzky, N. Simicevic, J. Singh, S. Sirca, A. Shahinyan, R. Snyder, P. Solvignon, P.A. Souder, N. Sparveris, R. Subedi, V. Sulkosky, W.A. Tobias, D.-C. Wang, K. Wang, S.P. Wells, B. Wojtsekhowski, X.-H. Zhan, X.-C. Zheng (co-spokesperson)

The Hall A Collaboration

Argonne, Cal State, Florida International, JLab, Kentucky, Louisiana Tech, Ljubljana (Slovenia), MIT, Maryland, Massachusetts, New Hampshire, Universidad Nacional Autonoma de Mexico, Ohio, Randolph-Mason, Smith, Syracuse, Temple, Virginia, William and Mary, Yerevan (Armenia)

6 GeV Hall A Measurement

Primary measurement:

- 2 kinematic points
- Similar x
- Q^2 = 1.1 and 1.9 GeV^2

Large Asymmetry!

Requires counting DAQ under development

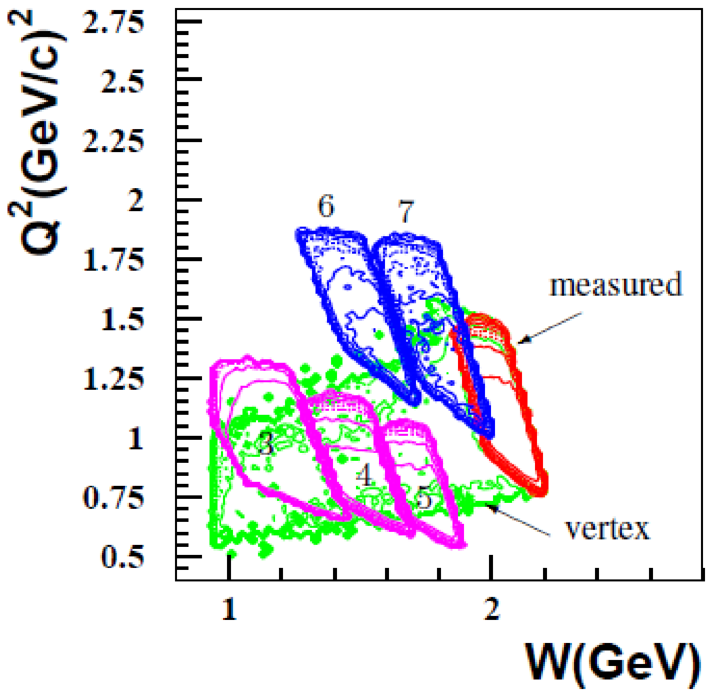
Kinematics	I	II
x_{Bj}	0.25	0.30
Q^2 (GeV)^2	1.11	1.90
E (GeV)	6.0	6.0
E' (GeV)	3.66	2.63
θ	$12.9^{\pm}$	$20.0^{\pm}$
W^2 (GeV)^2	4.16	5.30
Y	0.470	0.716
R_c	< 0.001	< 0.001
R_s	0.52	0.41
R_v	0.872	0.910
A_d (measured, ppm)	-91.3	-160.7
e^- rate (KHz)	269.8	25.1
π^-/e^- ratio	0.9	6.4
e^+/e^- ratio	0.073%	0.463%
total rate (KHz)	513.0	186.2
e^- production time (days)	9.0	32.0
dummy cell (endcap) runs (hours)	3.5	12.4
e^+ runs (hours)	4.0	4.0

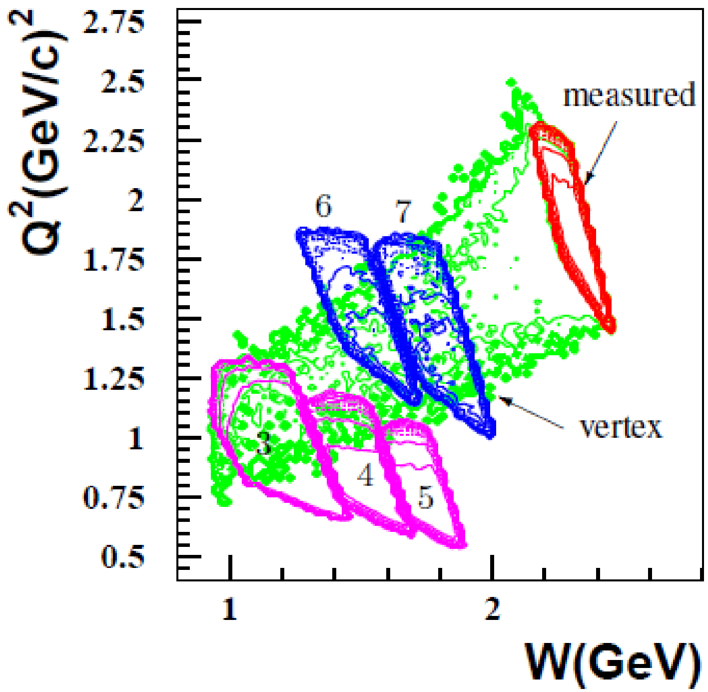
6 GeV A_d expected uncertainties

Source		$Q^2 = 1.11\ (\mathrm{GeV}/c)^2$	$Q^2 = 1.90\ (\mathrm{GeV}/c)^2$
Systematics	$\Delta P_{beam}/P_{beam} = 1\%$	1%	1%
	Deadtime correction	$\approx 0.3\%$	$\approx 0.3\%$
	Event pile-up	$\approx 0.1\%$	$\approx 0.1\%$
	Target endcap contamination	0.4%	0.4%
	Target density	0.1%	0.1%
	Target purity	$< 0.02\%$	$< 0.02\%$
	Pion background	$< 0.2\%$	$< 0.2\%$
	Pair production background	$< 0.2\%$	$< 0.2\%$
	Total syst.	1.36%	1.36%
Statistical		2.11%	2.09%
Total	Syst.+Stat.	2.52%	2.49%

