

# PR05-007: Pol $e$ - $^2\text{H}$ Parity Violating DIS at 6 GeV

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## PV DIS Asymmetry and the Proposed Measurement

- The high  $Q^2$  measurement and new physics
- The low  $Q^2$  measurement and the higher twist effects

Experimental Setup and Data Analysis

Expected Results and Uncertainties

Beam Time Request and Summary

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## The Hall A Collaboration

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UNH, Universidad Nacional Autonoma de Mexico, Rutgers, Smith C., Syracuse,  
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*We have strong support from theorists and experts of parity experiments.*



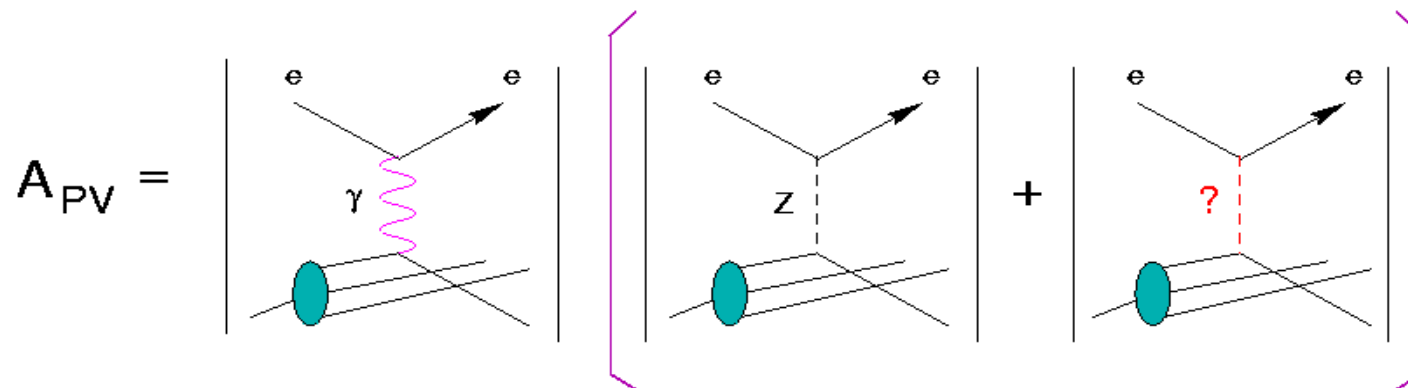


# DIS Parity Experiment – History and Future

- ◆ 1970's, result from SLAC E122 consistent with  $\sin^2\theta_W=1/4$ , confirmed the Standard Model prediction;

C.Y. Prescott, *et al.*, Phys. Lett. B77, 347 (1978)

