PR08-011 (E05-007 Update)

Measurement of Deuteron PVDIS Asymmetry at 6 GeV

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January 2008

- The Physics of PVDIS, including:
  - Updates on hadronic effects
  - Update on knowledge of C_{1q} and C_{2q}.
- Experimental Setup and Data Analysis
- Expected Results and Uncertainties
- Beam Time Request and Summary

The Collaboration

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The Hall A Collaboration

ANL, Calstate, FIU, JLab, Kentucky, Louisiana Tech, U. of Ljubljana (Slovenia), MIT, UMD, UMass, UNH, Universidad Nacional Autonoma de Mexico, Ohio U., Randolph-Mason C., Smith C., Syracuse, Temple U., UVa, W&M, Yerevan Phys. Inst.(Armenia)

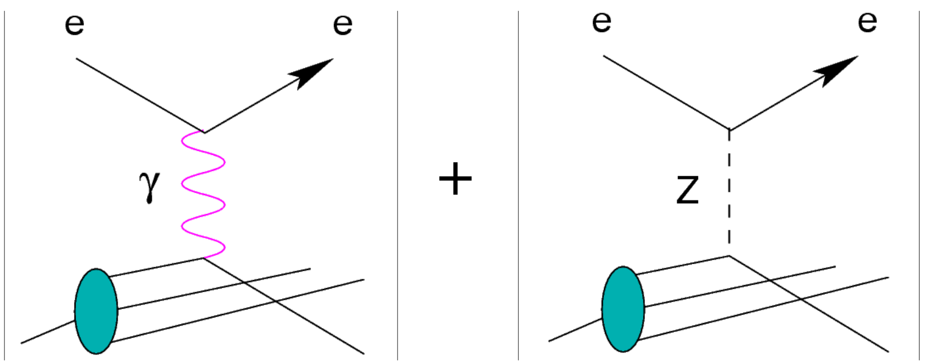
The Physics of PVDIS at 6 GeV (E05-007)

- Measure PVDIS asymmetry on a deuterium target, A_d, at Q^2=1.10 and 1.90 GeV^2 to 2% (stat.);
  - From Q^2=1.10 can help to investigate if there are significant HT effects;
    — "Baseline" measurement for the future 12 GeV program.
  - If HT is small, from Q^2=1.90 GeV^2 can extract $2C_{2u}-C_{2d}$ to ±0.033, a factor of 7.4 improvement;
- Total request 46 days, with 13 days approved (A-), $\Delta(2C_{2u}-C_{2d})$= ±0.066.

> PAC27 report: "The PAC recommends the approval of the first phase (13 days) ...... It will also allow extremely useful preparation for a second phase of the experiment which can be presented in the future."

- PAC33: requesting again for the full beam time (now 50 days).

PVDIS Asymmetries

$A_{PV} =$ 

- Deuterium:

$$A_d = (540\,ppm)\,Q^2 \frac{2C_{1u}[1+R_C(x)] - C_{1d}[1+R_S(x)] + Y(2C_{2u} - C_{2d})R_V(x)}{5 + R_S(x) + 4R_C(x)}$$

$$C_{1u} = g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \qquad C_{2u} = g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W)$$

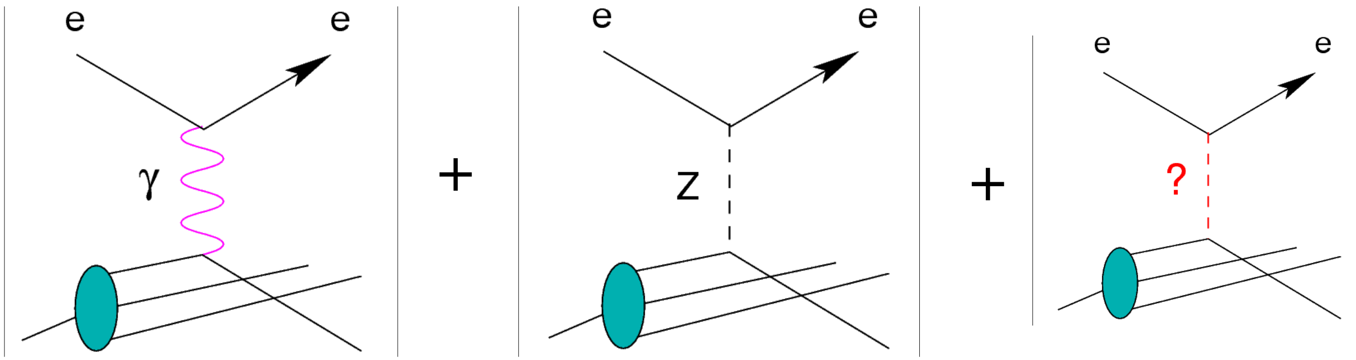
$$C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \qquad C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2\sin^2(\theta_W)$$

- Can extract $C_{1,2q}$ (and $\sin^2\theta_W$)

In the SM, tree level

PVDIS Asymmetries

$A_{PV} =$



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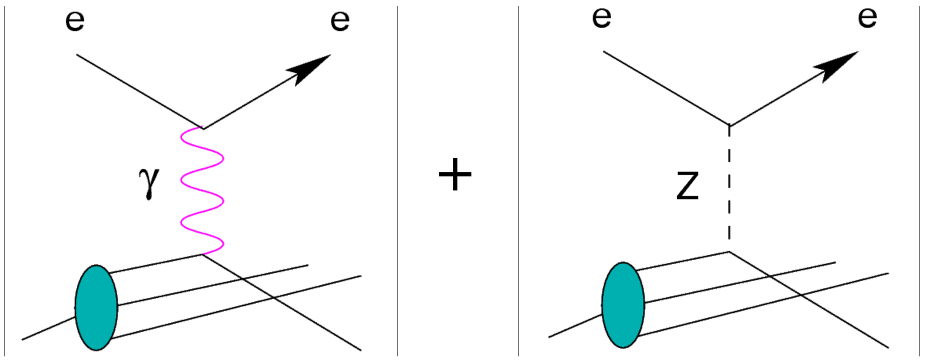
$$C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \qquad C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2\sin^2(\theta_W)$$

- Can extract $C_{1,2q}$ (and $\sin^2\theta_W$)– discover new physics beyond the SM
- Sensitive to: Z' searches, compositeness, leptoquarks
- Mass limit: $$\Lambda/g \approx \frac{1}{\left[\sqrt{8}\,G_F\left|\Delta(2C_{2u}-C_{2d})\right|\right]^{1/2}} \approx 1.0\,\text{TeV}$$

PVDIS Asymmetries

$A_{PV} =$ 

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$$R_S(x) = \frac{2[s(x)+\bar{s}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)} \quad R_C(x) = \frac{2[c(x)+\bar{c}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)} \quad R_V(x) = \frac{u_V(x)+d_V(x)}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

- Also sensitive to:
  - Non-perturbative QCD (higher-twist) effects ← Small, but need confirmation
  - Charge symmetry violation ← Small from MRST fit (90% CL), negligible compared to 2%

PVDIS Experiment – Past, Present and Future

- 1970's, result from SLAC E122 consistent with $\sin^2\theta_W$=1/4, established the Standard Model; C.Y. Prescott, *et al.*, Phys. Lett. B77, 347 (1978)

- PVDIS asymmetry has the potential to explore new physics, study hadronic effects/CSV ...... However, hasn't been done since 1978.
  - If we observe a significant deviation from the SM value, it will definitely indicate something exciting;
  - At higher precision, separation of the three (new physics, HT, CSV) requires a larger PVDIS program at 11 GeV; PVDIS at 6 GeV will serve as the first step, and could possibly make an impact on electroweak SM study already.

Current Knowledge on Weak Coupling Coeffecients

Facility	Process	Q^2	C_{iq} Combination	Result	SM Value
SLAC	e^--D DIS	1.39	$2C_{1u}-C_{1d}$	-0.90± 0.17	-0.7185
SLAC	e^--D DIS	1.39	$2C_{2u}-C_{2d}$	0.62± 0.81	-0.0983
CERN	$\mu^\pm$-D DIS	34	$0.66(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$	1.80± 0.83	1.4351
CERN	$\mu^\pm$-D DIS	66	$0.81(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$	1.53± 0.45	1.4204
MAINZ	e^--Be QE	0.20	$2.68C_{1u}-0.64C_{1d}+2.16C_{2u}-2C_{2d}$	-0.94± 0.21	-0.8544
Bates	e^--C elastic	0.0225	$C_{1u}+C_{1d}$	0.138±0.034	0.1528
Bates	e^--D QE	0.1	$C_{2u}-C_{2d}$	-0.042± 0.057	-0.0624
Bates	e^--D QE	0.04	$C_{2u}-C_{2d}$	-0.12± 0.074	-0.0624
JLab	e^--p elastic	0.03	$2C_{1u}+C_{1d}$	approved	-0.0357
	^{133}Cs APV	0	$-376C_{1u}-422C_{1d}$	-72.69±0.48	-73.16
	^{205}Tl APV	0	$-572C_{1u}-658C_{1d}$	-116.6±3.7	-116.8

$$C_{3q} = g_A^e g_A^q$$

PDG2002:
$\Delta(2C_{2u}-C_{2d})=\pm 0.24$
(PAC27)

J. Erler, M.J. Ramsey-Musolf, hep-ph/0404291 or Prog. Part. Nucl. Phys. **54**, 351 (2005)

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Fit	e^--A	low	$C_{1u}+C_{1d}$	0.1358±0.0326	0.1528
All			$C_{1u}-C_{1d}$	-0.4659±0.0835	-0.5297
PVES			$C_{2u}+C_{2d}$	-0.2063±0.5659	-0.0095
Data			$C_{2u}-C_{2d}$	-0.0762±0.0437	-0.0621