6 GeV electromagnetic radiative corrections

Kinematics	E (GeV)	θ θ	E' (GeV)	$\langle Q^2 \rangle$ $(\mathrm{GeV})^2$	$\langle x \rangle$	$\langle W \rangle$ (GeV)	e^- rate (KHz)	A_d (ppm)	goal for $\Delta A_d/Ad$
3	4.8	$12.9^{\pm}$	4.00	0.92	0.61	1.22	983.0	-72.4	5%
4	4.8	$12.9^{\pm}$	3.60	0.85	0.38	1.51	915.1	-68.4	5%
5	4.8	$12.9^{\pm}$	3.25	0.77	0.26	1.74	833.7	-63.0	5%
6	4.8	$19.0^{\pm}$	2.77	1.49	0.39	1.52	104.5	-120.7	8%
7	6.0	$14.0^{\pm}$	4.00	1.39	0.37	1.80	279.7	-113.0	8%



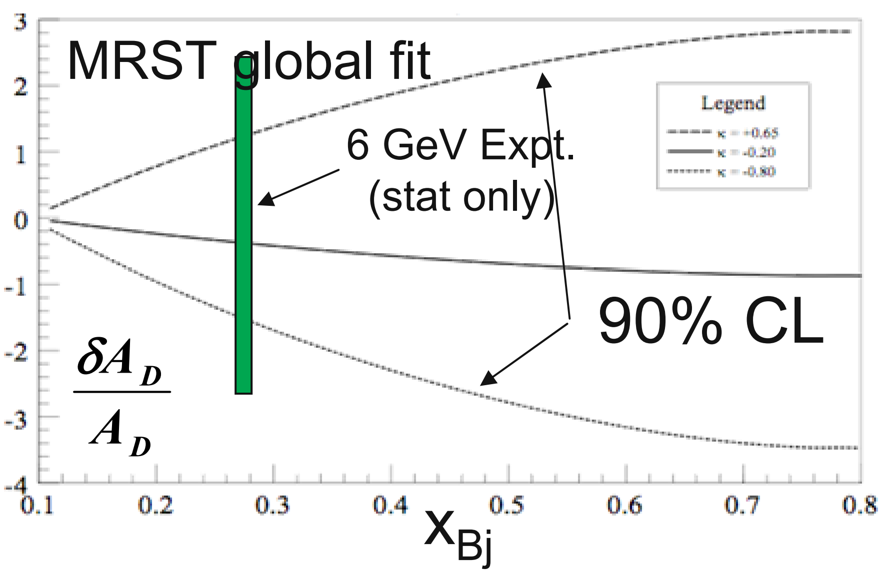


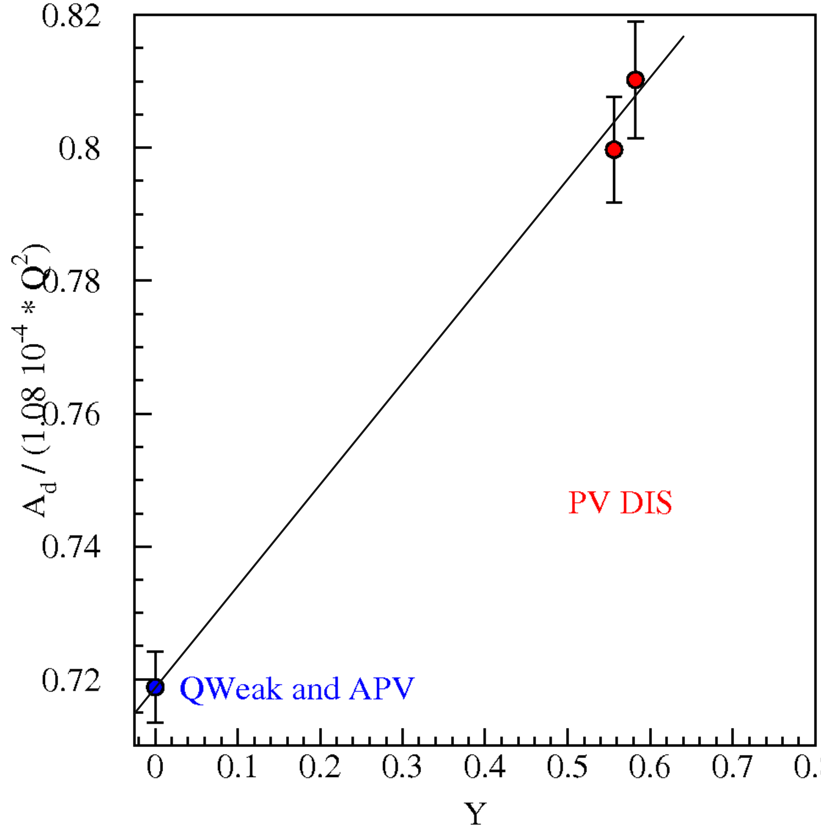
Interpretation of 6 GeV result

Treat Hadronic effects (CSV and HT) as uncertainties in extraction of $\Delta(2C_{2u}-C_{2d})$