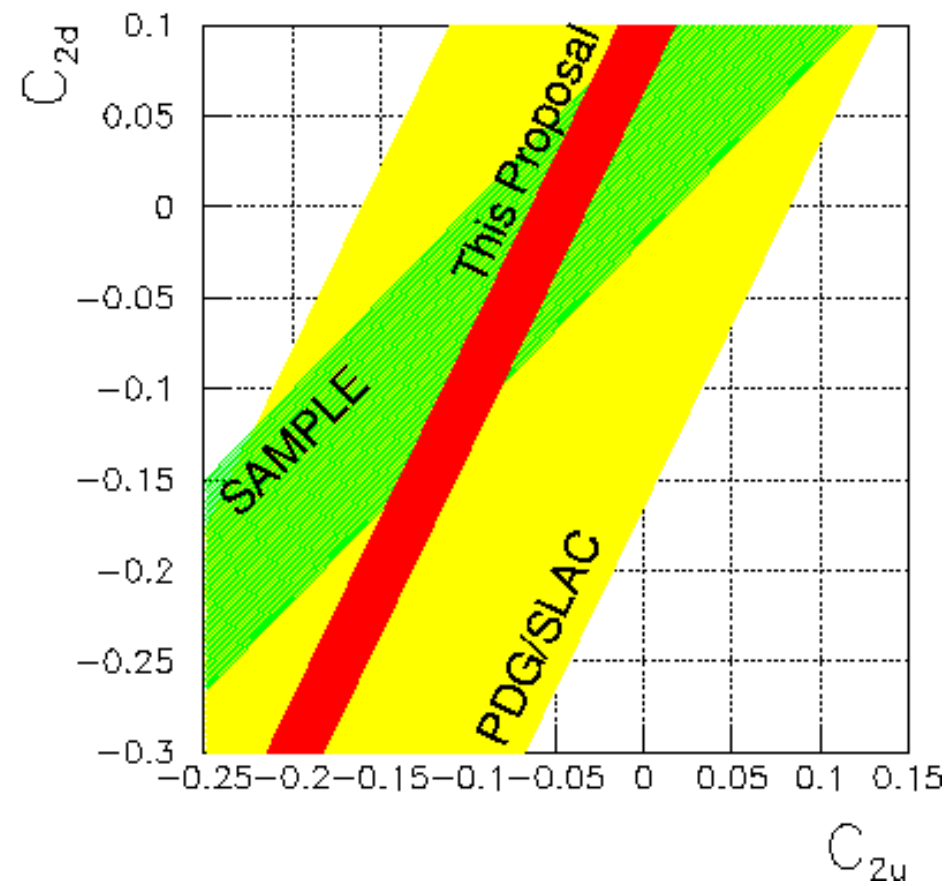
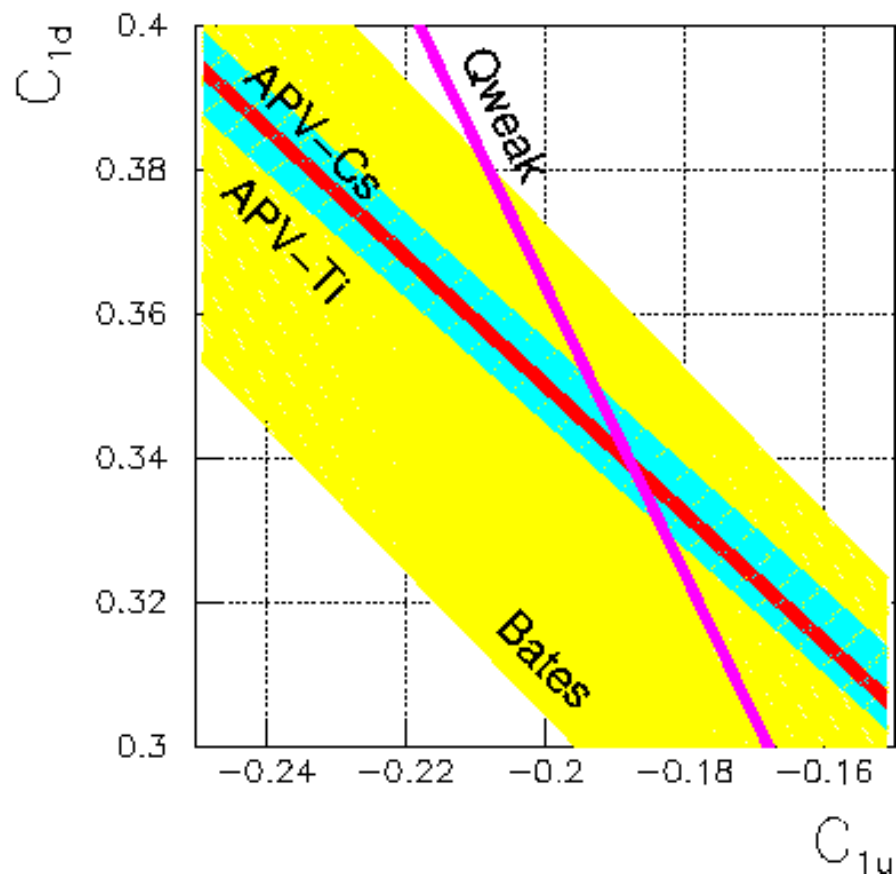
- ◆ Development in experimental technique allows us to search for new physics



- ◆ If all hadronic effects can be understood, then any deviation of  $\sin^2\theta_W$  or  $C_{iq}$  from their SM predictions could be a hint of new physics.

