PVDIS at JLab 6 GeV

Xiaochao Zheng (Univ. of Virginia)

September 6, 2011

- Electroweak Standard Model and PVDIS Physics
- History: SLAC E122
- PVDIS @ 6 GeV Status

Electroweak Interaction – The Standard Model

- Weak charged currents ($W^{\pm}$) are described by a $SU(2)_L$ group with weak isospin *T*, that couple only to left-handed particles;
- Weak neutral current (Z^0) can not be described by the same $SU(2)_L$ group. The neutral currents from $SU(2)_L$ is combined with QED [$U^{EM}(1)_\gamma$] to construct the proper description. This combination is described by the weak mixing angle θ_W.
- Lepton neutral currents are given by their vector and axial couplings – determined from their quantum numbers and θ_W.

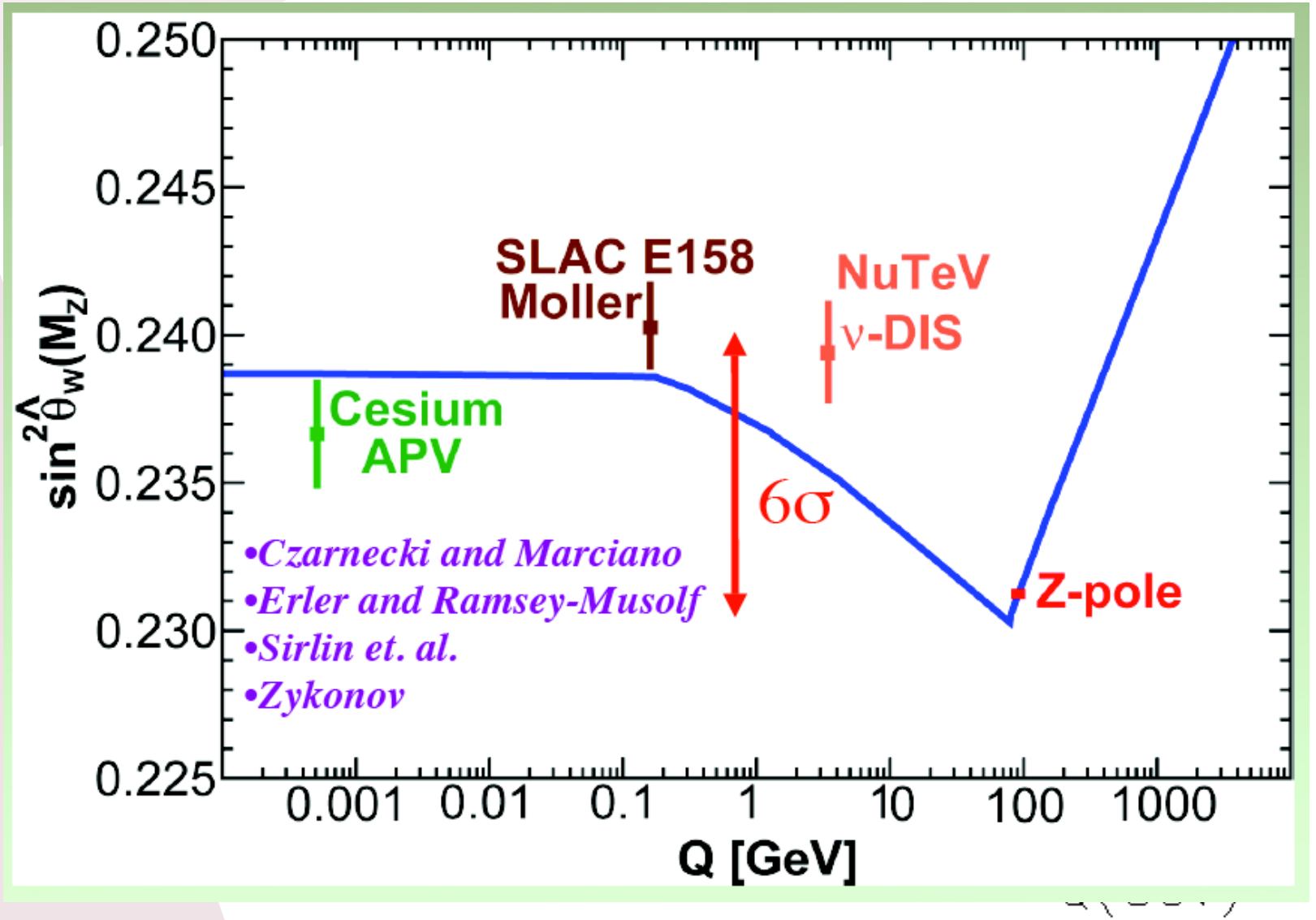
$$J_\mu^{NC}(\nu) = \frac{1}{2}\left(\bar{u}_\nu \gamma_\mu \frac{1}{2}(1-\gamma^5) u_\nu\right)$$

$$J_\mu^{NC}(q) = \left(\bar{u}_q \gamma_\mu \frac{1}{2}\left(c_V^q - c_A^q \gamma^5\right) u_q\right)$$

fermions	c_A^f	c_V^f
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
e-, μ-	$-\frac{1}{2}$	$-\frac{1}{2}+2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2}-\frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W$

In the Standard Model

Testing the EW Standard Model – Running of $\sin^2\theta_W$



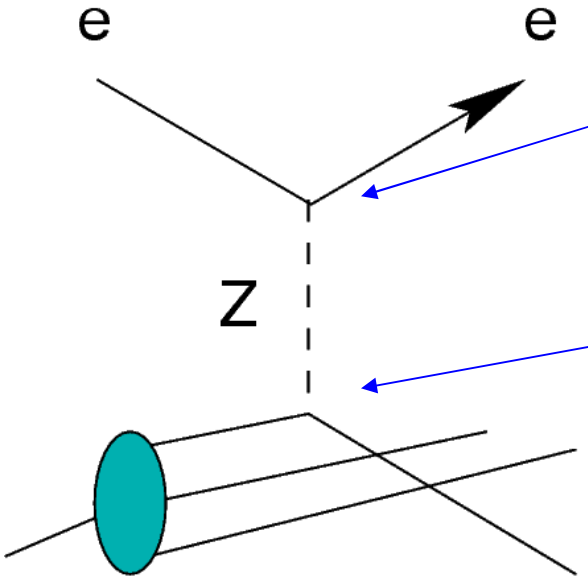
Also:
- Qweak (ongoing)
- PVDIS 12 GeV (planned)
- Moller 12 GeV (planned)

figure from K. Kumar, Seattle 2009 EIC Workshop EW talks

Parity Violating Electron Scattering

Weak Neutral Current (WNC) Interactions at $Q^2 \ll M_Z^2$

Longitudinally Polarized Electron Scattering off Unpolarized Fixed Targets



$$J_\mu^{NC}(e) = \left(\bar{u}_e \gamma_\mu \frac{1}{2}\left(c_V^e - c_A^e \gamma^5\right) u_e\right)$$

$$J_\mu^{NC}(q) = \left(\bar{u}_q \gamma_\mu \frac{1}{2}\left(c_V^q - c_A^q \gamma^5\right) u_q\right)$$

$$L_{NC}^{leptonscatt.} = \sum \left[c_A^l c_V^q \bar{l}\gamma^\mu\gamma_5 l\,\bar{q}\gamma_\mu q + c_V^l c_A^q \bar{l}\gamma^\mu l\,\bar{q}\gamma_\mu\gamma_5 q + c_A^l c_A^q \bar{l}\gamma^\mu\gamma_5 l\,\bar{q}\gamma_\mu\gamma_5 q\right]$$

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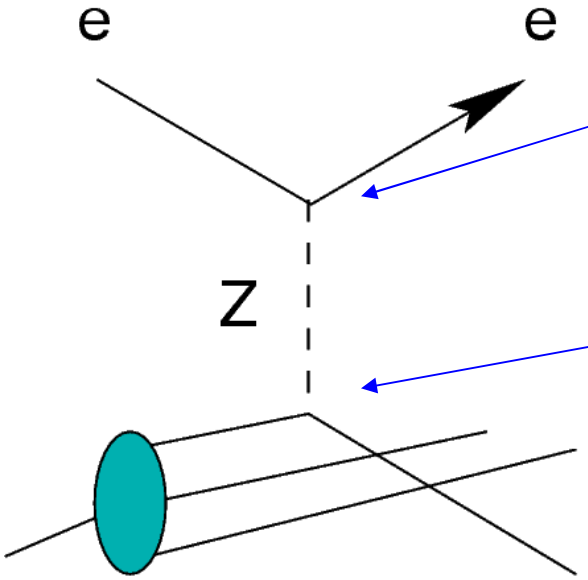

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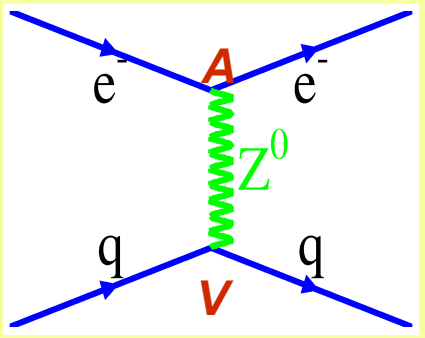
C_{1q} C_{2q} C_{3q}

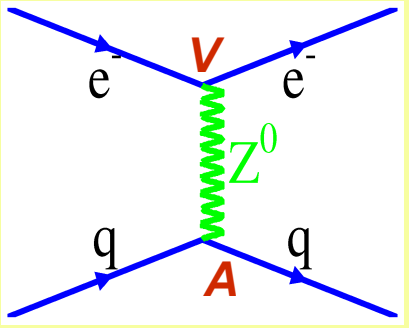
parity-violating, cause different e_L, e_R cross sections

lepton charge conjugate-violating, cause difference in e_L, $e^+{}_R$ cross sections

Weak Neutral Couplings

Different conventions exist, here:





$$C_{1q} \equiv 2g_A^e g_V^q \qquad C_{2q} \equiv 2g_V^e g_A^q$$

$$C_{1u} = 2g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) + \delta C_{1u} \approx 0.19$$

$$C_{1d} = 2g_A^e g_V^d = +\frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) + \delta C_{1d} \approx 0.35$$

$$C_{2u} = 2g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W) + \delta C_{2u} \approx -0.030$$

$$C_{2d} = 2g_V^e g_A^d = +\frac{1}{2} - 2\sin^2(\theta_W) + \delta C_{2d} \approx 0.025$$

SLAC DIS-parity proposal (E149) has no "2", so did the JLab 6GeV proposals (2005 and 2008 update)

now using $g_{A,V}$ follow PDG convention

X. Zheng, talk at PAVI11, Rome, Italy

Parity Violation in Deep Inelastic Scattering

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

$$x \equiv x_{Bjorken} \qquad y \equiv 1 - E'/E$$

$$q_i^{+\cdot}(x) \equiv q_i(x) + \bar{q}_i(x)$$

$$q_i^{-\cdot}(x) = q_i^V(x) \equiv q_i(x) - \bar{q}_i(x)$$

$$a(x) = \frac{1}{2} g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} = \frac{1}{2} \frac{\sum C_{1i} Q_i q_i^{+\cdot}(x)}{\sum Q_i^2 q_i^{+\cdot}(x)}$$

$$b(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}} = \frac{1}{2} \frac{\sum C_{2i} Q_i q_i^{-\cdot}(x)}{\sum Q_i^2 q_i^{+\cdot}(x)}$$

For an isoscalar target (^{2}H), structure functions largely simplifies:

$$a(x) = \frac{3}{10}\left(2C_{1u} - C_{1d}\right)\left(1 + \frac{0.6 s^{+\cdot}}{u^{+\cdot} + d^{+\cdot}}\right) \to 0$$

$$b(x) = \frac{3}{10}\left(2C_{2u} - C_{2d}\right)\left(\frac{u_V + d_V}{u^{+\cdot} + d^{+\cdot}}\right) \to 1$$

PVDIS can be used to access $C_{1,2q}$s at high x

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- PVDIS can also be used to access the nucleon structure beyond the simple parton model (it will all depend on precision of the measurement, the current knowledge on $C_{1,2q}$ and the nucleon PDF, and the kinematics chosen).

