Research Committee Review

Parity Violating Deep Inelastic Scattering at JLab 6GeV

Diancheng Wang

- DIS Asymmetry Results and Extraction of C_{2q}
- Asymmetry Results in the Resonance Region
- Technical Report: A Scaler based Counting DAQ
- Summary of Status and Plan

Jefferson Lab

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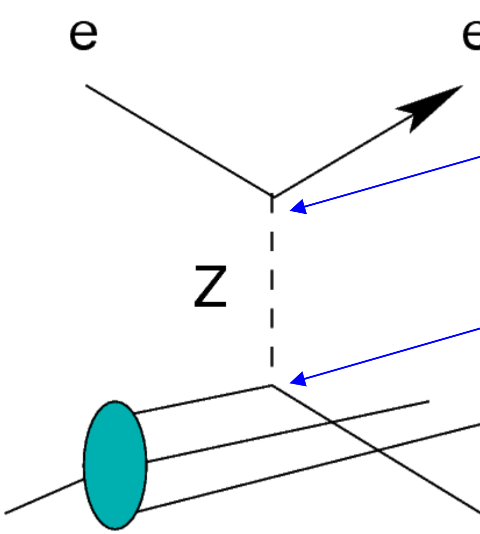
Physics



$$J^{NC}_\mu(e) = (\bar{u}_e \gamma_\mu \frac{1}{2}(g_V^e - g_A^e \gamma^5) u_e)$$

$$J^{NC}_\mu(q) = (\bar{u}_q \gamma_\mu \frac{1}{2}(g_V^q - g_A^q \gamma^5) u_q)$$

fermions	$g_A^f = I_3$	$g_V^f = I_3 - 2Q\sin^2\theta_W$
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
$e-, \mu-$	$-\frac{1}{2}$	$-\frac{1}{2} + 2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W$

$$L_{NC}^{electronscatt} = \sum [g_A^e g_V^q \bar{l} \gamma^\mu \gamma_5 l \bar{q} \gamma_\mu q + g_V^e g_A^q \bar{l} \gamma^\mu l \bar{q} \gamma_\mu \gamma_5 q + g_A^e g_A^q \bar{l} \gamma^\mu \gamma_5 l \bar{q} \gamma_\mu \gamma_5 q]$$