# The Proposed Measurement

- Measure  $A_d$  at  $Q^2=1.10$  and  $Q^2=1.90$  (GeV/c)<sup>2</sup> to about 2% (stat.);
- From  $A_d$  at  $Q^2=1.90$  (GeV/c)<sup>2</sup>, can extract  $2C_{2u}-C_{2d}$  to an uncertainty of 0.03 (factor of eight improvement);
  - This result will provide constraints on new physics;
- The  $A_d$  at  $Q^2=1.10$  (GeV/c)<sup>2</sup> will help to investigate if there are significant higher-twist effects; Meanwhile, this will be the first observation of HT in PV DIS, it
  - Will help understanding existing world data;
  - May have impacts on other areas;
  - Will provide important guidance to the future 12 GeV program.



# PV DIS and New Physics

- Interaction of new physics:

$$\mathcal{L}[V(e) \times A(q)] = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV}$$

$$\mathcal{L}_{SM}^{PV} = -\frac{G_F}{\sqrt{2}} \bar{e} \gamma_\mu e \sum_q C_{2q} \bar{q} \gamma^\mu \gamma^5 q \quad \mathcal{L}_{NEW}^{PV} = \frac{g^2}{4\Lambda^2} \bar{e} \gamma_\mu e \sum_f h_A^q \bar{q} \gamma^\mu \gamma^5 q$$

- $g$ : coupling constant;  $\Lambda$ : mass scale,  $h_A^q$ : effective coefficients;

- Mass limit of the proposed measurement:

$$\Lambda/g \approx 1/\sqrt{\sqrt{8}G_F|\Delta(2C_{2u} - C_{2d})|} \approx 1.0 \text{ TeV}$$

## PV DIS and New Physics (a few examples)

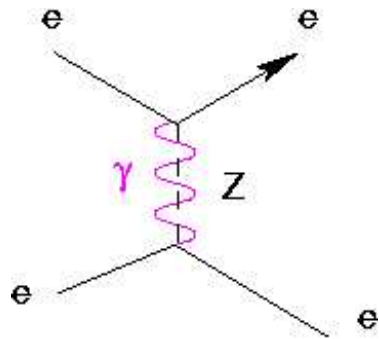
- **Z' Searches:** will give  $M_{Z'} = 0.8 \text{ TeV}$  ( $1\sigma$ ), or  $450 \text{ GeV}$  (90% C.L.);
- **Compositeness (8 four-fermion contact interactions):**
  - ★ SU(12): affect  $C_{2q}$  but not  $C_{1q} \Rightarrow C_{2q}$  provide a unique opportunity to explore quark and lepton compositeness;
  - ★ Will give  $\Lambda_1 = 3.56 \text{ TeV}$  ( $1\sigma$ ), or  $1.97 \text{ TeV}$  (90% C.L.);
  - ★ Provide important inputs for fitting all contact terms simultaneously.
- **Leptoquarks:** for a scalar LQ interacting with  $u$  quarks, will give

$$\Lambda_s < 0.14 (M_{LQ}/100 \text{ GeV})$$

(comparable to the Cs APV experiment)

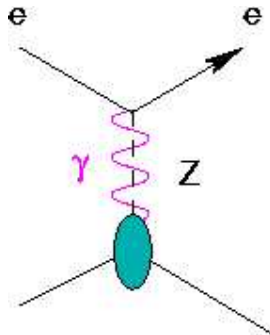
# PV DIS and Other SM Test Experiments

## ● E158/Moller (SLAC)



➔ Purely leptonic

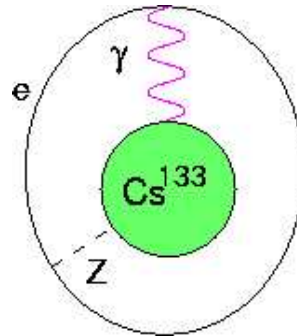
## ● Qweak (JLab)