- 6 GeV (moderate precision, two kinematics) – accessing the C_{2q}
  12 GeV (high precision, wide kinematics) – accessing both

The First PVDIS Experiment – SLAC E122

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

- 37% polarized beam, four energies 16.2-22.2 GeV, 30-cm LD2 and LH2 targets
- Spectrometers at 4°, various E'
- Q^2 = 1-1.9 GeV^2
- Integrating method for gas cherenkov and lead glass shower counters, independently.

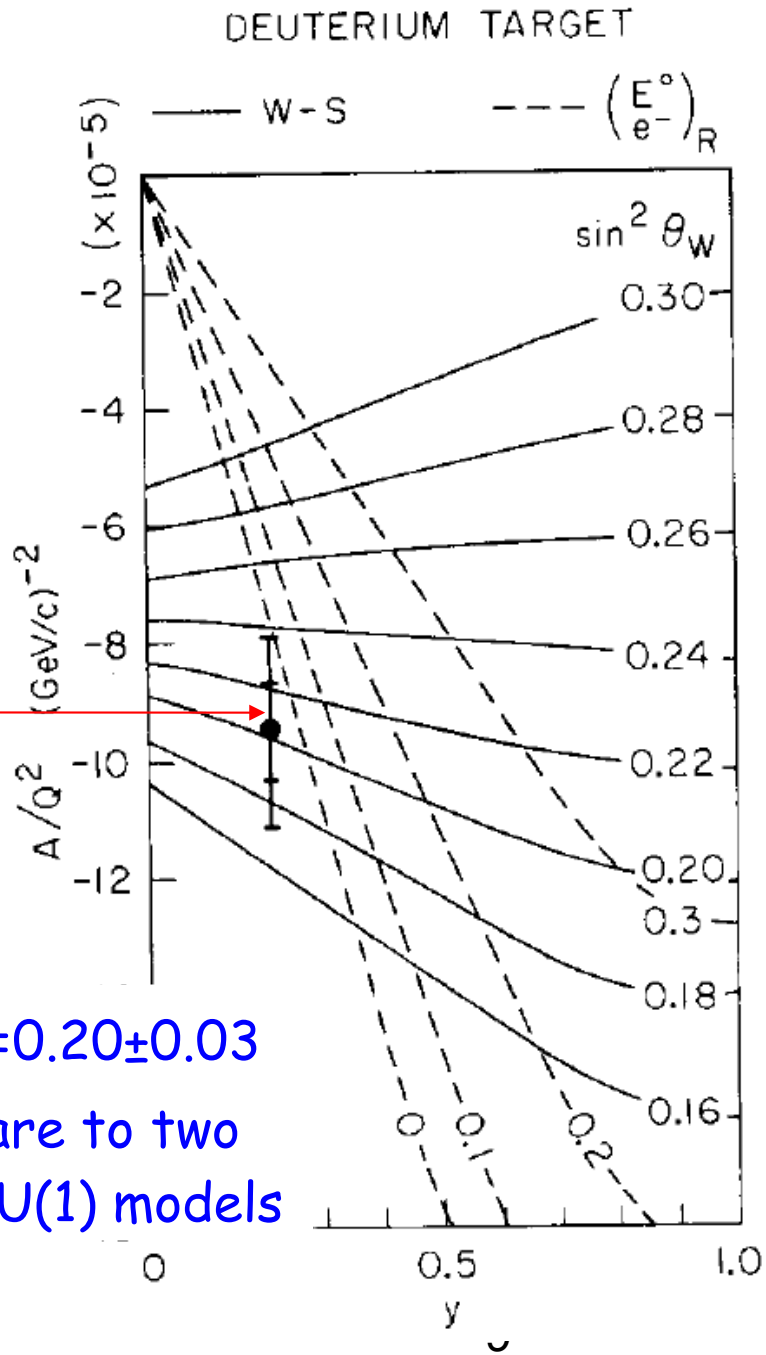
Deuteron data from 19.4 and 22.2 GeV:

$A/Q^2=(-9.5\pm1.6)\times10^{-5}\,(GeV/c)^{-2}$

$\pm0.86\times10^{-5}$(stat)±5%(Pb)±3.3%(beam)
±2%(π contamination)
±3%(radiative corrections)

Proton data from 19.4, 22.2 GeV:

$A/Q^2=(-9.7\pm2.7)\times10^{-5}\,(GeV/c)^{-2}$



$\sin^2\theta_W=0.20\pm0.03$

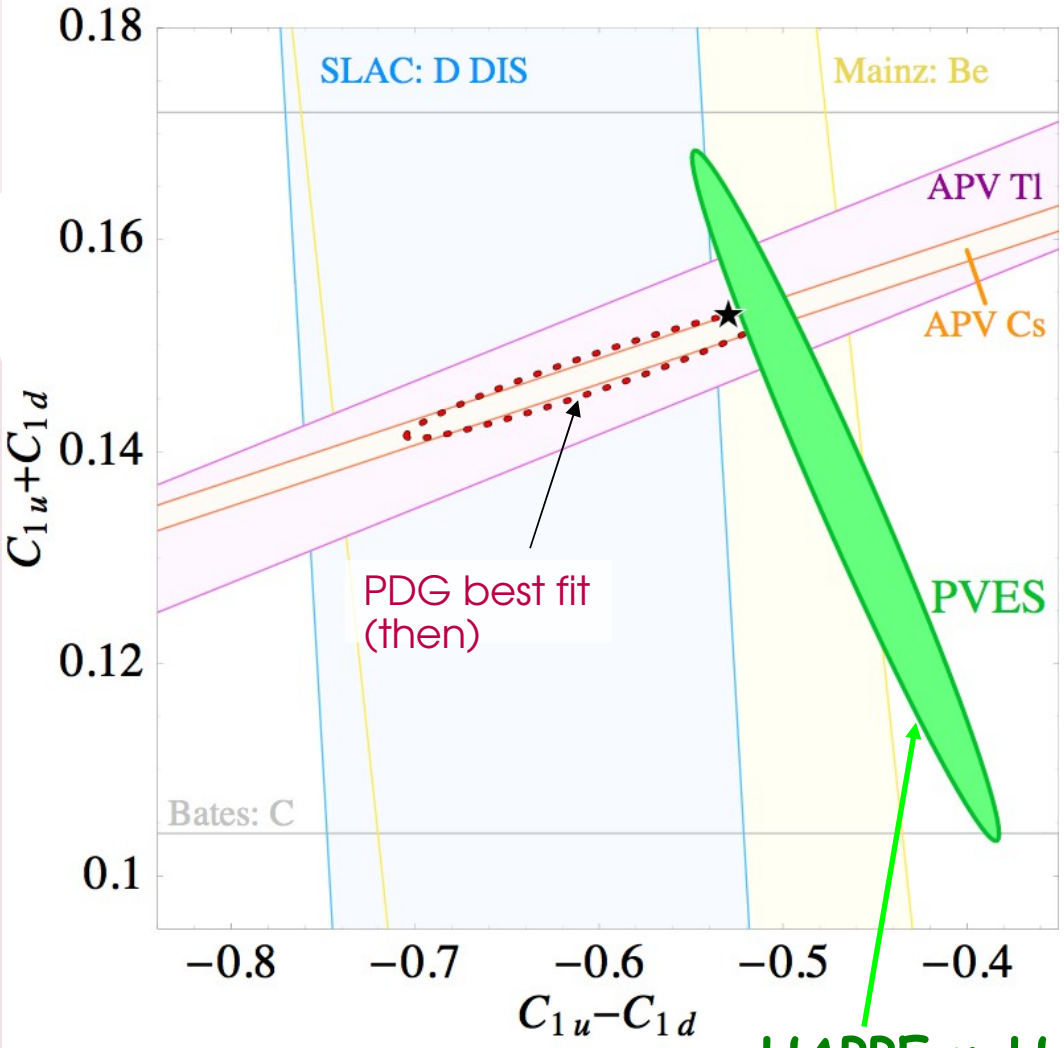
compare to two SU(2)xU(1) models

X. Zheng, talk at PAVI11, Rome, Italy

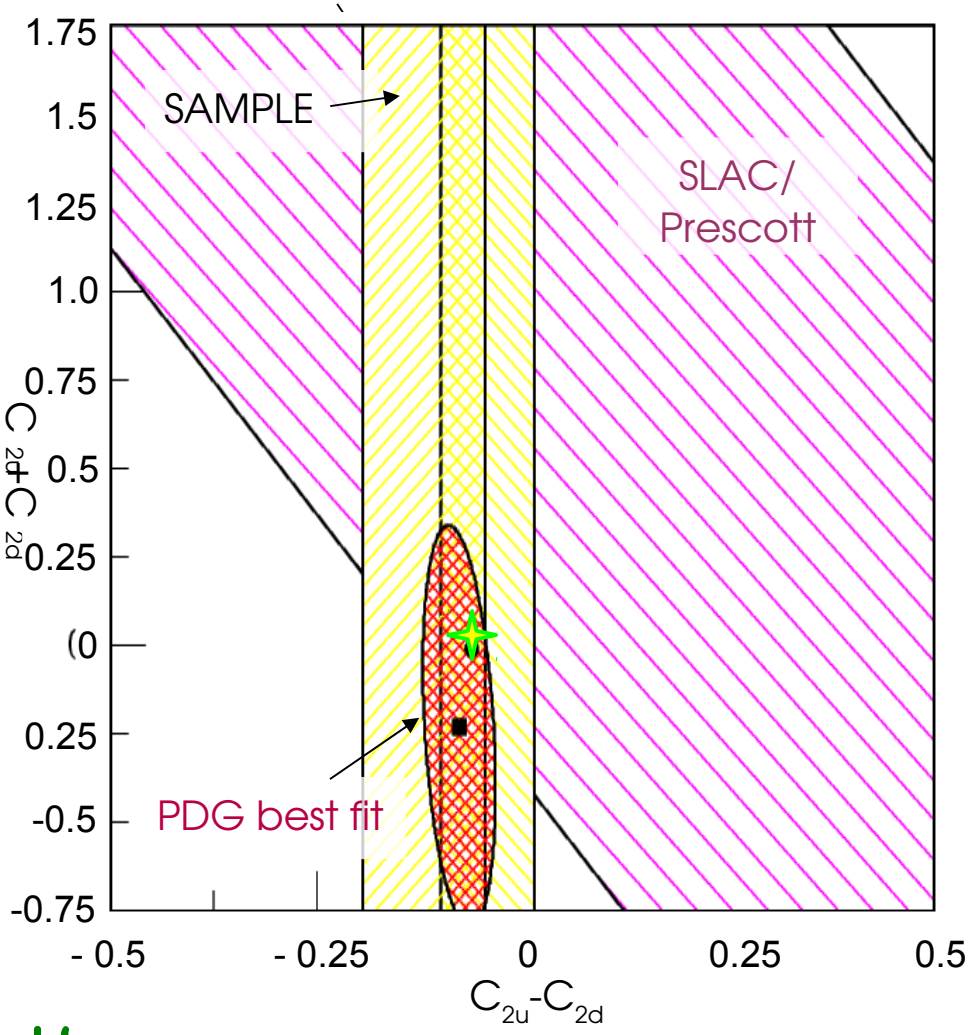
Quark Weak Neutral Couplings $C_{1,2q}$

all are 1 σ limit

with recent PVES data



without JLab PVDIS data



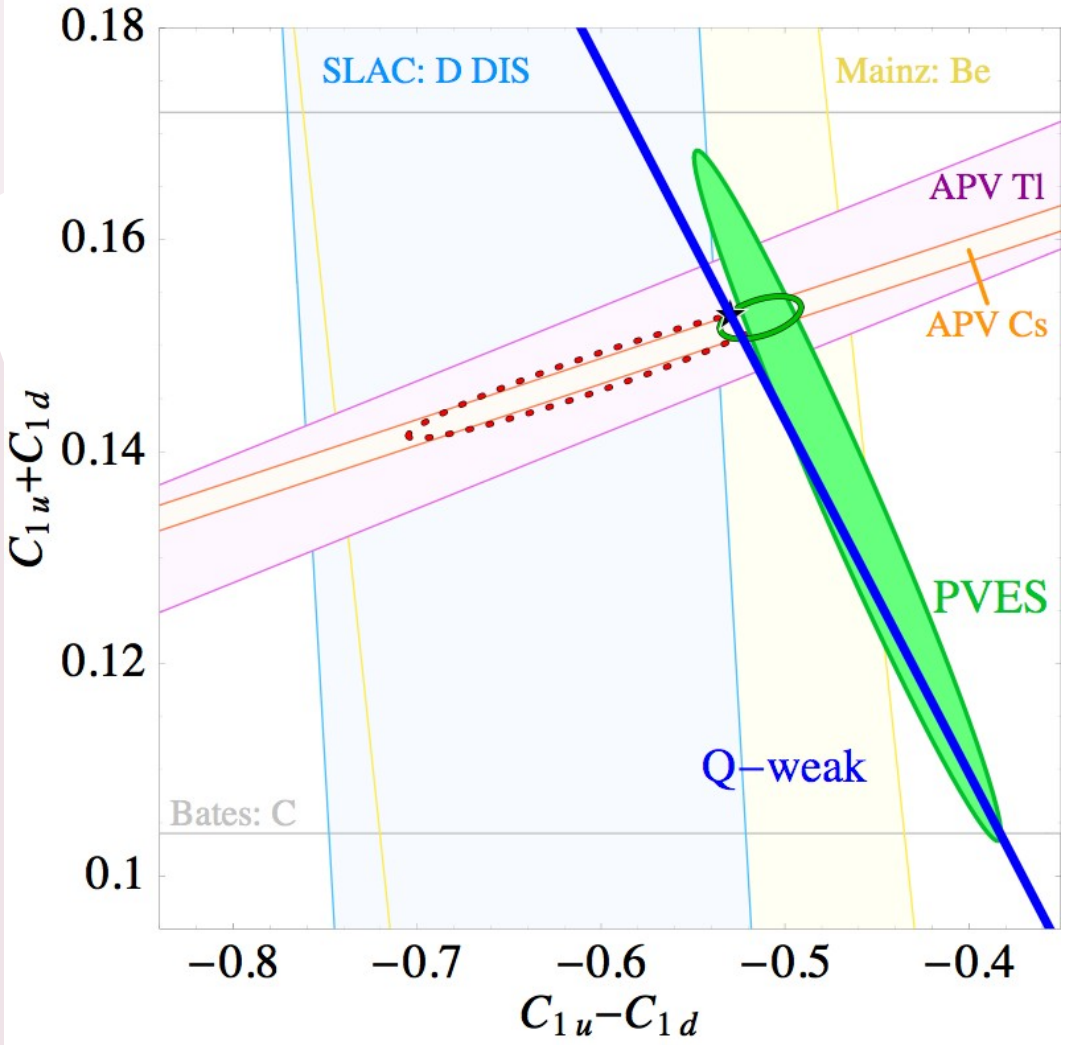
HAPPEx: H, He
G0: H,
PVA4: H
SAMPLE: H, D

X. Zheng, talk at PAVI11, Rome, Italy

Quark Weak Neutral Couplings $C_{1,2q}$

all are 1 σ limit

with recent PVES data and Qweak



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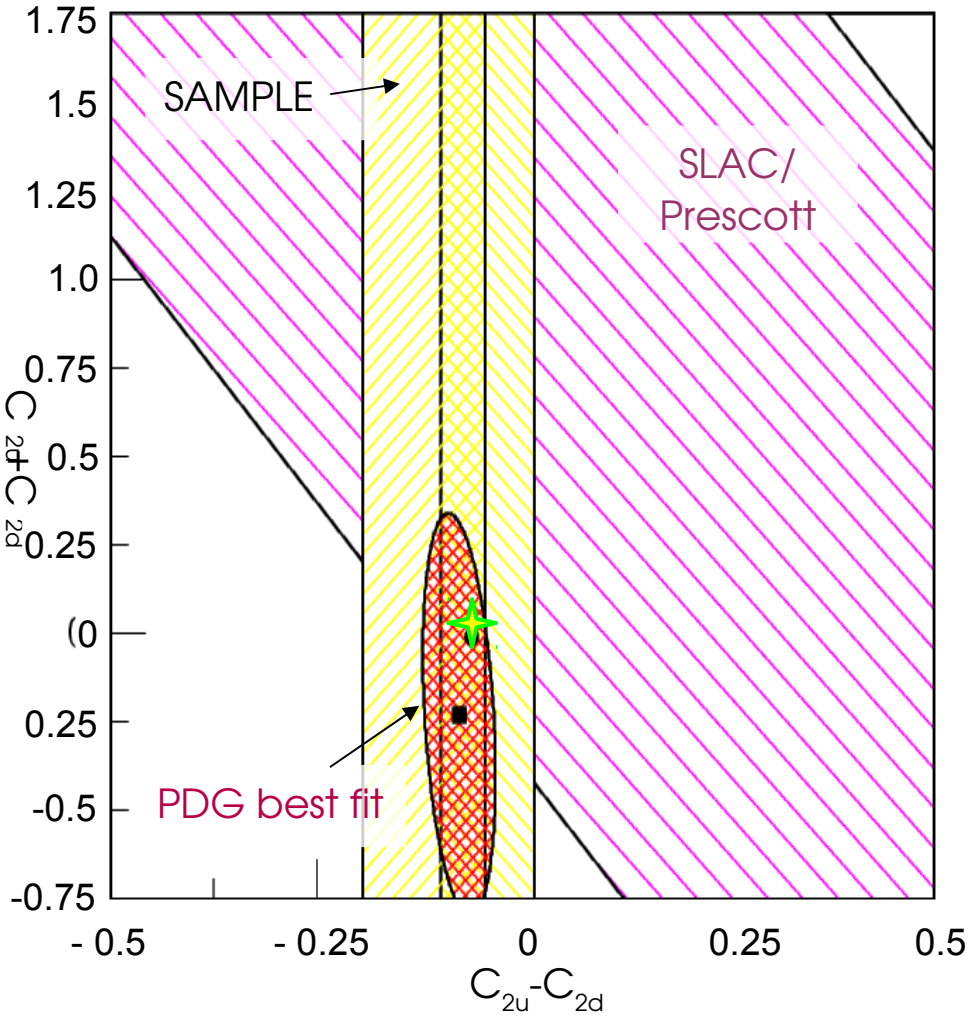

Qweak in Hall C (2010-): $^1\vec{H} + e \rightarrow e' + p$ **factor of 5 improvement** in knowledge of C_{1q}, New Physics scale from 0.9 to 2 TeV

X. Zheng, talk at PAVI11, Rome, Italy

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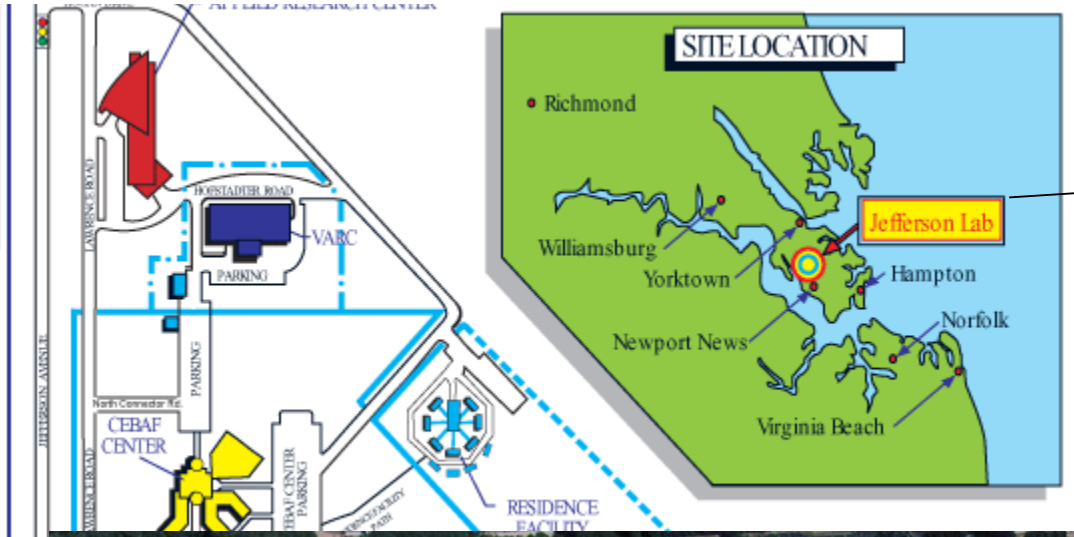
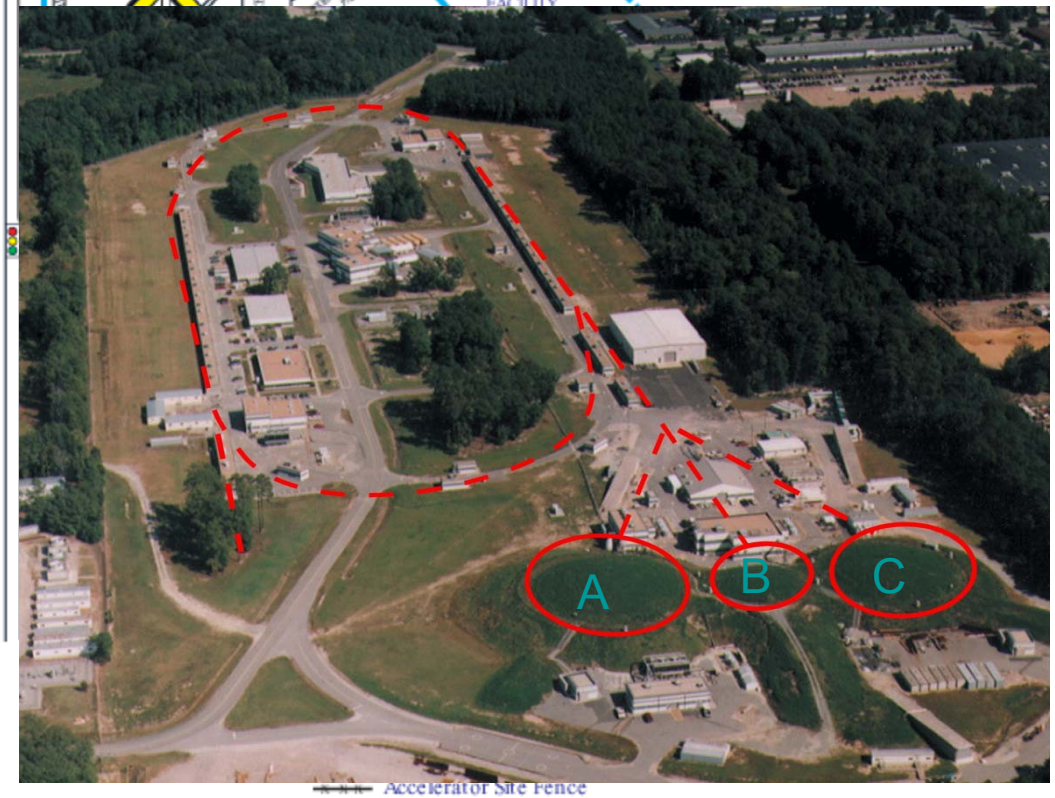
PVDIS: Only way to measure C_{2q} among current EW experiments