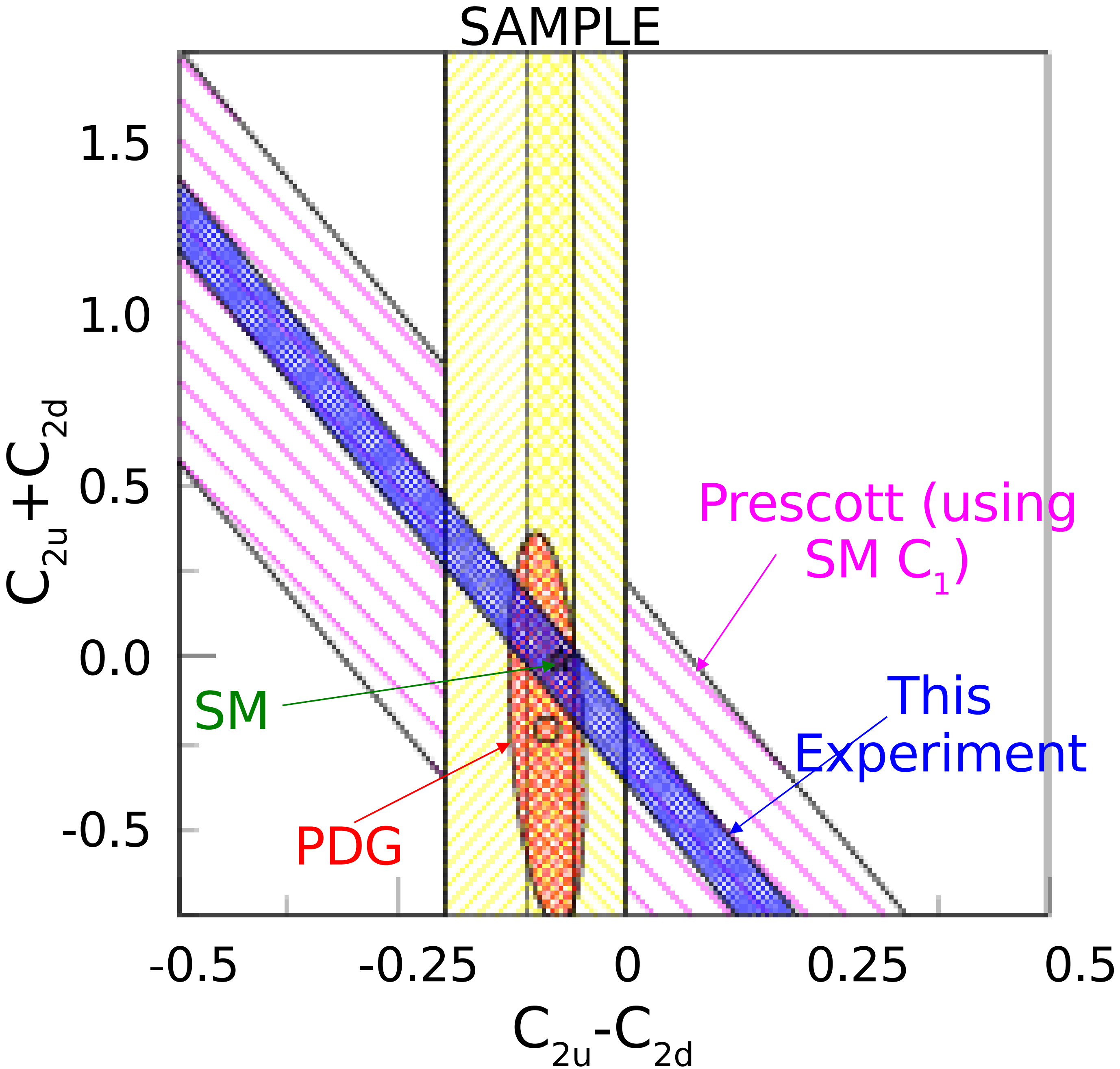
C_{1q} C_{2q} C_{3q}

parity-violating, cause different e_L, e_R cross sections

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

$$A_{PV}^D = \left(\frac{3 G_F Q^2}{2\sqrt{2}\pi\alpha}\right) \frac{2C_{1u}[1+R_C(x)] - C_{1d}[1+R_S(x)] + Y(2C_{2u} - C_{2d})R_V(x)}{5 + R_S(x) + 4R_C(x)}$$