new

correlation=-0.295
→ $\Delta(2C_{2u}-C_{2d})=\pm0.271$

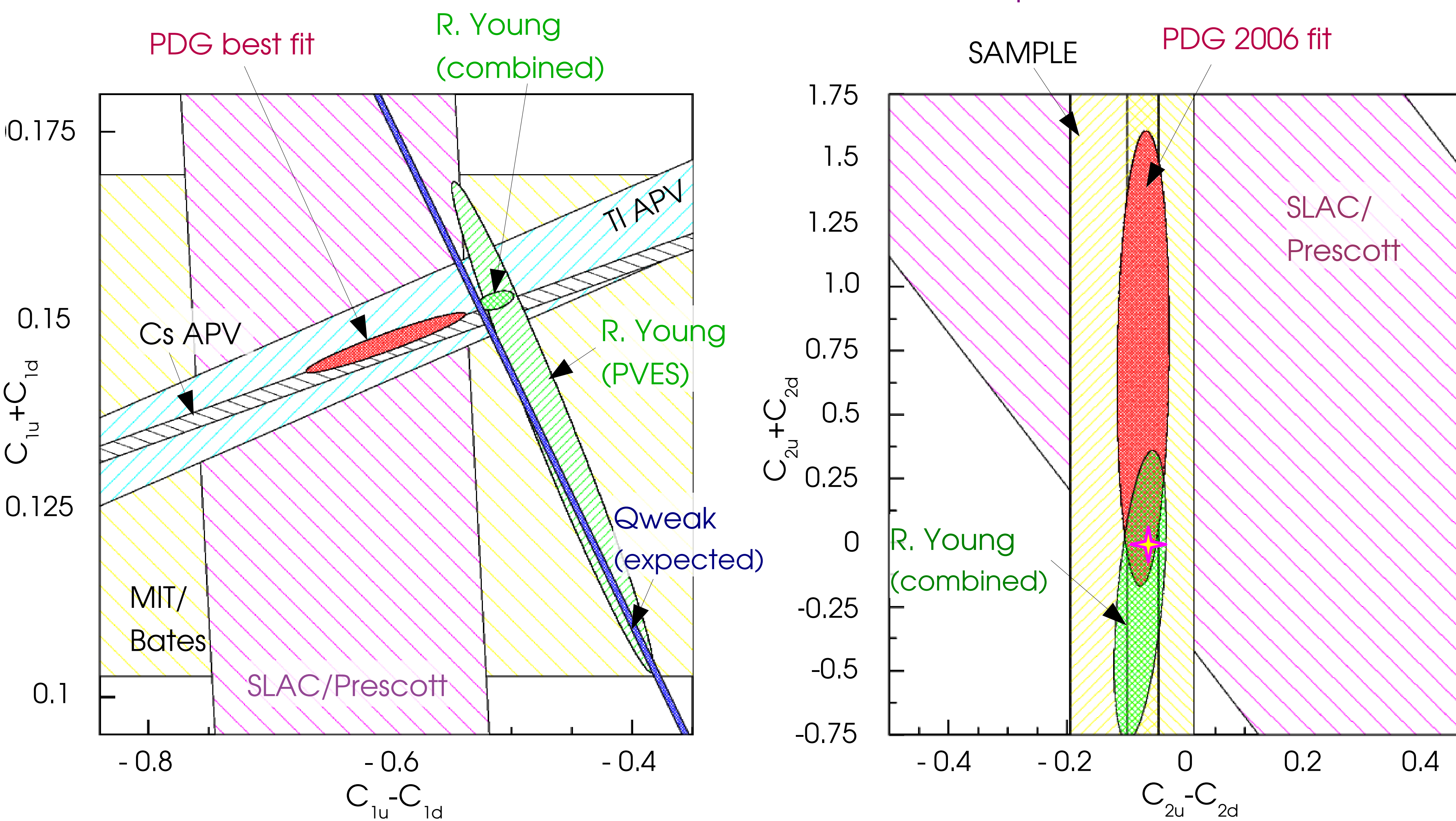
PDG2002:
$\Delta(2C_{2u}-C_{2d})=\pm0.24$
(PAC27)

J. Erler, M.J. Ramsey-Musolf, hep-ph/0404291 or Prog. Part. Nucl. Phys. **54**, 351 (2005)

R. Young, R. Carlini, A.W. Thomas, J. Roche, PRL 99, 122003 (2007) & priv. comm.

Current Knowledge on $C_{1,2q}$ (new)

all are 1 σ limit



- Best: PDG2002 $\Delta(2C_{2u}-C_{2d}) = 0.24 \longrightarrow$ factor of 7.4 improvement (same as PR05-007); New physics mass limit: 1.0 TeV. (used 0.19 and "factor of 6", should be updated)

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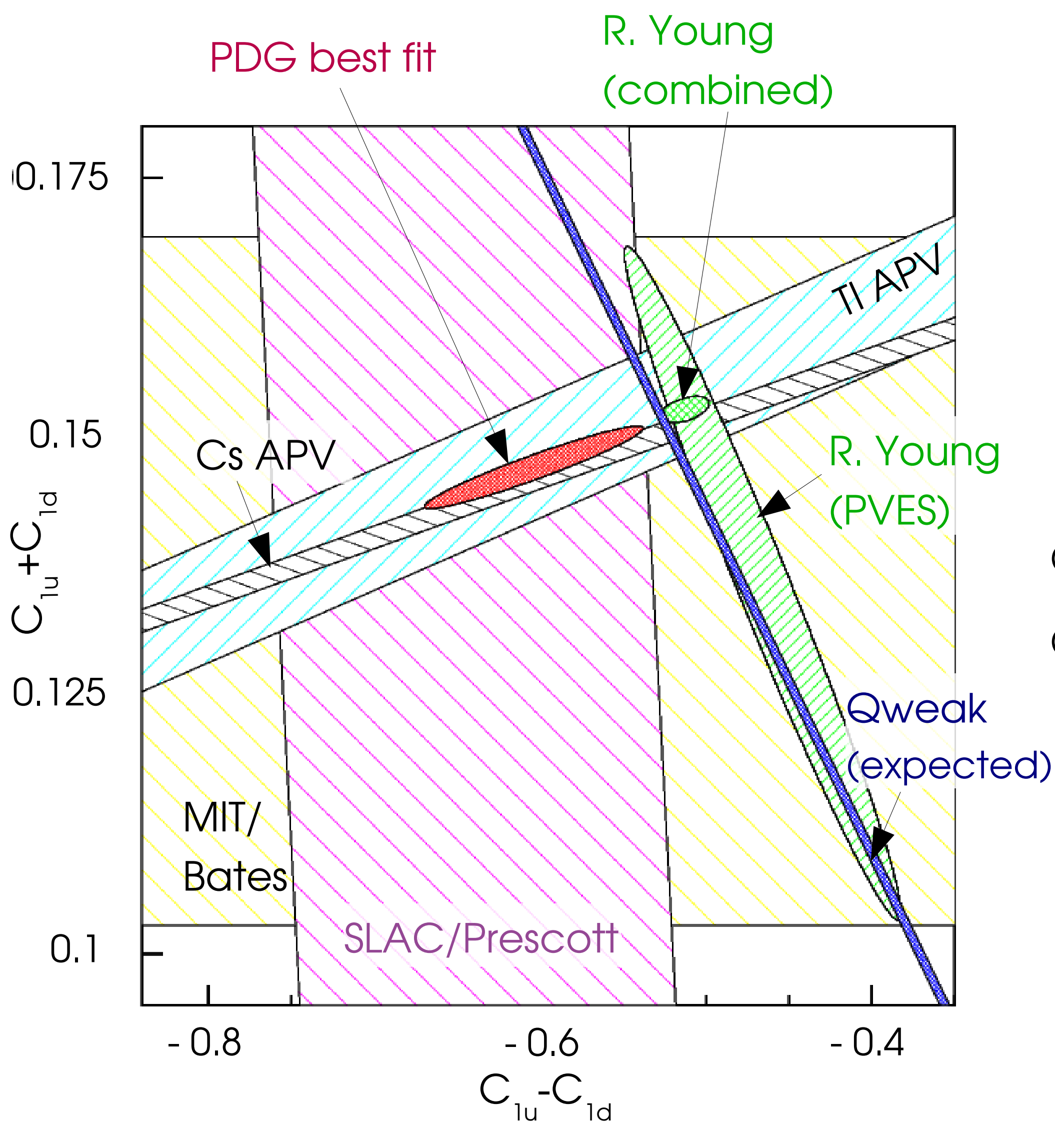

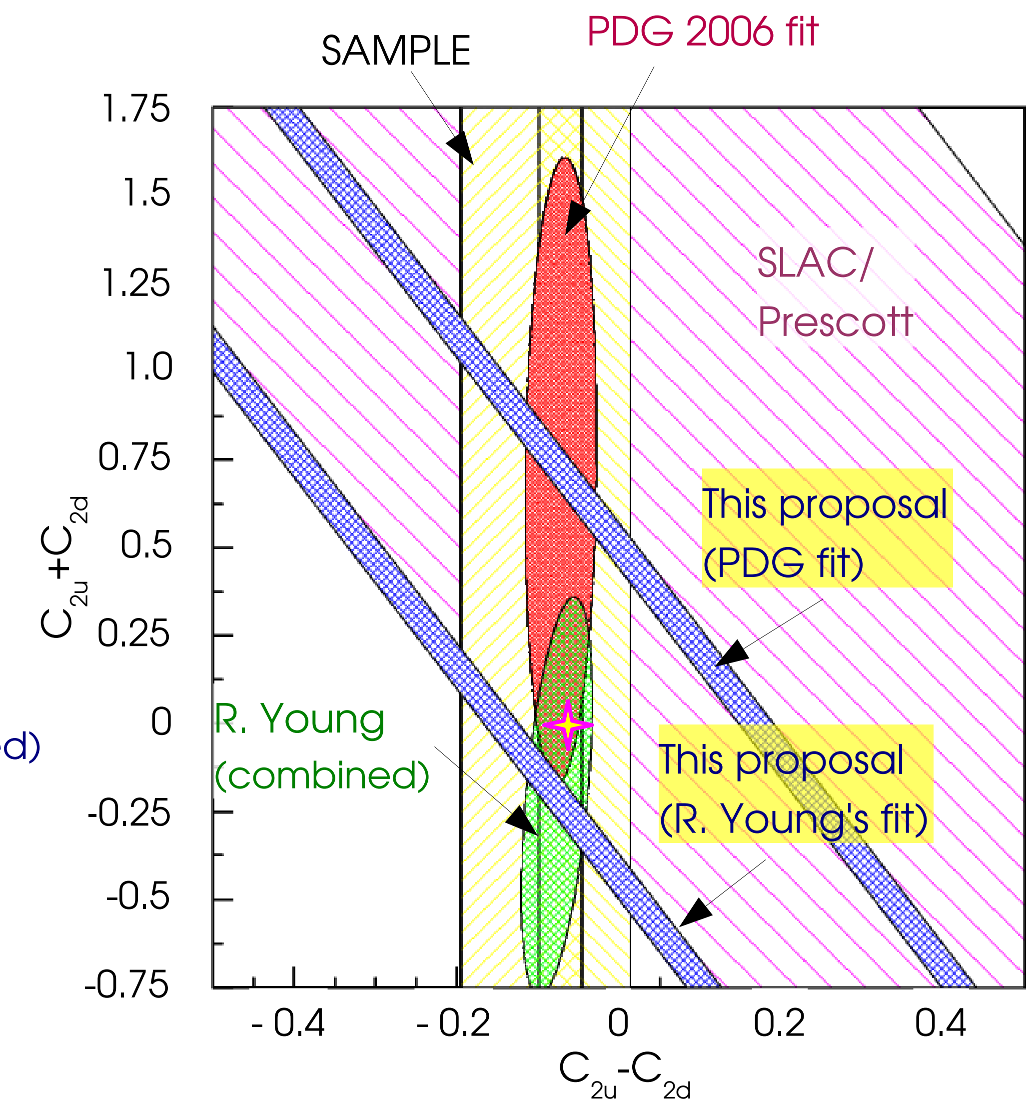

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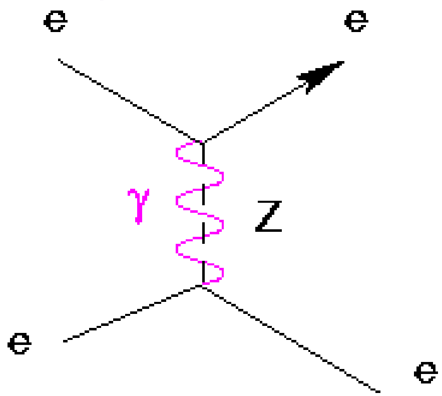
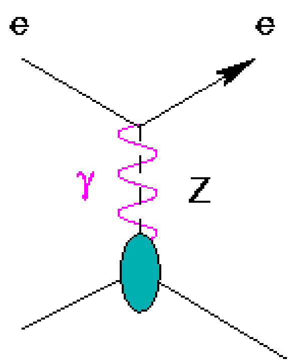
PV DIS and Other SM Test Experiments

E158/Moller (SLAC)



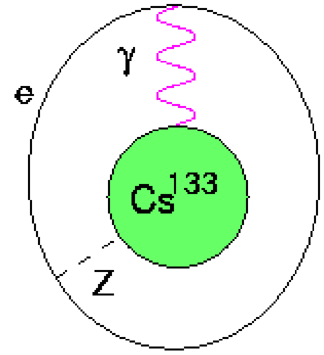
- Purely leptonic

Qweak (JLab)



- $2(2C_{1u}+C_{1d})$
- Coherent quarks in the proton

Atomic PV



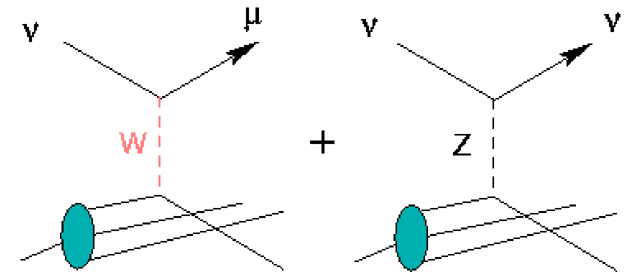
- Coherent Quarks in the Nucleus
- $-376C_{1u}-422C_{1d}$
- Nuclear structure?