- 90% CL on CSV from MRST fit significantly smaller than expected statistical uncertainty
- **Constrain HT to 1%/Q^2 on A_d from 1.1 and 1.9 GeV^2 measurements**

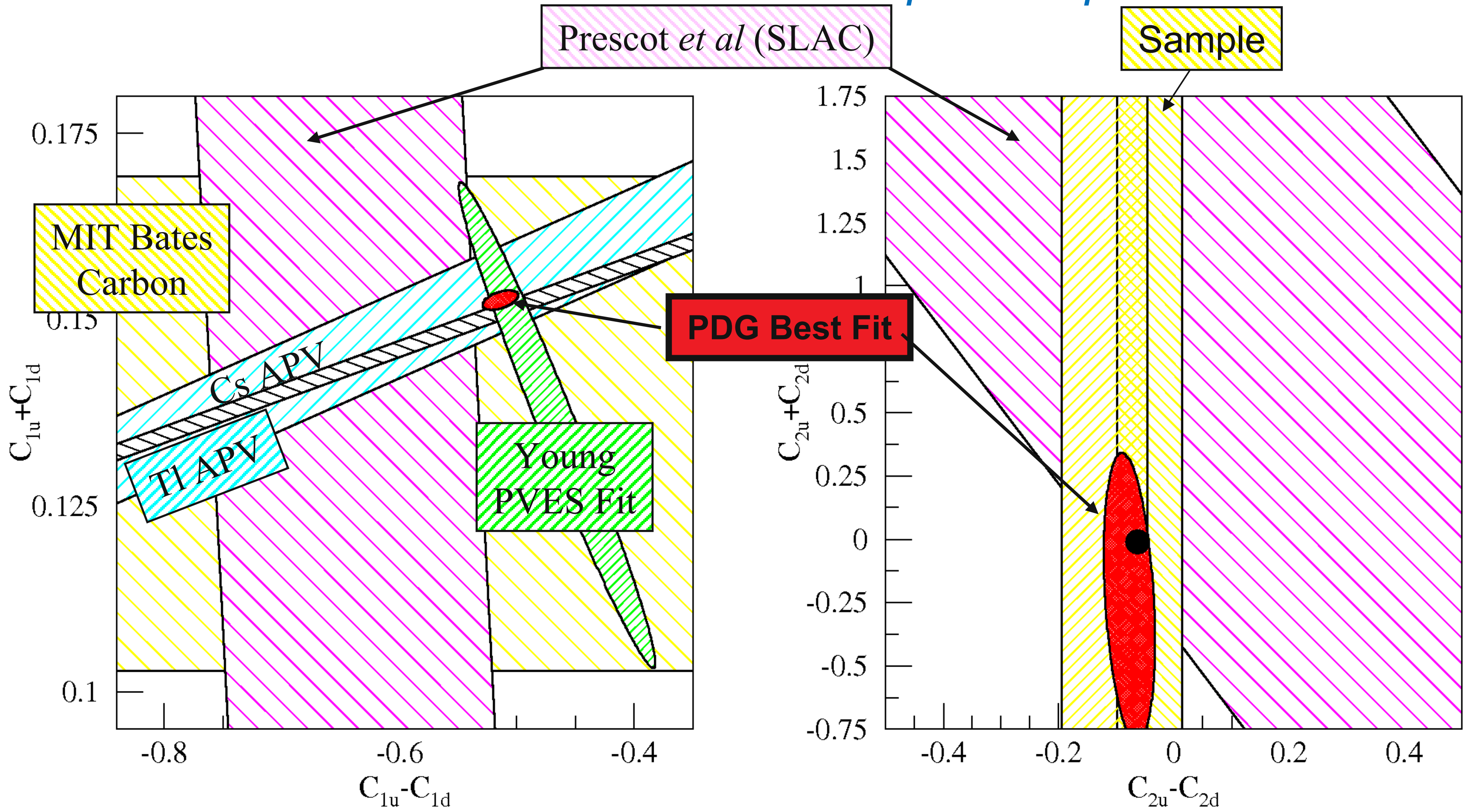
Assume Global fit including QWeak, APV, and Young's PVES fit for C_{1q}.





