JLab 6 GeV PVDIS

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for

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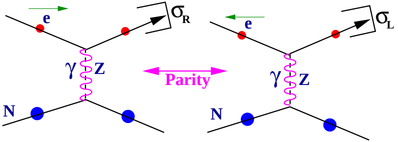
Parity Violating Deep Inelastic Scattering (PVDIS) experiment – introduction

- The electroweak interaction is Parity Violating as it changes sign if we flip the spin of the incoming electron beam. The study of such interaction in a Deep Inelastic Scattering region is PVDIS.
- If we measure two mirror-image scattering processes in the same experimental conditions, the difference between the two counting rates can isolate the weak contribution. In practice, we measure the ratio of the difference over the sum which cancels out all the errors of normalization and allows accurate measurement of small quantities.



$$A_{expt} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \cong Q^2\,[100\ \text{ppm/GeV}^2]$$

A_{expt}: Experimental parity violating asymmetry
σ_R : Right handed helicity electron cross section
σ_L : Left handed helicity electron cross section

- With M_γ and M_Z being the electromagnetic and weak amplitudes corresponding to γ and Z exchange, respectively,

$\sigma \propto |M_\gamma + M_Z|^2$. The interference term violates the parity and this term is immensely small too, because of a large M_γ value multiplied by a small M_Z value. The order of magnitude of the electroweak interference is:
$A_{pv} \sim \frac{M_\gamma . M_Z}{|M_\gamma|^2} \sim \frac{M_Z}{M_\gamma} \sim 10^{-4} Q^2$ GeV^2/c^2.

- The actual theoretical expression for the asymmetry A_{pv} for the PVDIS experiment will be given in a later slide.
- $A_{expt}/P_e = A_{pv}$ is the link between experiment and theory, where P_e is the magnitude of electron beam polarization.

- In PVDIS experiment, we are trying to measure the strength of the parity violation in DIS region by measuring an asymmetry and use this asymmetry to extract other quantities.
- In the past, there has been only one PVDIS expt, E122, at SLAC in 1970's using a polarized electron beam on an unpolarized deuterium target. It measured $sin^2\theta_w$ which provided one of the first tests for the Standard Model. In about 4 decades later: PVDIS at JLab.
- Unlike other parity violating experiments, PVDIS has access to the coupling constant C_{2q} with a possibility of factor $\sim$5 improvement. It will also study hadronic (higher twist) effects. Both of these quantities are important in studying electroweak Standard Model.
- Most of the tools developed during this expt can be adopted in the 12 GeV PVDIS.

- The goal of the experiment is to measure the parity violating asymmetry to a 3$\%$ (stat.) precision at two Q^2 points

- Q^2=1.11 (GeV/c)^2: θ=12.9°, E=6.0 GeV, E'=3.66 GeV, x_B=0.25, W^2 = 4.16 (GeV)^2.
- Q^2=1.90 (GeV/c)^2: θ=20.0°, E=6.0 GeV, E'=2.63 GeV, x_B=0.30, W^2 = 5.30 (GeV)^2.

$\&$ extract other quantities by using the following tools:

- Taking 100 μA beam at 6 GeV with 88$\%$ beam polarization on a 20 cm liquid deuterium target.
- Using both high resolution spectrometers (HRS) in hall A for an independent detection of scattered electrons.
- Developing and implementing new counting DAQs in both HRSs having hardware based PID with the event rate handling capability upto 1 MHz.
- Full event information sampled at lower rates by HRS DAQs for each kinematics, efficiencies and PID analysis.
- The timing alignment of the detector signals was performed by using FASTBUS TDCs and monitored continuously using the HRS DAQ.

- Using the measured asymmetry we can investigate:

  - coupling constant combination $(2C_{2u} - C_{2d})$ as shown in the next slide.
  - hadronic correction, $C(x)$, from higher-twist (HT) effects:
    $A_{expt}(x, Q^2) = A_{expt}(x)(1 + C(x)/Q^2)$.
  - From Q^2=1.11 (GeV/c)^2 we can investigate if there are significant HT effects – a "Baseline" measurement for the future 12 GeV PVDIS program.
  - If HT is small, from Q^2=1.90 (GeV/c)^2 we can extract $2C_{2u} - C_{2d}$ to about a factor of 5 improvement.

