PVDIS at JLab 6 and 11 GeV

Xiaochao Zheng 郑晓超 (Univ. of Virginia)

August 8, 2011

- Electroweak Standard Model and PVDIS Physics
- History: SLAC E122
- PVDIS @ 6 GeV Status
- PVDIS @ 11 GeV with the SoLID spectrometer
Parity Violation

- The **parity** symmetry: the physical laws behind all phenomena is the same as those behind their mirror images (The Lagrangian is invariant under transformation $\vec{r} \rightarrow -\vec{r}$);
- This symmetry is broken in weak interactions;
- Weak interaction is carried by charged or neutral weak currents.

1957 Nobel Prize in Physics:
"for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles"

Chen-Ning Yang
Tsung-Dao Lee
Chien-Shiung Wu

Experimental proof using beta decay of $^{60}$Co.

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Electroweak Interaction - The Standard Model

Weak charged currents ($W^\pm$) were discovered first, described by a $SU(2)_L$ group with weak isospin $T$;

When weak neutral current ($Z^0$) was discovered later, it could not be described by the same $SU(2)_L$ group. Must combine neutral currents from $SU(2)_L$ and QED [$U^\text{EM}(1)$] to construct the proper description. This combination is described by the weak mixing angle $\theta_W$.

Lepton neutral currents are given by vector and axial couplings

\[
J^{NC}_{\mu} (v) = \frac{1}{2} \left( \bar{u}_v \gamma_{\mu} \frac{1}{2} \left( 1 - \gamma^5 \right) u_v \right)
\]

\[
J^{NC}_{\mu} (q) = \left( \bar{u}_q \gamma_{\mu} \frac{1}{2} \left( c_V^q - c_A^q \gamma^5 \right) u_q \right)
\]

In the Standard Model

<table>
<thead>
<tr>
<th>fermions</th>
<th>$c_f^A$</th>
<th>$c_f^V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_e$, $\nu_\mu$</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>$e^-$, $\mu^-$</td>
<td>$-\frac{1}{2}$</td>
<td>$-\frac{1}{2} + 2\sin^2 \theta_W$</td>
</tr>
<tr>
<td>$u$, $c$</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{1}{2} - \frac{4}{3}\sin^2 \theta_W$</td>
</tr>
<tr>
<td>$d$, $s$</td>
<td>$-\frac{1}{2}$</td>
<td>$-\frac{1}{2} + \frac{2}{3}\sin^2 \theta_W$</td>
</tr>
</tbody>
</table>
Testing the EW Standard Model - Running of $\sin^2 \theta_W$

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    width=\textwidth,
    height=0.6\textwidth,
    xlabel=$Q$ [GeV],
    ylabel=$\sin^2 \theta_W(M_Z)$,
    xmin=0.001, xmax=1000,
    ymin=0.225, ymax=0.250,
    xtick={0.001, 0.01, 0.1, 1, 10, 100, 1000},
    ytick={0.225, 0.230, 0.235, 0.240, 0.245, 0.250},
    yticklabels={0.225, 0.230, 0.235, 0.240, 0.245, 0.250},
    xmajorgrids=true,
    ymajorgrids=true,
    grid style=dashed,
    legend pos=north west,
]

% Add data points and plot
\addplot[blue, thick, mark=none] table [x=Q, y=sin2thetaW] {data.csv};
\addlegendentry{\textbf{Z-pole}}
\addlegendentry{\textbf{NuTeV $\nu$-DIS}}
\addlegendentry{\textbf{SLAC E158 Moller}}
\addlegendentry{\textbf{Cesium APV}}
\addlegendentry{\textbf{Czarnecki and Marciano}}
\addlegendentry{\textbf{Erler and Ramsey-Musolf}}
\addlegendentry{\textbf{Sirlin et. al.}}
\addlegendentry{\textbf{Zykonov}}

\end{axis}
\end{tikzpicture}
\end{center}

figure from K. Kumar, Seattle 2009 EIC Workshop EW talks

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Parity Violating Electron Scattering

Weak Neutral Current (WNC) Interactions at $Q^2 \ll M_Z^2$

Longitudinally Polarized Electron Scattering off Unpolarized Fixed Targets

\[ J_{\mu}^{NC}(e) = \left( \bar{u}_e \gamma_\mu \frac{1}{2} (c_V^e - c_A^e \gamma^5) u_e \right) \]

\[ J_{\mu}^{NC}(q) = \left( \bar{u}_q \gamma_\mu \frac{1}{2} (c_V^q - c_A^q \gamma^5) u_q \right) \]

\[ L_{NC}^{leptonscatt.} = \sum \left[ c_A^l c_V^q \bar{l} \gamma_\mu \gamma_5 l \bar{q} \gamma_\mu q + c_V^l c_A^q \bar{l} \gamma_\mu \gamma_5 l \bar{q} \gamma_\mu q + c_A^l c_A^q \bar{l} \gamma_\mu \gamma_5 l \bar{q} \gamma_\mu \gamma_5 q \right] \]
Parity Violating Electron Scattering

