PVDIS at JLab 12 and 6 GeV

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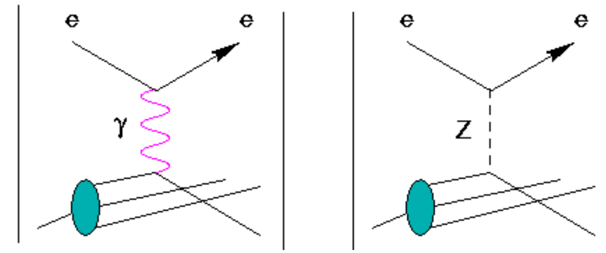
- PVDIS Asymmetry
- Physics Opportunities at 12 GeV
  - Baseline (Hall C) vs. New Device (Hall A)
  - Standard Model Test and Study of Hadronic Physics
  - d/u Measurement
  - Other measurements
- PVDIS at 6 GeV — E08-011

Parity Violation in Electron Scattering

- Parity violating asymmetries (A_{PV})

  (polarized beam + unpolarized target)

A_{PV} =



$$A_{LR} \equiv \frac{\sigma^r - \sigma^l}{\sigma^r + \sigma^l} \approx \frac{1/M_Z^2}{1/Q^2} \approx 120\ ppm \qquad at\ \ Q^2 = 1(GeV/c)^2$$

- 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)

- Now, development in polarized electron beam allows us to

  study nuclear matter (neutron skin)   PREx

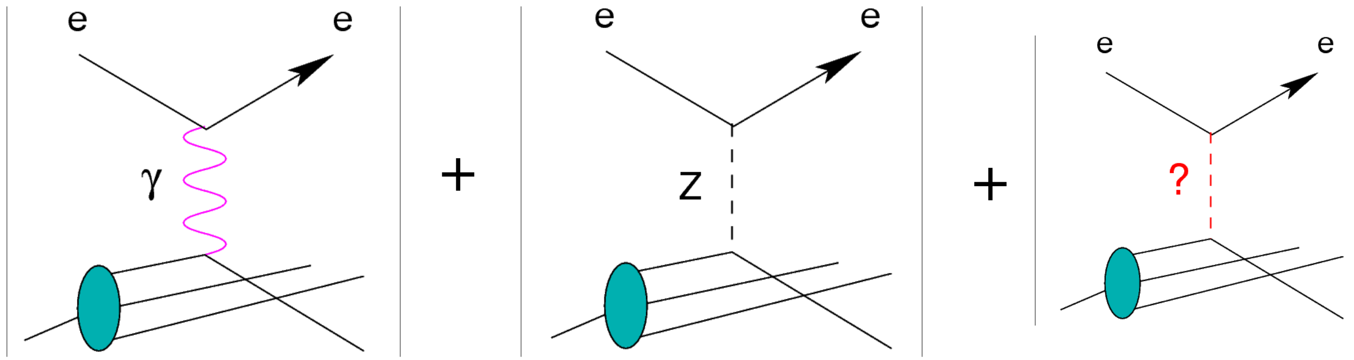
  study hadron structure

  - elastic scattering: strange form factors   A4, G0, HAPPEX, SAMPLE
  - DIS: non-perturbative higher twist effects, etc...   PVDIS

  test EW standard model   E158, Atomic PV, Qweak

PVDIS Asymmetries

$A_{PV} =$



- Deuterium:

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

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

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

- Improve knowledge on C_{2q} (and $\sin^2\theta_W$)
- Sensitive to: Z' searches, compositeness, leptoquarks
- Mass limit:

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

Current Knowledge on Neutral Weak Couplings

$C_{1q} = g_A^e g_V^q$ $\quad C_{2q} = g_V^e g_A^q$ $\quad C_{3q} = g_A^e g_A^q$

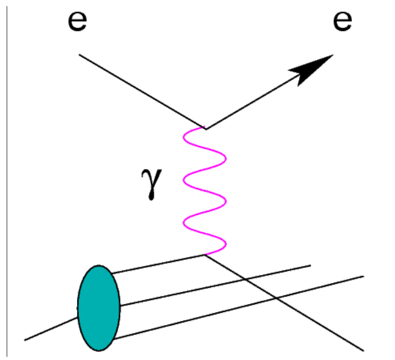
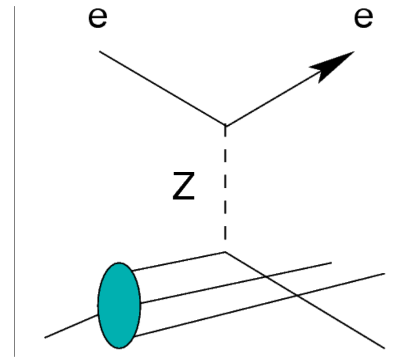
	Facility	Process	Q^2	C_{iq} Combination	Result
	SLAC	e^--D DIS	1.39	$2C_{1u}-C_{1d}$	0.90±0.17
	SLAC	e^--D DIS	1.39	$2C_{2u}-C_{2d}$	0.62±0.81
	CERN	$\mu^\pm$-D DIS	34	$0.66(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$	1.80±0.83
	CERN	$\mu^\pm$-D DIS	66	$0.81(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$	1.53±0.45
	MAINZ	e^--Be QE	0.20	$2.68C_{1u}-0.64C_{1d}+2.16C_{2u}-2C_{2d}$	0.94±0.21
	Bates	e^--C elastic	0.0225	$C_{1u}+C_{1d}$	0.138±0.034
	Bates	e^--D QE	0.1	$C_{2u}-C_{2d}$	-0.042±0.057
	Bates	e^--D QE	0.04	$C_{2u}-C_{2d}$	-0.12±0.074
	JLab	e^--p elastic	0.03	$2C_{1u}+C_{1d}$	approved
		^{133}Cs APV	0	$-376C_{1u}-422C_{1d}$	-72.69±0.48
		^{205}Tl APV	0	$-572C_{1u}-658C_{1d}$	-116.6±3.7
	Fit	e^--A	low	$C_{1u}+C_{1d}$	0.1358±0.0326
new	All			$C_{1u}-C_{1d}$	-0.4659±0.0835
	PVES			$C_{2u}+C_{2d}$	-0.2063±0.5659
	Data			$C_{2u}-C_{2d}$	-0.0762±0.0437

Compared to C_{1q}, $C_{2,3q}$ are poorly known

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

J. Erler, M.J. Ramsey-Musolf, Prog. Part. Nucl. Phys. **54**, 351 (2005)
R. Young, R. Carlini, A.W. Thomas, J. Roche, PRL 99, 122003 (2007) & priv. comm.

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
  - Charge symmetry violation

$$u^p(x) \neq d^n(x) \qquad d^p(x) \neq u^n(x)$$

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.
  - At 12 GeV, a large, well-planned PVDIS program could separate all three: New Physics, HT, CSV.
  - Do a first measurement at JLab 6 GeV:
    - If observe a significant deviation from the SM value, it will definitely indicate something exciting;
    - *Could possibly make an impact on EW SM study (via C_2s).*