➔  $2(2C_{1u} + C_{1d})$

➔ Coherent quarks in the proton

## ● Atomic PV

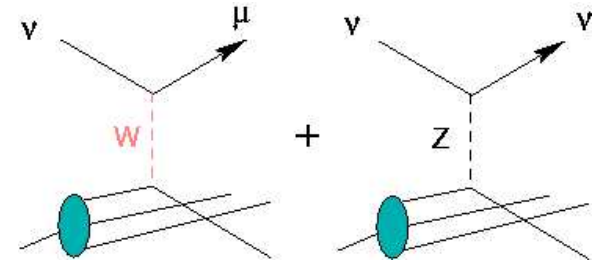


➔ Coherent Quarks in the Nucleus

➔  $-376C_{1u} - 422C_{1d}$

➔ Nuclear structure?

## ● NuTeV (FNAL)

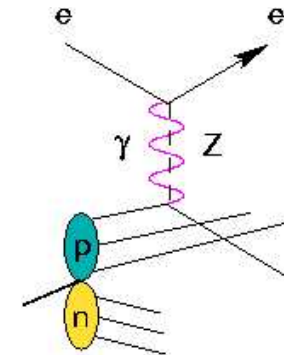


➔ Weak CC and NC diff

➔ Nuclear structure?

➔ Other hadronic effects?

## ● DIS Parity (JLab)



➔  $(2C_{1u} - C_{1d}) + Y(2C_{2u} - C_{2d})$

➔ Isoscalar quark scattering

*Different Experiments  
Probe Different  
Parts of Lagrangian*

*Cartoons borrowed  
from R. Arnold (UMass)*

## The Higher-Twist Effect (HT) From DIS Data

- MRST: HT effect on  $F_{1,2} < 0.1\%$  for  $0.1 < x < 0.3$  in NNLO and NNNLO;

Martin, Roberts, Stirling and Thorne, EPJC35, 325 (2004)

- LSS: HT on  $g_1^d$  and  $A_1^d$  consistent with zero for  $0.1 < x < 0.3$  in NLO analysis;

Leader, Sidorov and Stamenov, hep-ph/0309048, hep-ph/0411323, priv. comm.

- Moments of  $g_1$  show negligible HT;

Meziani *et al*, hep-ph/0404066 (*n*); Osipenko *et al*, hep-ph/0404195 (*p*)

- Overall:

➤ HT likely to be small.

## HT in PV DIS (Theories)

- Bag model: about  $0.3\%/Q^2$  correction to  $A_d$

Castorina and Mulders, Phys. Rev. D 31, 2760 (1985)

- OPE + bag model:  $< 2\%$  correction to  $A_d$  at  $Q^2 = 1.67 \text{ (GeV/c)}^2$