Jefferson Lab

Thomas Jefferson National Accelerator Facility



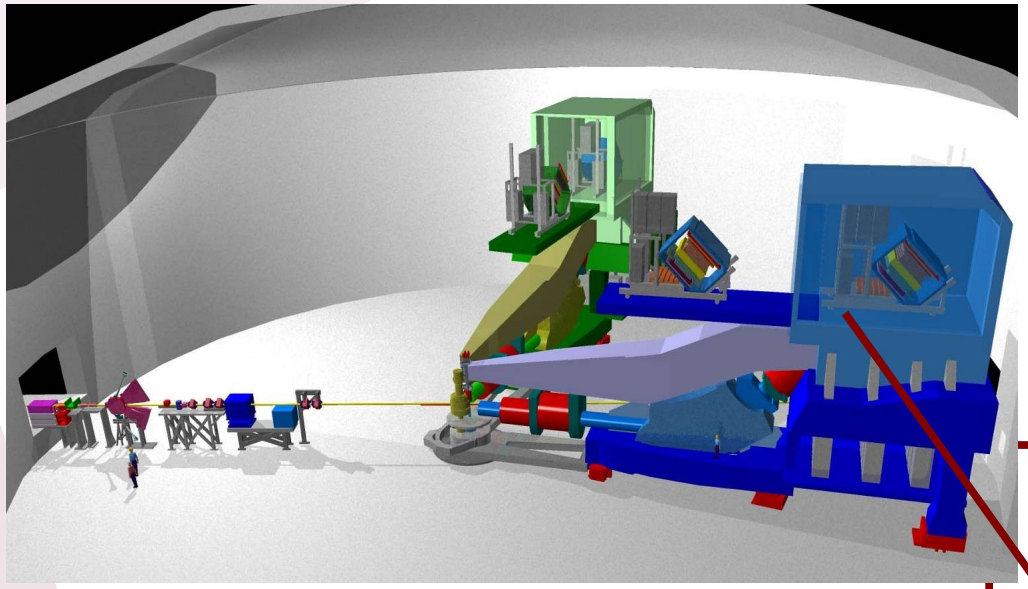


- **Staff: ~650**
- **User community: ~1300**

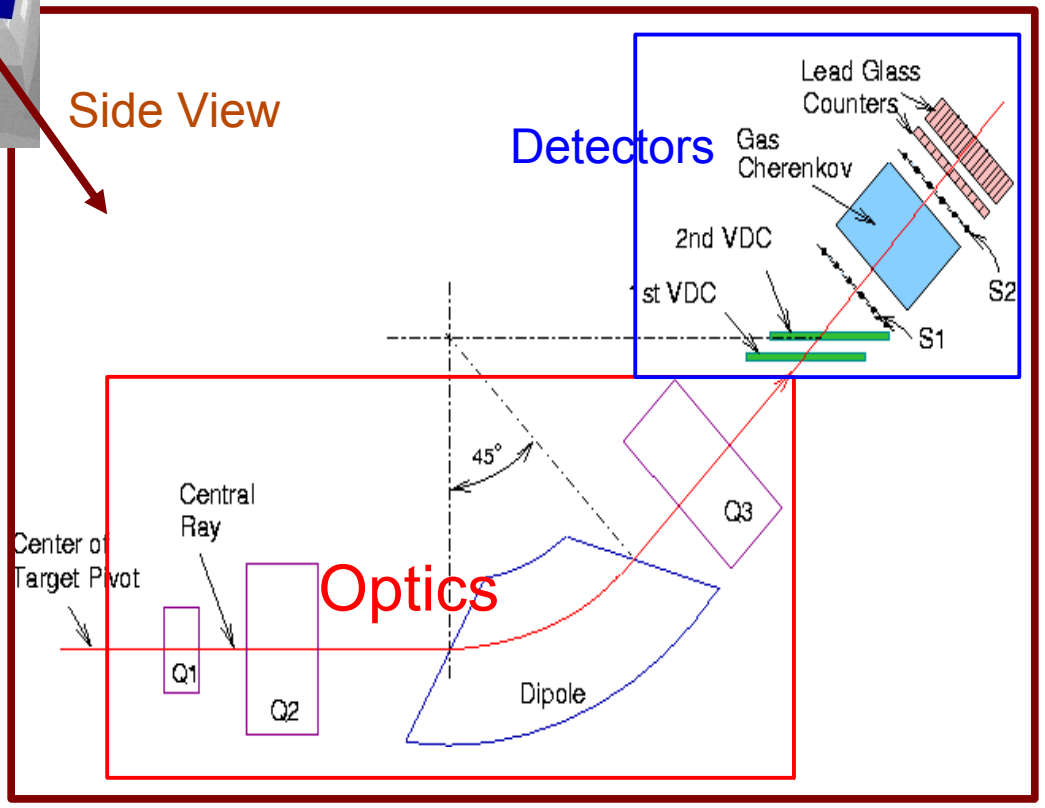
- Beam first delivered in 10/95
- In full operation for since 11/97
- "parity quality" beam since '99
- 334 PhDs to date and 249 in progress (~1/3 of US PhDs in Nuclear Physics)

PVDIS at 6 GeV (JLab E08-011)

spokespeople: R. Michaels, P.E. Reimer, X. Zheng



Grad students:
Xiaoyan Deng (UVa M.A.),
Diancheng Wang (UVa),
Kai Pan (MIT)
Postdoc: Ramesh Subedi

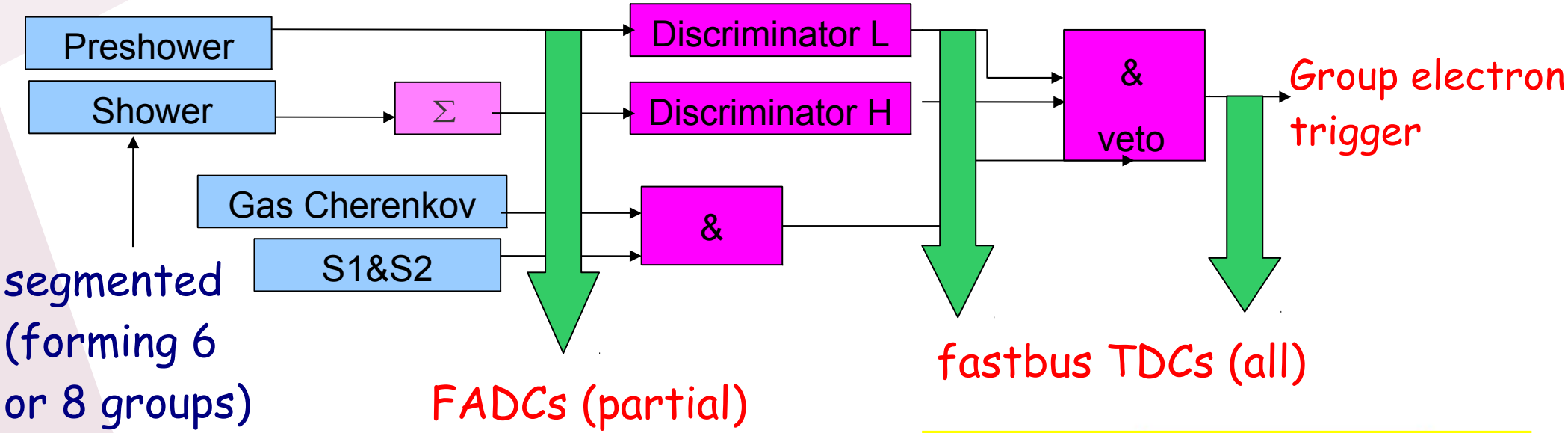


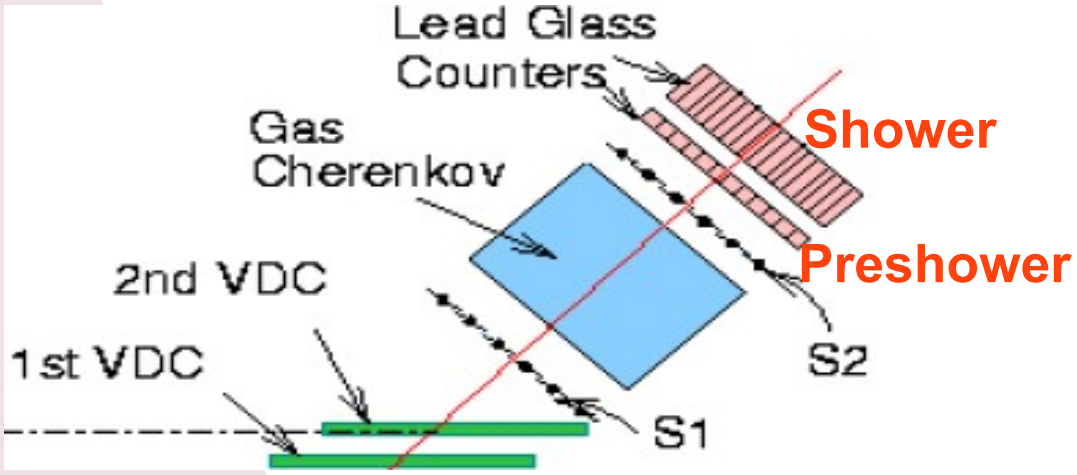
- 100uA, 90% polarized beam, 20-cm LD2 target
- Ran in Oct-Dec 2009
- Measured A_d at Q^2=1.1 and 1.9 GeV^2 to 3% and 4% (stat.), resp. Systematics dominated by beam polarization (2%).

X. Zheng, talk at PAVI11, Rome, Italy

Scaler-Based Counting DAQ with online (hardware) PID

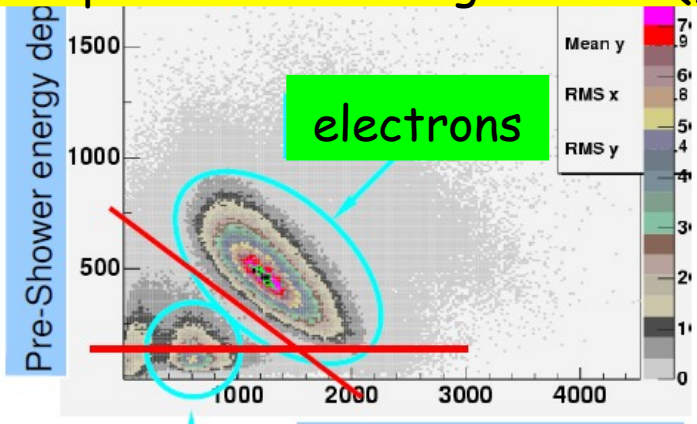
- DIS region, pions contaminate, can't use integrating DAQ.
- High event rate (~500KHz), exceeds Hall A regular DAQ's Limit (4kHz)