PVDIS Program at JLab 12 GeV

- Two approaches:
  - Hall C "baseline", 90uA,40-60cm targ: PR12-07-102 (P.E. Reimer, X-C. Z, K. Paschke)
    - 1% on A_d, extraction of C_{2q}, $\sin^2\theta_W$ (if higher-twist and CSV are negligible);
  - Hall A large acceptance "solenoid" device: to be proposed
    - Measure A_d to 1% for a wide range of (x,Q^2,y), clean separation of New Physics (via C_{2q} and $\sin^2\theta_W$), HT and CSV possible;
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    - Extract d/u at large x by comparing A_d with A_p;
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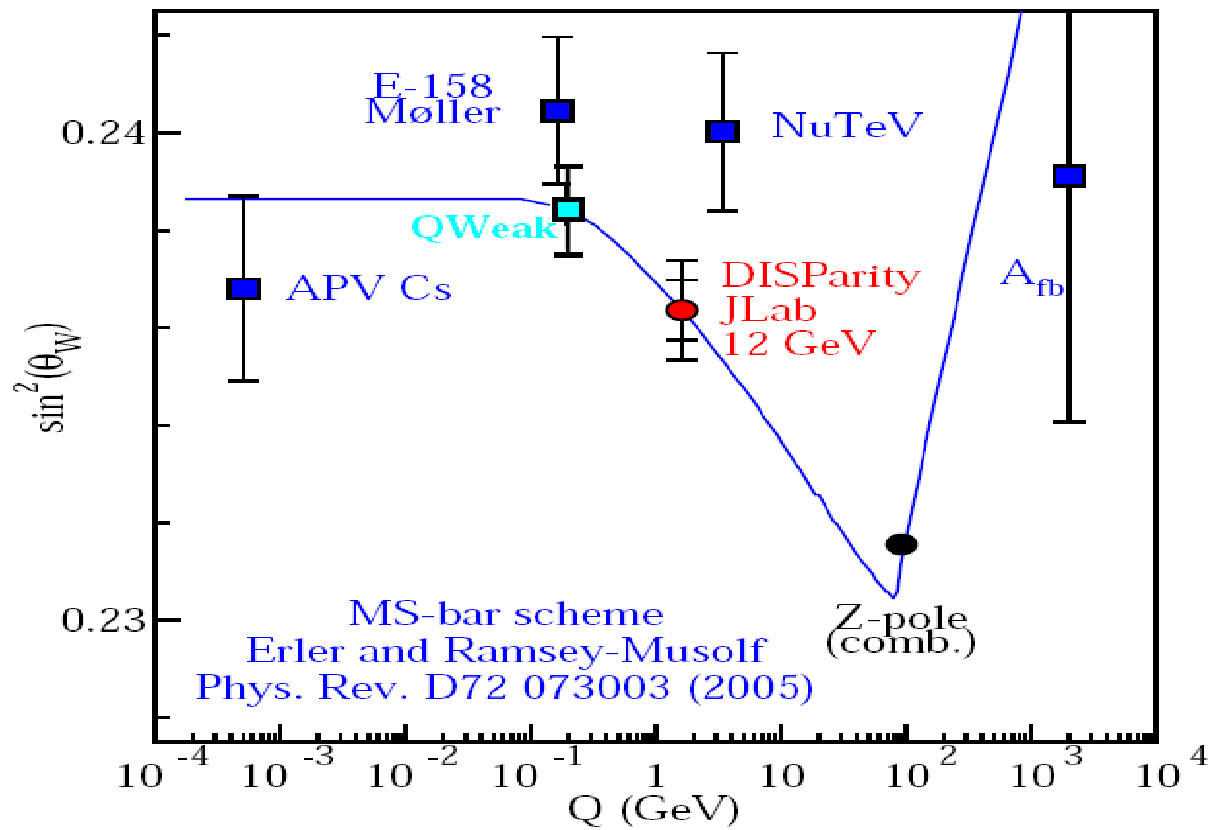

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	$x=Q^2/2M\nu$	$y=\nu/E$	Q^2
Higher Twist	Yes	No	Yes
CSV	Yes	No	No
New Physics	No	Yes	No

$$\frac{\delta A_{PV}}{A_{PV}} = 0.28 \frac{\delta u - \delta d}{u+d}$$

Hadronic Physics Effects in PV DIS

- Hadronic effects are equally interesting as SM test!
- PVDIS may be a better way to study these hadronic effects than the "conventional" cross section measurements because:
  - A_d can be measured to <1% level, only uncertainties come from beam polarimetry and Q^2;
  - Absolute cross section experiments: uncertainties come from beam charge, target thickness, solid angle, acceptance etc... — impossible to reach 1%;
  - For higher twist study, A_d^{LT} unambiguously determined by the Standard Model.

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- *solid angle > 200 msr*
- *resolution < 2%*
- *count at 100 kHz*
- *online pion rejection of 10^2*

Meeting July 22

PVDIS Program at JLab 12 GeV

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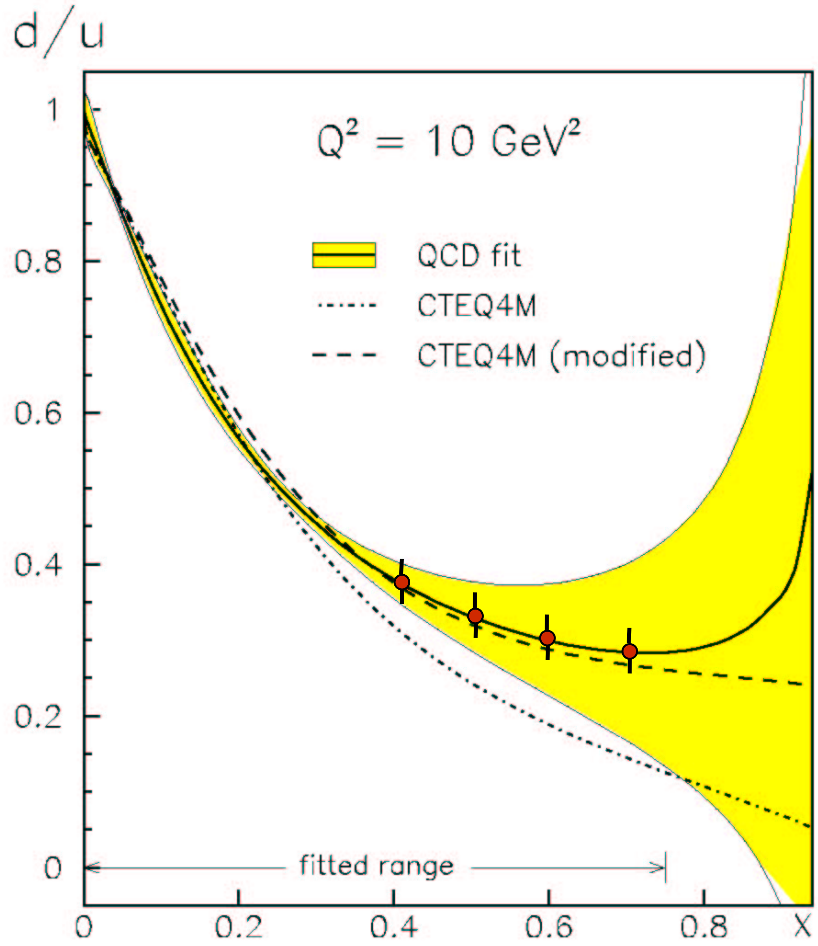

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Workshop 8/12-13

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http://www.jlab.org/~gen/jlab12gev/sol_sim/

http://www.jlab.org/~gen/jlab12gev/tor_sim/

High-Acceptance Electroweak Spectrometer Steering Committee:

Paul Souder, Dave Armstrong, Jian-Ping Chen, Gordon Cates, Eugene Chudakov, Krishna Kumar, Kent Paschke, Robert Michaels, Paul Reimer, Xiaochao Zheng