Different Experiments Probe Different Parts of Lagrangian,

PVDIS is the only one accessing C_{2q}

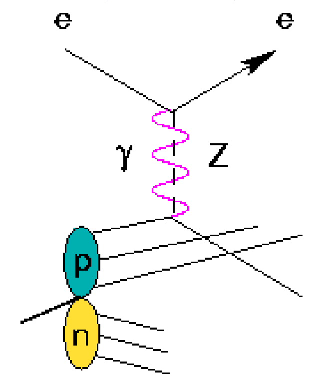
Cartoons borrowed from R. Arnold (UMass)

NuTeV (FNAL)



- Weak CC and NC difference
- Nuclear structure?
- Other hadronic effects?

PVDIS (JLab)



- $(2C_{1u}-C_{1d})+Y(2C_{2u}-C_{2d})$
- Isoscalar quark scattering

Status of Higher Twist Effects (HT)

- MRST: HT effect on $F_2 < 0.1\%$ for $0.1<x<0.3$ in NNLO and NNNLO;

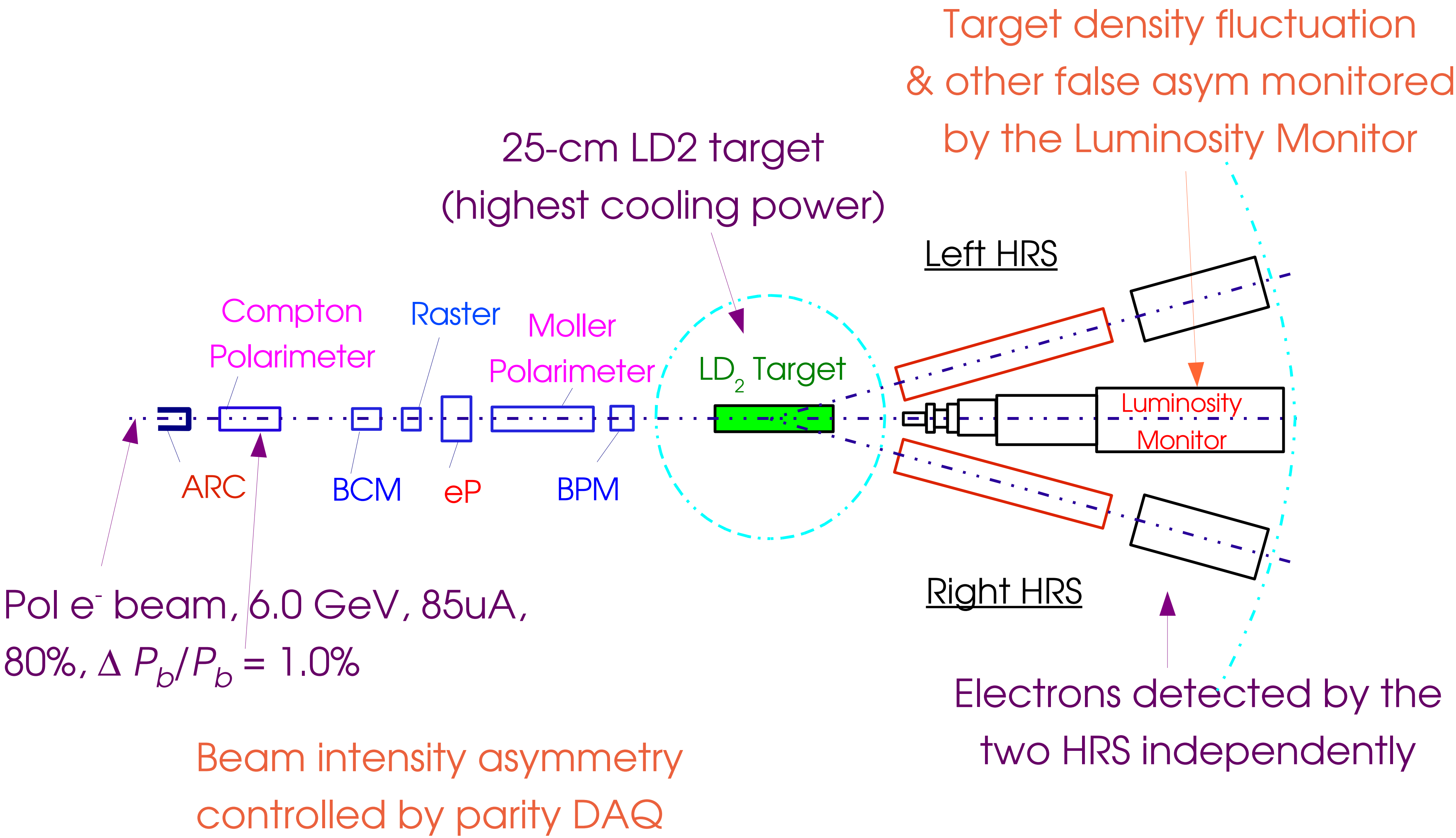
  Martin, Roberts, Stirling and Thorne, EPJC35, 325 (2004)

- HT on PV calculations:
  - MIT Bag Model I: $0.3\%/Q^2$
  - MIT Bag Model II: $<2\%/Q^2$
  - Calculation using C_{HT} from F_2 data ($F_2=(F_2^{LT}(1+C_{HT}/Q^2))$: $<1\%/Q^2$ for $0.1<x<0.3$

- HT likely to be small at $Q^2=2$ (GeV/c)^2, nevertheless, will measure A_d at 1.1 (GeV/c)^2 to check
- More up-to-date calculations are possible if PR is re-approved.

- May help to investigate the HT contribution to the NuTeV anomaly (model-dependent)

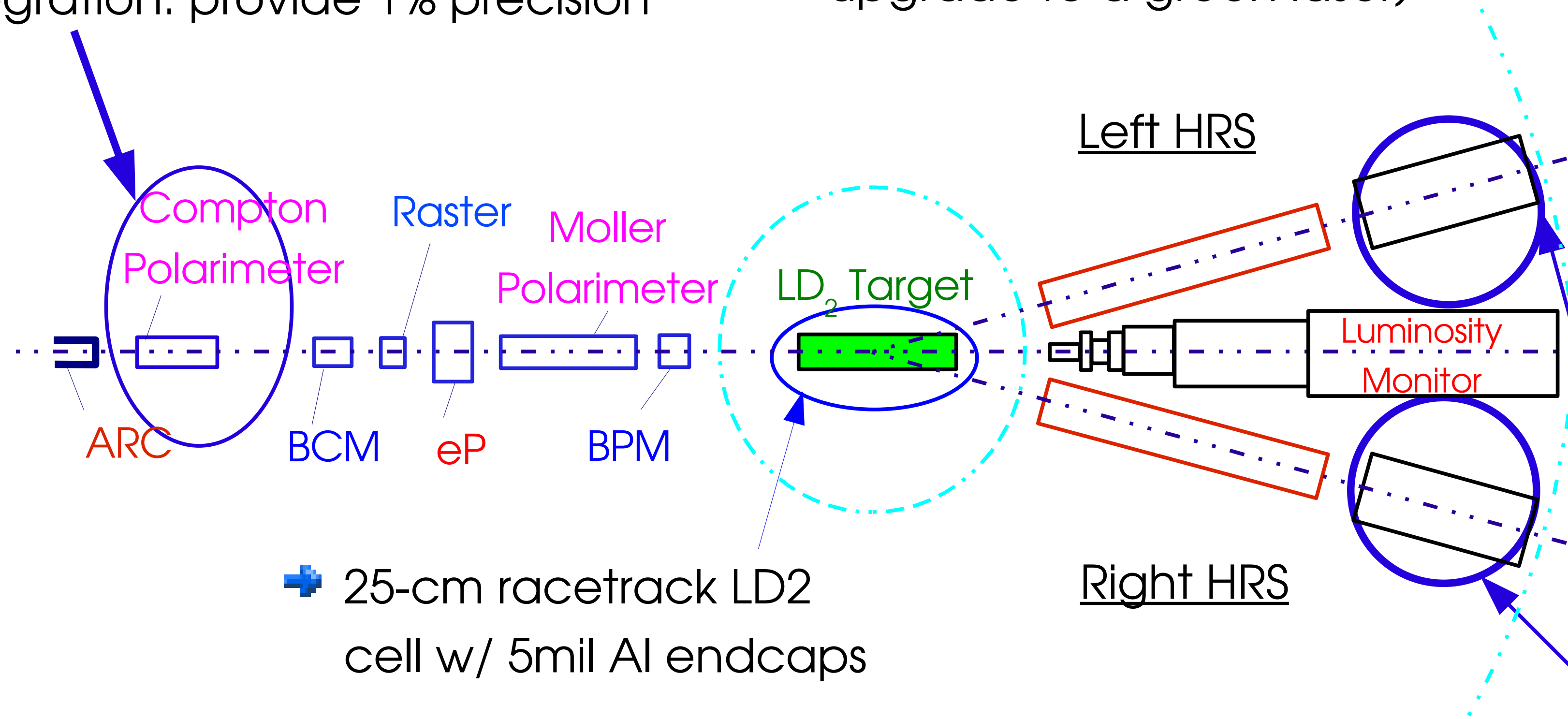
Overview of the Experimental Setup



In Addition to the Standard Hall A Setup

- electron method + photon integration: provide 1% precision

Also needed for PREX, HAPPEX-III, making progress now (including the upgrade to a green laser)