C_{2q} from Q^2=1.9 GeV^2 Point

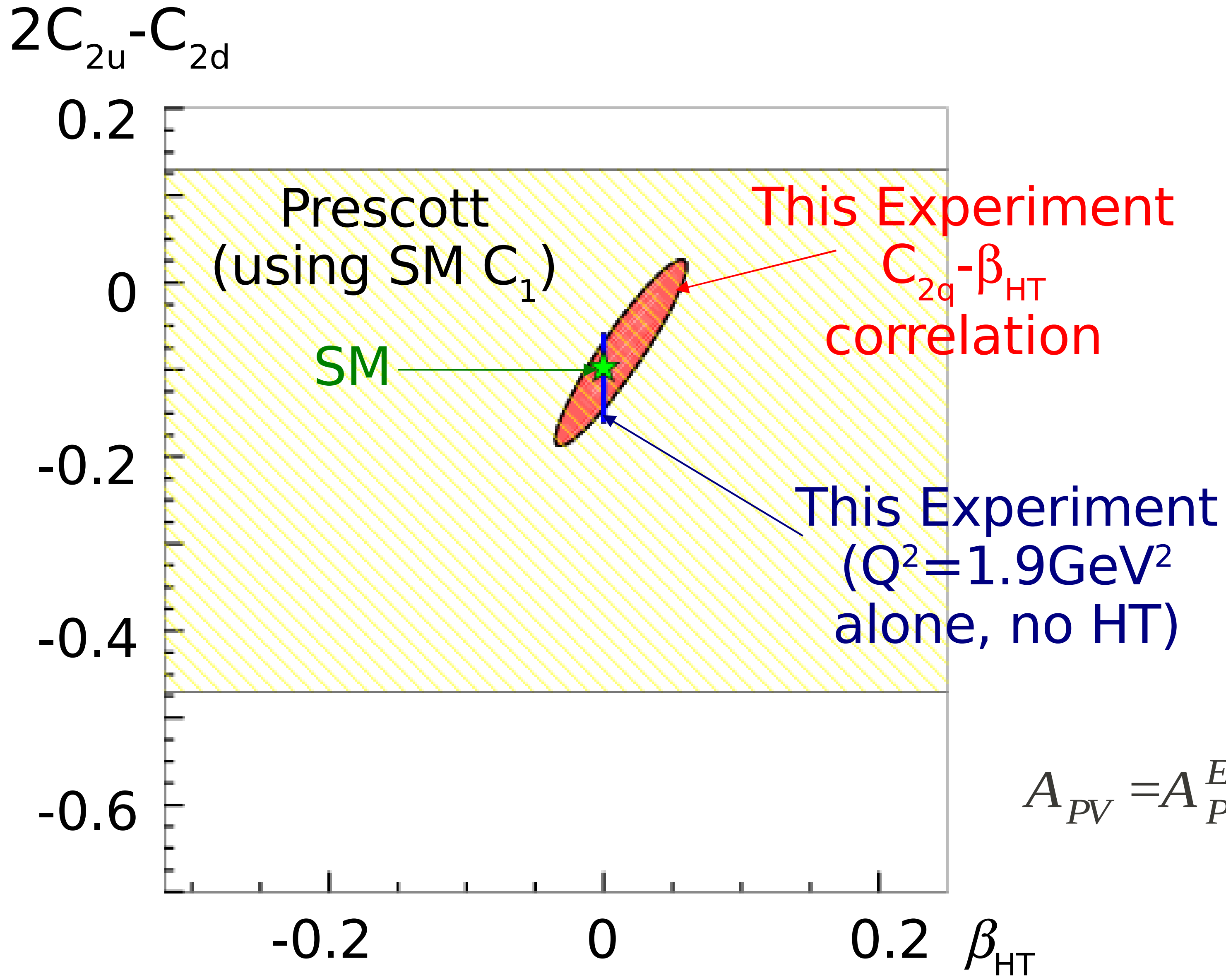


Assuming no HT

Preliminary
$\Delta(2C_{2u}-C_{2d})=0.052$
(expt. error only)

(compared to PDG
±0.24 → factor of
4.6153846)

C_{2q}- β_{HT} Correlation from Q^2=1.1 and 1.9 GeV^2 Combined



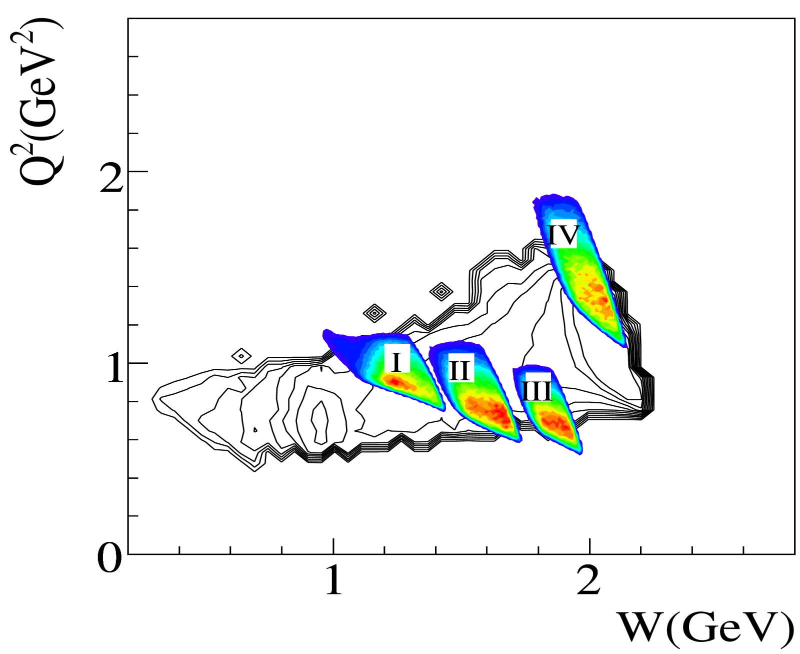
- No obvious Q^2 dependence (HT) at the 6 GeV precision.

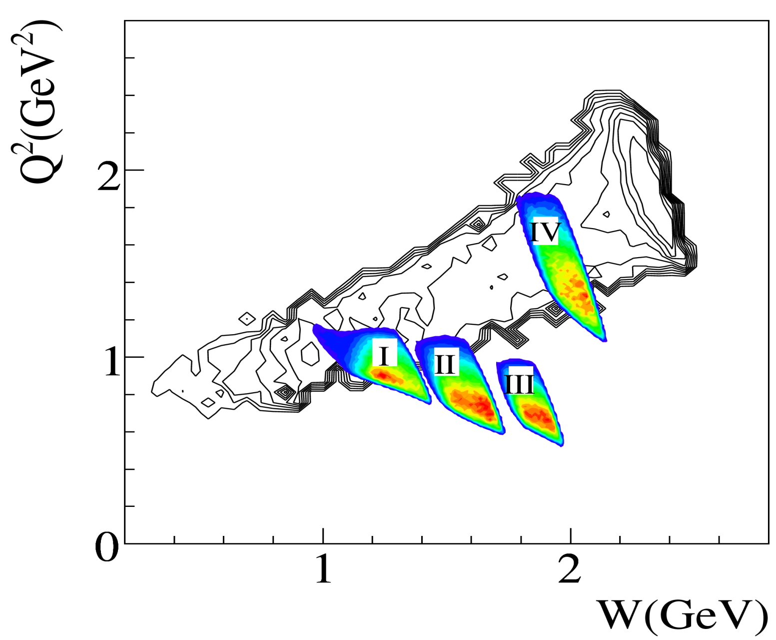
$$A_{PV} = A_{PV}^{EW}\left(1+\frac{\beta_{HT}}{(1-x)^3 Q^2}\right)$$