X. Zheng, talk at PAVI11, Rome, Italy

ADC spectrum from regular DAQ,



pions

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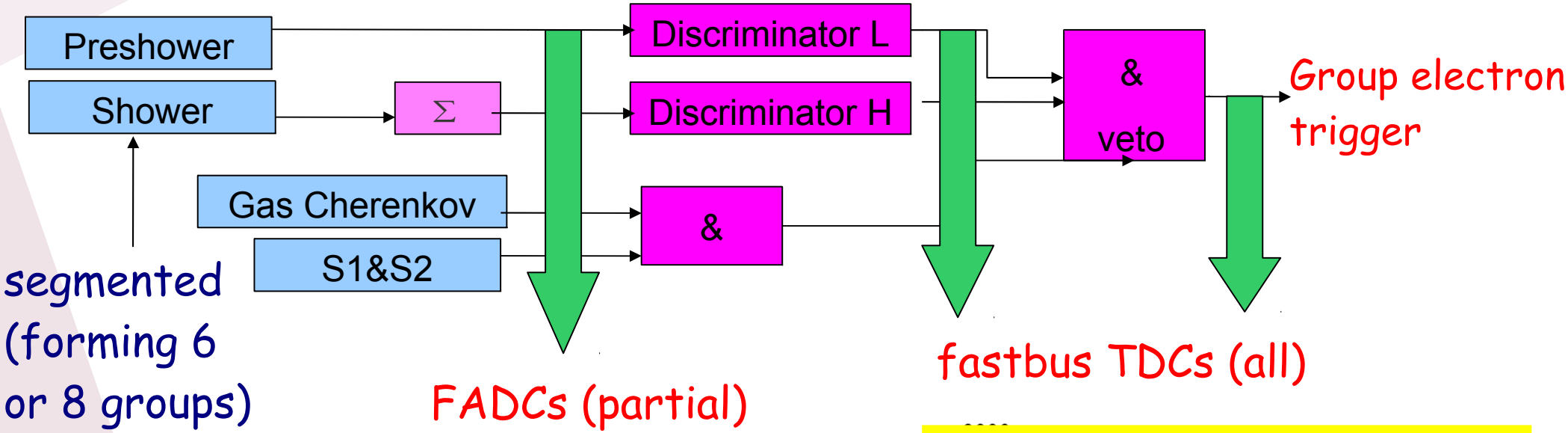
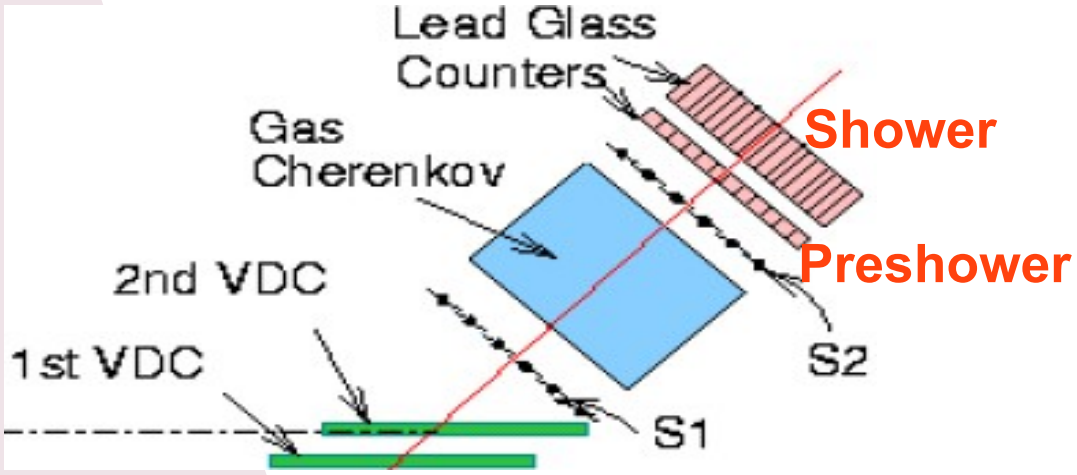
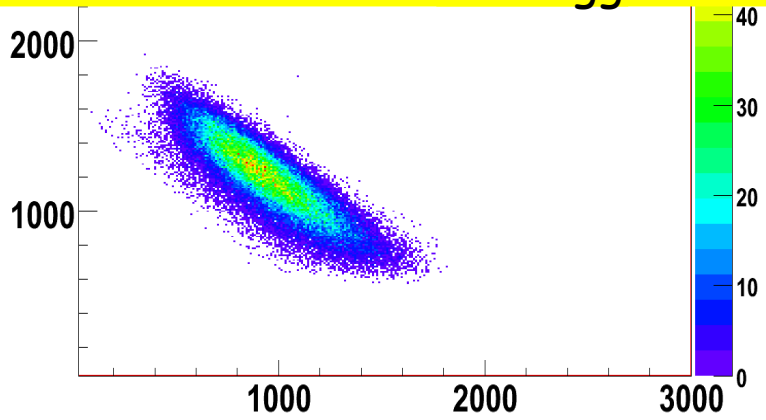


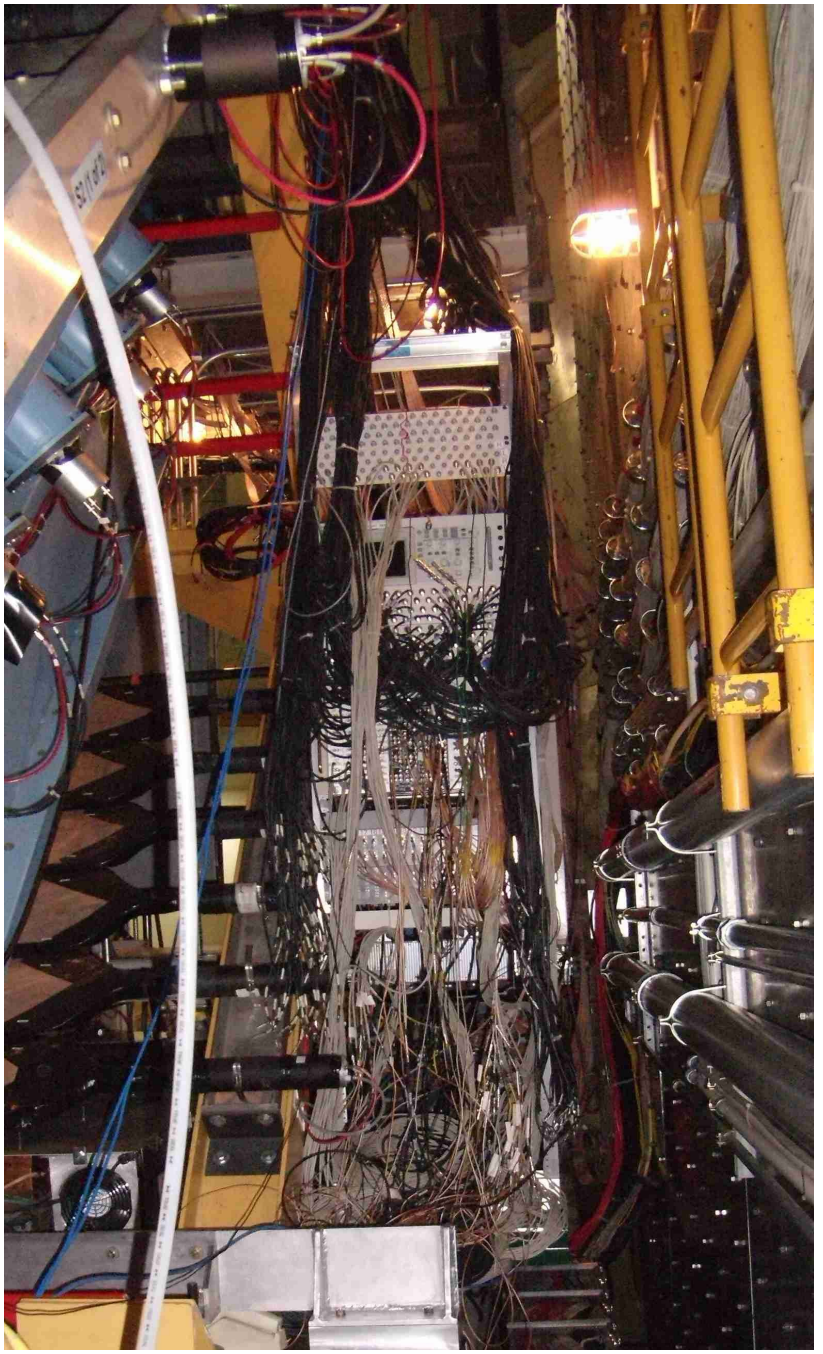


ADC spectrum from regular DAQ, with PVDIS electron trigger



X. Zheng, talk at PAVI11, Rome, Italy

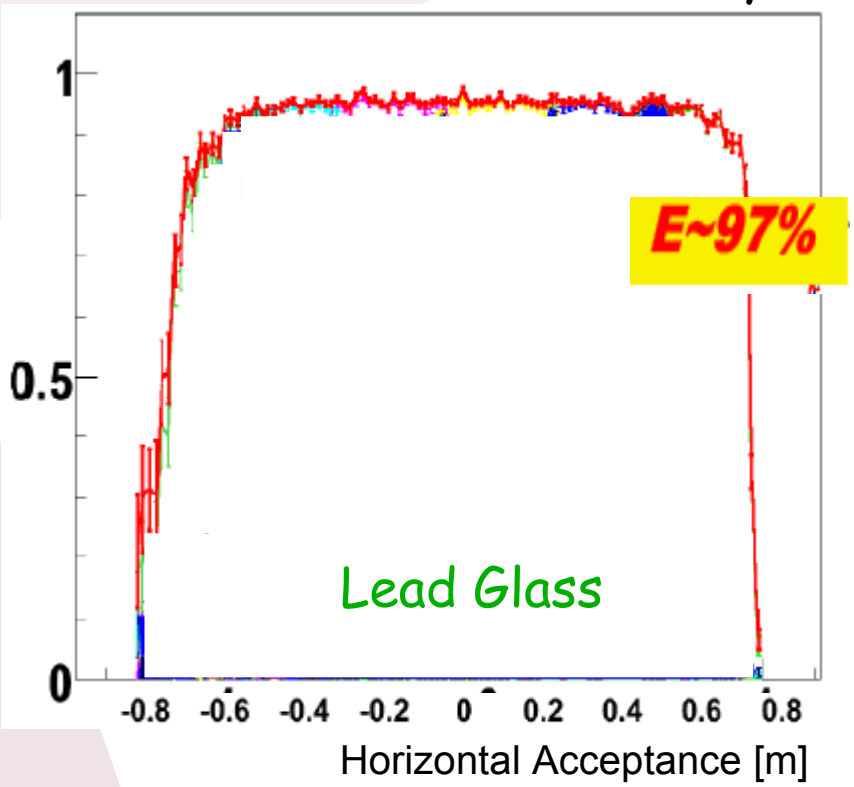
Online (Hardware) PID Scaler Based Counting DAQ



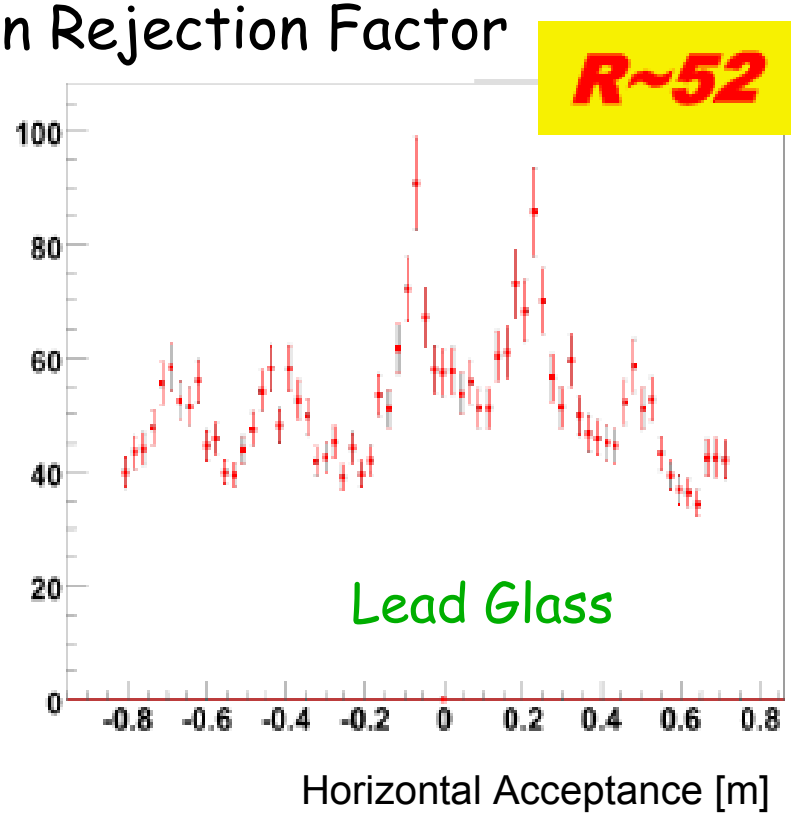
PID Performance

(PID analysis done by Kai Pan)