PVDIS at 6 GeV — E08-011

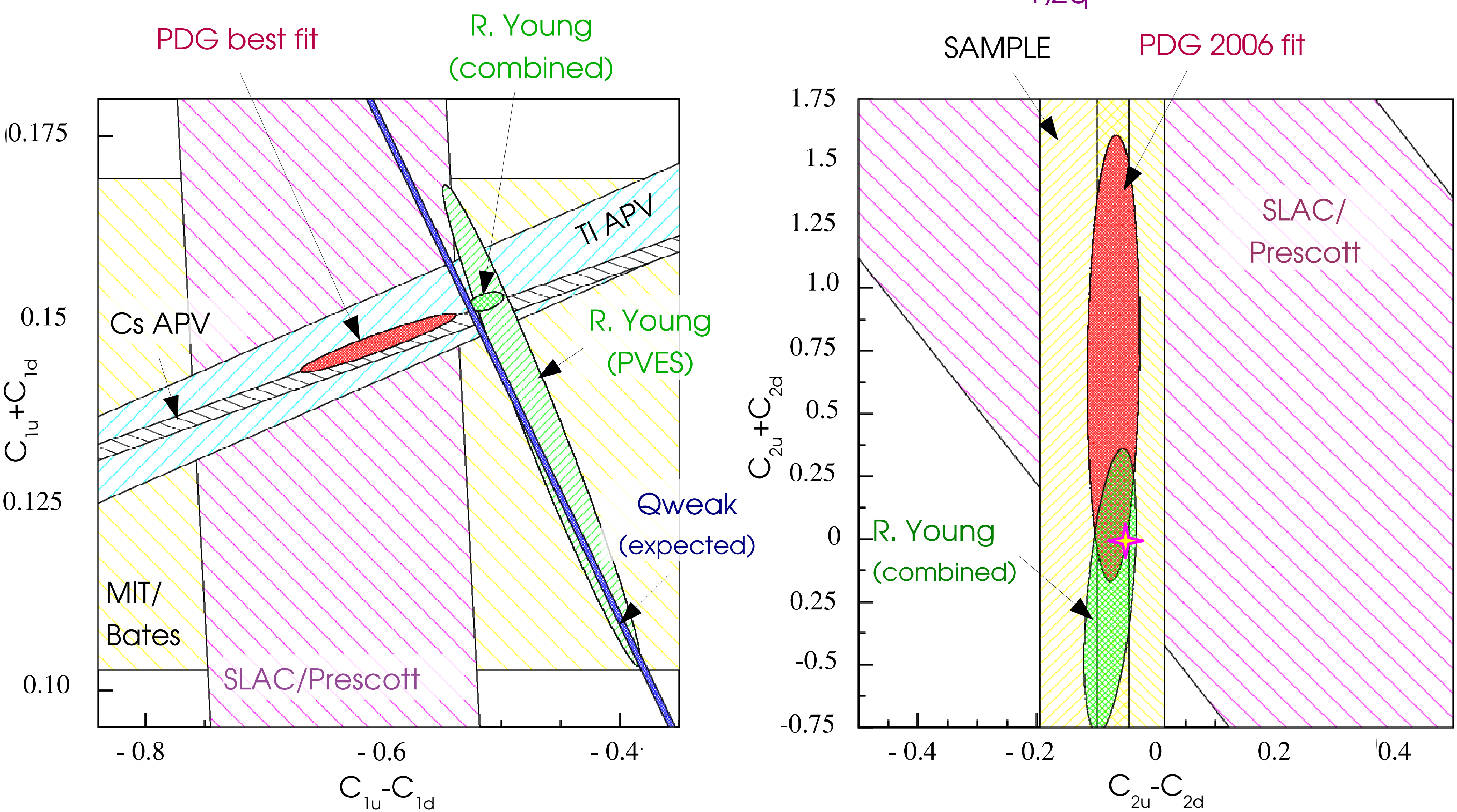
- Measure PVDIS asymmetry using 85uA, 25-cm deuterium target, at Q^2=1.10 and 1.90 GeV^2 to (stat) 3% within 32 days (50 days originally requested to achieve 2%);
- Currently scheduled to run
  - Nov-Dec. 2009 (about 50 calendar days);
  - Shorter/longer running possible pending on budget outcome;

- Spokespeople: X. Zheng (UVa), P.E. Reimer (ANL), R. Michaels (JLab) (Hall-A Collaboration Experiment, PAC33 rated A-)
- Postdoc: R. Subedi (UVa), Students: X. Deng (UVa), D. Wang(UVa), H. Ding (TsingHua U.)

ANL, Calstate, FIU, Jlab, Kentucky, U. of Ljubljana (Slovenia), MIT, UMD, UMass, UNH, Universidad Nacional Autonoma de Mexico, Rutgers, Smith C., Syracuse, UVa, W&M

Current Knowledge on $C_{1,2q}$

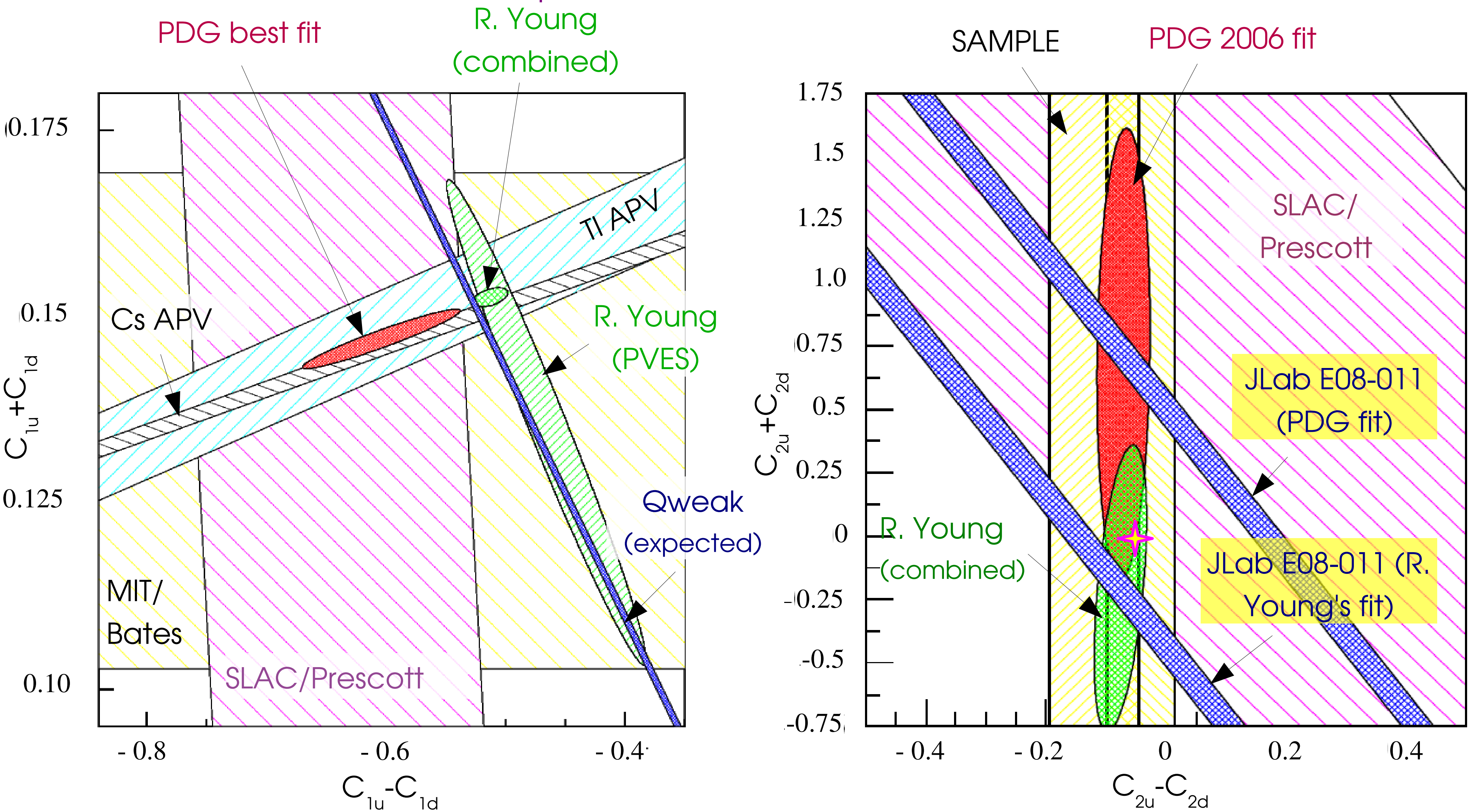
all are 1 σ limit



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

C_{2q} from JLab E08-011

all are 1 σ limit



- Best: PDG2002 $\Delta(2C_{2u}-C_{2d}) = 0.24 \longrightarrow 0.04$ (factor of 6 improvement) in 50 PAC days;
- New physics mass limit: $$\Lambda/g \approx \left[\sqrt{8}\,G_F \left|\Delta(2C_{2u}-C_{2d})\right|\right]^{-1/2} \approx 0.9\ \mathrm{TeV}$$

Kinematics Overview (beam time = half of requested)

- Commissioning: 4 days (DAQ, target/boiling test, Compton)
  ➔ could be down to 2-3 days if following HAPPEX-III (install leadglass)

- DIS Production:

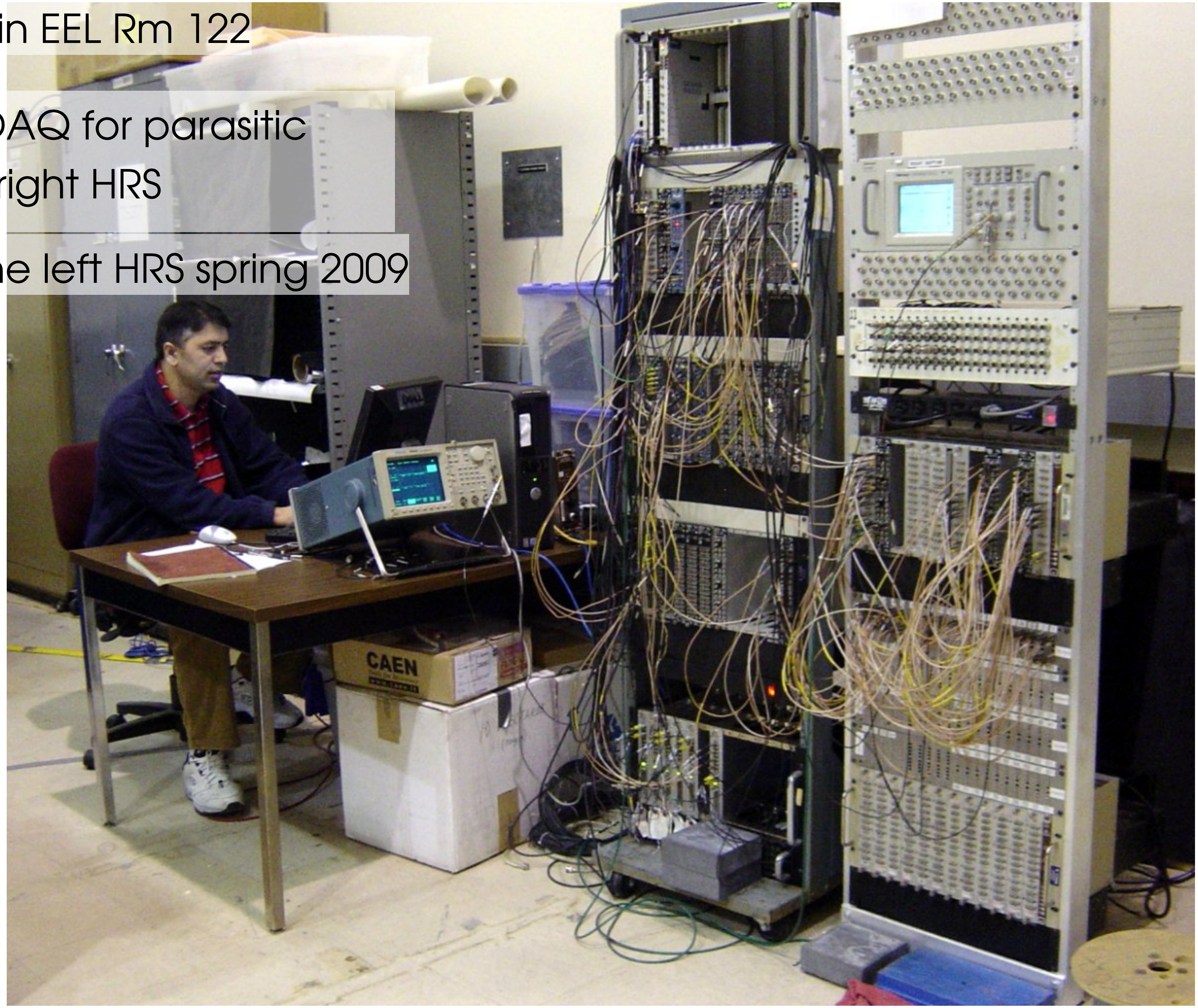
E_b (GeV)	θ	E' (GeV)	Q^2 $(GeV/c)^2$	DIS tot rate ($e+\pi$,KHz)	e^- prod (days)	e^+ prod (hours)	Dummy (hours)
6.0	12.9°	3.66	1.1	~500	4.5	2	2
6.0	20.0°	2.63	1.9	~200	16.0	2	6.2

- Resonance Measurement: 2 days

E (GeV)	θ	E' (GeV)	e- rate (KHz)	A_d (ppm)	$\Delta A_d/A_d$	Beam time (hours)
4.8	12.5	4.00(L)	1288	-68.7	7.5%	14.3
4.8	12.9	3.55(L)	888	-67.7	7.5%	21.3
4.8	12.9	3.10(R)	791	-60.6	7.5%	29.9
4.8	19.0	2.77(R)	105	-120.7	12%	22.3
6.0	14.0	4.00	280	-113.0	12%	9.5

E08-011 DAQ Status

- Being tested in EEL Rm 122
- Installing full DAQ for parasitic testing in the right HRS
- Will install in the left HRS spring 2009

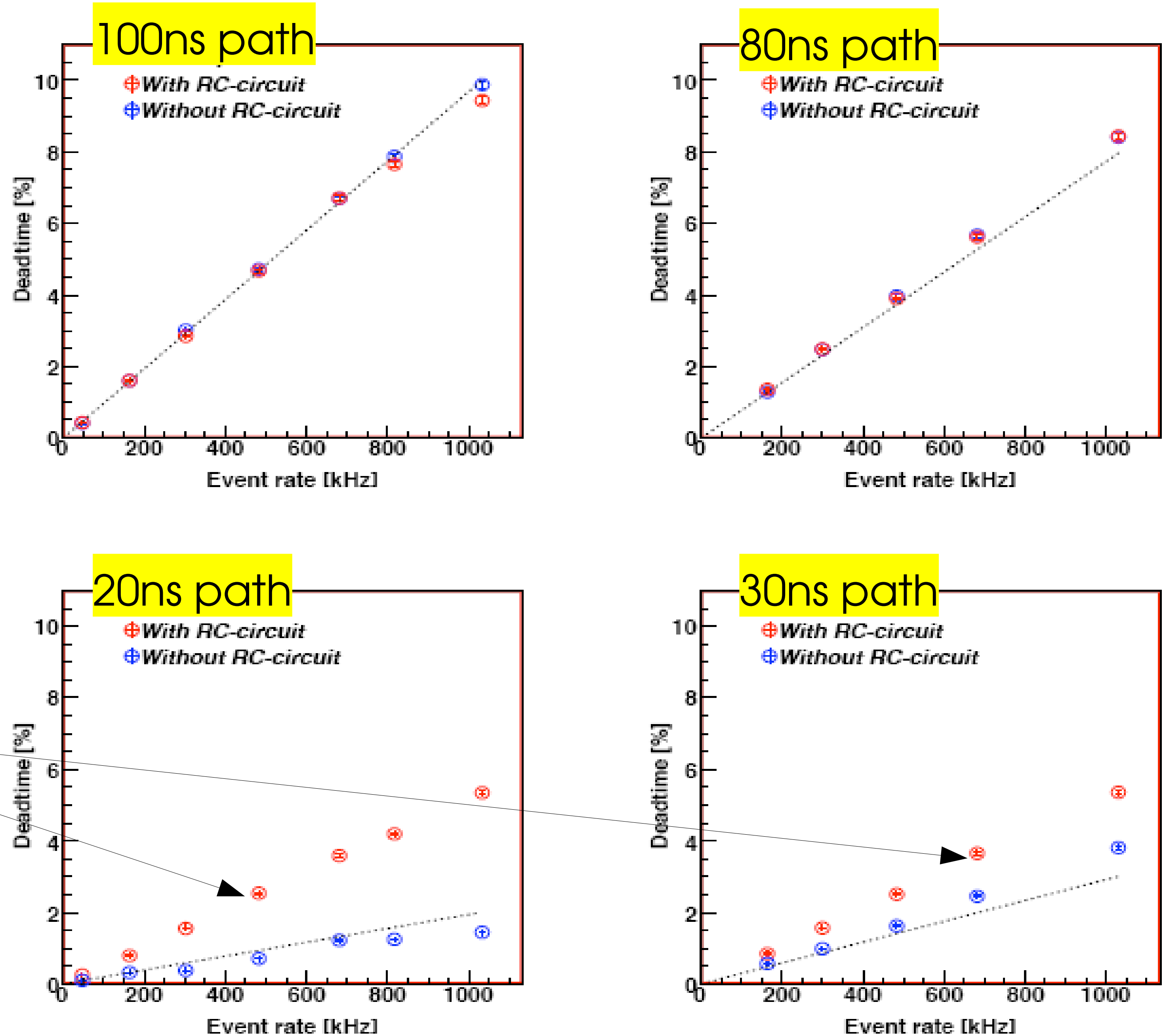


DAQ Deadtime Measurement

- Set discriminator width to 20, 30, 80, 100ns – should determine the system deadtime;
- Use high-rate PMT signal as input, fixed rate pulser as tagger;
- For tagger, use "RC" circuit to mimic real PMT signal
- Three methods used in EEL122:
  - TDC "dead-zone" observation using a tagger;
  - "Tagging" method using scalers + TDC (overcounting correction);
  - "Direct" method using scalers; ⟵ cannot be used in real running
- Will use/measure induced large charge asymmetries in the Hall.

