$\vec{e}-^2$H Parity Violation DIS at 6 GeV

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- PV-DIS asymmetry and the proposed measurements:
  - the high Q^2 measurement and new physics
  - the low Q^2 measurement and higher-twist effects
- Experimental setup, expected results and uncertainties
- Beam time request and summary

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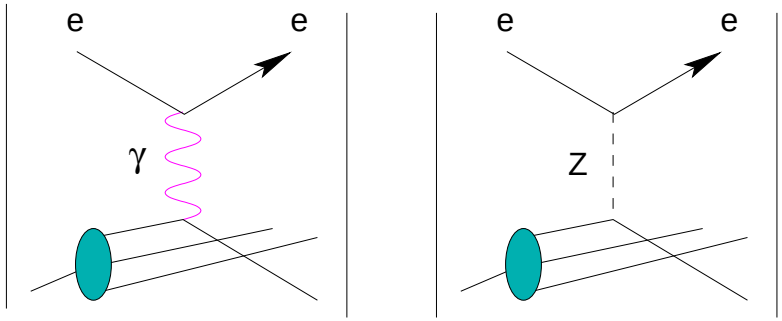
The Hall A Collaboration

DIS-PV Asymmetry for a Deuterium Target

A_{PV} =



$$A_d = \left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u}[1+R_c(x)] - C_{1d}[1+R_s(x)] + Y(2C_{2u}-C_{2d})R_v(x)}{5+R_s(x)+4R_c(x)}$$

where (at the tree level)

$$C_{1u} = g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \qquad R_c(x) \equiv \frac{2[c(x)+\bar{c}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

$$C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \qquad R_s(x) \equiv \frac{2[s(x)+\bar{s}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

$$C_{2u} = g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W) \qquad R_v(x) \equiv \frac{u_V(x)+d_V(x)}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

$$C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2\sin^2(\theta_W) \qquad Y = \frac{1-(1-y)^2}{1+(1-y)^2-y^2R/(1+R)}$$

- From A_d one can extract $C_{1,2q}$ and $\sin^2\theta_W$.

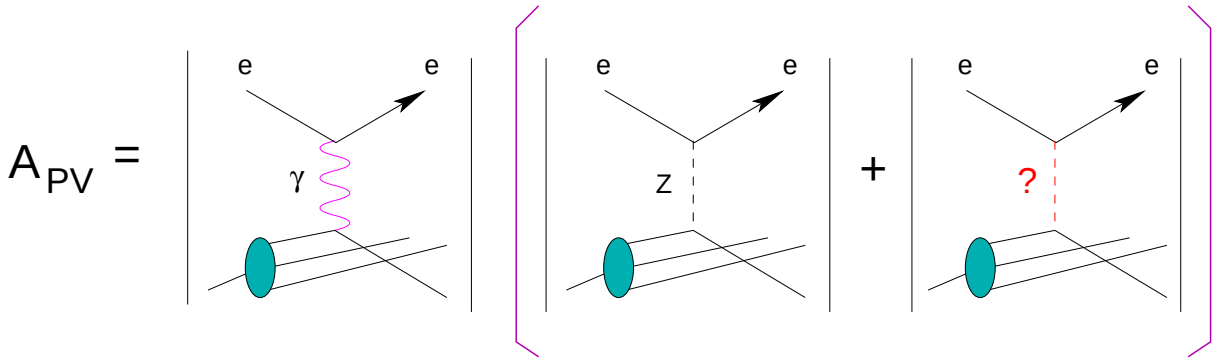
HISTORY

- 1970's, result from SLAC E122 consistent with $\sin^2\theta_W = 1/4$, implied a small $V(\mathrm{e})\times A(\mathrm{q})$ NC interaction, confi rmed the SM prediction.