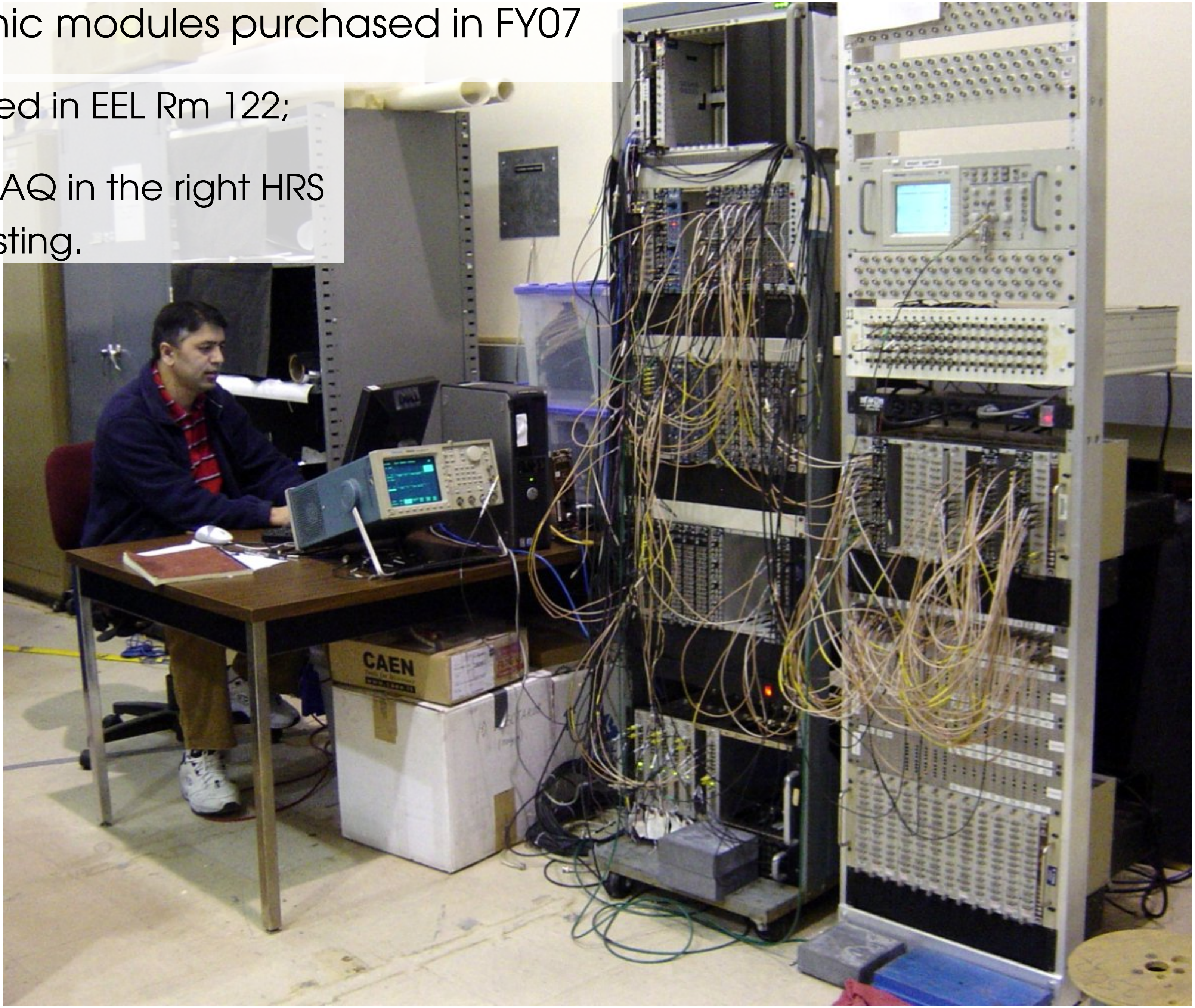


- 25-cm racetrack LD2 cell w/ 5mil Al endcaps

- upgrade to fast-counting DAQ, design goal: 1MHz; (scaler-based, partially w/ FADC)

E05-007 DAQ Status

- Most electronic modules purchased in FY07
- Being assembled in EEL Rm 122;
- Will install full DAQ in the right HRS for parasitic testing.



Kinematics

Kinematics	I	II
x_{bj}	0.25	0.3
Q^2 $(GeV/c)^2$	1.11	1.9
E_{beam} (GeV)	6.0	6.0
E' (GeV)	3.66	2.63
$\theta(^o)$	12.9^o	20.0^o
W^2 $(GeV)^2$	4.16	5.30
Y	0.470	0.716
R_C	<0.001	0.001
R_S	0.052	0.041
R_V	0.872	0.910
A_d (measured, ppm)	-91.3	-160.7
e^- rate/HRS (kHz)	269.8	25.1
π^-/e^- ratio	0.9	6.4
e^+/e^- ratio	0.073%	0.463%
Total rate/HRS (kHz)	513.0	186.2

Expected Uncertainties on A_d

Source \ $\Delta A_d/A_d$	Q^2=1.1 GeV^2	Q^2=1.9 GeV^2
$\Delta P_b/P_b$=1%	1.0%	1.0%
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	1.36%	1.36%
Statistical	2.11%	2.09%
Total	2.52%	2.49%

now 5mil Al
(was 3mil Be)

Data Analysis

- Extracting A_d from data:

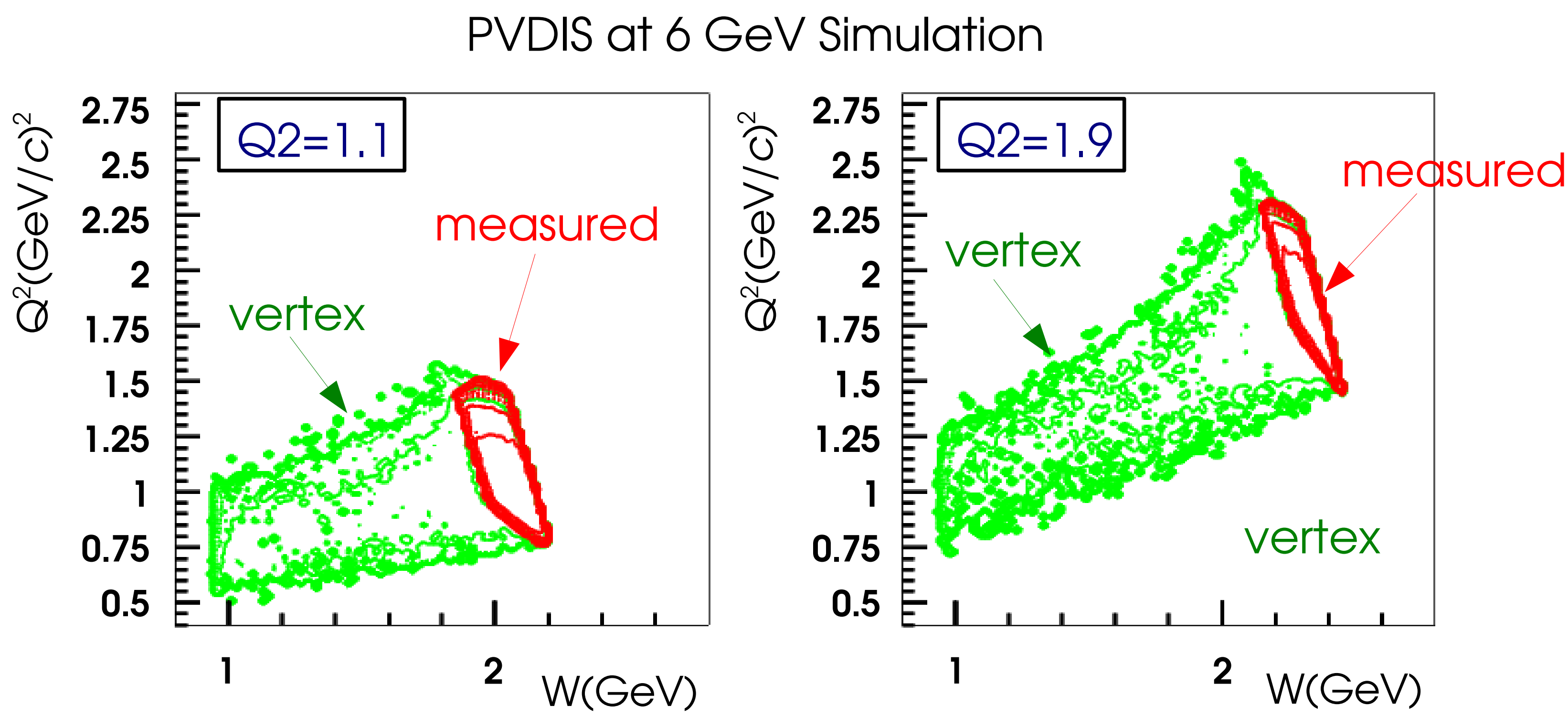
$$A_d = \frac{A_{raw}}{P_{beam}} + \Delta A_{EM}^{RC}$$

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

$$2C_{2u} - C_{2d} = a_2 A_d + b_2$$

$$a_2 = \frac{1}{K Q^2} \frac{5 + R_S + 4 R_C}{Y R_V} \qquad b_2 = -\frac{2 C_{1u}(1+R_C) - C_{1d}(1+R_S)}{Y R_V}$$

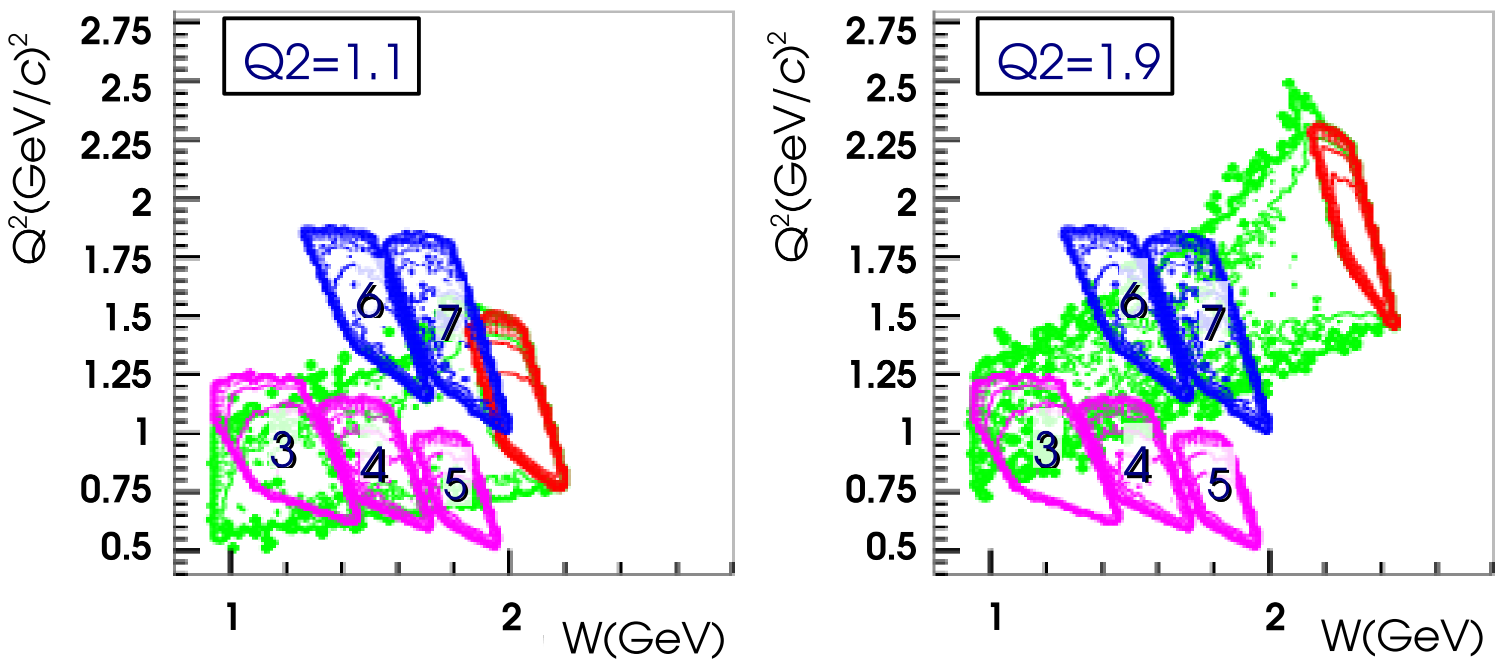
Data Analysis (Update on EM Radiative Corrections)



- Resonance events contribute to 15%
- No reliable way to calculate PV asymmetry at low W and Q^2
- Almost impossible to calculate resonance structure
- Will measure resonance PV asymmetry to control ΔA_d below 1%.