Deadtime using scaler and TDC.

- Set discrir
  deadtime
- Use high-r
- For tagge
- Three me
  - TDC "d
  - "Taggi
  - "Direct

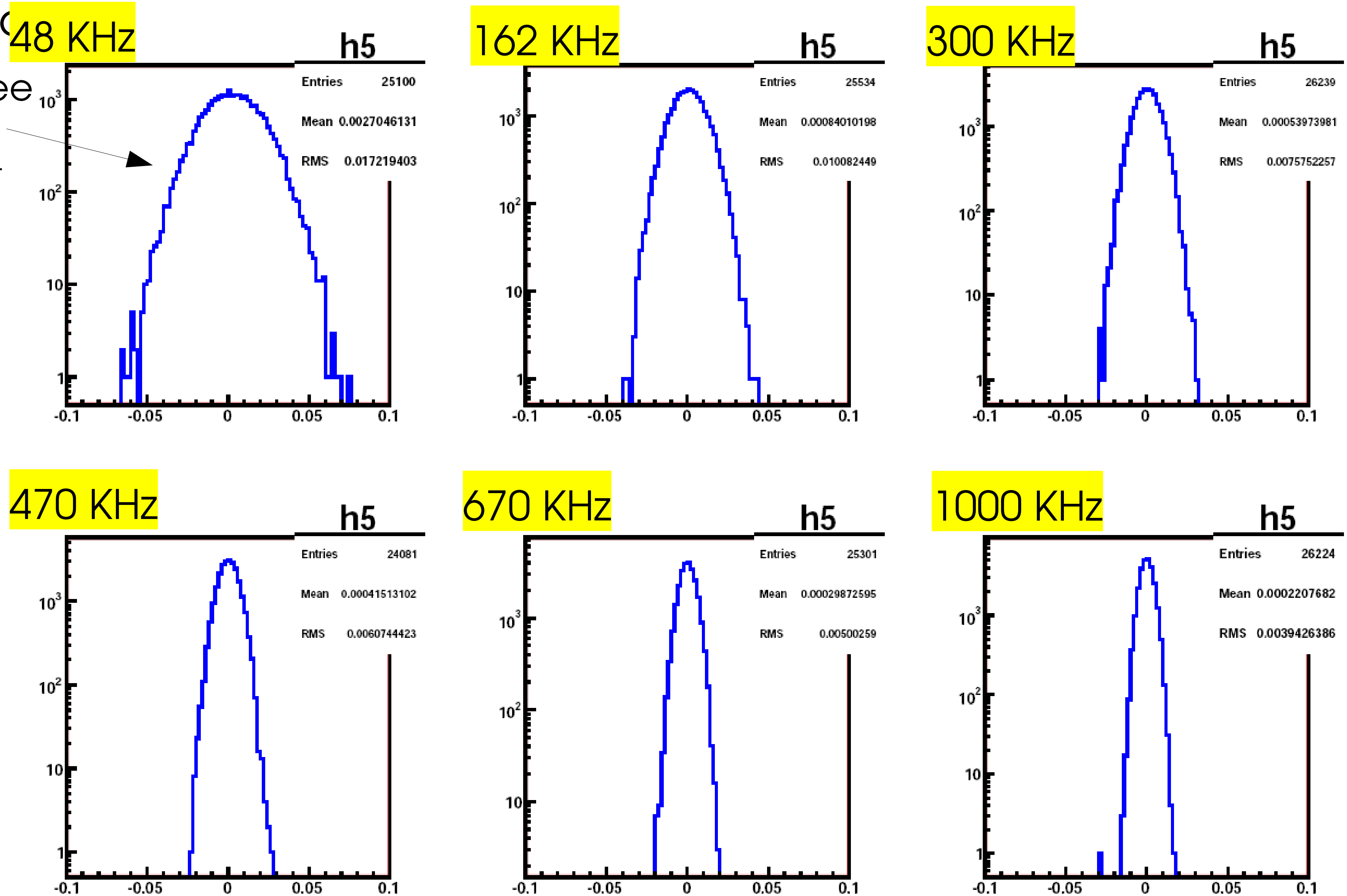


Simulation being worked on (D.Wang) to explain this "overcorrection"