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

PRESENT

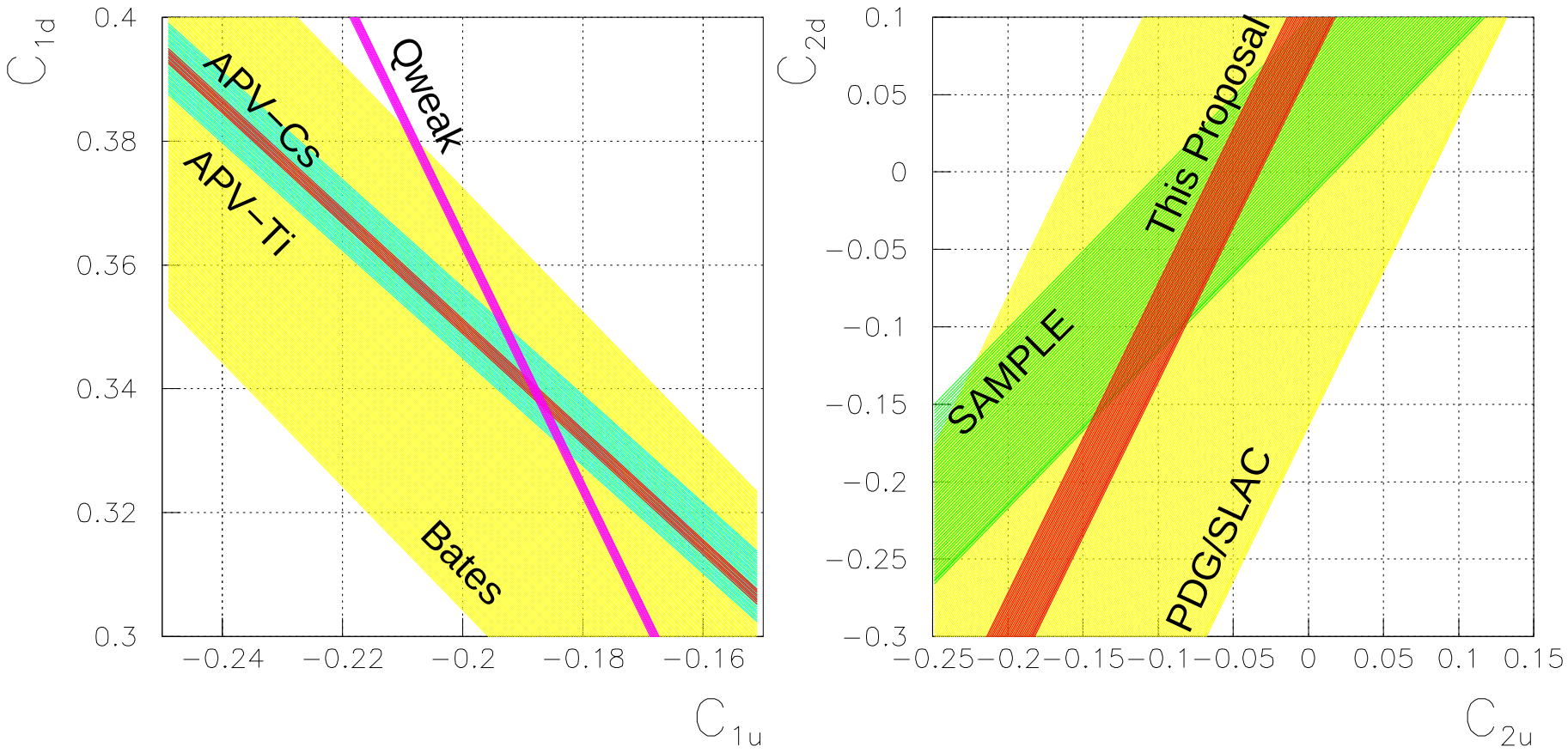
- Developement in experimental technology allows us to search for new physics using DIS-PV



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

THE PROPOSED EXPERIMENT

- Measure A_d at $Q^2 = 1.10$ and $Q^2 = 1.90$ (GeV/c)^2 to $\approx 2\%$ level;
- From A_d at $Q^2 = 1.90$ (GeV/c)^2, can extract $2C_{2u} - C_{2d}$ to ± 0.0307(factor of eight improvement); This result will provide constraints on new physics;
- The A_d at $Q^2 = 1.10$ (GeV/c)^2 will help to investigate if there is signifi cant higher-twist effect; Meanwhile, this will be the fi rst precise observation of HT in PV-DIS, it will help understanding existing world data (NuTeV), and will provide important guidance to the 12 GeV program.


C_{1d}
0.4
0.38
0.36
0.34
0.32
0.3
−0.24
−0.22
−0.2
−0.18
−0.16
C_{1u}
APV−Cs
APV−Ti
Qweak
Bates
C_{2d}
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−0.3
−0.25
−0.2
−0.15
−0.1
−0.05
0
0.05
0.1
0.15
C_{2u}
SAMPLE
This Proposal
PDG/SLAC

DIS-PV and New Physics

- Interaction of new physics

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

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

g: coupling constant; Λ: mass scale, h^q_A: effective coeffi cients.