Data Analysis (Update on EM Radiative Corrections)

PVDIS at 6 GeV Simulation



adjusted to balance L/R HRS

Kine#	E (GeV)	θ	E' (GeV)	e- rate (KHz)	A_d (ppm)	$\Delta A_d/A_d$	Beam time (hours)
3	4.8	12.5	4.00(L)	1288	-68.7	5%	28.6
4	4.8	12.9	3.55(L)	888	-67.7	5%	42.6
5	4.8	12.9	3.10(R)	791	-60.6	5%	59.8
6	4.8	19.0	2.77(R)	105	-120.7	8%	44.6
7	6.0	14.0	4.00	280	-113.0	8%	19.0

RES beam time: 4days

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

Source \ $\Delta(2C_{2u}-C_{2d})$	Q^2=1.1 (GeV/c)^2	Q^2=1.9 (GeV/c)^2
Statistical	0.0399	0.0253
Systematics (from A_d)	0.0257	0.0165
Experimental (Q^2)	0.0040	0.0017
$\Delta R = \Delta(\sigma_L/\sigma_T)$	0.00006	0.00013
Parton distribution functions	0.0071	0.0031
Electro-magnetic rad. cor.	0.0189	0.0121
Electro-weak rad. cor.	0.0038	0.0024
Higher Twist (using 1%/Q^2on A_d)	0.0170	0.0064
CSV (MRST nominal)	0.0054	0.0031
CSV (MRST 90% C.L.)	0.0132	0.0085
Total uncertainty	0.0518	0.0329

not included below

Need 42 DIS production days

Beam Time Request

- Commissioning: 4 days (DAQ, target/boiling test, Compton)
  → could be down to 1-2 days if next to other PV experiments
- DIS Production:

E_b (GeV)	θ	E' (GeV)	Q^2 $(GeV/c)^2$	e^- prod (days)	e^+ prod (hours)	Dummy (hours)	Total (days)
6.0	12.9°	3.66	1.1	9.0	4	3.5	9.3
6.0	20.0°	2.63	1.9	32.0	4	12.4	32.7

- Resonance Measurement: 4 days
- Total beam time requested: 50 days

Summary – part I

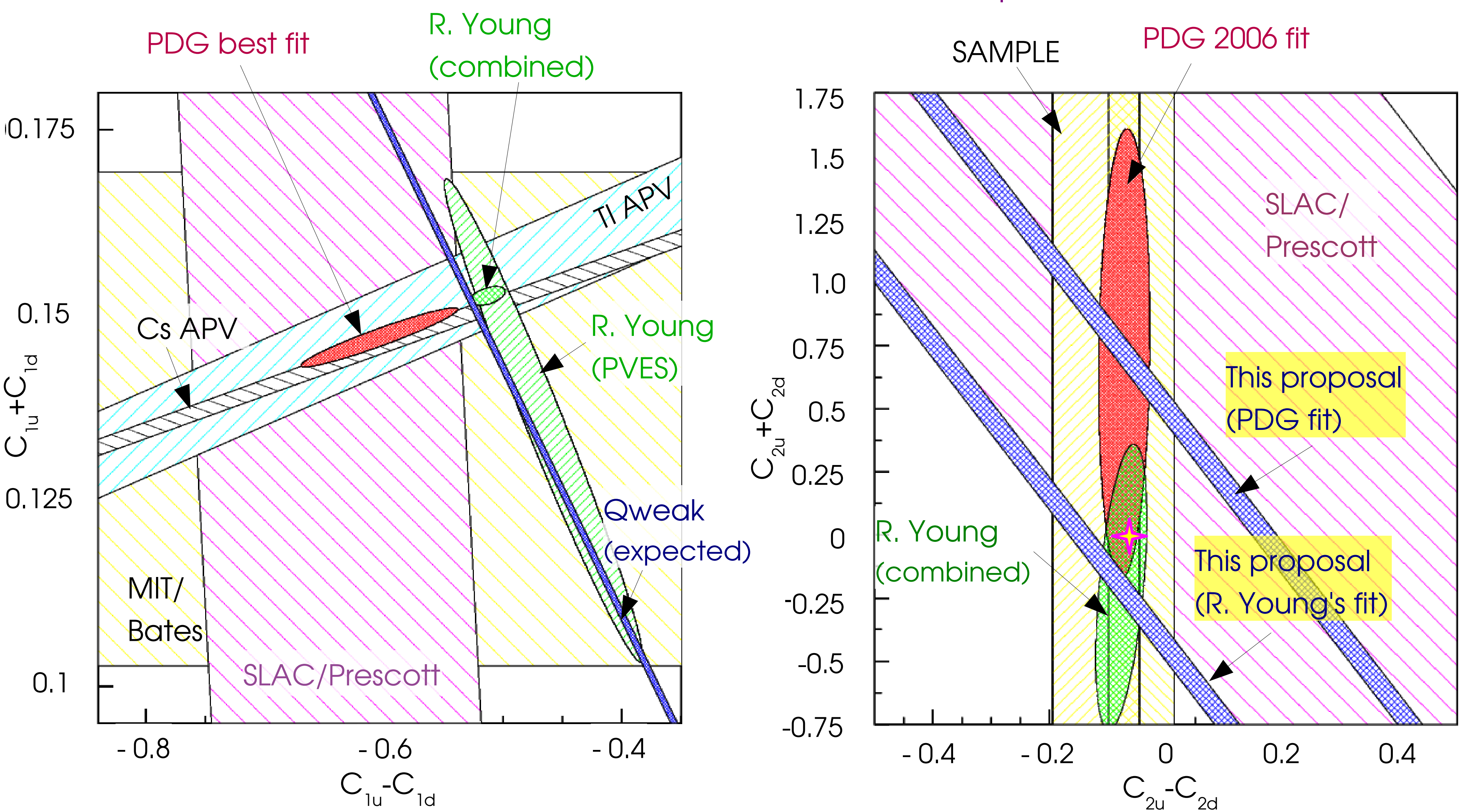
- Measure PVDIS Asym. A_d at Q^2=1.10 and Q^2=1.90 GeV^2 to ~2% (stat.);
- The A_d at Q^2=1.10 GeV^2 will help to investigate if there are significant higher-twist effects:
  - the first limit on HT in PV DIS; might help understand other data;
- If HT is small, from A_d at Q^2=1.90 GeV^2, can extract $\Delta(2C_{2u}-C_{2d}) = 0.033$;
  - factor of 7.4 improvement;
  - will provide constraints on various new physics;
- Request for 50 days;
- Compton upgrade, fast counting DAQ well under way;
- Will start/establish the PV DIS program at JLab, provide important guidance to the 12 GeV program.

Why Now, and why 50 days?

- Doing PVDIS is hard, but nevertheless will have some information about PV DIS, and will be able to answer:
  - 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, and the 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 (1-2 GeV^2, to better than 2%, using lower beam energy) to set limit on the HT. (PR12-07-102: 0.5% at $<Q^2>\sim 3.2\ GeV^2$ using HMS+SHMS; or large solenoid: 1% for a wide (x,y,Q^2))
- If HT is small, then we (JLab) could already make an impact on EW physics study at 6 GeV, we should do this ASAP.
- This is a necessary exploratory step, yet still could make an impact (wider than medium/high energy community).

Current Knowledge on $C_{1,2q}$ (new)

all are 1 σ limit



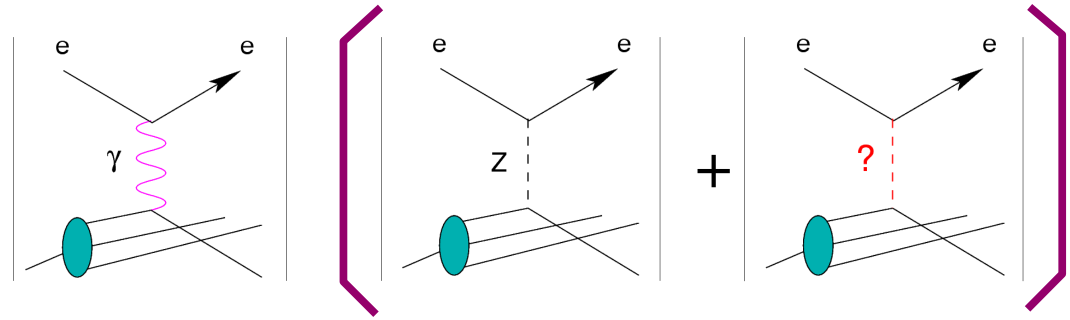
- Full beam time (50 days): $\Delta(2C_{2u}-C_{2d}) = 0.033$ $\longrightarrow$ factor of 7.4 improvement;

  New physics mass limit: 1.0 TeV.

Backup Slides

PV DIS and New Physics

$A_{PV} =$



- Interaction of new physics:

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

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

  - *g*: coupling constant; Λ: mass scale, $h^q{}_A$: effective coefficients;

- Sensitive to: Z' searches, compositeness, leptoquarks

- Mass limit of the proposed measurement:

$$\Lambda / g \approx \frac{1}{\left[\sqrt{8}G_F\left|\Delta(2C_{2u}-C_{2d})\right|\right]^{1/2}} \approx 1.0\,\mathrm{TeV}$$

- Some new physics can affect C2, but not C1.

PV DIS and New Physics (a few examples)

- Z' Searches: will give $M_{Z'} = 0.8$ TeV (1σ), or 450 GeV (90% C.L.);
- Compositeness (8 four-fermion contact interactions):
  - SU(12): affect C_{2q} but not C_{1q} ⟶ C_{2q} provide a unique opportunity to explore quark and lepton compositeness;
  - Will give $\Lambda_1 = 3.56$ TeV (1σ), or 1.97 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)

Status of CSV Calculations

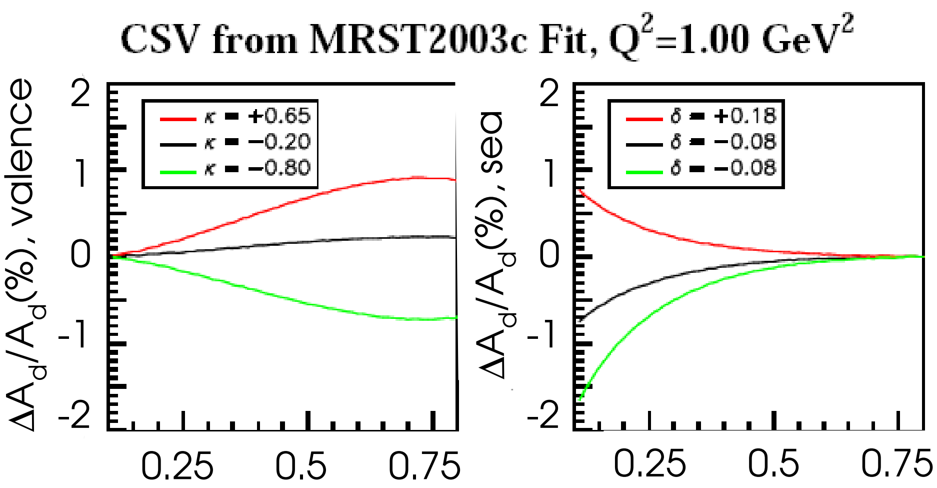
- Latest MRST fit: Martin, Roberts, Stirling and Thorne, EPJC35, 325 (2004)