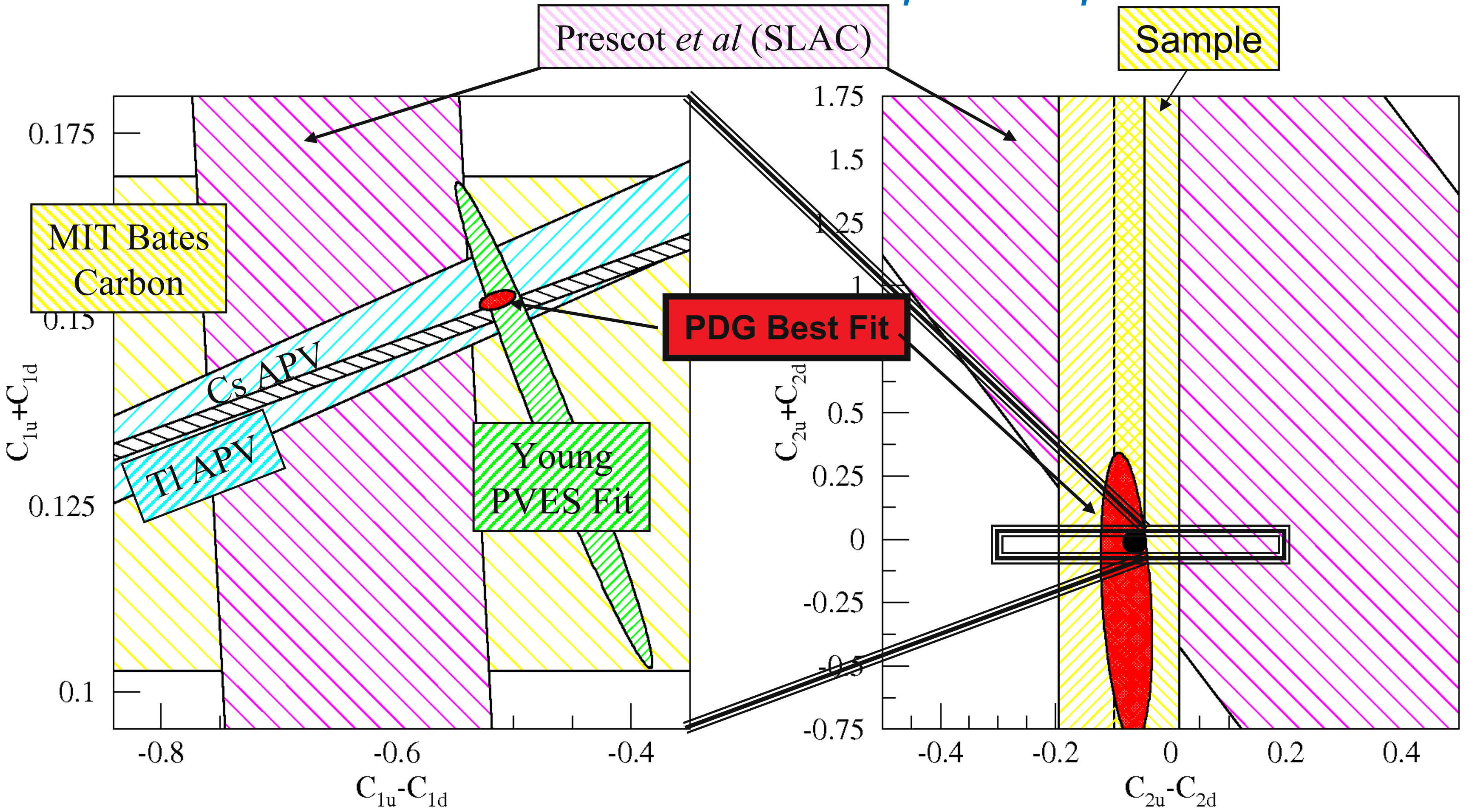
$$A_d \propto 2C_{1u} - C_{1d} + Y\,(2C_{2u} - C_{2d})$$

Present experimental knowledge of C_{1q} and C_{2q}



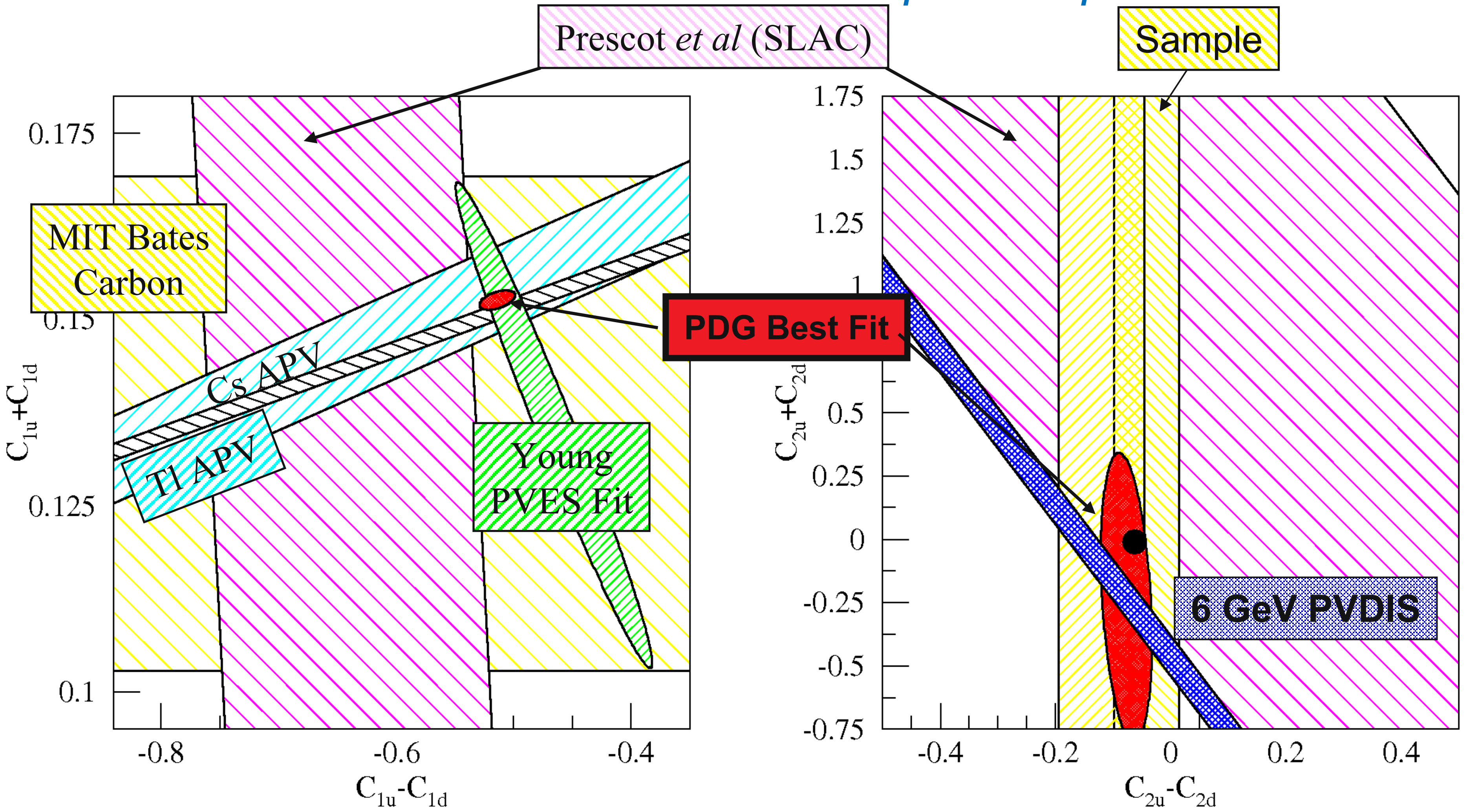
Status: Scheduled to run in Fall 2009; parasitic DAQ tests underway now.