- Mass limit of the proposed measurement:

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

NEW PHYSICS (A FEW EXAMPLES)

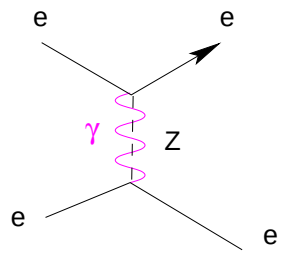
- Z' Searches: will give $M_{Z'} \approx 0.8$ TeV.
- Compositeness (8 four-fermion contact interactions)
  - SU(12): affect C_{2q} but not $C_{1q} \Rightarrow C_{2q}$ provide a unique opportunity to explore quark and lepton compositeness.
  - will give $\Lambda_1 = 3.56$ TeV;
  - neccessary for fi tting all contact terms simultaneously.
- Leptoquarks:
  - for a scalar leptoquark interacting with u quarks, will set

$$\lambda_s \leq 0.14(M_{LQ}/100\ \text{GeV})$$

(comparable to the current limit from the Cs APV experiment.)

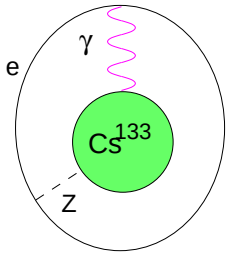
DIS-Parity and other tests of the SM

⋆ E158/Moller (SLAC)



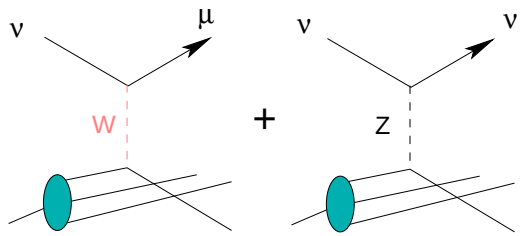
- Purely Leptonic

⋆ Atomic PV



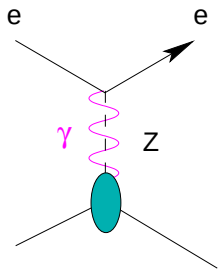
- Coherent Quarks in the Nucleus
- $-376\ C_{1u} - 422\ C_{1d}$
- Nuclear Structure?

⋆ NuTeV (FNAL)



- Weak CC and NC difference
- Nuclear Structure Uncertainty?

⋆ Qweak (JLab)



- $2(2C_{1u} + C_{1d})$
- Coherent Quarks in the Proton

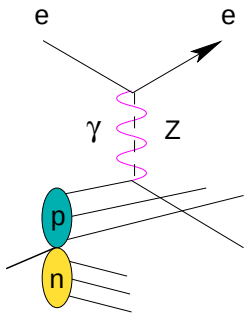
Different Experiments

Probe Different

Parts of Lagrangian

Figure by
R. Arnold (UMass)

⋆ DIS-Parity (JLab)



- $(2C_{1u} - C_{1d}) + Y(2C_{2u} - C_{2d})$
- Isoscaler Quark Scattering

THE HIGHER-TWIST EFFECT (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: $< 2\%$ effect on A_d at $Q^2 = 1.67$ (GeV/c)^2

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

- QCD NLO, NNLO calculations (using C_{HT} from Virchaux & Milsztajn as input): HT change A_d by $1\%/Q^2$ for $0.1 < x < 0.3$ W.L. van Neerven