Weak Neutral Current (WNC) Interactions at $Q^2 \ll M_Z^2$

Longitudinally Polarized Electron Scattering off Unpolarized Fixed Targets

$$L_{NC}^{\text{leptonscatt}} = \sum \left[ c_A^l c_V^q \bar{l} \gamma^\mu \gamma_5 l q + c_A^l c_V^q \bar{l} \gamma^\mu l q + c_A^l c_V^q \bar{l} \gamma^\mu \gamma_5 l q + c_A^l c_V^q \bar{l} \gamma^\mu \gamma_5 l q \right]$$

$C_{1q}$, parity-violating, cause different $e_L$, $e_R$ cross sections

$C_{2q}$, lepton charge conjugate-violating, cause difference in $e_L$, $e_R^+$ cross sections

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Weak Neutral Couplings

Different conventions exist, here:

\[ C_{1q} \equiv 2 g^e_A g^q_V \]

\[ C_{2q} \equiv 2 g^e_V g^q_A \]

\[ C_{1u} = 2 g^e_A g^u_V = -\frac{1}{2} + \frac{4}{3} \sin^2(\theta_W) + \delta C_{1u} \approx 0.19 \]

\[ C_{1d} = 2 g^e_A g^d_V = +\frac{1}{2} - \frac{2}{3} \sin^2(\theta_W) + \delta C_{1d} \approx 0.35 \]

\[ C_{2u} = 2 g^e_V g^u_A = -\frac{1}{2} + 2 \sin^2(\theta_W) + \delta C_{2u} \approx -0.030 \]

\[ C_{2d} = 2 g^e_V g^d_A = +\frac{1}{2} - 2 \sin^2(\theta_W) + \delta C_{2d} \approx 0.025 \]

g_{A,V} \text{ follow PDG convention}
Parity Violation in Deep Inelastic Scattering

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

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

\[ a(x) = \frac{1}{2} g_A^e \frac{F_1^{\gamma Z}}{F_1^\gamma} = \frac{1}{2} \sum Q_i^2 f_i^+(x) \]

\[ b(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^\gamma} = \frac{1}{2} \sum Q_i^2 f_i^-(x) \]

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

\[ b(x) = \frac{3}{10} \left( 2C_{2u} - C_{2d} \right) \left( \frac{u_+ + d_+}{u^+ + d^+} \right) \]

\[ x \equiv x_{\text{Bjorken}} \quad y \equiv 1 - E'/E \]

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

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

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at high \(x\)
The First PVDIS Experiment - SLAC E122


- 37% polarized beam 16.2-22.2 GeV, 30-cm LD2 and LH2 targets
- Spectrometers at 4°, various $E'$
- $Q^2 = 1-1.9 \text{ GeV}^2$
- Integrating method for gas cherenkov and lead glass shower counters, independently.

Deuteron data from 19.4 and 22.2 GeV:

\[
A/Q^2 = (-9.5 \pm 1.6) \times 10^{-5} \text{ (GeV/c)}^{-2}
\]

$\pm 0.86 \times 10^{-5} \text{(stat)} \pm 5\%\text{(Pb)} \pm 3.3\%\text{(beam)}$

$\pm 2\%\text{($\pi$ contamination)}$

$\pm 3\%\text{(radiative corrections)}$

Proton data from 19.4 22.2 GeV:

\[
A/Q^2 = (-9.7 \pm 2.7) \times 10^{-5} \text{ (GeV/c)}^{-2}
\]

$\sin^2 \theta_W = 0.20 \pm 0.03$

compare to two\nSU(2)$\times$U(1) models

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Quark Weak Neutral Couplings $C_{1,2q}$

with recent PVES data

HAPPEX: H, He
GO: H,
PVA4: H
SAMPLE: H, D

without JLab PVDIS data

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Quark Weak Neutral Couplings $C_{1,2q}$ all are 1σ limit

with recent PVES data and Qweak

without JLab PVDIS data

Qweak in Hall C (2010-): $^1\text{H} + e \rightarrow e' + p$ another factor of 5 improvement in knowledge of $C_{1q}$, New Physics scale from 0.9 to 2 TeV

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Parity Violation in Deep Inelastic Scattering