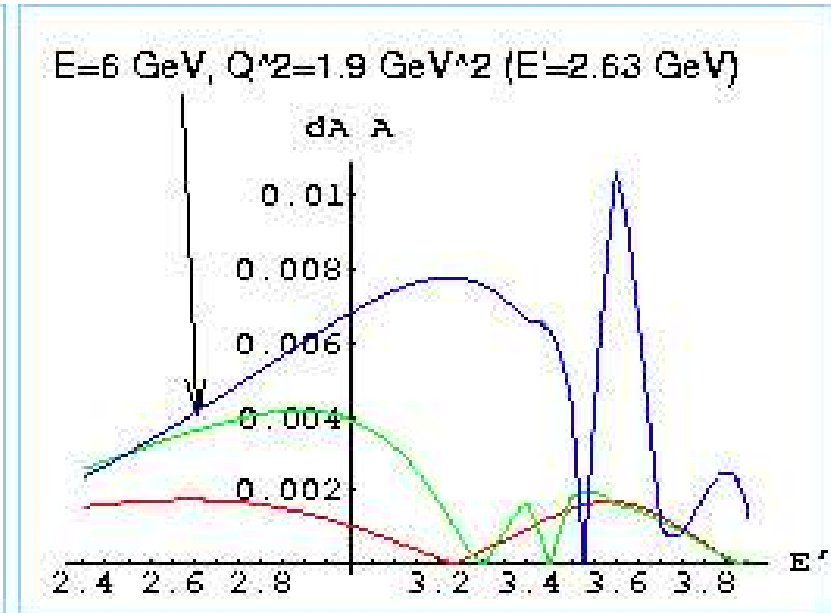
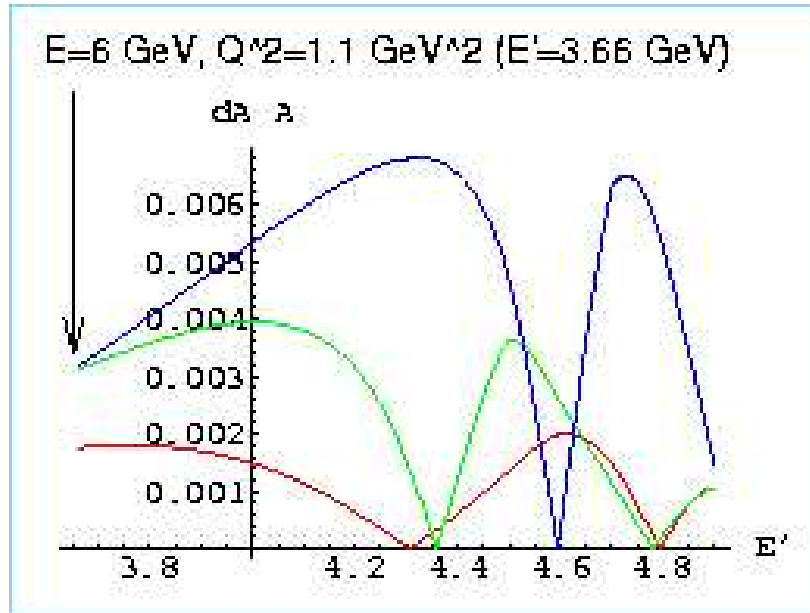
Fajfer and Oakes, Phys. Rev. D 30, 1585 (1984)

- QCD NLO, NNLO calculations (using  $C_{HT}$  from Virchaux & Milsztajn as input): about  $1\%/Q^2$  correction to  $A_d$  for  $0.1 < x < 0.3$

W. L. van Neerven (Jlab LOI 03-106)

## HT in PV DIS (Additional Theories)

- Calculation from three MIT Bag Models show (0.2-0.4)% HT effect on  $A_d$ ,  
by G. Sacco, model details in Ph.D. Thesis (supervised by Ramsey-Musolf)



- Overall:
  - Most theories predict  $<1\%/Q^2$  HT correction to  $A_d$ ;
  - No data to directly confirm these predictions.