Present experimental knowledge of C_{1q} and C_{2q}



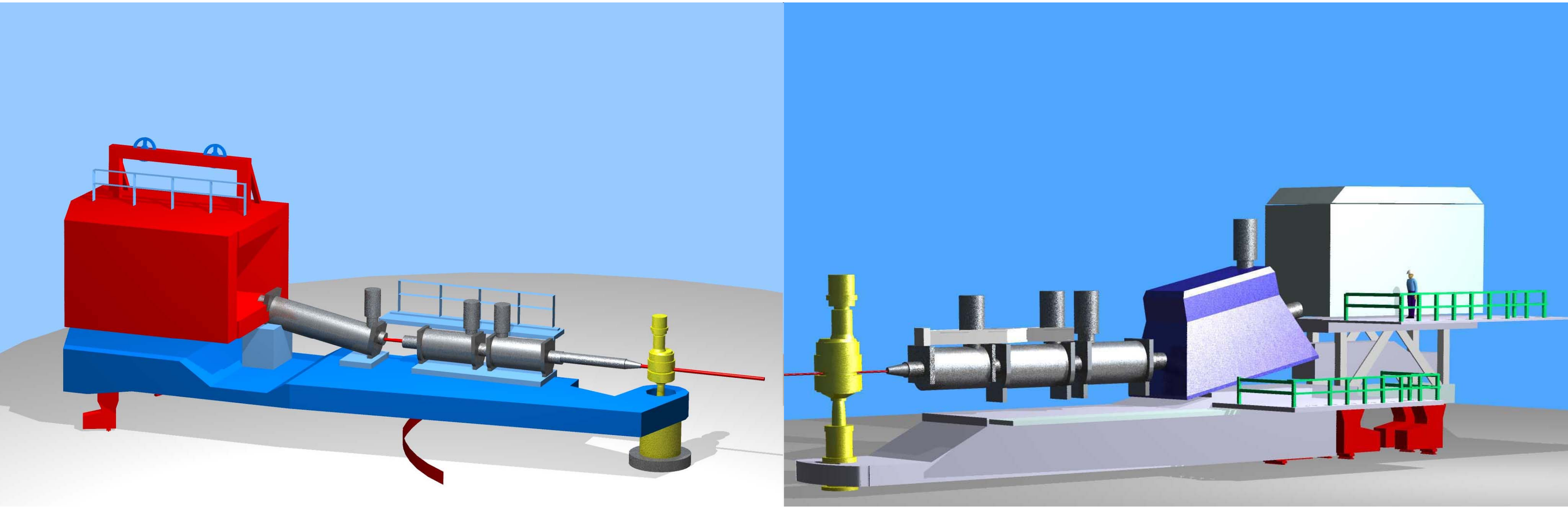
Room for improvement in C_{2q} measurement

Present experimental knowledge of C_{1q} and C_{2q}



Status: Scheduled to run in Fall 2009; parasitic DAQ tests underway now.