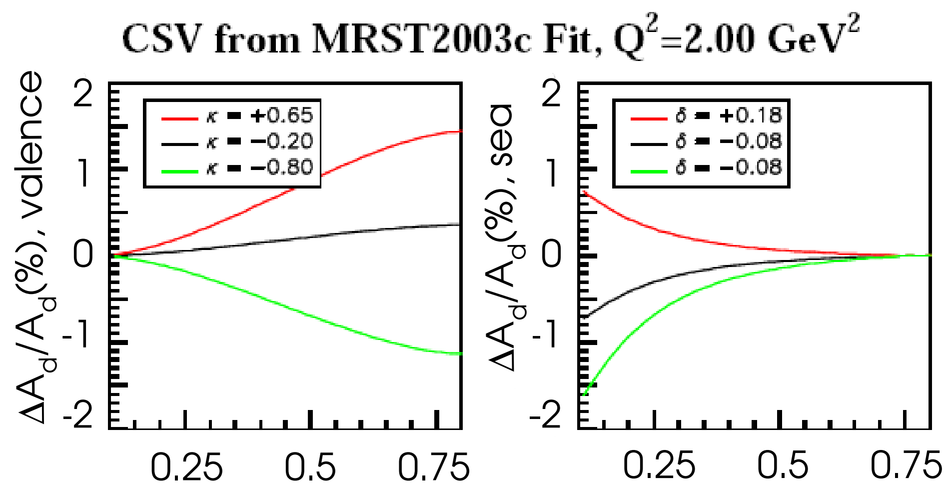
$$u_V^n(x) = d_V^p(x) + \kappa f(x) \qquad d_V^n(x) = u_V^p(x) + \kappa f(x)$$

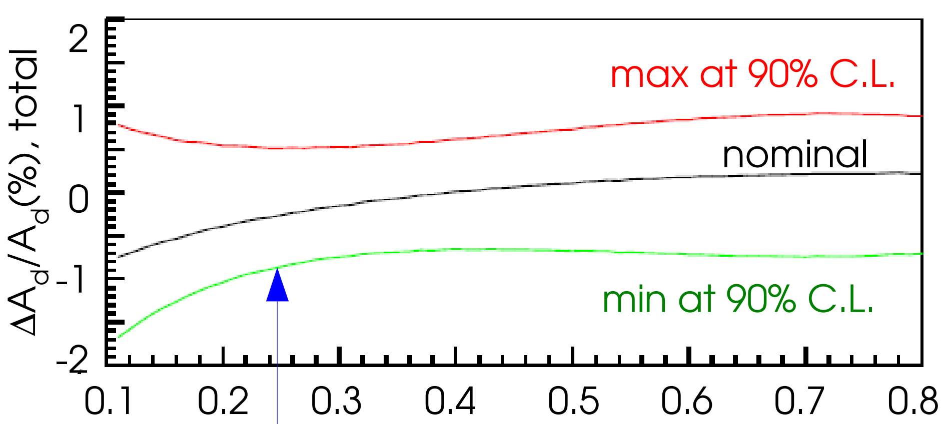
$$u_{sea}^n(x) = d_{sea}^p(x)(1+\delta) \qquad d_{sea}^n(x) = u_{sea}^p(x)(1+\delta)$$

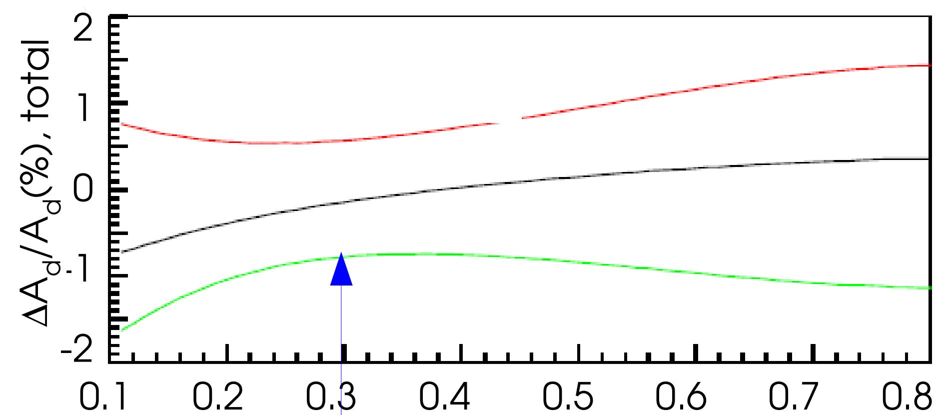
nominal: $\kappa = 0.20 \quad \delta = 0.08$

90% C.L.: $\kappa = (-0.80, 0.65)$ $\delta = (-0.08, 0.18)$









proposed Q2=1.1

(90%C.L. ~1/2 of ΔA_{stat})

proposed Q2=1.9

Electroweak Radiative Corrections to C_{2u} and C_{2d}

- Studied originally in the context of Atomic Parity Violation, well understood.

Marciano and Sirlin, PRD 27, 552 (1983)

Marciano, "Radiative Corrections to Neutral Current Processes" from Precision Tests of the Standard Model edited by Langacker

- Numerical values from PDG
  — GAPP program J. Erler, hep-ph/0005084.
- Small effect for PVDIS
  - **A_d correction**
    2.2% ($Q^2 = 1.1$) and
    2.6% ($Q^2 = 1.9$)
  - **$\Delta A_d < 0.3\%$**

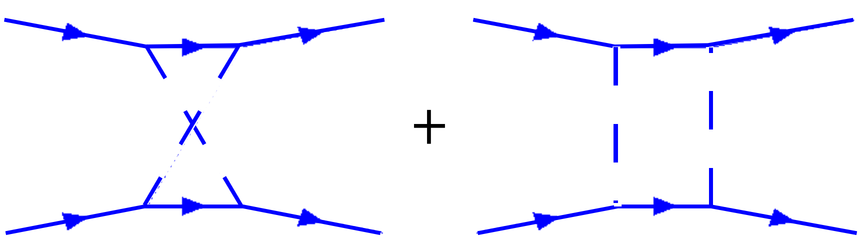
$$C_{1u} = \rho'_{eq}\left(-\frac{1}{2} + \frac{4}{3}\hat{\kappa}'_{eq}\hat{s}^2_Z\right) + \lambda_{1u}$$

$$C_{1d} = \rho'_{eq}\left(\frac{1}{2} - \frac{2}{3}\hat{\kappa}'_{eq}\hat{s}^2_Z\right) + \lambda_{1d}$$

$$C_{2u} = \rho_{eq}\left(-\frac{1}{2} + 2\hat{\kappa}_{eq}\hat{s}^2_Z\right) + \lambda_{2u}$$

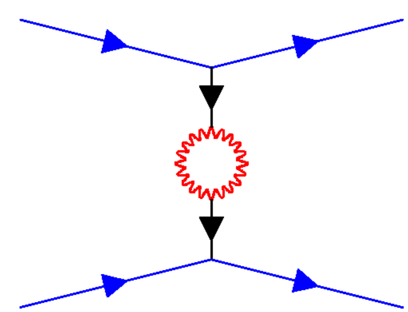
$$C_{2d} = \rho_{eq}\left(\frac{1}{2} - 2\hat{\kappa}_{eq}\hat{s}^2_Z\right) + \lambda_{2d}$$

Box diagrams



+ . . .

$\kappa \sim \gamma$-Z mixing



+ . . .

Design and Structure for the Fast Counting DAQ

- Using
  - A double-layered lead-glass counter, summed by 8-block groups
  - A gas cherenkov detector
  - Scintillator signals to suppress background
  - Discriminators and logic modules to choose e^- and π, two time windows (100 and 20ns)
  - Helicity-gated scalers to count e^- and π (15 subgroups + "OR"ed)
- Some channels with FADC, allowing full sampling of signals
- All detector signals passively splitted, allowing parasite, non-invasive testing
- Deadtime measured by multiple methods

Physics Outcome from Reduced Beam Time

Production time (days)			$\Delta A_d/A_d$		$\Delta(2C_{2u}-C_{2d})$	Total
Q^2=1.1	Q^2=1.9	Res	Q^2=1.1	Q^2=1.9	(Q^2=1.9)	(days)
9.3	32.7	4.1	2.52%	2.49%	0.033 (7.3)	50
7.5	26.3	3.2	2.72%	2.70%	0.036 (6.7)	41
5.6	19.8	2.4	3.04%	3.01%	0.040 (6.0)	32
1.8	6.4	0.8	4.98%	4.92%	0.066 (3.6)	13

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"Two phases running", not "two phases beam time approval"

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way above expectation for HT

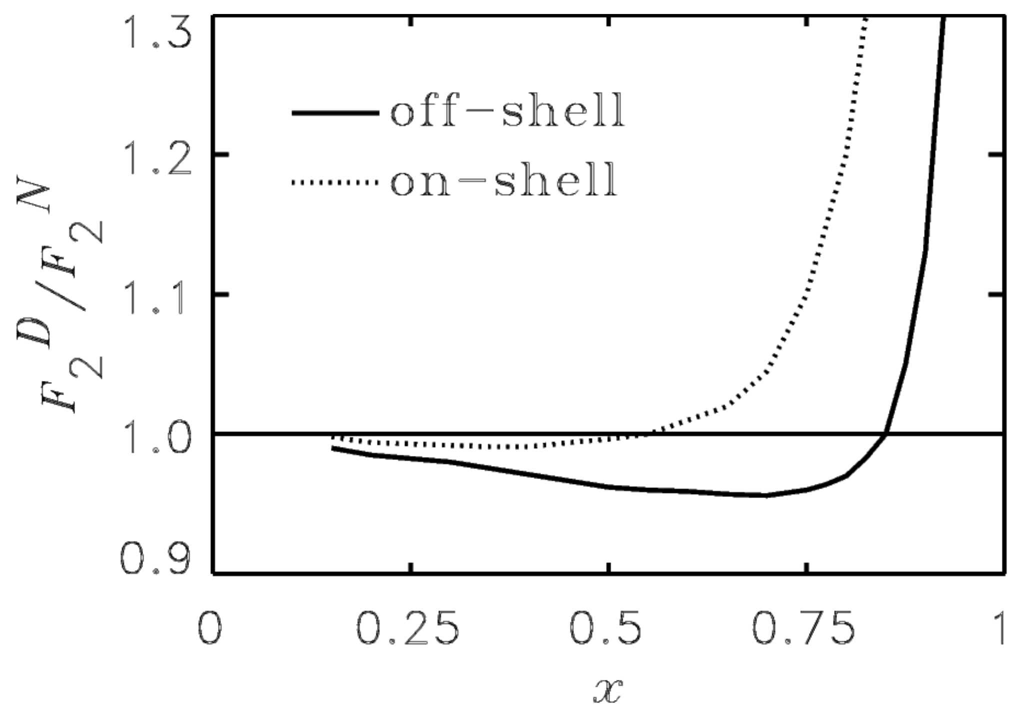
2 years of preparation for 9 production days

Rescattering Background

- Effect depends on:
  - How many particles will be re-scattered? — 1% near central momenta, mostly from the Q3 exit (studied by HAPPEX-H and HAPPEX-He).
  - Whether these events carry different asymmetries? — Unlikely, most have DIS kinematics very close to central setting
  - Expect an effect on A_d at the 10^{-3} level.
- Will take data at low rate and compare with simulation to pin down the effect.

Deuteron EMC Effect?

- Calculations show very small effect on F_2^d: (1.2±0.5)% for x=0.25 and (1.5±0.6)% for x=0.3. W. Melnitchouk, A.W. Thomas, nucl-th/9603021



- Effect on the asymmetry should be much smaller – 2×10^{-4} on A_d using the smearing technique:

$$q^D(x)=\int_x^1 dy\, f_{N/D}(y)\, q^N(x/y)$$

Status of HT Calculations

- MIT Bag Model I: 0.3%/Q^2
- MIT Bag Model II: <2%/Q^2
- Calculation using C_{HT} from $F_{1,2}$ data: <1%/Q^2 for $0.1<x<0.3$
  - HT likely to be small at Q^2=2 (GeV/c)^2, nevertheless, will measure A_d at 1.1 (GeV/c)^2 to check
  - More up-to-date calculations are possible if PR is re-approved.