DAQ Asymmetry Measurement

- Use JLab "asym module" mixed with high rate PMT random sign

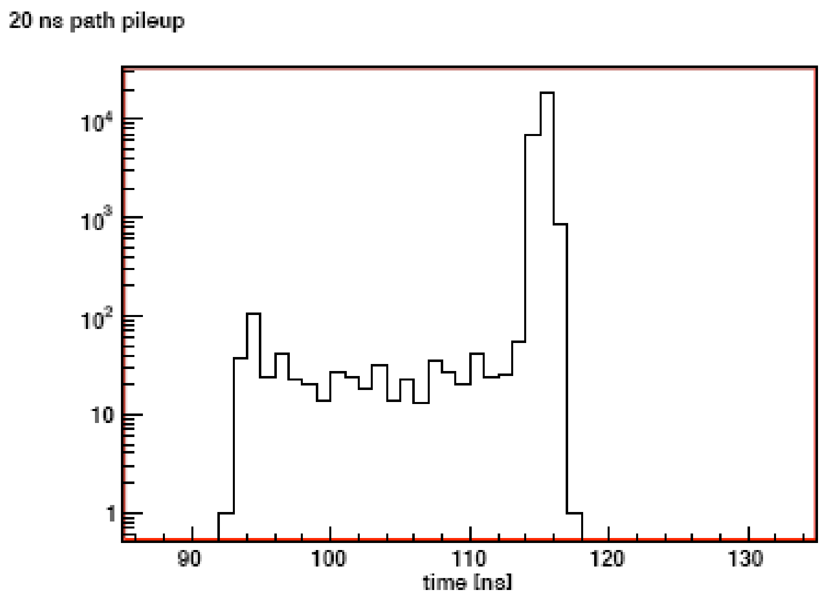
Width agree with $1/\sqrt{RT}$

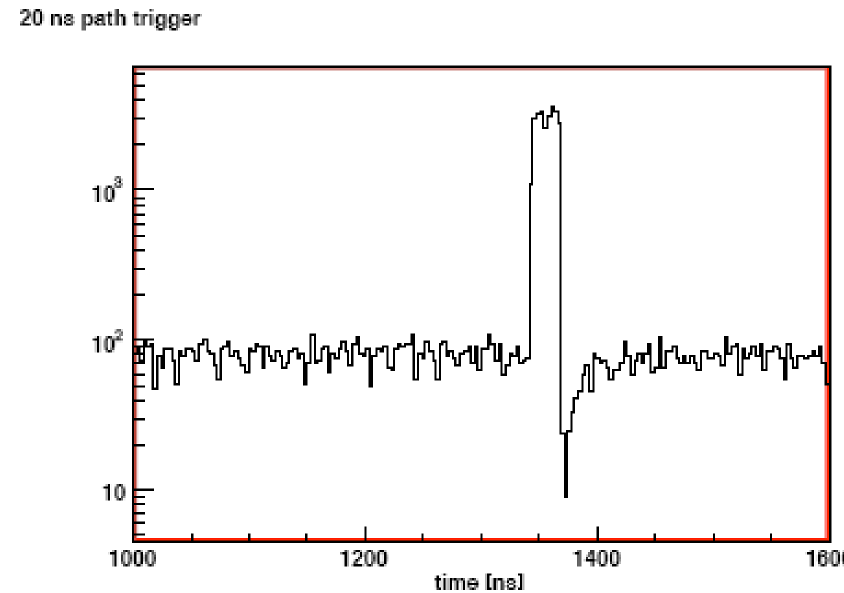


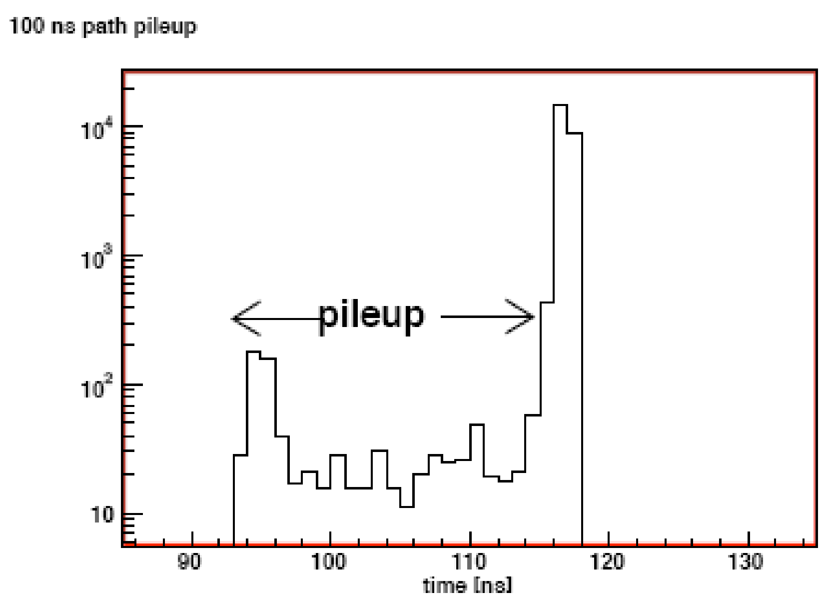
Summary

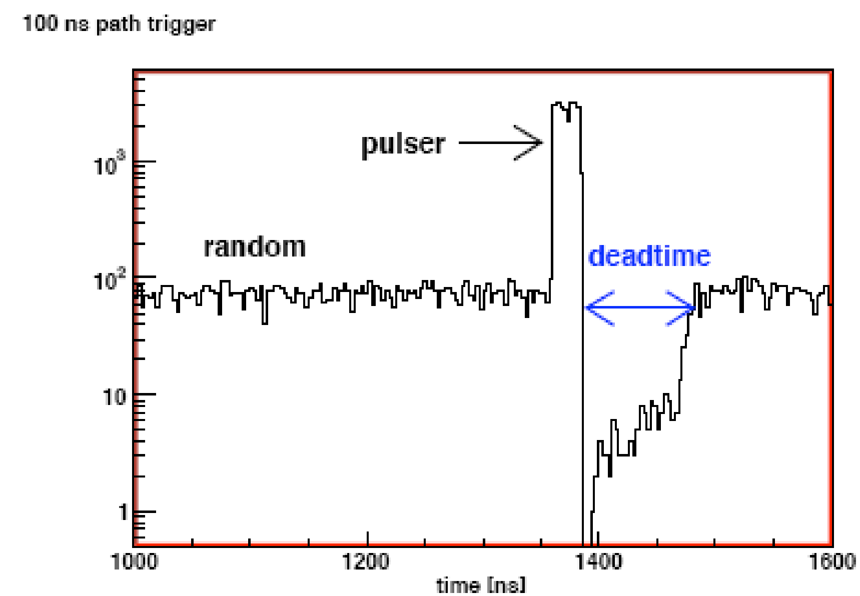
- PV-DIS is a powerful (and complicated) tool to study the EW Standard Model *and* many interesting hadronic effects:
  - C_{2q}'s, $\sin\theta_W$;
  - CSV, d/u at high x, higher twist...
- The first (exploratory) step will happen soon at 6 GeV (E08-011):
  - DAQ upgrade in progress, will run in late 2009;
  - Extract ($2C_{2u}$-C_{2d}), factor of 4-5 improvement;
  - First HT observation from PVDIS.
- Will be extended at the 12 GeV Upgrade:
  - Hall C Baseline proposed;
  - Initiation of a solenoid (or toroid) device being worked on;
  - Lot of more exciting physics could be studied: (A_1^n, $g_3^{\gamma Z}$ ...)
- *You are all invited!*

Result of the deadtime measurement Method I, and pileup using a TDC.









A_{PV} in DIS on ¹H — d/u Measurement

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

$$a(x)=\frac{3}{2}\left[\frac{2C_{1u}u(x)-C_{1d}[d(x)+s(x)]}{4u(x)+d(x)+s(x)}\right]$$

$$b(x)=\frac{3}{2}\left[\frac{2C_{2u}u_V(x)-C_{2d}d_V(x)}{4u(x)+d(x)+s(x)}\right]$$

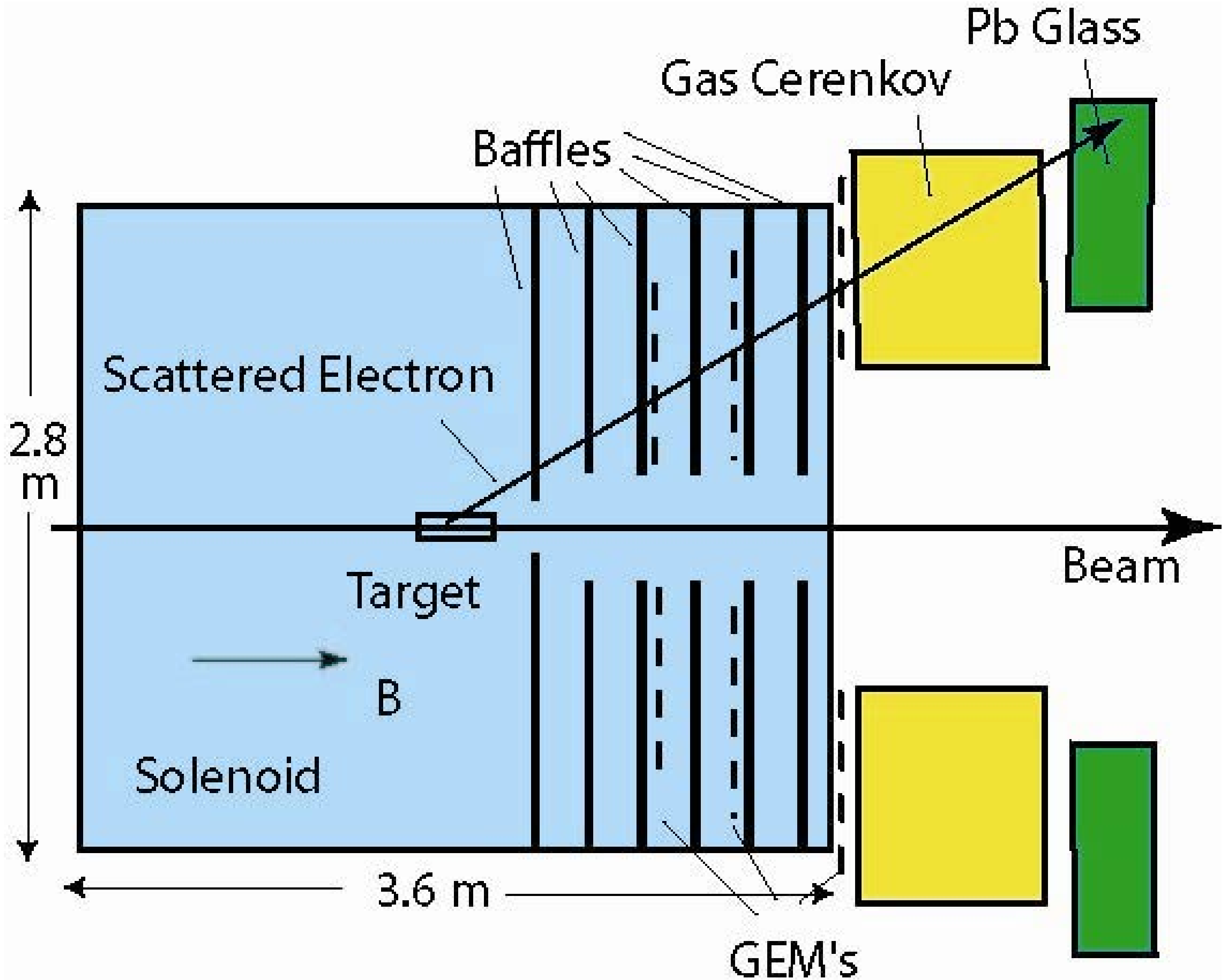
$$a(x)=\frac{u(x)+0.91\,d(x)}{u(x)+0.25\,d(x)}+small\ \ corrections$$