12 GeV PVDIS E12-07-102
Hall C



JLab E12-07-102 12 GeV Hall C PVDIS Collaboration

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Argonne, Florida Int., JLab, Louisiana Tech, Maryland, U. Mass., MIT, Ohio U., Randolph-Macon, Syracuse, Temple, Virginia, William and Mary,

12 GeV Hall C Measurement with Baseline Spectrometers

	HMS		SHMS	
	Average	Range	Average	Range
Central Angle	13.5°	-	13.5°	-
Momentum (GeV)	6.0	$5.4 - 6.6$ ($\pm 10\%$)	5.8	$4.9 - 6.7$ ($-15/+15\%$)
$\delta\Omega$ (msr)	-	6.8	-	3.5
Q^2 (GeV^2)	3.3	$2.6 - 4.0$	3.2	$2.6 - 3.8$
W^2 (GeV^2)	7.1	$6.1 - 8.1$	7.6	$6.3 - 8.8$
x	0.35	$0.27 - 0.43$	0.33	$0.25 - 0.41$
Y	0.56		0.58	
DIS Rate (kHz)	190		138	
A_d (ppm)	285	$220 - 350$	280	$210 - 340$
$\delta A_d/A_d$[%] (672 hours)	0.65		0.77	
π/e ratio	0.3	$0.1 - 0.6$	0.45	$0.1 - 1.0$
e^+/e ratio	0.00031	$2.7 \times 10^{-5} - 0.001$	0.0007	$3.2 \times 10^{-6} - 0.0036$
Total Rate (kHz)	240		202	

- Use both HMS and SHMS to minimize beam time requirements
- **Could adjust to slightly different kinematics to obtain (x, Q^2) dependence**
- **Calorimeter automatically provides some binning in W and Y**

Experimental Uncertainties

Source	$\frac{\delta A_d}{A_d}$
Polarization measurement	5.0×10^{-3}
Determination of Q^2	3.9×10^{-3}
Target Endcaps	1×10^{-3}
Target Purity	0.4×10^{-3}
Rescatter background	0.2×10^{-3}
π^- contamination	0.01×10^{-3}
Radiative Corrections	4×10^{-3}
Total Syst	7.6×10^{-3}
Stat	5×10^{-3}

- Q^2 Determination—$Q^2 = 2EE'(1 - \cos\theta)$
  - $\delta E/E \approx 1 \times 10^{-3}$, $\delta E'/E' \approx 1 \times 10^{-3}$ and $\delta\theta \approx 0.4$mrad (HMS)
  - Will require low current running with both “Counting” and “Standard” DAQ running concurrently for calibration.

Charge Symmetry

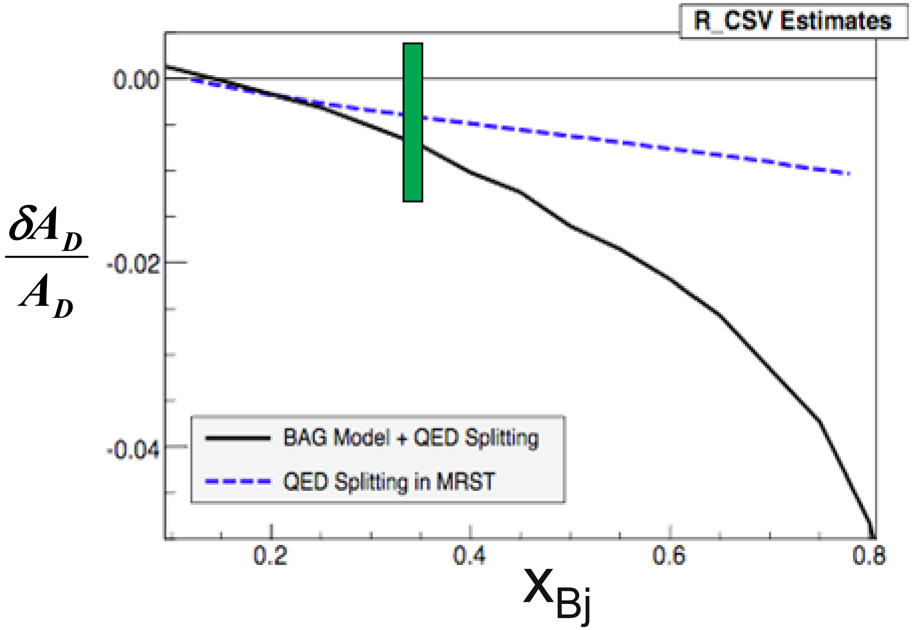
$\delta u(x) = u^p(x) - d^n(x)$

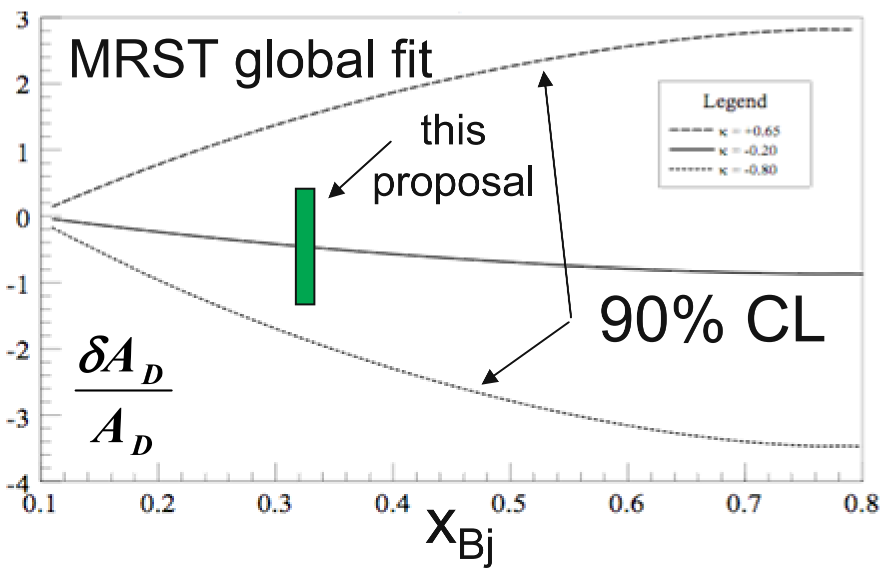
$\delta d(x) = d^p(x) - u^n(x)$

$$\frac{\delta A_d}{A_d} \approx 0.3 \left(\frac{\delta u - \delta d}{u + d} \right)$$