- May help to investigate the HT contribution to the NuTeV anomaly (model-dependent:
  - 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 2.5% in the P-W ratio (the NuTeV anomaly has its P-W ratio 2.5% from the SM) $\longrightarrow$ 5% on our A_d at $Q^2 = 1.9$ (GeV/c)^2 and 8% at $Q^2 = 1.1$ (GeV/c)^2

Advantages of "Two Phases" Running

- The expected results from the first phase running (13 days) are
  - 5%/Q^2 on the HT in PV (first limit);
  - $\Delta(2C_{2u}-C_{2d})$ = 0.066 (factor of 3.5 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.

Advantages of "Two Phases" Running

Not "Two Phases" beam time approval

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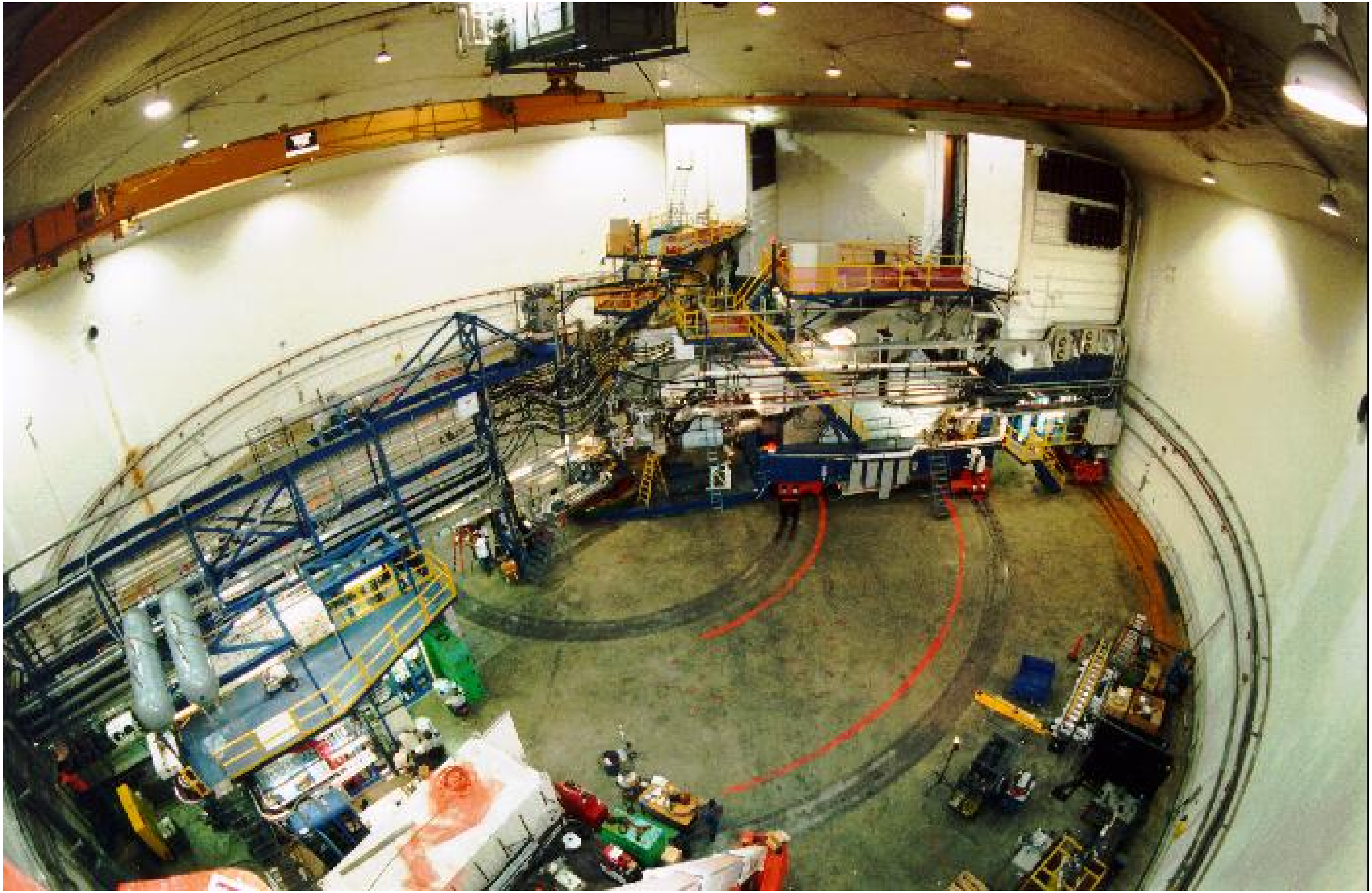
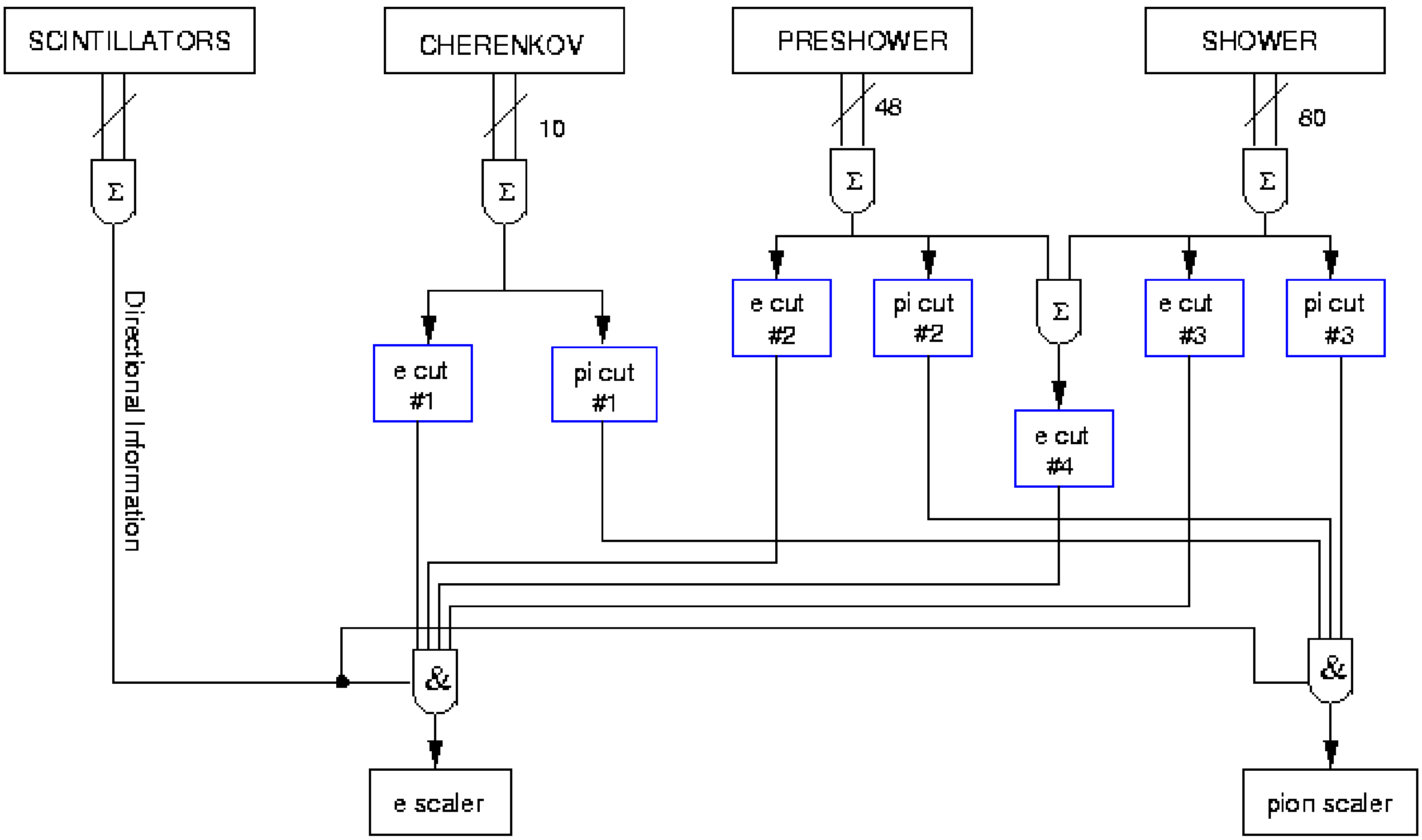
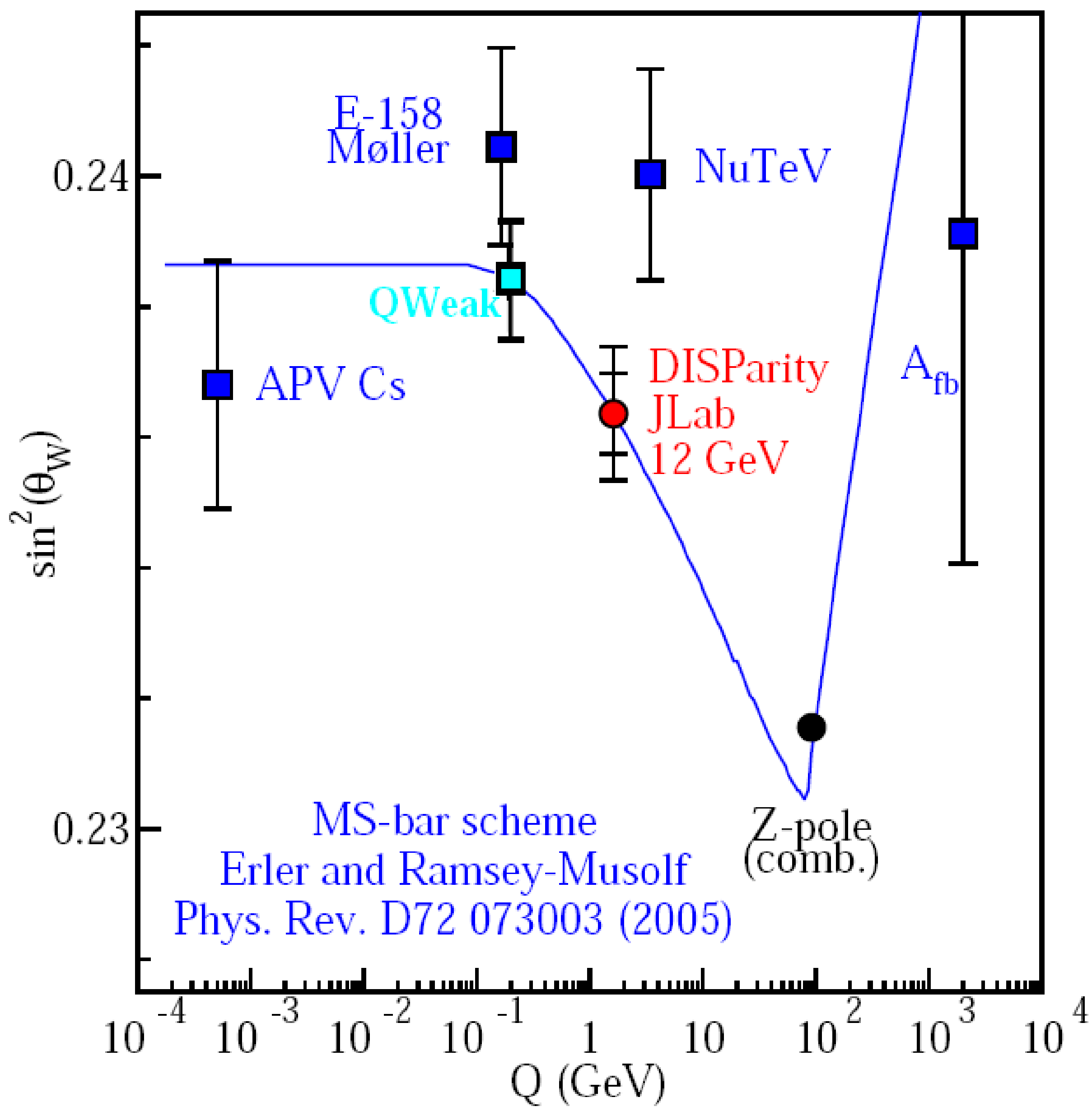
Experimental Hall A