- *Allows d/u measurement on a single proton!*

- Determine that higher twist is under control
- Determine standard model agreement at low x
- Obtain high precision at high x

Plan View of the Spectrometer

Price~$10M
But the physics
worth the money

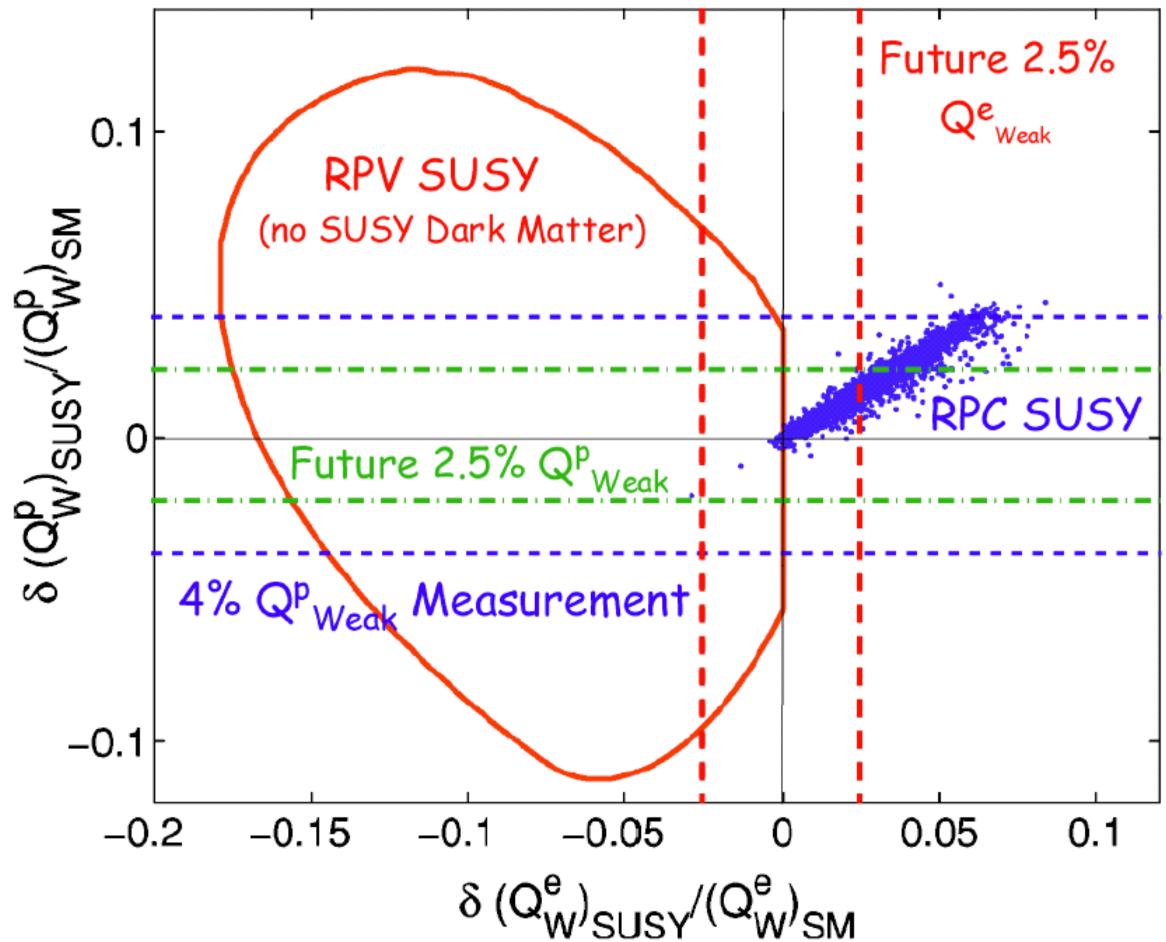


CDF or
BaBar
Solenoid?

New Physics Reach: Q_{weak} and Møller

Kurylov, Ramsey-Musolf, Su

To be relevant, new SM tests must have small enough errors to show up on plots like this



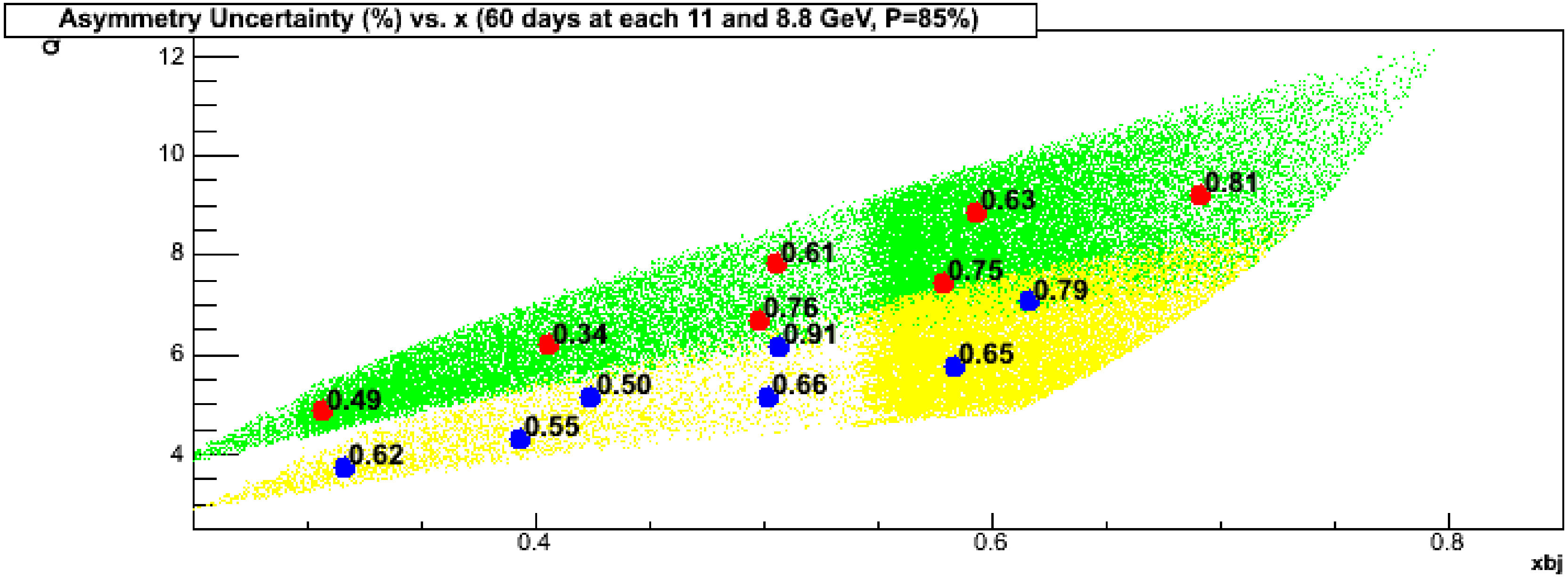
Examples:

Using PV DIS to study Higher Twists

- Higher twist effects describe the strong coupling (exchange of gluons) between the struck quark and spectator quarks;
- Is a non-perturbative effect, difficult to calculate from QCD;
- From cross sections (F2), can extract $F_2 = F_2^{L.T.}(1 + \frac{C_4^{HT}}{Q^2})$
  - F2 uncertainties are large
  - Calculation of the leading twist term depends on truncation in α_s (LO, NLO, NNLO?) -- MRST Phys. Lett. B 582, 222 (2004)
- Using PV DIS to study HT:
  - A_d^{LT} unambiguously determined by the Standard Model (no QCD-like "order" problem!) $A_d = A_d^{SM}(1 + \frac{C_4^{HT}}{Q^2})$
  - High precision