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

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

\[ a(x) = \frac{1}{2} g^e \frac{F^\gamma Z_1}{F^\gamma_1} = \frac{1}{2} \sum C_{1i} Q_i f^+_{i}(x) \]

\[ b(x) = g^e \frac{F^\gamma Z_3}{F^\gamma_1} = \frac{1}{2} \sum C_{2i} Q_i f^-_{i}(x) \]

\[ x \equiv x_{Bjorken} \quad y \equiv 1 - E'/E \]

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

\[ q_i^-(x) = q_i^y(x) \equiv q_i(x) - \bar{q}_i(x) \]

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

\[ a(x) = \frac{3}{10} (2C_{1u} - C_{1d}) \left( 1 + \frac{0\cdot 6s^+}{u^+ + d^+} \right) \]

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

**PVDIS**: Only way to measure $C_{2q}$ at high $x$

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
- **Staff**: ~650
- **User community**: ~1300

- Beam first delivered in 10/95
- In full operation for since 11/97
- “parity quality” beam since ’99
- 334 PhDs to date and 249 in progress (~1/3 of US PhDs in Nuclear Physics)
PVDIS at 6 GeV (JLab E08-011)

(last reported at JLab/China symposium in 2006)

- 100uA, 90% polarized beam, 20-cm LD2 target
- Ran in Oct-Dec 2009, measured $A_d$ at $Q^2=1.1$ and 1.9 GeV$^2$ to 3% and 4% (stat.), resp. Systematics dominated by beam polarization (2%).

Grad students: Xiaoyan Deng 邓小燕 (UVa MA), Diancheng Wang 王殿成 (UVa), Kai Pan 潘凯 (MIT)
Postdoc: Ramesh Subedi

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Online (Hardware) PID Scaler Based Counting DAQ

- DIS region, pions contaminate, can't use integrating DAQ.
- High event rate (~500KHz), exceeds Hall A regular DAQ's Limit

- Group electron trigger

Segmented (forming 6 or 8 groups)

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Online (Hardware) PID Scaler Based Counting DAQ

- DIS region, pions contaminate, can't use integrating DAQ.
- High event rate (~500KHz), exceeds Hall A regular DAQ's Limit

![Diagram of detector components](image)

**DIS region, pions contaminate, can't use integrating DAQ.**

**High event rate (~500KHz), exceeds Hall A regular DAQ's Limit**

**Preshower**

**Shower**

**Gas Cherenkov**

**S1&S2**

**∑**

**Discriminator L**

**Discriminator H**

**&**

**& veto**

**Group electron trigger**

**segmented**

**(forming 6 or 8 groups)**

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Online (Hardware) PID Scaler Based Counting DAQ

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
PID Performance

Electron Detection Efficiency

Pion Rejection Factor

Lead Glass

Horizontal Acceptance [m]

E~97%

Lead Glass

Horizontal Acceptance [m]

Electron Efficiency 97%

Pion Rejection Factor 52

Gas Cherenkov

Overall

96% 1e4

Asymmetry correction due to electron efficiency <0.5%
pion contamination <0.1%

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Deadtime Correction

Deadtime correction to asymmetry:

Methods to study Deadtime:
- **FADC data**: direct way to study deadtime, but low statistics.
- **Tagger method**: use a tagger signal to mimic physics signal.
- **Software simulation**: simulating all the signals and electronics.

\[ A' = A_{\text{measure}} \left( 1 - \text{Deadtimeloss} \right) \]

Deadtime corrections to asymmetry is:
- ~3% +/- 0.6% (Q^2=1.1)
- ~1% +/- 0.2% (Q^2=1.9)
**Experimental Method**

Count electrons $N$ for each window

$$A_{\text{window pair}} = \frac{N_R - N_L}{N_R + N_L}$$

Statistical quality of data (blinded pair-wise asymmetry):

- $Q^2 = 1.1$
- $Q^2 = 1.9$
The final task: EM Radiative Corrections

- Resonance events contribute to 15%?
- Calculations for PV asymmetry in the resonance region are difficult, and have not been proven by data (only G0 had limited data in the Delta region)

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
The final task: EM Radiative Corrections

- Measured resonance PV asymmetries (10-15% stat.)
- Calculations from Lee/Sato (Delta) and M. Gorshteyn (whole resonance)
- Stan B. will provide calculations (whole res) - thanks to Weihai organizers!
- "Toy" models using unpolarized F1(res)/F1(DIS), implying duality (or not)
- Goal: control systematic error due to Radiative corrections to below 1%
- (These RES data deserve a separate publication)