Electron Detection Efficiency



Pion Rejection Factor



	Lead Glass	Gas Cherenkov	Overall
Electron Efficiency	97%	96%	95%
Pion Rejection Factor	52	200	1e4

Asymmetry correction due to **electron efficiency <(<) 0.5%**
pion contamination <0.1%

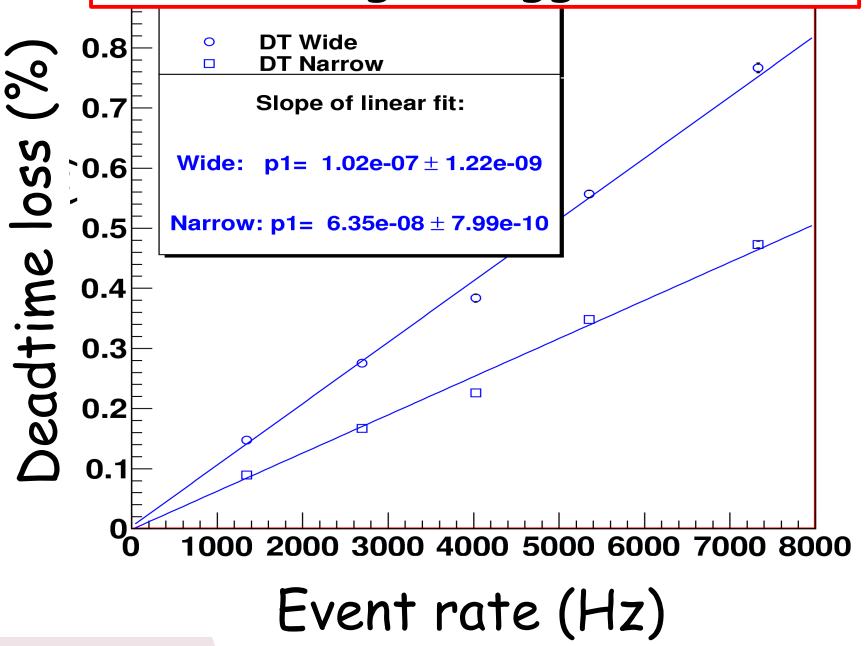
Deadtime Correction (done by Diancheng Wang)

Deadtime correction to asymmetry: $A_{measured} = A_{phys}$ (1 – deadtime loss)

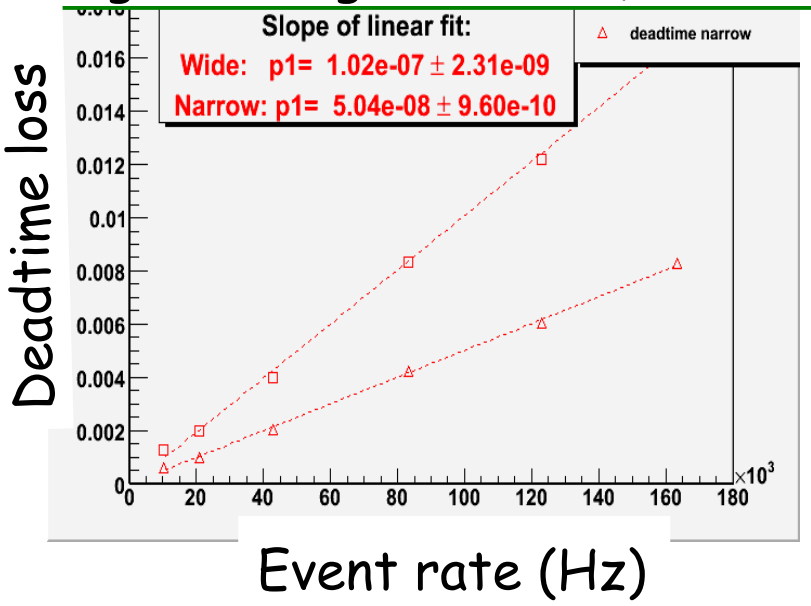
Methods to study Deadtime:

- FADC data: direct way to study deadtime, but low statistics.
- Tagger method: use a tagger signal to mimic physics signal.
- Software simulation: simulating all the signals and electronics ("HATS").

Left HRS gr3 tagger data



Right HRS gr4 HATS (simulation)



Deadtime corrections to asymmetry is: ~3% +/- 0.6% (Q^2=1.1)

~1% +/- 0.2% (Q^2=1.9)

X.

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- Software simulation: simulating all the signals and electronics ("HATS").

HATS (Hall A Timing Simulation, developed by Diancheng Wang):
Very generic, easy to adopt, available for all collaborators.

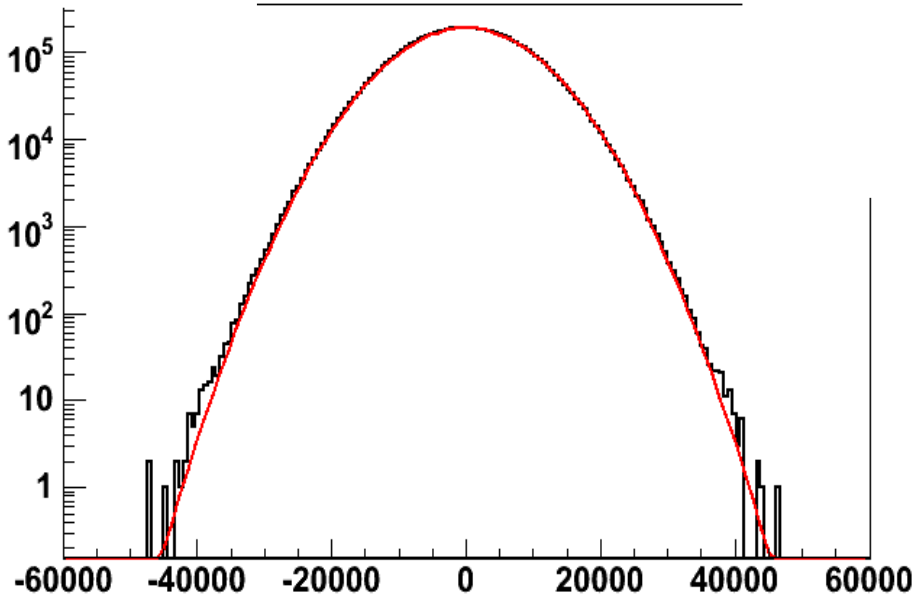
Asymmetry Analysis

done in parallel by Diancheng Wang (completed), and Kai Pan (on-going)

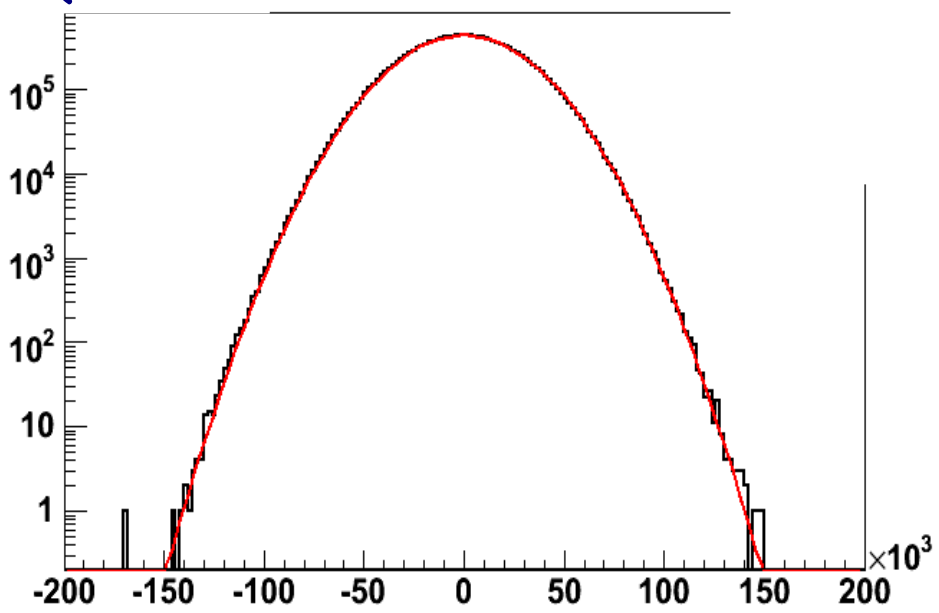
Same methods as in HAPPEX-III and PREX, but beam regression/dithering corrections much smaller (relatively).

Statistical quality of data (blinded pair-wise asymmetry):

Q^2=1.1



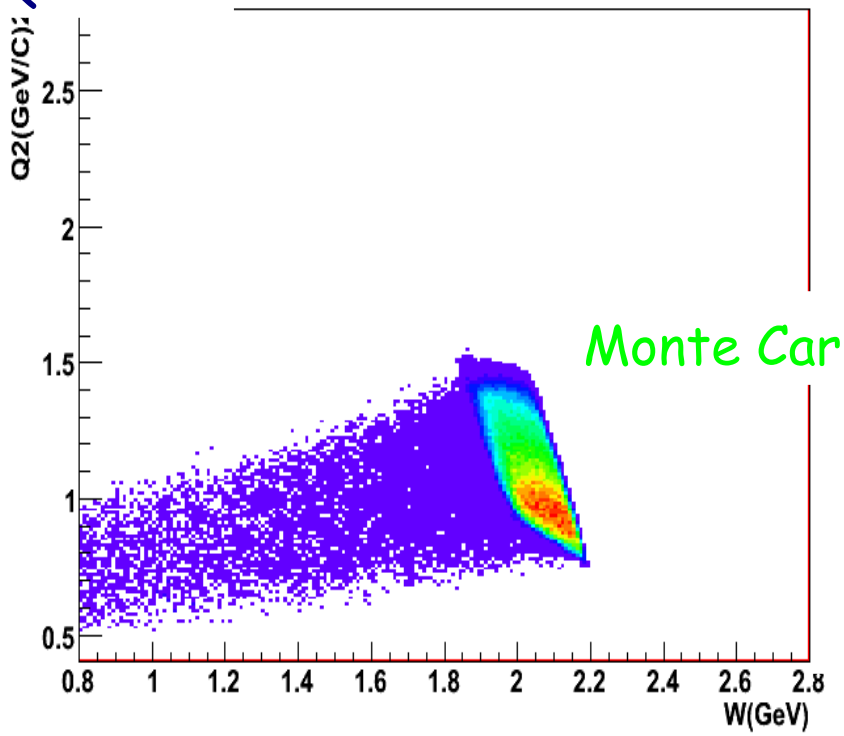
Q^2=1.9



EM Radiative Corrections

being performed by Diancheng Wang

Q^2=1.1



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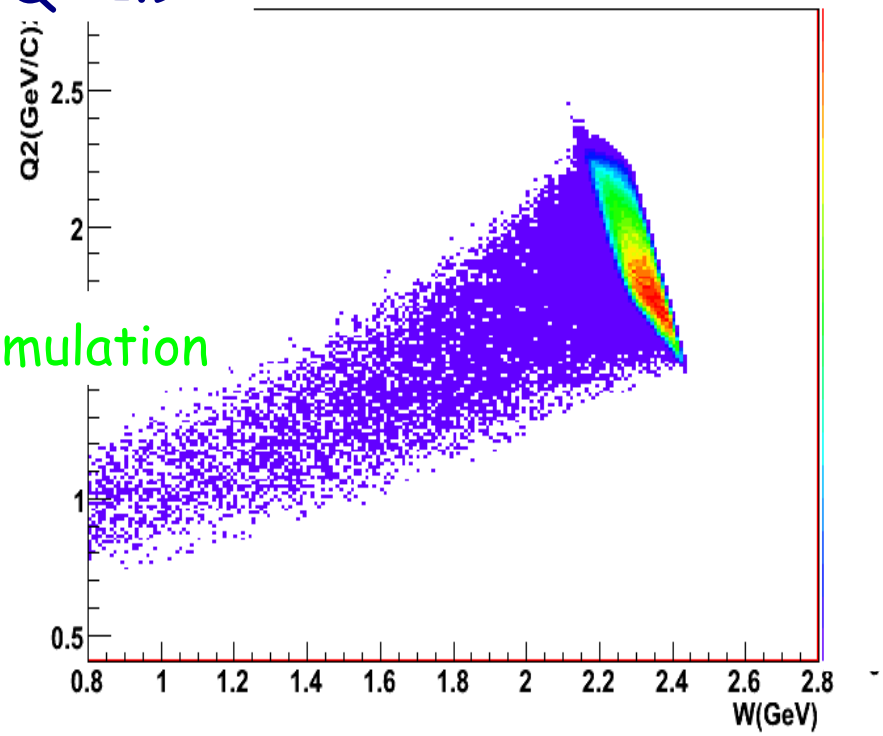