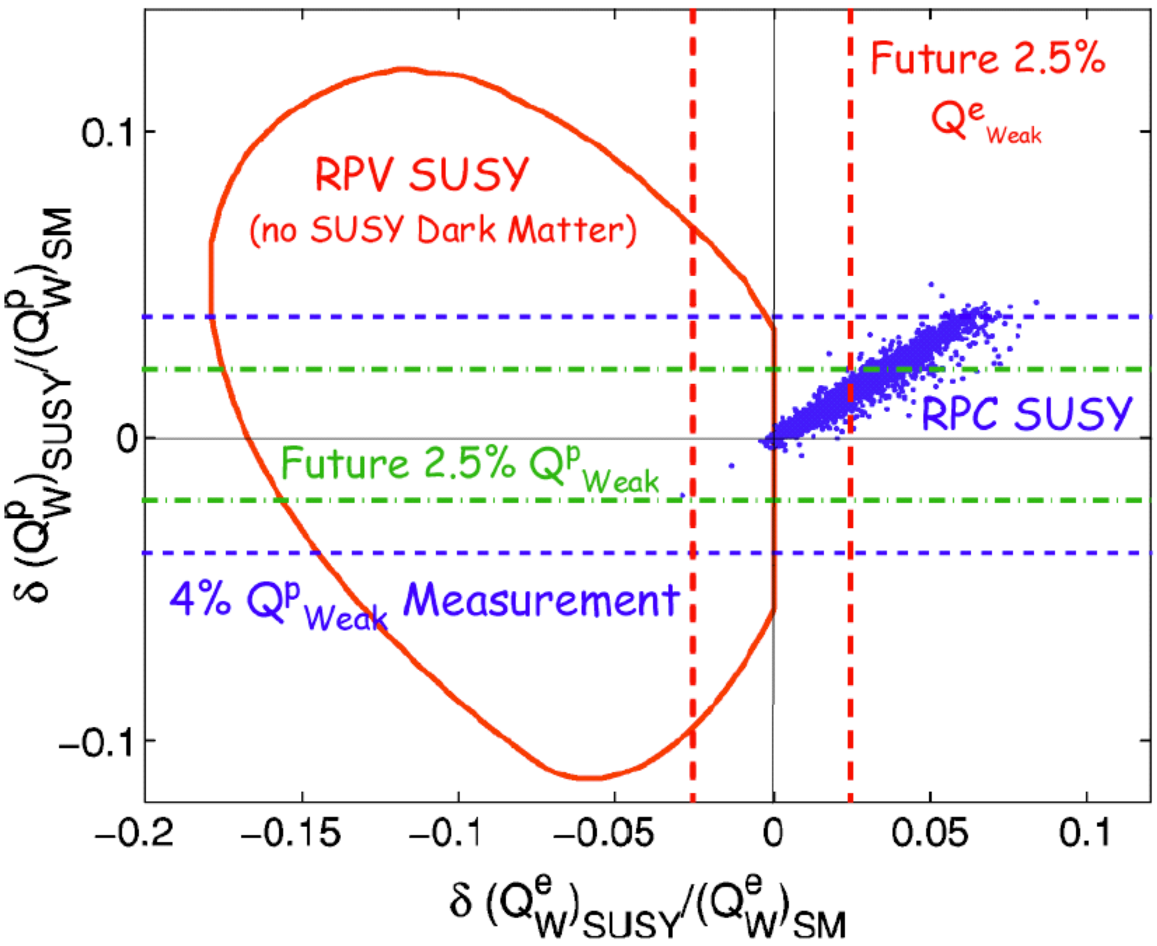


An alternative option (LOI03-106): Scaler-Logic-based Fast Counting DAQ

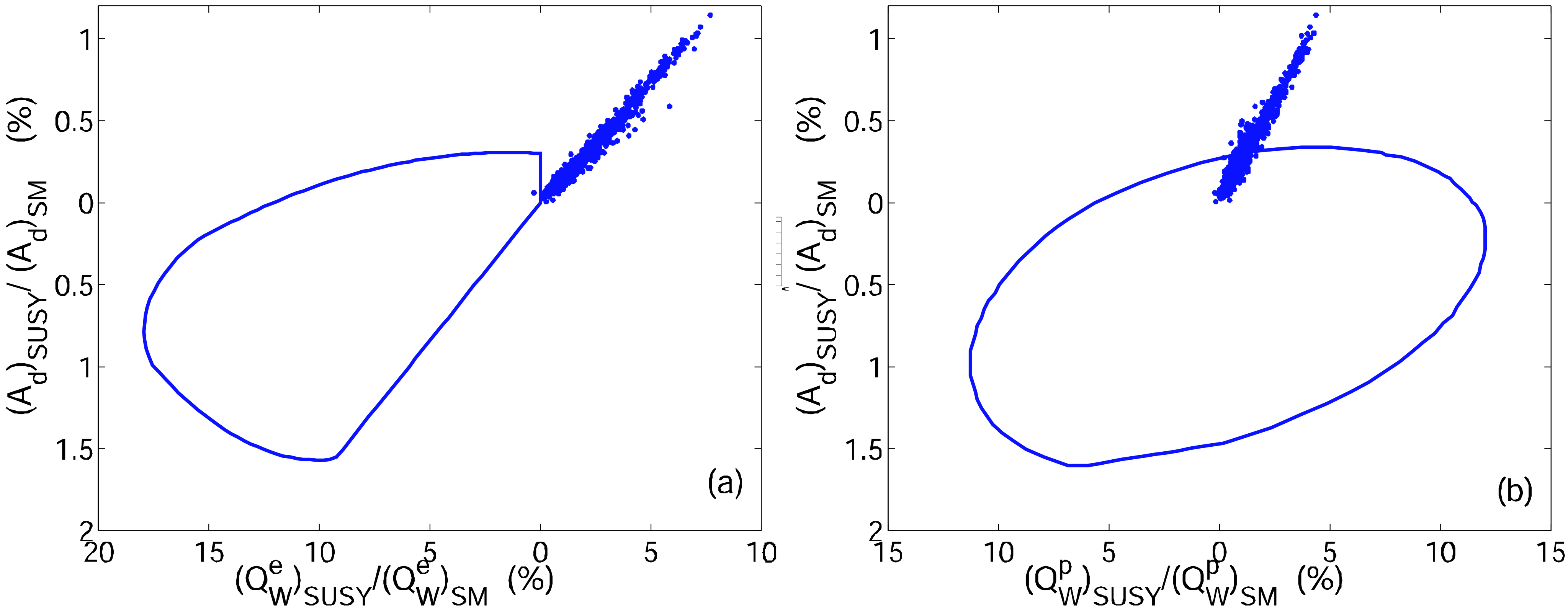



E-158
Møller
NuTeV
0.24
QWeak
APV Cs
DISParity
JLab
12 GeV
A_{fb}
$\sin^2(\theta_W)$
MS-bar scheme
Erler and Ramsey-Musolf
Phys. Rev. D72 073003 (2005)
Z-pole
(comb.)
0.23
10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4}
Q (GeV)

New Physics Reach: Q_{weak} and Møller



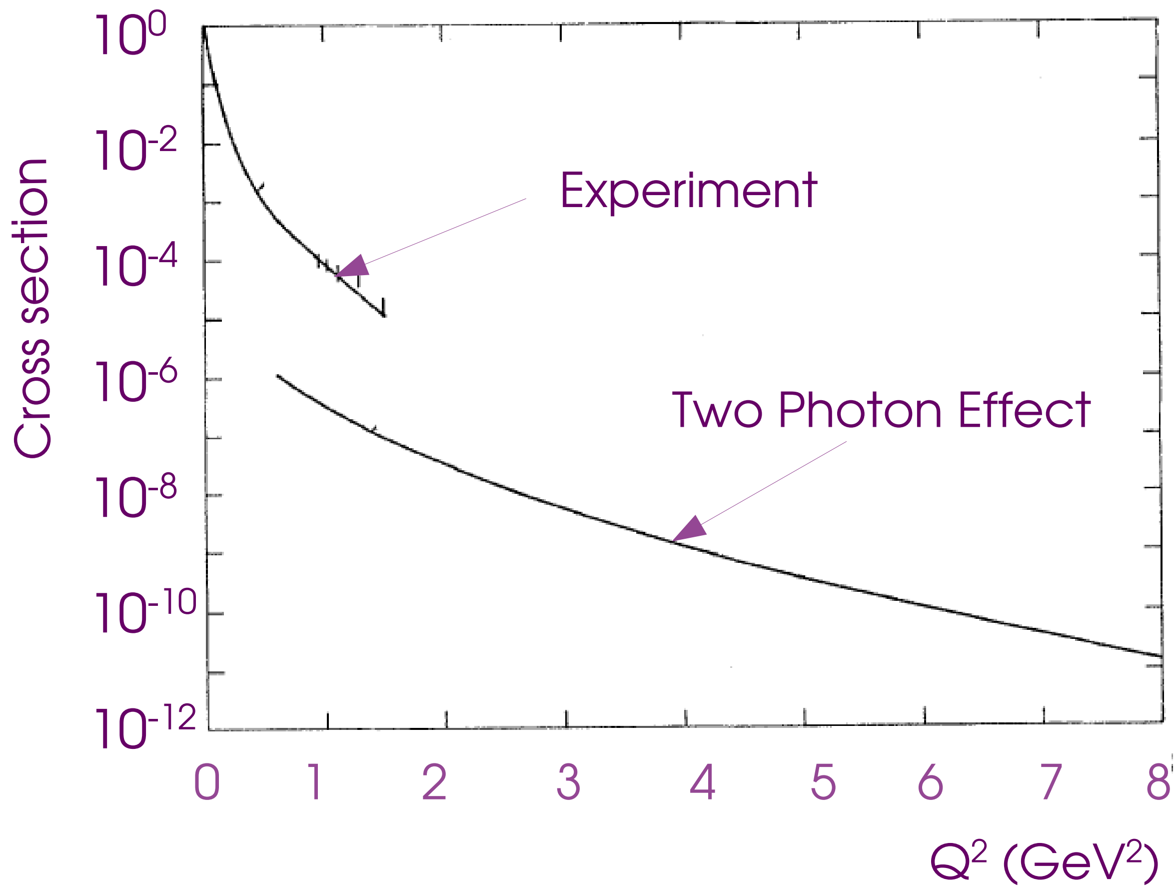
Add data on PVDIS: ± 1.0%



Two Photon Exchange Effect?

- TPE contribute to <1% of cross section for $1<Q^2<2$ $(GeV/c)^2$

"Two-Photon Exchange in Electron-Deuteron Scattering",
J. Gunion & L. Stodolsky (SLAC), Phys. Rev. Lett. 30, 345 (1973)



- Effect on the asymmetry should be even smaller.