A_{pv} in the Resonance Region

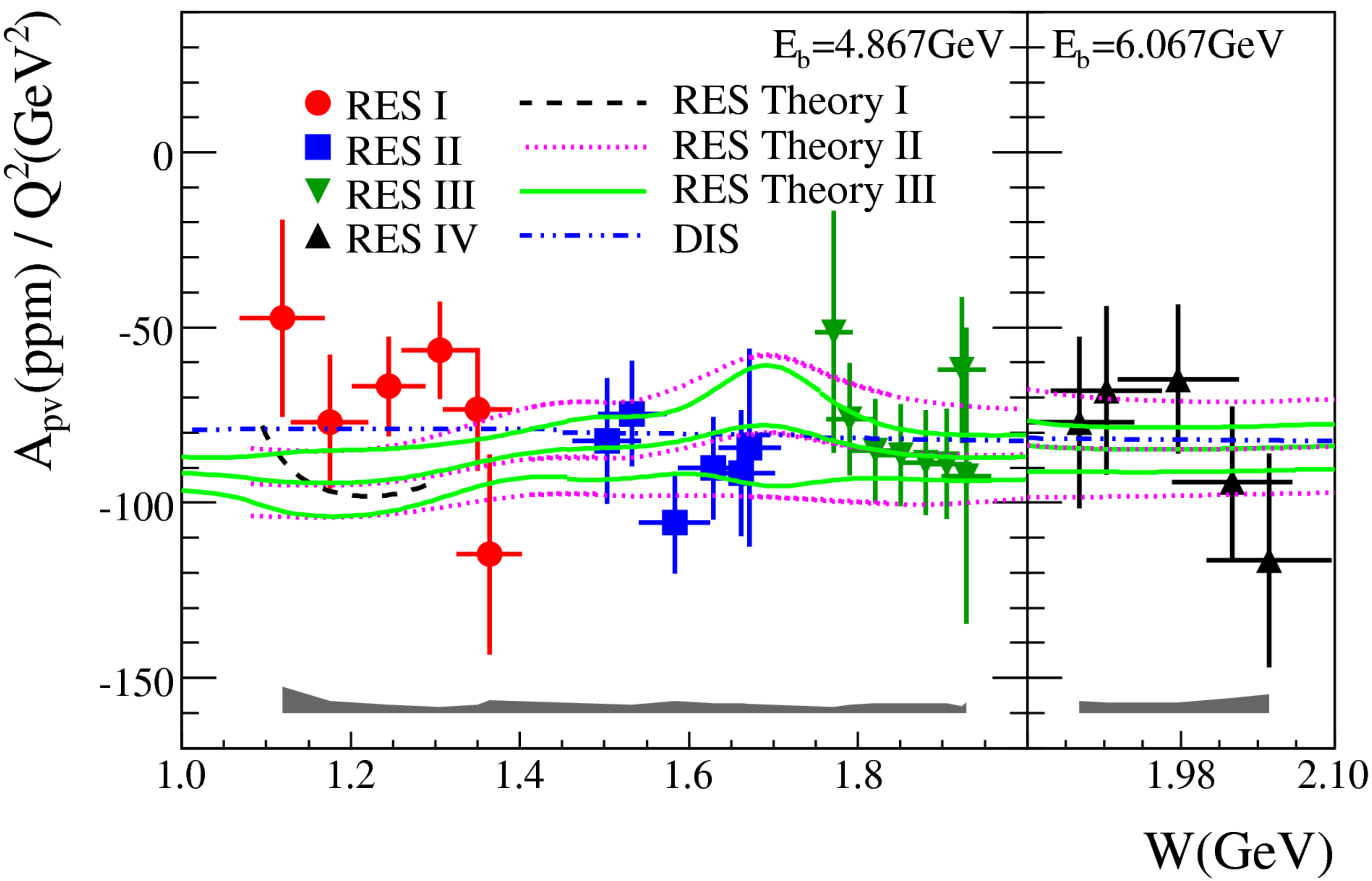
Motivation:

- Real Motivation: Radiative Correction for DIS
- After-the-Experiment Motivation:
  - Apv in the resonance region has never been measured (G0 Δ)
  - Provides inputs for calculating γZ box diagram corrections to elastic PVES
  - Check theoretical calculations
  - Quark-Hadron Duality





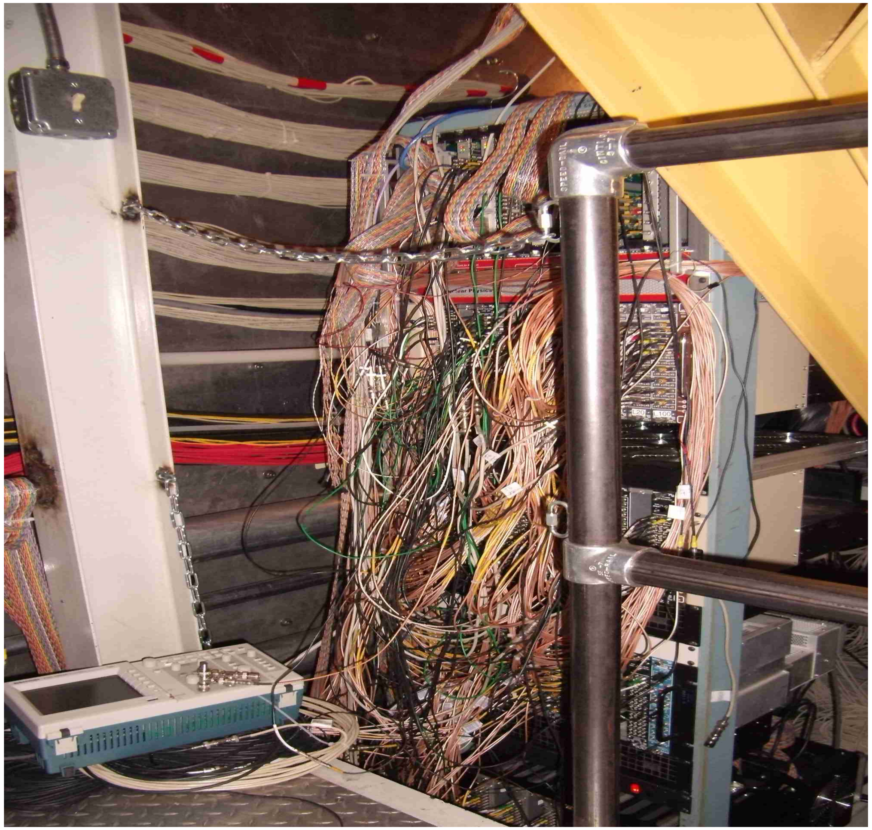
Resonance A_{pv} Results

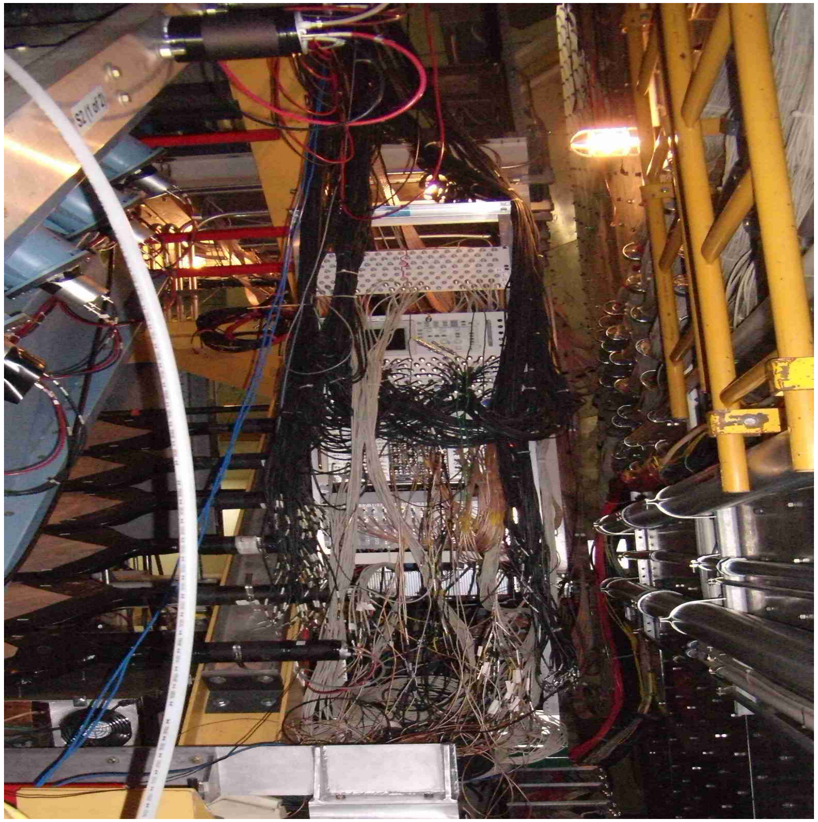


Theoretical Calculations:

I: T.-S.H. Lee et.al, Phys. Rev. C72, 025204
II: M. Gorchtein et.al, Phys. Rev. C84, 015502
III: N. Hall, W. Melnitchouk, private communication

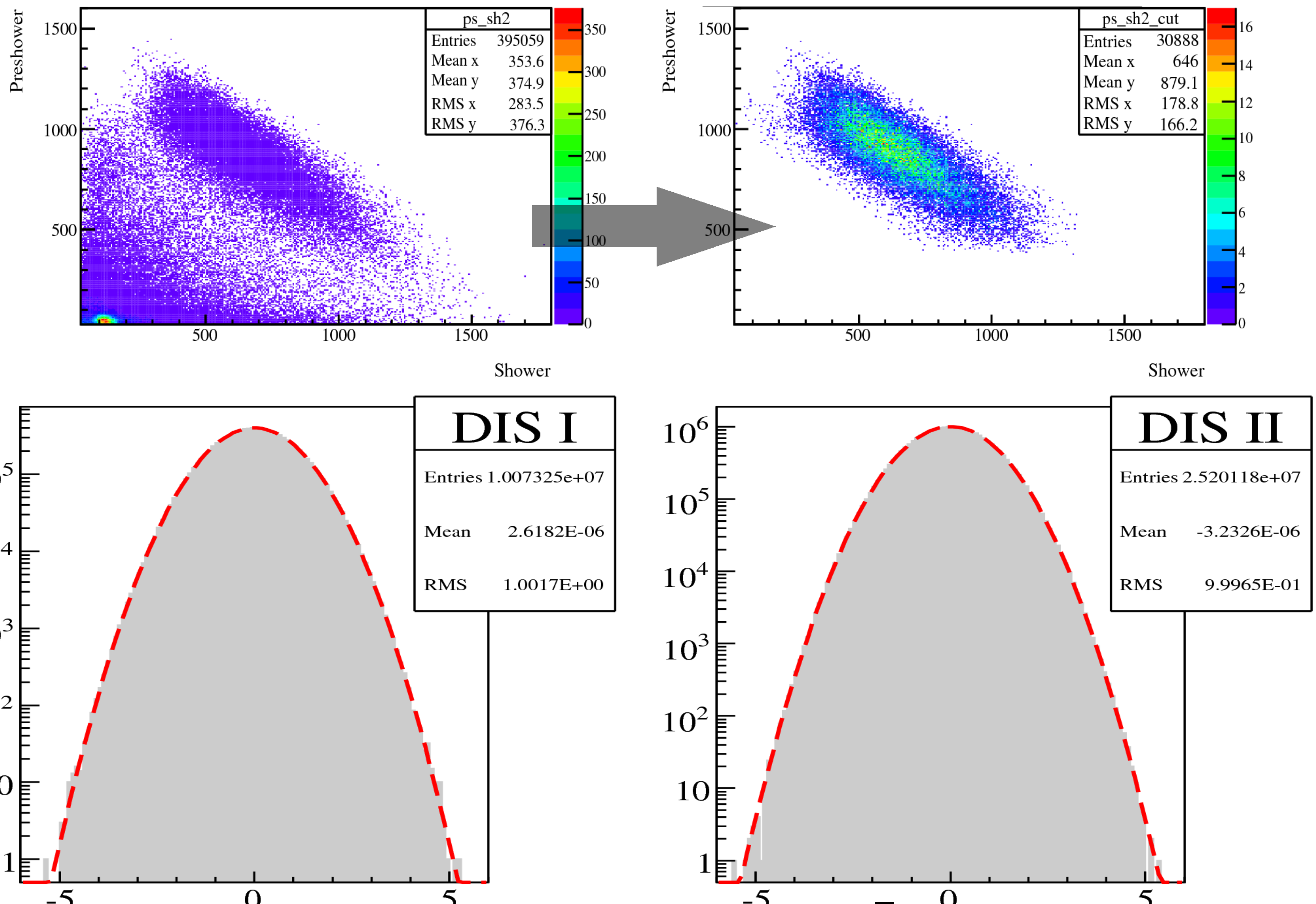
Online (Hardware) PID Scaler Based Counting DAQ