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
### Error Budget

<table>
<thead>
<tr>
<th>Source \ $\Delta A_d/A_d$</th>
<th>$Q^2=1.1 \text{ GeV}^2$</th>
<th>$Q^2=1.9 \text{ GeV}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta P_b/P_b$</td>
<td>2.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Radiative Correction</td>
<td>1.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Deadtime correction</td>
<td>0.6%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Target endcap contamination</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Transverse Asymmetry</td>
<td>0.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>PID efficiency</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>False Asymmetry</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Systematics</td>
<td>2.48%</td>
<td>2.41%</td>
</tr>
<tr>
<td>Statistical</td>
<td>3.00%</td>
<td>4.00%</td>
</tr>
<tr>
<td>Total</td>
<td>3.89%</td>
<td>4.67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source \ $\Delta(2C_{2u}-C_{2d})$</th>
<th>$A_d$</th>
<th>$\Delta(2C_{2u} - C_{2d})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_d$</td>
<td>0.0735</td>
<td>0.0565</td>
</tr>
<tr>
<td>Parton distribution functions</td>
<td>0.0071</td>
<td>0.0031</td>
</tr>
<tr>
<td>Electro-weak rad. cor.</td>
<td>0.0038</td>
<td>0.0024</td>
</tr>
<tr>
<td>Higher Twist (using $F_3^V$ data)</td>
<td>$-0.021\pm0.004$</td>
<td>$-0.010\pm0.002$</td>
</tr>
<tr>
<td>CSV (MRST nominal)</td>
<td>0.0054</td>
<td>0.0031</td>
</tr>
<tr>
<td>CSV (MRST 90% C.L.)</td>
<td>0.0132</td>
<td>0.0085</td>
</tr>
<tr>
<td>Total uncertainty</td>
<td>0.0739</td>
<td>0.0566</td>
</tr>
</tbody>
</table>

### Not Included Below

- Higher Twist (using $F_3^V$ data)
- CSV (MRST nominal)
- CSV (MRST 90% C.L.)

---

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Quark Weak Neutral Couplings $C_{1,2q}$

with recent PVES data and Qweak

without JLab data

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Quark Weak Neutral Couplings $C_{1,2q}$ all are $1\sigma$ limit

with recent PVES data and Qweak

PVDIS in Hall A (Oct-Dec 2009): potential to improve $C_{2q}$ knowledge if hadronic effects are small.

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
ONGOING JLab Upgrade Construction Effort

- Hall D - Central Drift Chamber
  - Endplates @ CMU

- Hall B - Drift Chambers @ JLab, ODU and ISU

- Hall C - Drift Chambers @ HU
  - & Scintillators @ JMU

12 GeV Groundbreaking (Apr 2009)

Hall D Concrete Wall Erection (Apr 2010)

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
PVDIS at Higher Precision – Hadronic Physics Study

• **CSV**
  \[ u^p(x) = d^n(x) ? \]
  \[ d^p(x) = u^p(x) ? \]
• **u-d mass difference**
  \[ \delta u(x) \equiv u^p(x) - d^n(x) \]
  \[ \delta d(x) \equiv d^p(x) - u^p(x) \]

• **EM effects**

For \( A_{P^V} \) in electron-\(^2\)H DIS:

\[
\frac{\delta A_{P^V}}{A_{P^V}} = 0.28 \frac{\delta u - \delta d}{u + d}
\]

Sensitivity will be further enhanced if \( u+d \) falls off more rapidly than \( \delta u - \delta d \) as \( x \to 1 \)

• Direct observation of parton-level CSV would be very exciting!
• Important implications for high energy collider pdfs
• Could explain a significant portion of the NuTeV anomaly

• **Higher Twist (non-perturbative nature of strong interactions)**
Coherent PVDIS Program with SoLID @ 11 GeV

Strategy: requires precise kinematics and broad range

see talk by Xin Qian & Zhiwen Zhao

"SoLID" spectrometer

\[ A = A \left[ 1 + \beta_{HT} \frac{1}{(1-x)^3 Q^2} + \beta_{CSV} x^2 \right] \]

also see talk by Nilanga Liyanage et al. on GEM detectors

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
<th>Q^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Physics</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>CSV</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Higher Twist</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
Coherent PVDIS Program with SoLID @ 11 GeV

figure from K. Kumar, Seattle 2009 EIC Workshop EW talks

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Knowledge on $C_{1,2q}$ with Projected JLab 12 GeV Results

PVDIS@11 GeV with SoLID: potential to improve $C_{2q}$ knowledge by another order of magnitude and better separation from hadronic effects.