- This experiment will serve as an exploratory step for the 12-GeV PVDIS program.

The important outcome of the experiment will be the extraction of $(2C_{2u} - C_{2d})$, shown in Eqn.(1), with a high precision.

$$A_{pv} = \left(\frac{3G_F Q^2}{\pi\alpha^2\sqrt{2}}\right)\frac{2C_{1u}[1+R_C(x)] - C_{1d}[1+R_S(x)] + Y(2C_{2u} - C_{2d})R_V(x)}{5 + R_S(x) + 4R_C(x)} \quad (1)$$

with effective coupling constants $C_{1,2q}$:

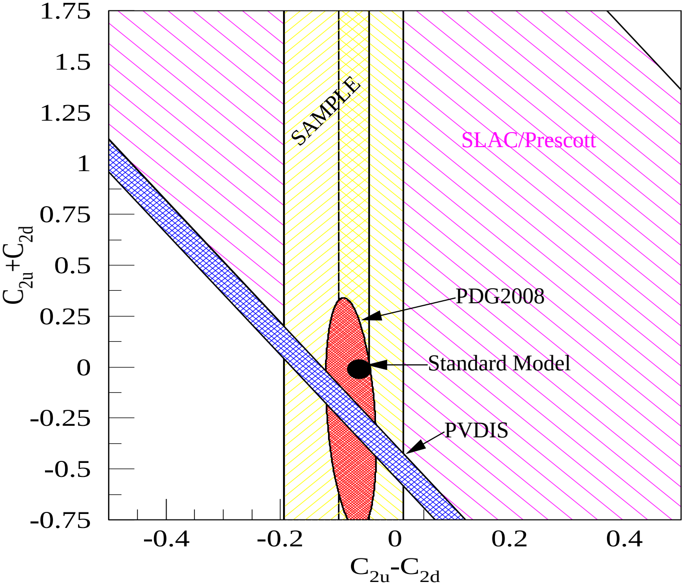
$$C_{1u} = g_a^e g_v^u = -\frac{1}{2} + \frac{3}{4} sin^2(\theta_w) \sim -0.19, \quad (2)$$

$$C_{1d} = g_a^e g_v^d = \frac{1}{2} - \frac{2}{3} sin^2(\theta_w) \sim 0.34, \quad (3)$$

$$C_{2u} = g_v^e g_a^u = -\frac{1}{2} + 2 sin^2(\theta_w) \sim -0.04, \quad (4)$$

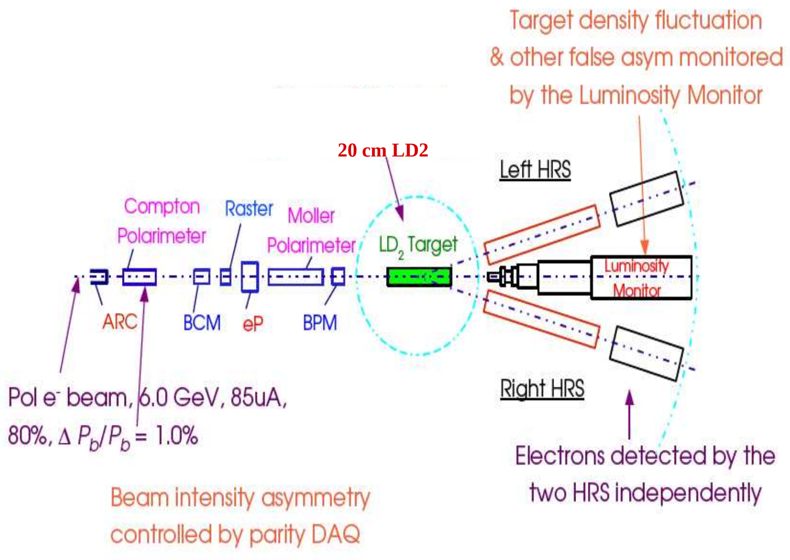
$$C_{2d} = g_v^e g_a^d = \frac{1}{2} - 2 sin^2(\theta_w) \sim 0.026, \quad (5)$$