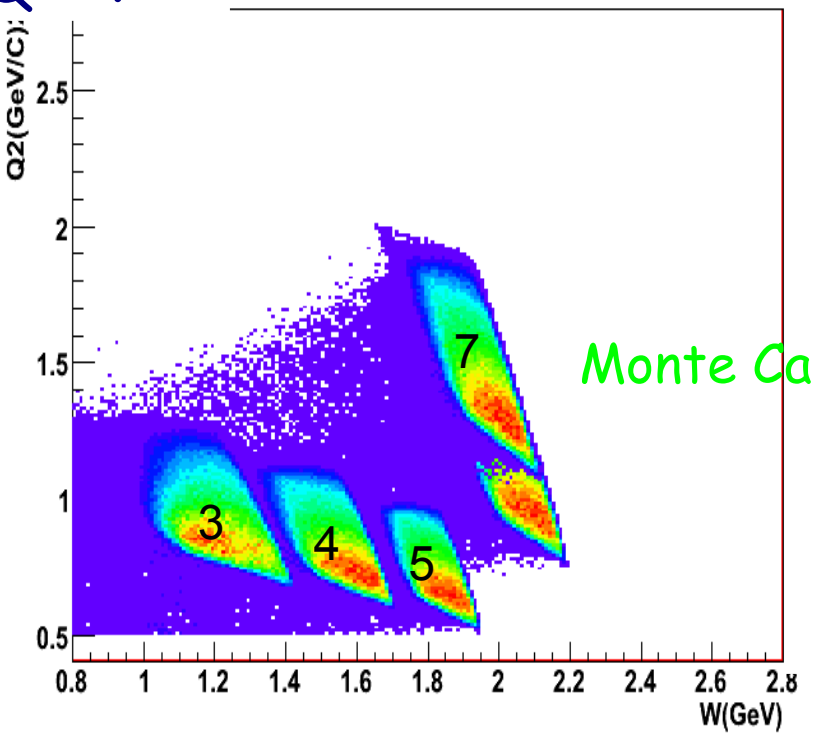
Monte Carlo Simulation

- Resonance events contribute to 15 %?
- Calculations for PV asymmetry in the resonance region are difficult, and have not been proven by data (only G0 had limited data – 15%? – in the Delta region)

EM Radiative Corrections

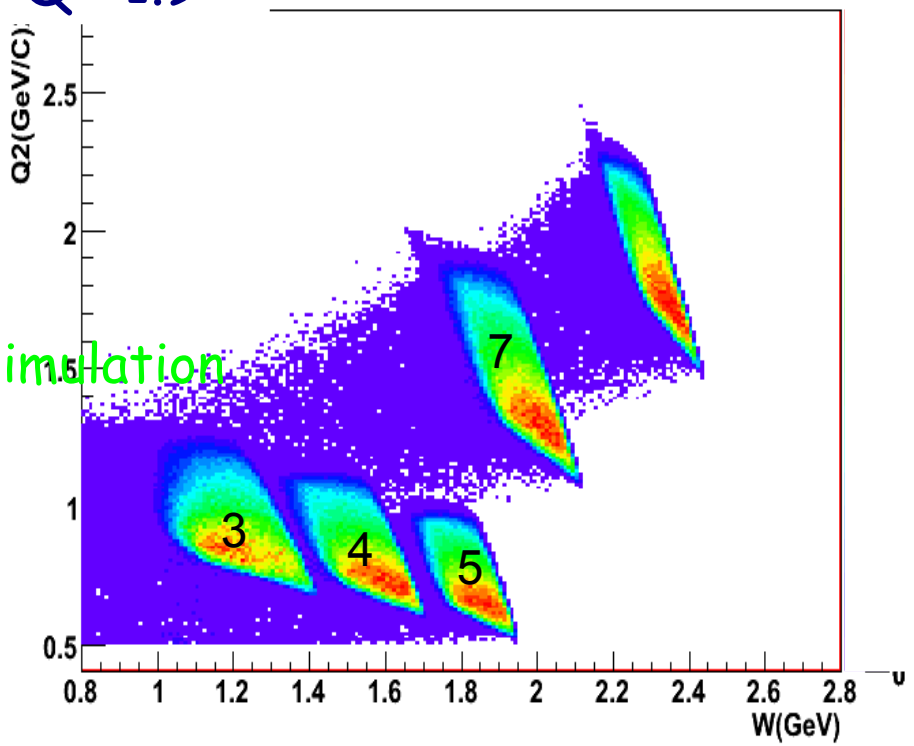
being performed by Diancheng Wang

Q^2=1.1



Monte Carlo Simulation

Q^2=1.9



- Measured resonance PV asymmetries (10-15% stat.)
- Calculations of RES asymmetries being performed by 3 theory groups
- "Toy" models using unpolarized F^{γ}_1(res)/F^{γ}_1(DIS), implying duality (or not)
- Goal: control systematic error due to Radiative corrections to below 1%

EM Radiative Corrections

being performed by Diancheng Wang

Three theory calculations (cover all kinematic area needed by Rad.Corr):

Lee/Sato: Delta(1232)

- Current: D=n+p
- On-going: with wavefunctions – will be available for publication

M. Gorshteyn (Indiana)

- whole resonance
- isospin rotation p -> n

Stan Brodsky (meeting on hadronic physics in Weihai, China, Aug2011)

- whole resonance
- need to find manpower to do it

From our side, machinery to incorporate these calculations into the simulation are ready, but need thorough checks. May need iterations (as requested by theorists).

Error Budget

	Source \ $\Delta A_d/A_d$	Q^2=1.1 GeV^2	Q^2=1.9 GeV^2
ΔA_d	$\Delta P_b/P_b$	2.0%	2.0%
	Radiative Correction	1.0%	1.0%
	Q^2	0.7%	0.6%
	Deadtime correction	0.6%	0.2%
	Target endcap contamination	0.4%	0.4%
	Transverse Asymmetry	0.2%	0.4%
	PID efficiency	0.2%	0.2%
	False Asymmetry	0.2%	0.2%
	Systematics	2.48%	2.41%
	Statistical	3.00%	4.00%
	Total	3.89%	4.67%
$\Delta(2C_{2u}-C_{2d})$	Source \ $\Delta(2C_{2u}-C_{2d})$		
	A_d	0.0735	0.0565
	Parton distribution functions	0.0071	0.0031
	Electro-weak rad. cor.	0.0038	0.0024
	Higher Twist (using F_3^ν data)	-0.021±0.004	-0.010±0.002
	CSV (MRST nominal)	0.0054	0.0031
	CSV (MRST 90% C.L.)	0.0132	0.0085
	Total uncertainty	0.0739	0.0566