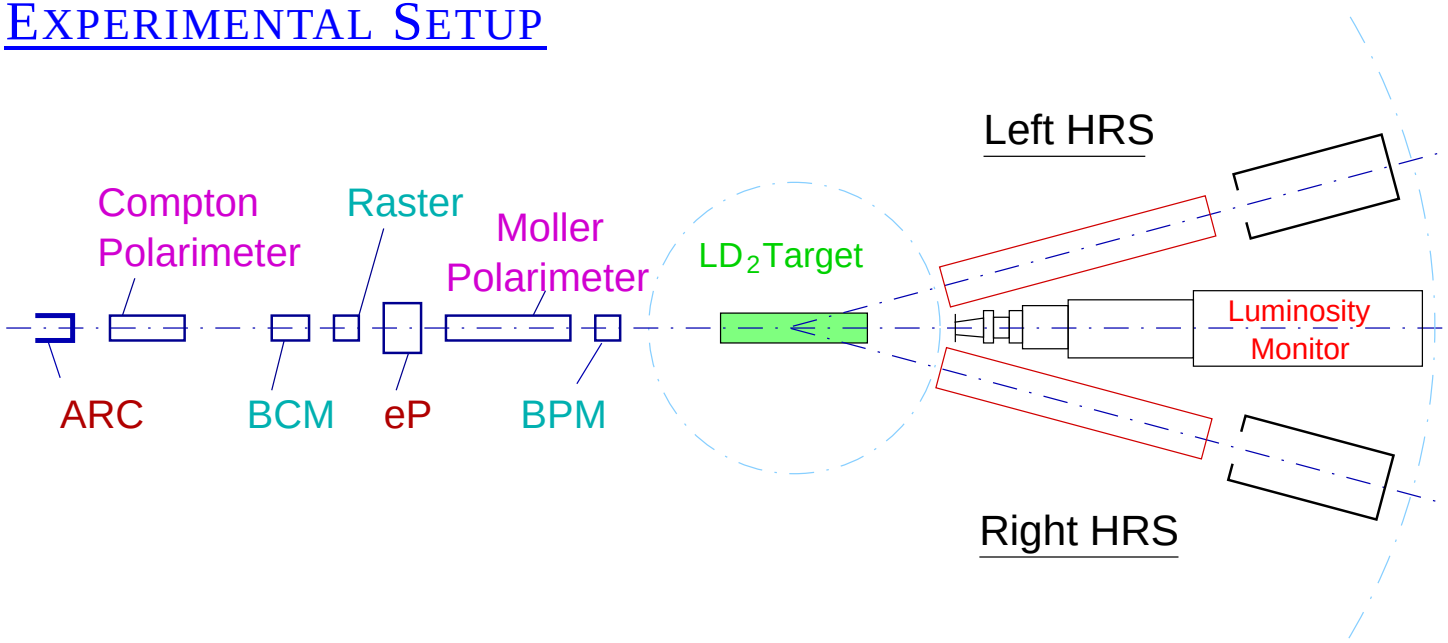
- Overall:
  - Most theories predict $< 1\%/Q^2$ HT effect on A_d;
  - No data to confi rm these predictions.

HT FROM THE PROPOSED MEASUREMENT

- Will measure A_d at $Q^2 = 1.10$ (GeV/c)^2 to $\Delta A_d/A_d = \pm 2.08\%$(stat.)$\pm 1.30\%$(syst.)
- Will help to understand the result at $Q^2 = 1.90$ (GeV/c)^2 if a signifi cant deviation from SM is observed;
- The proposed measurement will help to investigate the HT contribution to the NuTeV anomaly:
  - a 3% HT contribution to $\sin^2\theta_W$ from A_d at $Q^2 = 2$ (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 $Q^2 = 1.90$ and 10% at $Q^2 = 1.10$ (GeV/c)^2; (numbers in proposal should be updated)
- Provided with calculations, may help to establish the HT for other processes, and may help to extract α_S from low Q^2 DIS data.