- DIS scattering, pions contaminate, integrating DAQ not an option.
- High event rate (~500KHz), FADC => huge amount of data, not an option.
- Systematics:
  - Deadtime: detailed study using simulation and diagnostic data.
  - PID Efficiency and Pion Rejection Factor: studied for each individual detectors

Online (Hardware) PID Scaler Based Counting DAQ



Pairwise Pull Plot $$\frac{A_i - \bar{A}}{\sigma_i}$$

Summary

- Papers:

  DIS results: 1 short + 1 long, under development
  Resonance results: completed, under circulation
  DAQ technical report: submitted to NIM, under review

- Conferences:

  GHP 2013, April, 2013, Denver, CO
  Gordon Conference, August, 2012, Holderness, NH
  CIPANP 2012, May, 2012, St. Petersburg, FL

- Thesis: Working on it...

Parity Violating Deep Inelastic Scattering at JLab 6GeV

Diancheng Wang (Univ. of Virginia)

GHP 2013, Denver

- Introduction of Physics
- Experiment Method and Systematic Uncertainties
- DIS Asymmetry Results and Extraction of C_{2q}
- Asymmetry Results in the Resonance Region

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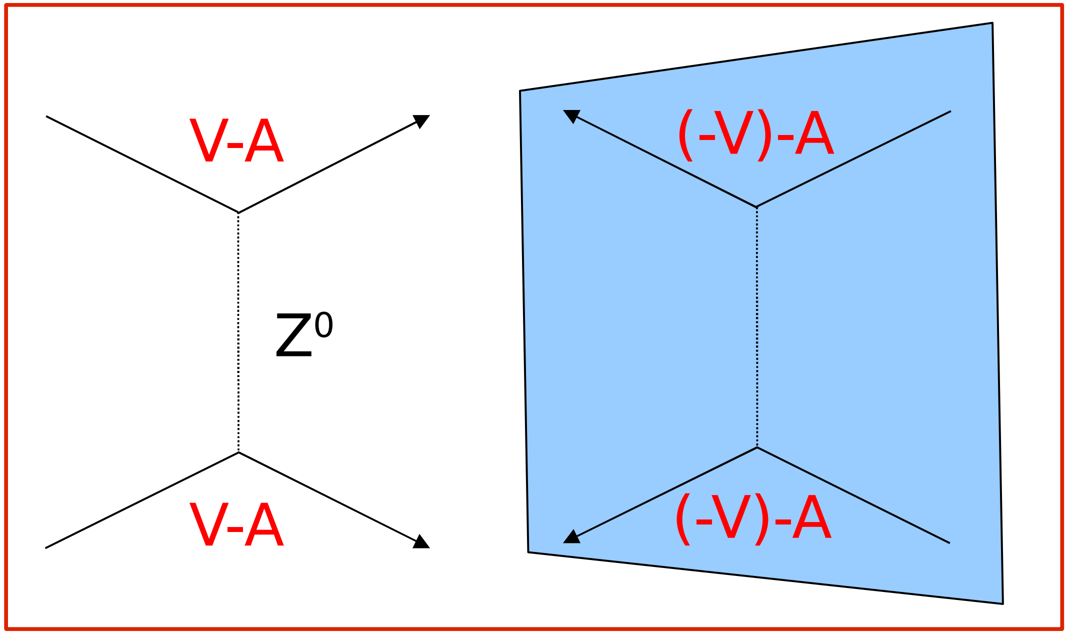
Signature of Weak Interaction (Z^0 Exchange) – Parity Violation Asymmetry Between L- and R-handed Electrons

In the Standard Model,

- Weak interaction current = V(vector) minus A(axial-vector)
- Parity violation is from the cross products V x A:

fermions	$g_A^f = I_3$	$g_V^f = I_3 - 2Q\sin^2\theta_W$
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
$e-, \mu-$	$-\frac{1}{2}$	$-\frac{1}{2} + 2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W$

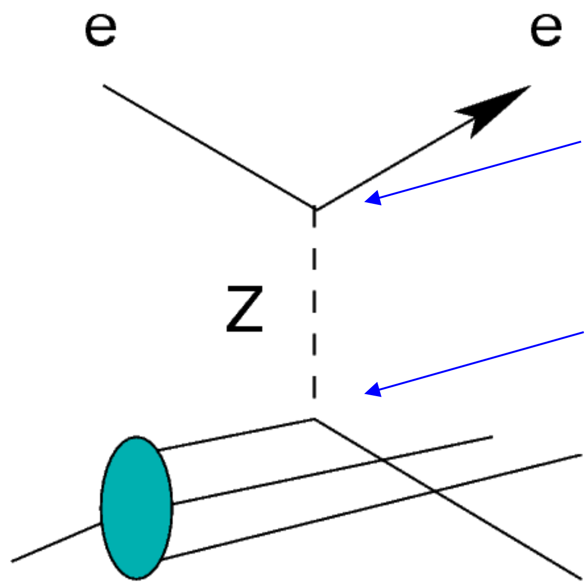
$$C_{1q} \equiv 2 g_A^e g_V^q$$
$$C_{2q} \equiv 2 g_V^e g_A^q$$