likely to be (slightly) smaller

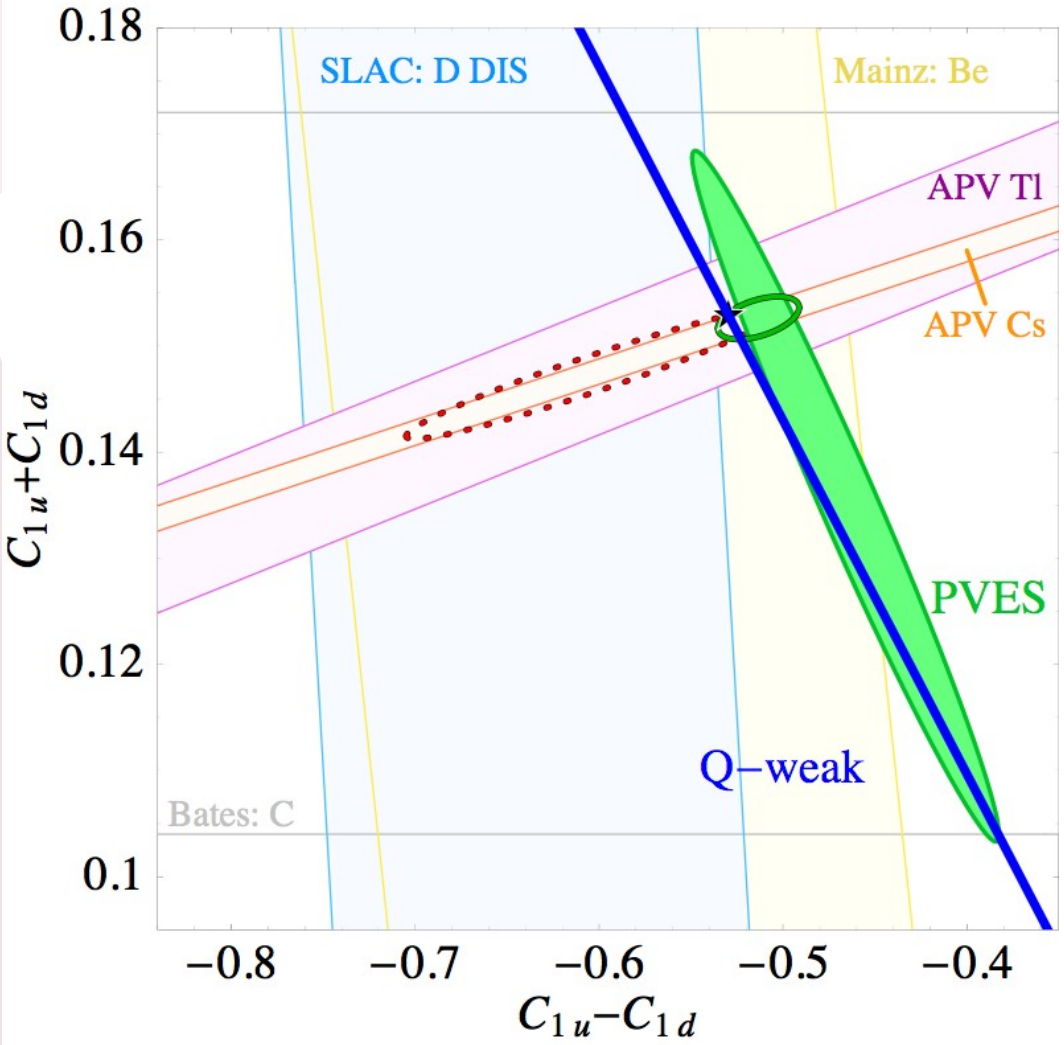
not included below

X. Zheng, talk at PAVI11, Rome, Italy

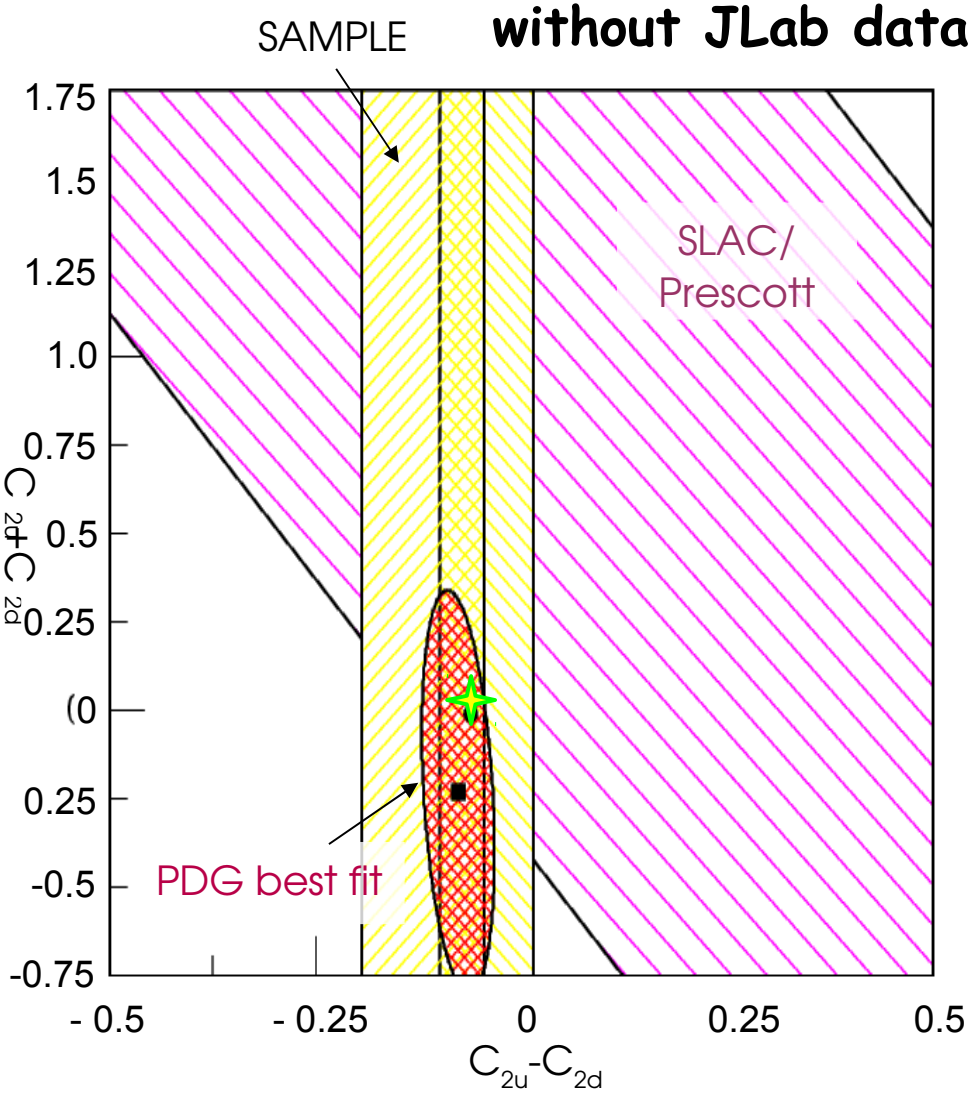
Quark Weak Neutral Couplings $C_{1,2q}$

all are 1 σ limit

with recent PVES data and Qweak



without JLab data



X. Zheng, talk at PAVI11, Rome, Italy

Quark Weak Neutral Couplings $C_{1,2q}$

all are 1 σ limit

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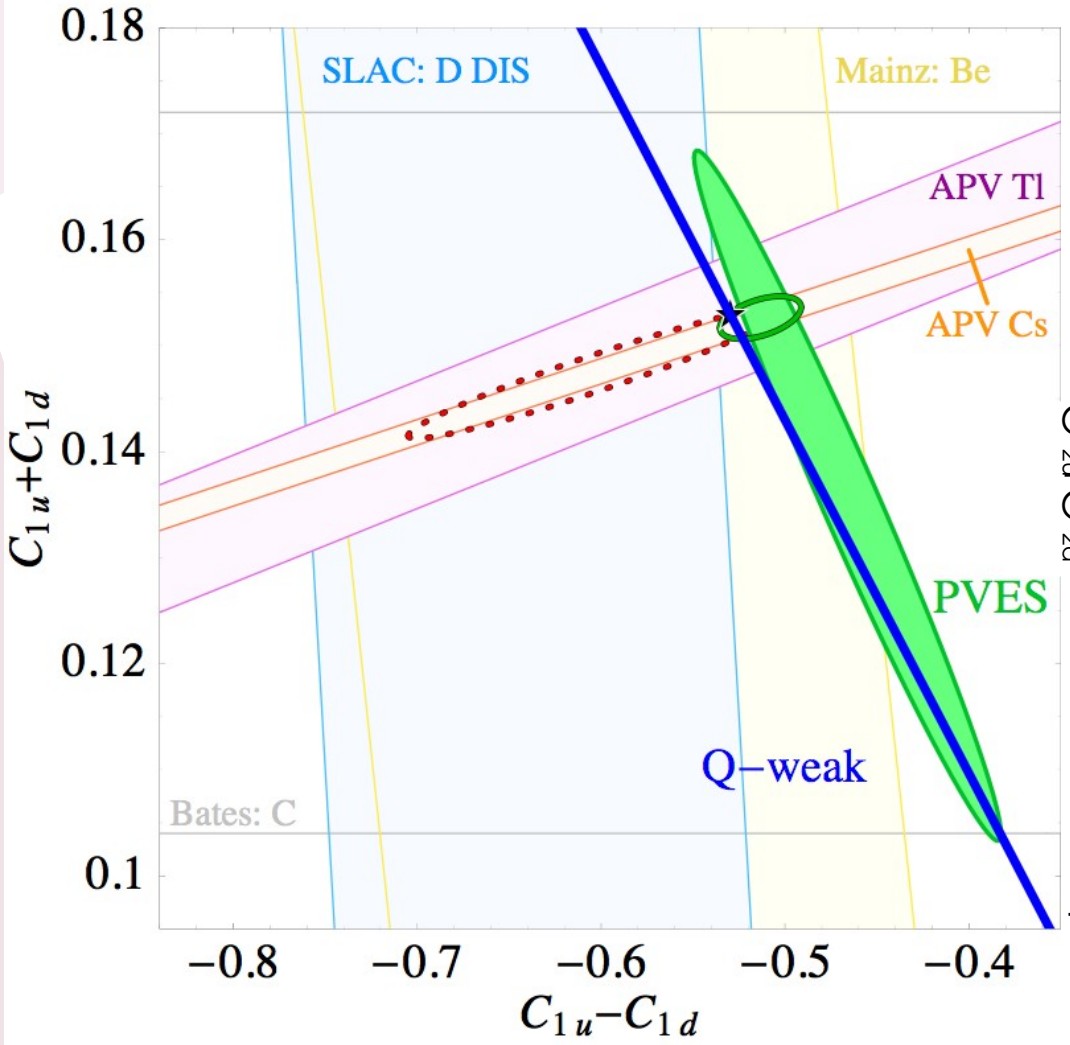
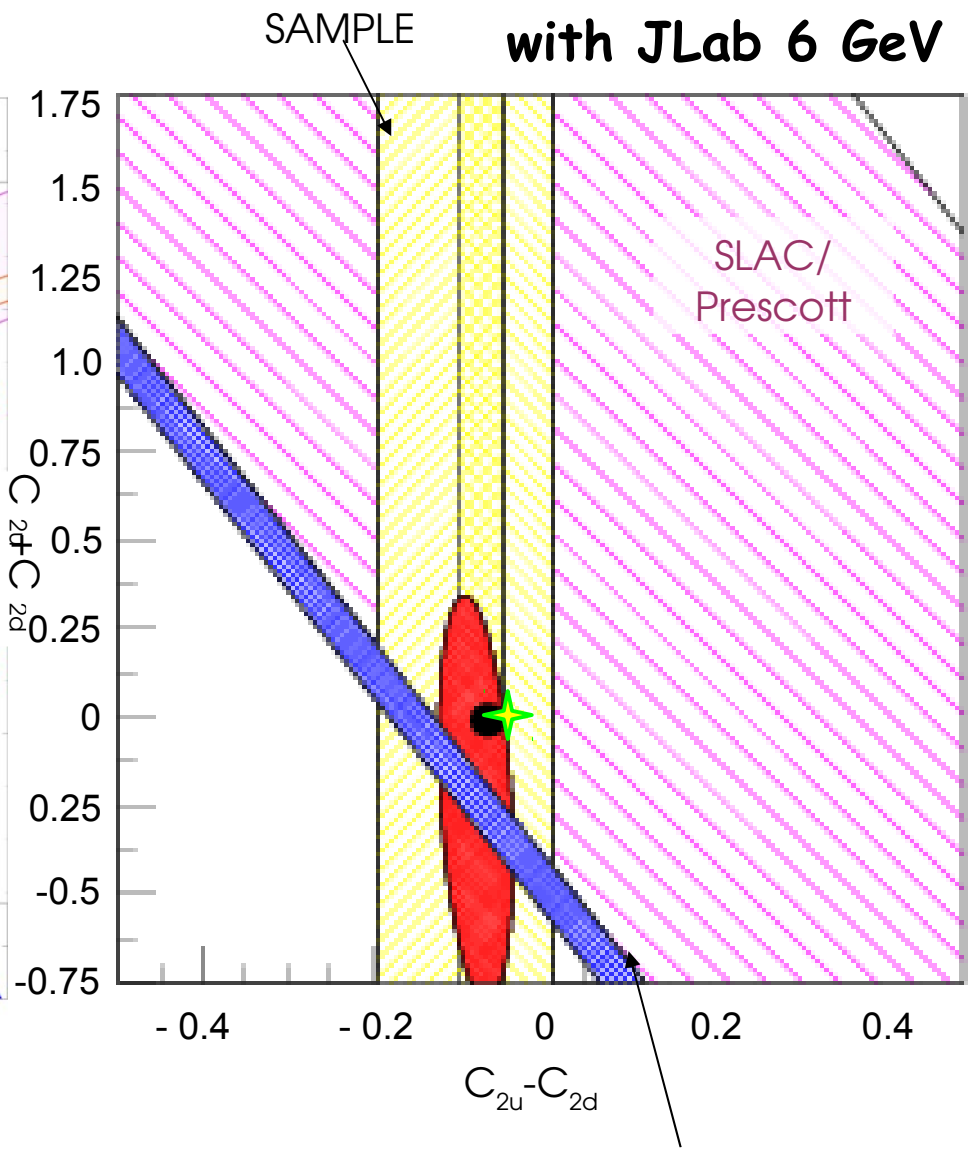


with JLab 6 GeV



PVDIS in Hall A (Oct-Dec 2009): potential to improve C_{2q} knowledge if hadronic effects are small.

X. Zheng, talk at PAVI11, Rome, Italy

Summary and Perspectives

- PVDIS is sensitive to the quark neutral weak coupling C_{2q} and the structure of the nucleon
- A PVDIS experiment using the 6 GeV beam was completed in 2009, analysis near final
- Radiative corrections are taking longer than expected, but is very worth the effort:
  - control of systematics of the final analysis
  - deserve a separate publication
  - reliable information for other experiments
- Also serves as an exploratory step for the 11 GeV PVDIS program – see P. Reimer's talk