EXPERIMENTAL SETUP

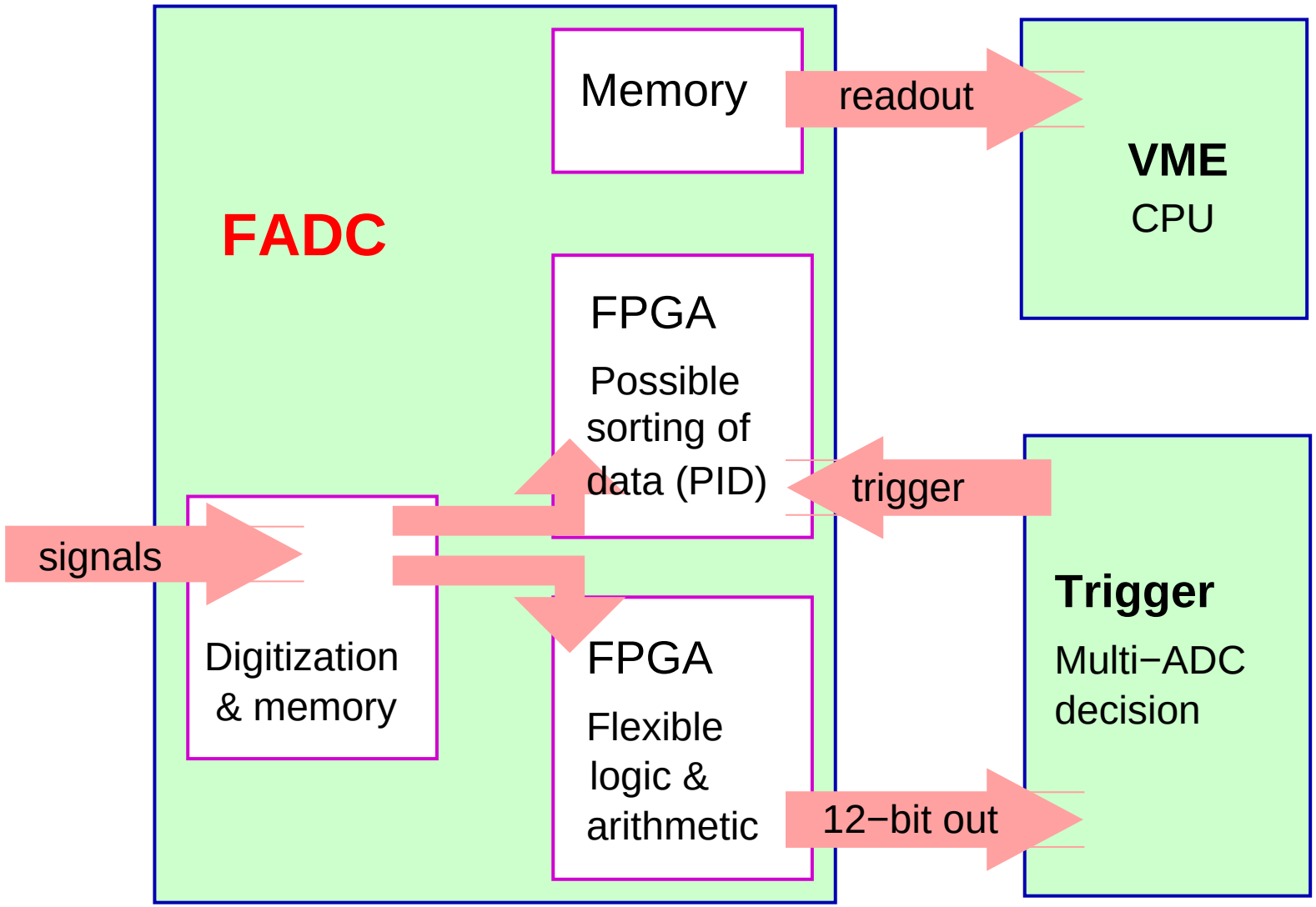


- 6 GeV beam, 85 μA, 80% polarization (1% by Compton);
- 25-cm LD2 target (at its highest cooling power);
- Beam intensity asymmetry controlled by parity DAQ;
- Target density fluctuation and other false asym. checked by the Lumi.
- Two HRS taking data independently;
- Fast counting DAQ will handle up to 1 MHz rate with 10^{+3} pion rej.

NEW INSTRUMENTS

- Compton polarimeter: upgrade the electron detector from 600 μm strips to 300 μm strips, provide $< 1\%$ precision;
- 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 part of the 12 GeV program, expected to be ready in 2007.

250 MHz, 2 usec latency, 1 MHz on−board analysis, 0.1% DT measurement



DATA ANALYSIS

- Extracting Asymmetry 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 and b_2 are given at the tree level by

$$a_2 = \frac{1}{\mathcal{K}Q^2} \frac{5 + R_s + 4R_c}{Y R_v}$$

$$b_2 = -\frac{2C_{1u}(1 + R_c) - C_{1d}(1 + R_s)}{Y R_v}$$

with $\mathcal{K} \equiv \frac{3G_F}{\pi\alpha 2\sqrt{2}} = 539.5$ ppm/GeV^2

KINEMATICS

Kinematics	I	II
x_{Bj}	0.25	0.30
Q^2 (GeV/c)^2	1.10	1.90
E (GeV)	6.0	6.0
E' (GeV)	3.66	2.63
θ	12.9°	20.0°
W^2 (GeV)^2	4.18	5.31
Y	0.471	0.717
R_c	< 0.001	0.001
R_s	0.046	0.044
R_v	0.875	0.909
A_d (measured, ppm)	-90.5	-160.6
e^- rate/HRS (KHz)	284.6	26.7
π^-/e^- ratio	0.8	5.3
e^+/e^- ratio	0.087%	1.199%
total rate/HRS (KHz)	501.6	168.1