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Knowledge on $\sin^2 \theta_W$ with Projected JLab 12 GeV Results
Deuteron $F_{1,2}^d$ analysis has large nuclear corrections (yellow band)

$A_{PV}^p(x) \approx \frac{u(x) + 0.91 d(x)}{u(x) + 0.25 d(x)}$

$A_{PV}$ for the proton has no such corrections

The challenge is to get statistical and systematic errors $\sim 2\%$
Summary and Perspectives

- PVDIS is sensitive to the quark neutral weak coupling $C_{2q}$ and the structure of the nucleon.
- A PVDIS experiment using the 6 GeV beam was completed in 2009, analysis near final.
- The future PVDIS program using the SoLID spectrometer at the upgraded 12 GeV JLab will bring rich information to the Standard Model test and the nucleon structure study. We have strong collaboration with Chinese institutions on the SoLID detector construction, but more will be welcome.
Backup Slides
### Medium & High Energy Physics Facilities for Lepton Scattering

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Accelerator</th>
<th>Beam</th>
<th>Energy, polarization</th>
<th>Luminosity (cm² s⁻¹)</th>
<th>Time</th>
<th>duty factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>FermiLab</td>
<td>Tevatron</td>
<td>$\nu_e, \bar{\nu}_e$</td>
<td>1.96 TeV</td>
<td>low</td>
<td>1995-... ...</td>
<td></td>
</tr>
<tr>
<td>SLAC</td>
<td>Stanford Linear Accelerator</td>
<td>$e^-, e^+$</td>
<td>50 GeV, 80%</td>
<td>$10^{36}$</td>
<td>1962-... ...</td>
<td>0.03%</td>
</tr>
<tr>
<td>JLab</td>
<td>Continuous Electron Beam Accelerator Facility (CEBAF)</td>
<td>$e^-$</td>
<td>6 GeV, 85% 12 GeV, 85%</td>
<td>$10^{38-39}$</td>
<td>1985-... ...</td>
<td>“CW”</td>
</tr>
<tr>
<td>CERN</td>
<td>Large e-/e+ Collider (LEP)</td>
<td>$\nu_e, \bar{\nu}_e$</td>
<td>90-209 GeV</td>
<td>low</td>
<td>1989-2000</td>
<td></td>
</tr>
<tr>
<td>DESY</td>
<td>Deutsches Elektronen Synchrotron</td>
<td>$e^-, e^+$</td>
<td>27.5 GeV</td>
<td>low</td>
<td>1987-... ...</td>
<td></td>
</tr>
<tr>
<td>(DESY-II)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAINZ</td>
<td>Mainz Microtron MAMI</td>
<td>$e^-, e^+$</td>
<td>0.8/1.6 GeV</td>
<td>$10^{38}$</td>
<td>1979-... ...</td>
<td>“CW”</td>
</tr>
<tr>
<td>MIT Bates</td>
<td>MIT Bates Linear Accelerator</td>
<td>$e^-$</td>
<td>0.8 GeV</td>
<td>$10^{37}$</td>
<td>1975-2005</td>
<td></td>
</tr>
</tbody>
</table>

- **High luminosity, yet “continuous” polarized beam makes JLab an unique facility.**

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
PV DIS and Other SM Test Experiments

- **E158/Moller (SLAC)**
  - Purely leptonic

- **Atomic PV**
  - Coherent Quarks in the Nucleus
    - \(376C_{1u} - 422C_{1d}\)
    - Nuclear structure?

- **NuTeV (FNAL)**
  - Weak CC and NC difference
  - Nuclear structure?
  - Other hadronic effects?

- **Qweak (JLab)**
  - Coherent quarks in the proton

- **PVDIS (JLab)**
  - \(2(2C_{1u} + C_{1d})\)
  - Isoscalar quark scattering

Different Experiments Probe Different Parts of Lagrangian,
PVDIS is the only one accessing \(C_{2q}\)

Cartoons borrowed from R. Arnold (UMass)

X. Zheng, University of Virginia, Talk at Hadron2011, August 8-11, Weihai, China
Three Experimental Halls (Present)

Hall A:
- pair of high resolution spectrometers (HRS), $E'$ up to 4 GeV/c, $\Delta \Omega = 7$ msr
- luminosity up to $10^{39}$ cm$^{-2}$ s$^{-1}$

Hall B:
- CEBAF Large Acceptance Spectrometer (CLAS)
- luminosity up to $10^{34}$ cm$^{-2}$ s$^{-1}$

Hall C:
- High Momentum (HMS and Short-Orbit Spectrometers (SOS)
- luminosity up to $10^{39}$ cm$^{-2}$ s$^{-1}$