where $C_{1u(d)}$ represents the axial Z-electron coupling g_a^e times the vector Z-u(d) quark coupling $g_v^{u(d)}$, and the $C_{2u(d)}$ is the vector Z-electron coupling g_v^e times the axial Z-u(d) quark coupling $g_a^{u(d)}$. G_F is the Fermi weak coupling constant, Y is kinematical factor, R_C, R_S and R_V being sea- and valence- quark distribution functions (see proposal E08-011 for detail).



Current (2008) experimental knowledge of C_{2q}. The PVDIS band passes through the best-fit central value of PDG (also R. Young et al.)

Overview of the Experimental Setup



Some highlights of the PVDIS experiment

- Took high rate data (electrons, pions): $\sim$400 kHz per arm.
- No use of integrating DAQ, as used by other parity violating expts at JLab, since electrons and pions had to be identified.
- Developed/used a scaler based counting DAQ with electron and pion PID for the first time in Hall A. Found no issue.

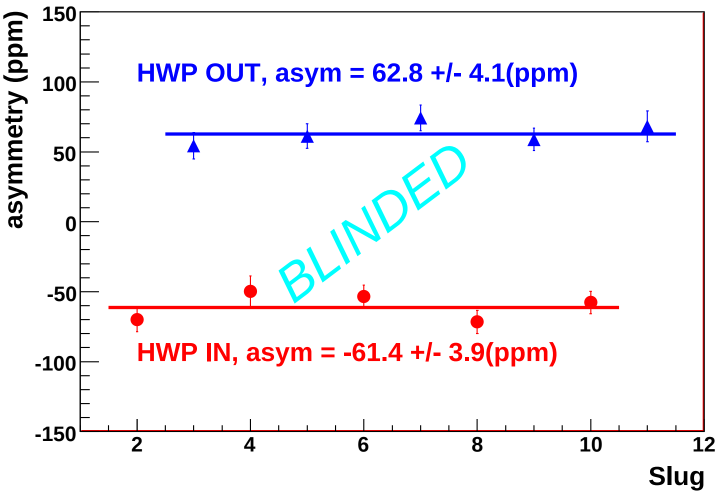
- Used a 10 kHz pulser as a tagger to determine deadtime. Diancheng Wang will talk on tagger result later.
- Routinely monitored: beam polarization (using Moller: polarization $\sim$88%), and the PID efficiency. The Compton polarimeter was also continuously operational but not fully understood the electron detection part.
- Took Flash ADC data, it will be analyzed for pileup.

- For background checks:
  - A continuous monitoring of target noise using lumi and beam charge asymmetry controlled by a feedback loop.
  - Took aluminum dummy data, and also positron data on the aluminum dummy. Rates agree with calculations.
  - Measured transverse beam polarization, found to be $< 2\%$.