EXPECTED UNCERTAINTY ON A_d

Source/$\frac{\Delta A_d}{A_d}$	$Q^2 = 1.10$ (GeV/c)^2	$Q^2 = 1.90$ (GeV/c)^2
$\Delta P_{beam}/P_{beam} = 1\%$	1%	1%
deadtime correction	$\approx 0.3\%$	$\approx 0.3\%$
target endcap contamination	0.3%	0.3%
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%
stat.+syst.	2.45%	2.41%

EXPECTED UNCERTAINTY ON $2C_{2u} - C_{2d}$

Source/$\Delta(2C_{2u} - C_{2d})$	$Q^2 = 1.10$ (GeV/c)^2	$Q^2 = 1.90$ (GeV/c)^2
statistical	0.0388	0.0246
systematics (from A_d)	0.0243	0.0158
experimental (Q^2)	0.0039	0.0019
$\Delta R \equiv \sigma_L/\sigma_T$	0.0013	0.0017
parton distributions	0.0021	0.0025
charge symmetry violation (MRST)	0.0074	0.0068
electro-magnetic radiative correction	0.0075	0.0049
electro-weak radiative correction	0.0037	0.0024
total uncertainty	0.0473	0.0307

BEAM TIME REQUEST

- Commissioning: four days;
- Production (time given in two HRS-equivalent)

E_b (GeV)	θ	E_p (GeV)	Q^2 (GeV/c)^2	e^- prod. (days)	e^+ run (days)	dummy (days)	total (days)
6.0	12.9°	3.66	1.10	9.0	0.2	0.2	9.4
6.0	20.0°	2.63	1.90	32.0	0.2	0.7	32.9

- Total beam time requested: 46 days.

BEAM TIME ALLOCATION FOR RUNNING IN TWO PHASES

- Phase I: 13 days
  1. 4 days of commissioning and systematic checks including: commissioning fast counting DAQ and Compton; measuring Q^2 and checking PID with the regular and the fast counting DAQ.
  2. 9 days with the HRS-L at $Q^2 = 1.10$ and the HRS-R at $Q^2 = 1.90$ (GeV/c)^2, including e^+ and dummy runs for each.
- Phase 2: 33 days
  1. 9 days with the HRS-L at $Q^2 = 1.10$ and the HRS-R at $Q^2 = 1.90$ (GeV/c)^2 $\Rightarrow$ complete the low Q^2 measurement;
  2. 24 days with both HRS taking data at $Q^2 = 1.90$ (GeV/c)^2 $\Rightarrow$ complete the high Q^2 measurement.

- Advantage of "two phases"
  - the expected uncertainty on the HT and C_{2q} from the first phase running are $3.5\%/Q^2$ and $\Delta(2C_{2u} - C_{2d}) = \pm 0.05$ (factor of 5), respectively $\Rightarrow$ already significant.
  - Results of the first running will provide guidance for beam time allocation during the 2nd phase $\Rightarrow$ minimize impacts of possible instrumental problems on the final results.

SUMMARY

- Measure A_d at $Q^2 = 1.10$ and $Q^2 = 1.90$ (GeV/c)^2 to $\approx 2\%$ level;
- From A_d at $Q^2 = 1.90$ (GeV/c)^2, can extract $2C_{2u} - C_{2d}$ to ± 0.0307
  - factor of eight improvement;
  - will provide constraints on various new physics;
- The A_d at $Q^2 = 1.10$ (GeV/c)^2 will help to investigate if there is signifi cent higher-twist effect;
  - the fi rst precise observation of HT in PV-DIS;
  - will help understanding the NuTeV anomaly;
  - may have impacts to other areas (extracting α_s at low Q^2);
- Request for 46 days. Require Compton upgrade, 25-cm long LD2 cell, new fast counting DAQ;
- Start/establish the DIS-parity program at JLab.