# HT from the Proposed Measurement

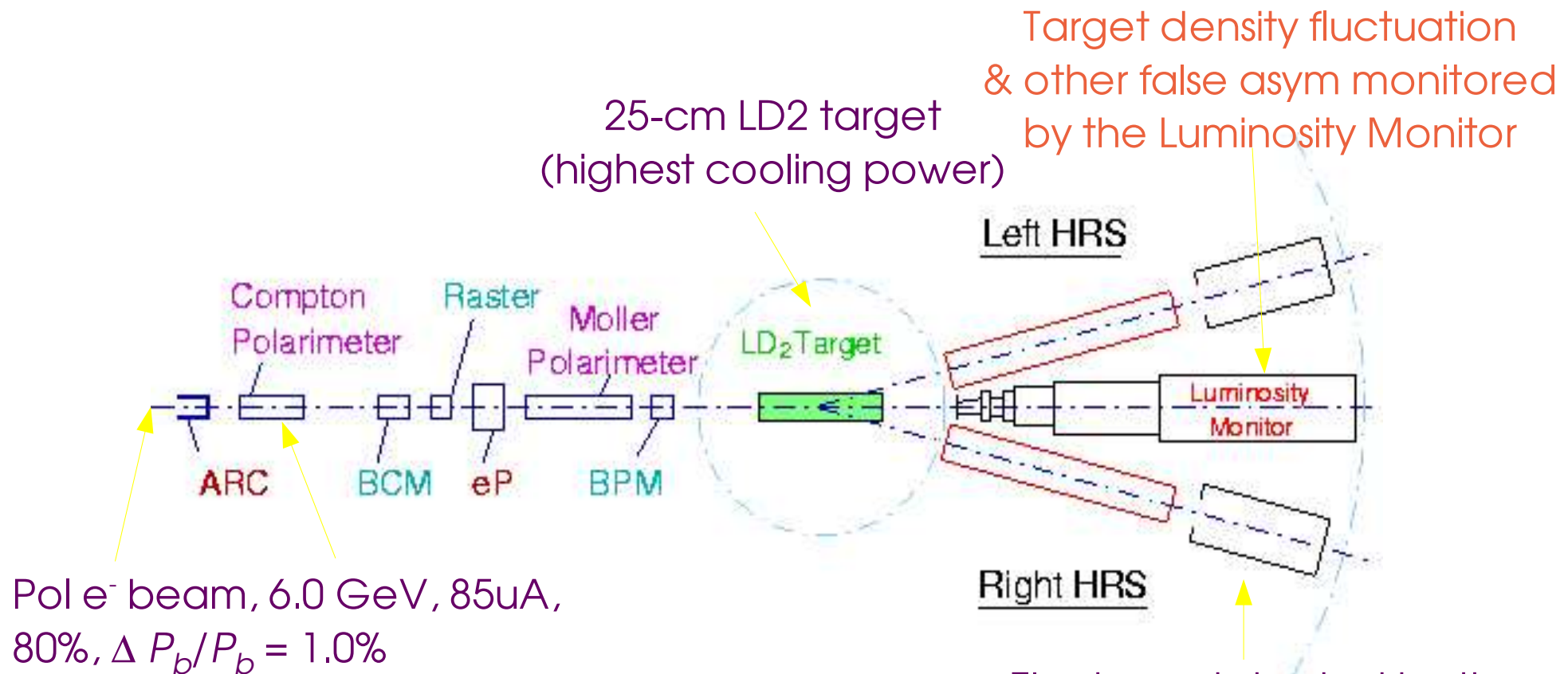
- Will measure  $A_d$  at  $Q^2 = 1.1(\text{GeV}/c)^2$  to  $\Delta A_d / A_d = 2.08\%$  (stat.);
- Will help to understand the result at  $Q^2 = 1.9 (\text{GeV}/c)^2$  if a significant deviation from SM is observed;
- Will help to investigate the HT contribution to the NuTeV anomaly:
  - A 3% HT contribution to  $\sin^2\theta_W$  from  $A_d$  at  $Q^2 = 2 (\text{GeV}/c)^2$  implies the same size (3%) of correction to the NuTeV P-W ratio;  
*M. Gluck and E. Reya, Phys. Rev. Lett. 47, 1104 (1981)*
  - If the HT correction is 2% in the P-W ratio (the NuTeV anomaly has its P-W ratio 2.5% from the SM) $\Rightarrow$  6% on our  $A_d$  at  $Q^2 = 1.9 (\text{GeV}/c)^2$  and 10% at  $Q^2 = 1.1 (\text{GeV}/c)^2$

(numbers in the proposal should be updated)

## HT from the Proposed Measurement (cont.)

- If the HT is un-expectedly large, then the result for HT will have its own value:
  - The Leading Twist (LT) term is un-ambiguously defined in the SM; (opposed to other HT analysis: renormalons, N<sup>2</sup>LO)
  - PV DIS will provide the first CLEAN data on twist-4;
- Provided with theories, may help to establish the HT for other processes, e.g. may help to extract  $\alpha_s$  from low  $Q^2$  DIS data.