Sensitivity to CSV will be further enhanced if u+d falls off more rapidly than δu-δd as $x \to 1$

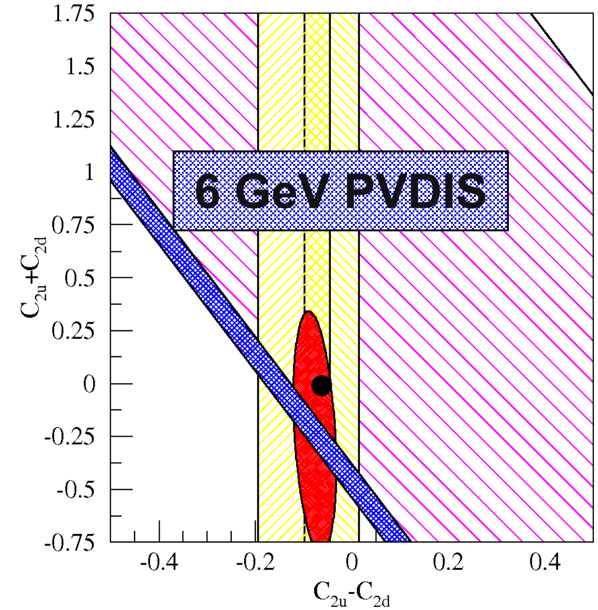
- Direct observation of parton-level CSV would be very exciting!
- Important implications for high energy collider PDFs
- Could explain significant portion of the NuTeV anomaly (or within 90% CL significantly increase anomaly).

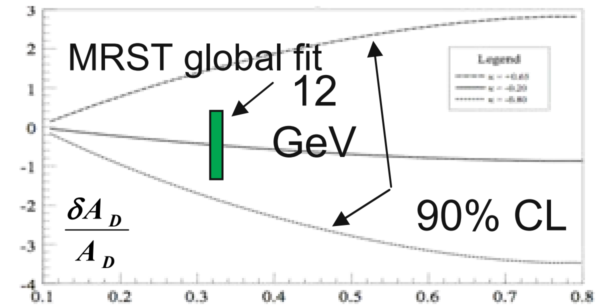


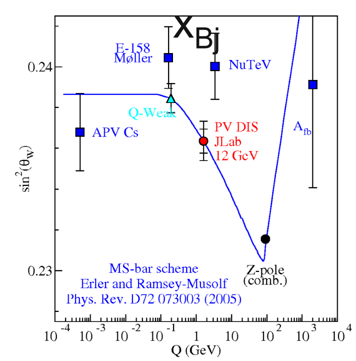


Conclusion

- Parity Violation in Deep Inelastic Scattering offers an opportunity for additional exciting physics at JLab.
  - $2C_{2u}$-C_{2d} is essentially unconstrained
  - Charge Symmetry Violation
  - **Higher Twist Effects**
- At 6 GeV we can constrain relatively unmeasured C_{2q} couplings
- At 12 GeV, this measurement can be realized in Hall C with baseline 12 GeV Spectrometers
  - Large Asymmetry, $A_d \approx 280$ ppm
  - $\delta A_d/A_d = \pm 0.005$ (stat.) ± 0.007 (syst.)
- **We will have high statistics measurement at Q^2=1.1, 1.9 and 3.3 GeV^2. What can we learn about Higher Twist Effects from this data?**
- Is there other data we should be taking?