Run-time problems & solutions

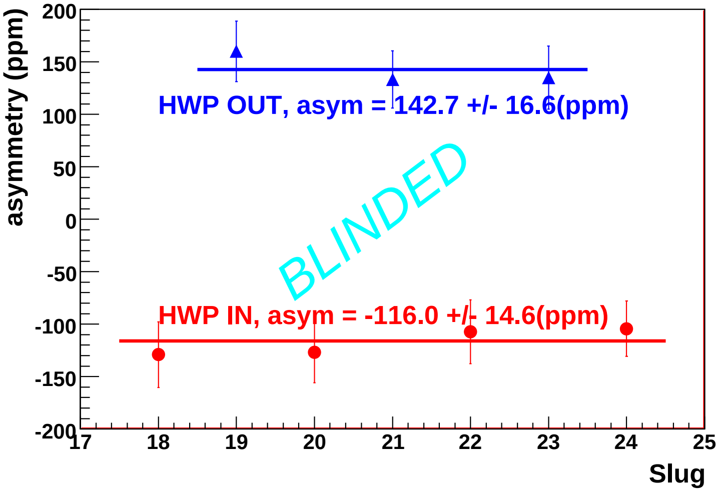
- Like every other experiments, we also had some minor problems:
    - Had to use a 20 cm liquid deuterium target instead of a 25 cm one as said in the proposal.
    - Though the 4-day PVDIS commissioning was supposed to start on Oct 30, 2009, we took production beam only on Nov 8, 2009 due to the spectrometer magnet problems (right Q^2 came back online on Nov 6th).
    - Spectrometer motion had to be done by hand held drills: hours of overhead for rotation by even about a degree. To move both spectrometers, we had to go to "restricted access" due to a need of a dozen people.
    - Due to the Central Helium Liquifier (CHL) crash, we lost target for about 26 hours (Dec 19-20) in about the end of the run-period.
- Despite such problems, obtaining a higher beam current of $>100\mu$A, instead of 85μA as in the proposal, compensated the experiment's need of luminosity.

Data check: asymmetry from left arm at Q^2=1.1 GeV^2/c^2, P_0=3.66 GeV^2/c^2

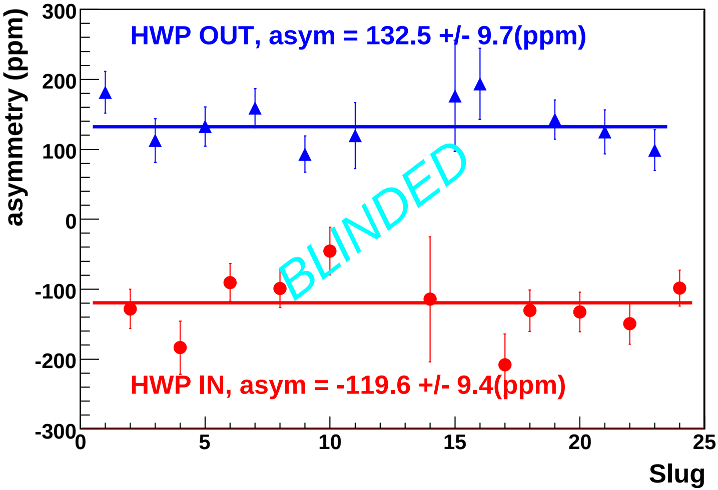


A slug has 1 M pairs of events collected in about 24 hours of time.

Data check: asymmetry from left arm at Q^2=1.9 GeV^2/c^2, P_0=2.63 GeV^2/c^2



Data check: asymmetry from right arm at Q^2=1.9 GeV^2/c^2, P_0=2.63 GeV^2/c^2



Analysis for deadtime, BCM calibration, Compton analysis, and simulations being tackled at moment (see talks from Dianchang and Xiaoyan).

Conclusion

- Implemented a scaler based counting DAQ.
- Successfully finished data taking in Dec'09 in a quality-controlled way with a robust online monitoring scheme.
- The Compton polarimetry was not as good as expected, but a careful analysis could meet expectation: 2% accuracy in electron beam polarization. This may not be an issue since the statistical accuracy of data may not be below 3%.
- Offline data analysis is underway.

Memorable Event

Both spectrometers had to be moved by hand held drills, 8 persons with one drill each, per spectrometer. Moving by about 7° would take several hours.

Error on physics asymmetry

Source \ $\Delta A_d/A_d$	Q^2=1.1 GeV^2	Q^2=1.9 GeV^2
$\Delta P_b/P_b$=1%	2.0%	2.0%
Deadtime correction	0.3%	0.3%
Target endcap contamination	0.4%	0.4%
Target purity	<0.02%	<0.02%
Pion background	<0.2%	<0.2%
Pair production background	<0.2%	<0.2%
Systematics	2.08%	2.08%
Statistical	3.0%	4.0%
Total	3.7%	4.5%