# Overview of the Experimental Setup



Beam intensity asymmetry  
controlled by parity DAQ

## New Instruments and/or Upgrades

- Compton polarimeter: will use green laser (in progress); need to upgrade the electron detector from 600  $\mu\text{m}$  strips to 300 $\mu\text{m}$  to achieve  $\Delta P_b/P_b \leq 1.0\%$  for electron analysis method;
- Compton polarimeter: photon integration method under study, may provide  $<1\%$  precision  $\Rightarrow$  cross-check of the electron method;
- 25-cm long LD2 cell;
- Fast counting DAQ: currently planned as part of the 12 GeV program, expected to be ready in 2007;
- An alternative option: scaler-logic-based fast counting DAQ system (LOI03-106).

# DAQ: Comparison of two options

- FADC-based:

- ◆ Is what we eventually need, have more general applications;
- ◆ Full event sampling for detailed off-line analysis;
- ◆ If there is a highly-rated experiment, 2 years is possible.

- Scaler-based:

- ◆ Similar to previous SLAC, and current Hall C scalers;
- ◆ Mostly work for the electronics group, easy to do (sooner);
- ◆ Still, need extra man-power and cost;
- ◆ Specialized;
- ◆ Only scaler info is recorded (on-line PID critical).

## Data Analysis

- Extracting  $A_d$  from data:

$$A_d = \frac{A_{raw}}{P_{beam}} + \Delta A_{EM}^{RC}$$

- Extracting  $2C_{2u}-C_{2d}$  from  $A_d$ :

$$2C_{2u} - C_{2d} = a_2 A_{d,LT} + b_2$$

$$a_2 = \frac{1}{\kappa Q^2} \frac{5 + R_s + 4R_c}{Y R_v} \quad b_2 = -\frac{2C_{1u}(1 + R_c) - C_{1d}(1 + R_s)}{Y R_v}$$

# Kinematics

Kinematics	I	II
$X_{bj}$	0.25	0.3
$Q^2$ (GeV/c) <sup>2</sup>	1.1	1.9
$E_b$ (GeV)	6	6
$E'$ (GeV)	3.66	2.63
$\theta$ (°)	12.9	20.0
$W^2$ (GeV) <sup>2</sup>	4.18	5.31
$Y$	0.471	0.717
$R_c$	<0.001	0.001
$R_s$	0.05	0.04
$R_v$	0.88	0.91
$A_d$ (measured, ppm)	-90.5	-160.6
$e^-$ rate/HRS (kHz)	284.6	26.7
$\pi^-/e^-$ ratio	0.8	5.3
$e^+/e^-$ ratio	0.09%	1.20%
Total rate/HRS (kHz)	501.6	168.1

## Expected Uncertainties on $A_d$

Source \ $\Delta A_d/A_d$	$Q^2=1.1$ (GeV/c) <sup>2</sup>	$Q^2=1.9$ (GeV/c) <sup>2</sup>
$\Delta P_b/P_b=1\%$	1.00%	1.00%
Deadtime correction	0.30%	0.30%
Target endcap contamination	0.30%	0.30%
Target purity	<0.02%	<0.02%
Pion background	<0.2%	<0.2%
Pair production background	<0.2%	<0.2%
Systematics	1.30%	1.30%
Statistical	2.08%	2.02%
Total	2.45%	2.41%

## Expected Uncertainties on $2C_{2u} - C_{2d}$

Source \ $\Delta(2C_{2u} - C_{2d})$	$Q^2=1.1 \text{ (GeV/c)}^2$	$Q^2=1.9 \text{ (GeV/c)}^2$
Statistical	0.0388	0.0246
Systematics (from $A_d$ )	0.0243	0.0158
Experimental ( $Q^2$ )	0.0039	0.0019
$\Delta R = \Delta(\sigma_L/\sigma_T)$	0.0013	0.0017
Parton distribution functions	0.0021	0.0025
Charge symm. Violation (MRST)	0.0074	0.0068
Electro-magnetic rad. Cor.	0.0075	0.0049
Electro-weak rad. Cor.	0.0037	0.0024
Total uncertainty	0.0473	0.0307