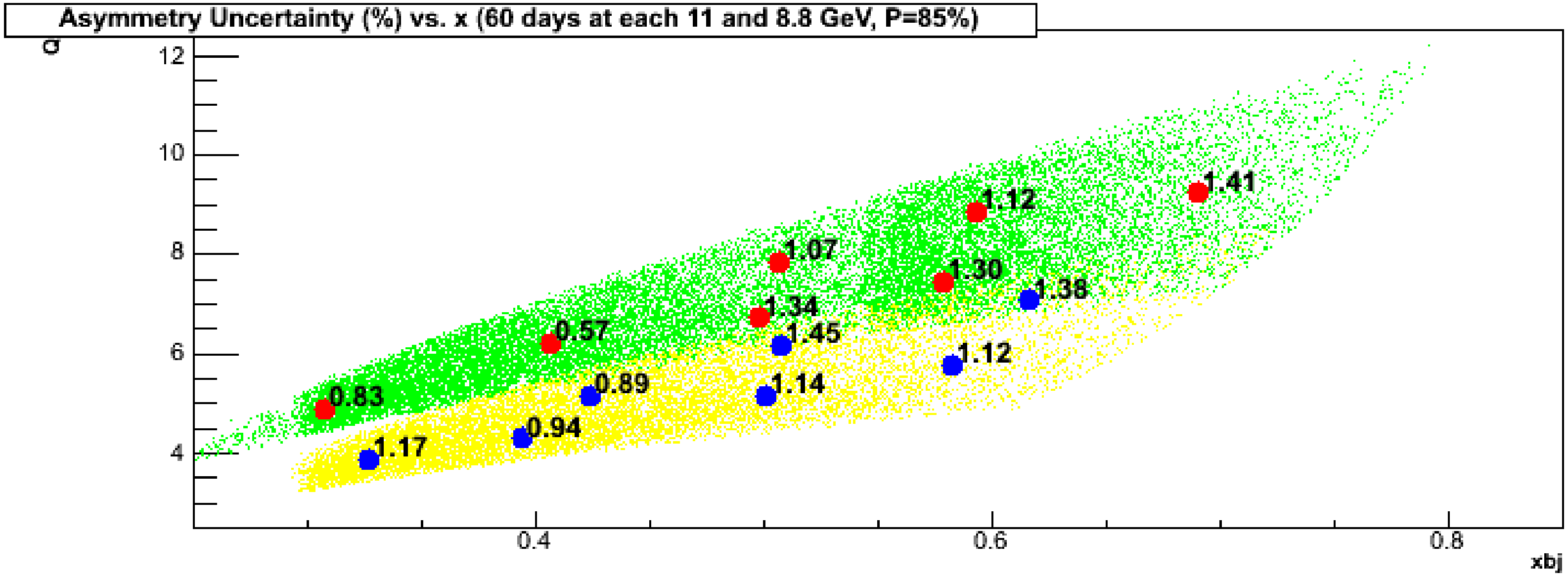
Projected errors, 60 days, deuterium

- 11 GeV
- 8.8 GeV



- Good enough to fit: CSV, HT, and Standard Model Test

Projected errors, 60 days, proton

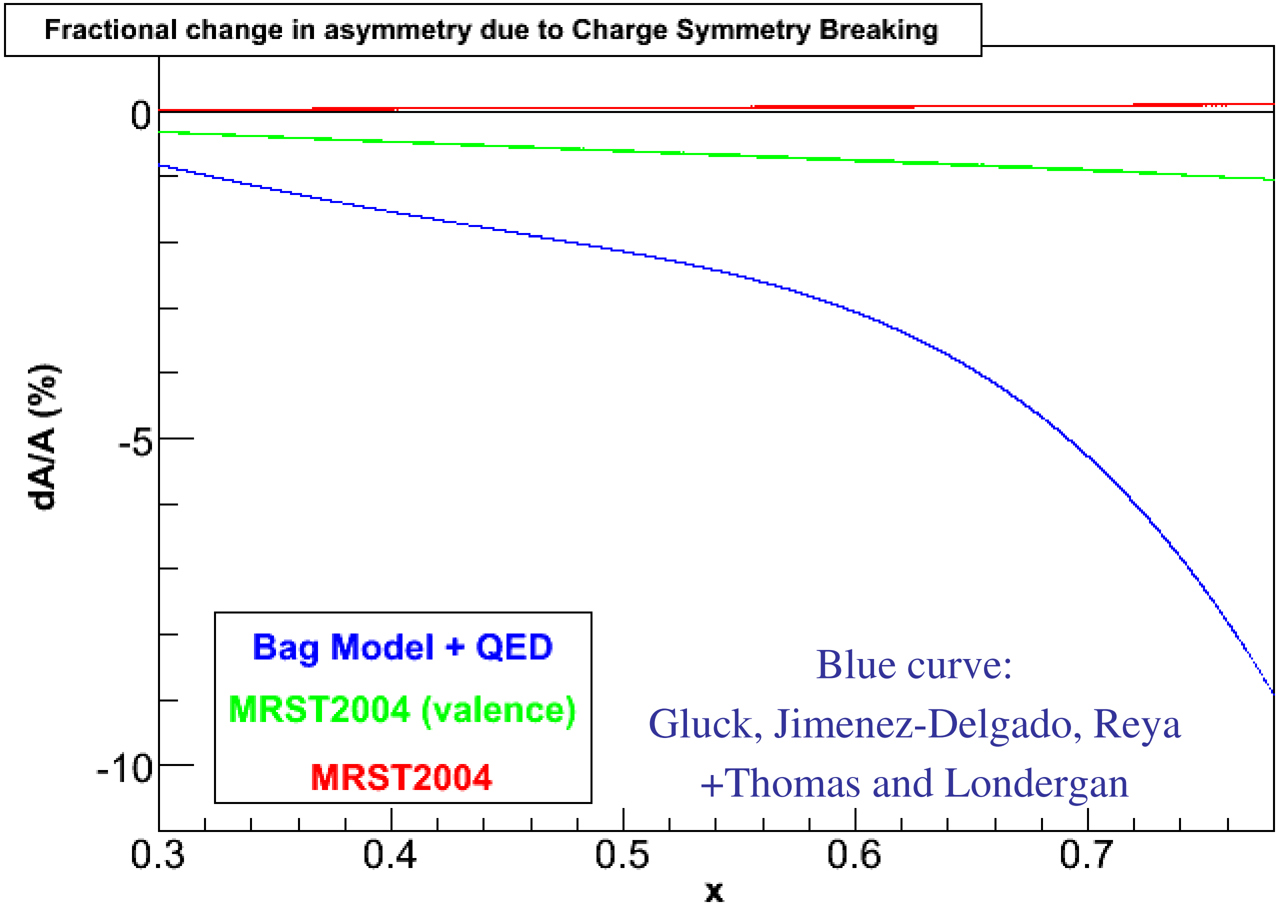


Physics

b) d/u

c) Higher twist

Search for CSV in PV DIS



Search for CSV in PV DIS

$$u^p(x) \neq d^n(x)$$
$$d^p(x) \neq u^n(x)$$

- u-d mass difference
- electromagnetic effects

$$\boldsymbol{u^p(x) \neq d^n(x)}$$
$$\boldsymbol{d^p(x) \neq u^n(x)}$$

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

For A_{PV} in electron-^{2}H DIS:

$$\frac{\delta A_{PV}}{A_{PV}} = 0.28 \frac{\delta u - \delta d}{u + d}$$

Sensitivity will be further enhanced if u+d falls off more rapidly than δu-δd as $x \rightarrow 1$

Strategy:

- *measure or constrain higher twist effects at $x \sim 0.5$-0.6 and low Q^2;*
- *precision measurement of A_{PV} at $x \rightarrow 0.8$ to search for CSV*