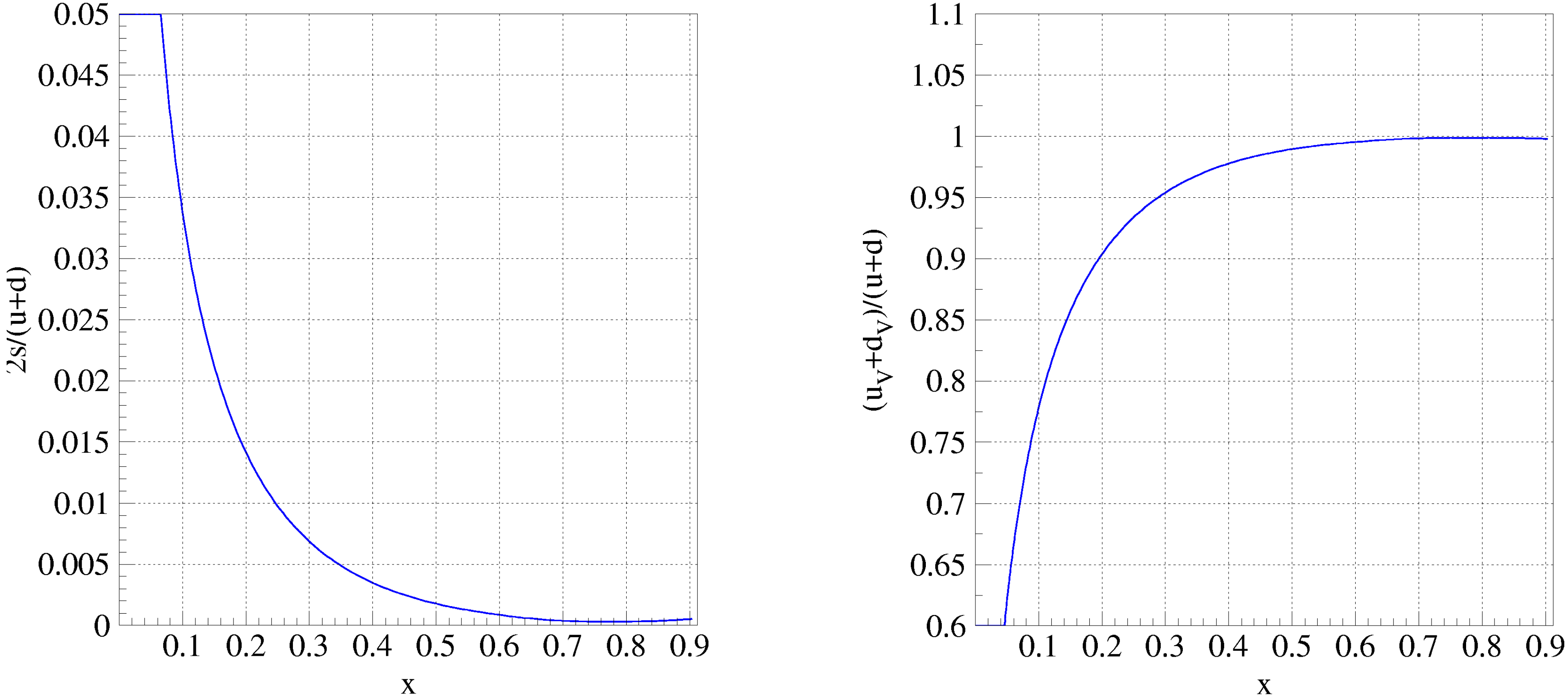




Parton distributions $R_s(x)$ and $R_V(x)$

$$R_s(x) = \frac{2\left[s(x)+\bar{s}(x)\right]}{u(x)+d(x)} \xrightarrow{\text{large } x} 0$$

$$R_v(x) = \frac{u_v(x)+d_v(x)}{u(x)+d(x)} \xrightarrow{\text{large } x} 1$$



Uncertainties in PDF's have been estimated

Counting DAQ

- Tracking chambers will be turned off.
- Two counting modes: scaler- and FADC-based, goal: count up to 1MHz
- Particle Identification (PID) realized by
  - Will use gas Cerenkov and lead glass detectors for PID;
  - Scintillators help reject other background;
  - *Carefully set thresholds in scalar-logic units;*
  - *On-board algorithm using FADC signals;*
  - *Two methods provide strict cross-checks;*
  - *FADC allows full off-line analysis of a subset of data.*
  - *Can cross-check with the regular DAQ at low rates.*
- PVDIS @ 6 GeV (E05-007)
  - will use scaler-based counting DAQ, partially equipped with FADCs.
  - A subset of DAQ will be assembled and tested late '07/early '08 (most of modules already purchased);
- The method is being tested parasitically NOW;

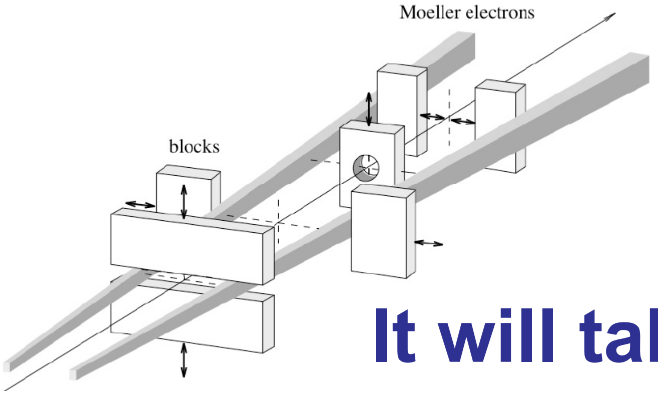
Polarimetry Goal: $\delta P/P = 0.5\%$

High precision polarimetry will be key for all components of the 12 GeV PV program

No <1% polarimetry at high current for any experiment has been *demonstrated* at JLab

Hall C Møller

- Presently reports **0.5% systematic** error
- Magnet upgrade required for 11 GeV
- Significant effort will be required to assure a robust and credible 0.5% uncertainty at 11 GeV
- Pulsed beam scheme may allow measurement at few 10 uA



Hall C Compton

- Being designed for 1% at 1 GeV
- **Nothing fundamental** in design or technique which **prevents 0.5%** at 11 GeV
- Dominant systematic error due to energy calibration (to normalize the analyzing power) can be removed in both electron and photon analyses
- 1% claimed in Hall A at 3 GeV, and technique gets easier at higher energy

It will take hard work, but it can be done!