Need 42 days to achieve 0.03

# Beam Time Request

- Commissioning: 4 days

- Production:

$E_b$ (GeV)	$\theta$	$E$ (GeV)	$Q^2$ (GeV/c) <sup>2</sup>	e <sup>-</sup> prod (days)	e <sup>+</sup> prod (days)	Dummy (days)	Total (days)
6.0	12.9°	3.66	1.1	9.0	0.2	0.2	9.4
6.0	20.0°	2.63	1.9	32.0	0.2	0.7	32.9

- *Will add one shift at each  $Q^2$  to measure single beam spin asymmetry*
- Total beam time requested: 46 days

# Beam Time Allocation for Running In Two Phases

- Phase I: 13 days
  - ★ 4 days of commissioning and systematic checks including:
    - ◆ Commissioning fast counting DAQ and Compton
    - ◆ Measuring  $Q^2$  and checking the PID with regular & fast DAQ;
  - ★ 9 days with the HRS-L at  $Q^2=1.10 \text{ (GeV/c)}^2$  and the HRS-R at  $Q^2=1.90 \text{ (GeV/c)}^2$ , including  $e^+$  and dummy (Be) runs for each.
- Phase II: 33 days
  - ★ 9 days with the HRS-L at  $Q^2=1.10 \text{ (GeV/c)}^2$  and the HRS-R at  $Q^2=1.90 \text{ (GeV/c)}^2 \Rightarrow$  complet the low  $Q^2$  measurement;
  - ★ 24 days with both HRS at  $Q^2=1.90 \text{ (GeV/c)}^2 \Rightarrow$  complet the high  $Q^2$  measurement;

## Advantages of “Two Phases” Running

- The expected results from the first phase running are
  - ◆  $3.5\%/Q^2$  on the HT (first limit);
  - ◆  $\Delta(2C_{2u}-C_{2d}) = 0.05$  (factor of 5 improvement);
  - ◆ Already significant.
- Results of the first phase running will provide guidance for beam time allocation during the second phase
  - ◆ Minimize impacts of possible instrumentational problem on the final results.

# Summary

- Measure  $A_d$  at  $Q^2=1.10$  and  $Q^2=1.90$  ( $\text{GeV}/c$ )<sup>2</sup> to about 2% (stat.);
- From  $A_d$  at  $Q^2=1.90$  ( $\text{GeV}/c$ )<sup>2</sup>, can extract  $\Delta(2C_{2u}-C_{2d}) = 0.0307$ ;
  - ◆ factor of eight improvement;
  - ◆ will provide constraints on various new physics;
- The  $A_d$  at  $Q^2=1.10$  ( $\text{GeV}/c$ )<sup>2</sup> will help to investigate if there are significant higher-twist effects:
  - ◆ the first limit on HT in PV DIS;
  - ◆ Will help understanding the NuTeV anomaly;
  - ◆ May have impacts to other areas (extracting  $\alpha_s$  at low  $Q^2$ );
- Request for 46 (13+33) days; Require Compton upgrade, 25-cm LD2 cell, FADC-based fast counting DAQ;
- Will start/establish the PV DIS program at JLab.

# Why Now?

- Why not? Concerns about HT?
- It's hard, but nevertheless we will have some information about PV DIS, and we will be able to answer the following questions:
  - ★ Is the HT contribution un-expectedly large? (Impacts on theories, plan for PV DIS program at 12 GeV)
  - ★ Does it affect our interpretation of the data?
  - ★ Does it explain NuTeV anomaly?
- If we don't do it now, we will still know nothing about PV DIS;
  - ★ No guidance for HT theories for another decade, no guidance for the 12 GeV program;
  - ★ At the beginning of 12 GeV, first thing to do is still to measure  $A_d$  at low  $Q^2$  (lower beam energy) to set limit on the HT.
- This is just the starting point of the PV DIS program at Jlab (12 GeV).