Parity Violating Electron Scattering

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

Longitudinally Polarized Electron Scattering off Unpolarized Fixed Targets



$$J_\mu^{NC}(e) = (\bar{u}_e \gamma_\mu \frac{1}{2}(g_V^e - g_A^e \gamma^5) u_e)$$

$$J_\mu^{NC}(q) = (\bar{u}_q \gamma_\mu \frac{1}{2}(g_V^q - g_A^q \gamma^5) u_q)$$

$$L_{NC}^{electronscatt} = \sum [g_A^e g_V^q \bar{l} \gamma^\mu \gamma_5 l \bar{q} \gamma_\mu q + g_V^e g_A^q \bar{l} \gamma^\mu l \bar{q} \gamma_\mu \gamma_5 q + g_A^e g_A^q \bar{l} \gamma^\mu \gamma_5 l \bar{q} \gamma_\mu \gamma_5 q]$$

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

Parity Violation in Deep Inelastic Scattering

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

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

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

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

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

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

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

$$A_{PV}^D = \left(\frac{3 G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\frac{2C_{1u}[1+R_C(x)] - C_{1d}[1+R_S(x)] + Y(2C_{2u} - C_{2d})R_V(x)}{5 + R_S(x) + 4R_C(x)}$$

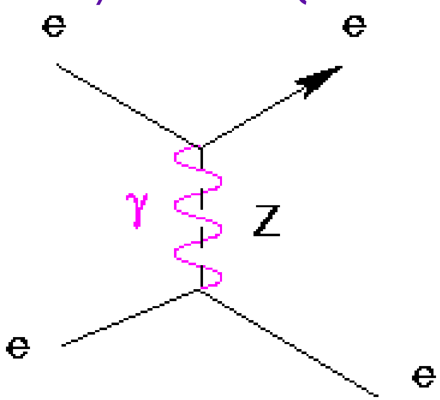
$$C_{1u} = 2g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \qquad C_{2u} = 2g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W)$$

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

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

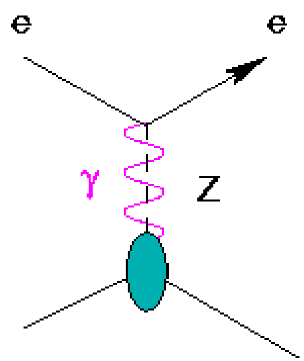
PVDIS and Other SM Test Experiments

- *E158/Moller (SLAC)*



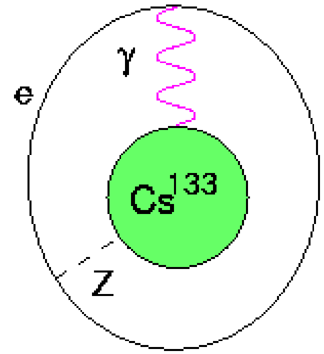
  - Purely leptonic

- *Qweak (JLab)*



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

- *Atomic PV*



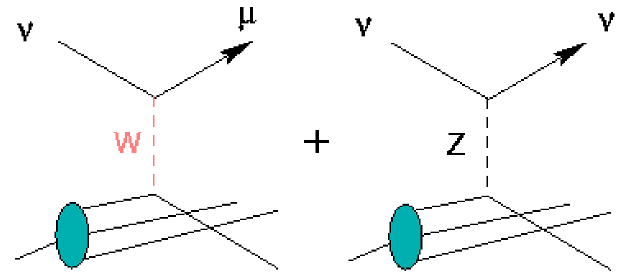
  - Coherent Quarks in the Nucleus
  - $-376C_{1u}-422C_{1d}$
  - Nuclear structure?

Different Experiments Probe Different Parts of Lagrangian,

PVDIS is the only one accessing C_{2q}

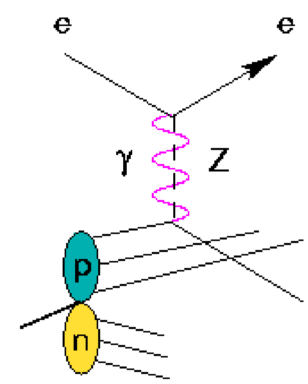
Cartoons borrowed from R. Arnold (UMass)

- *NuTeV (FNAL)*



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

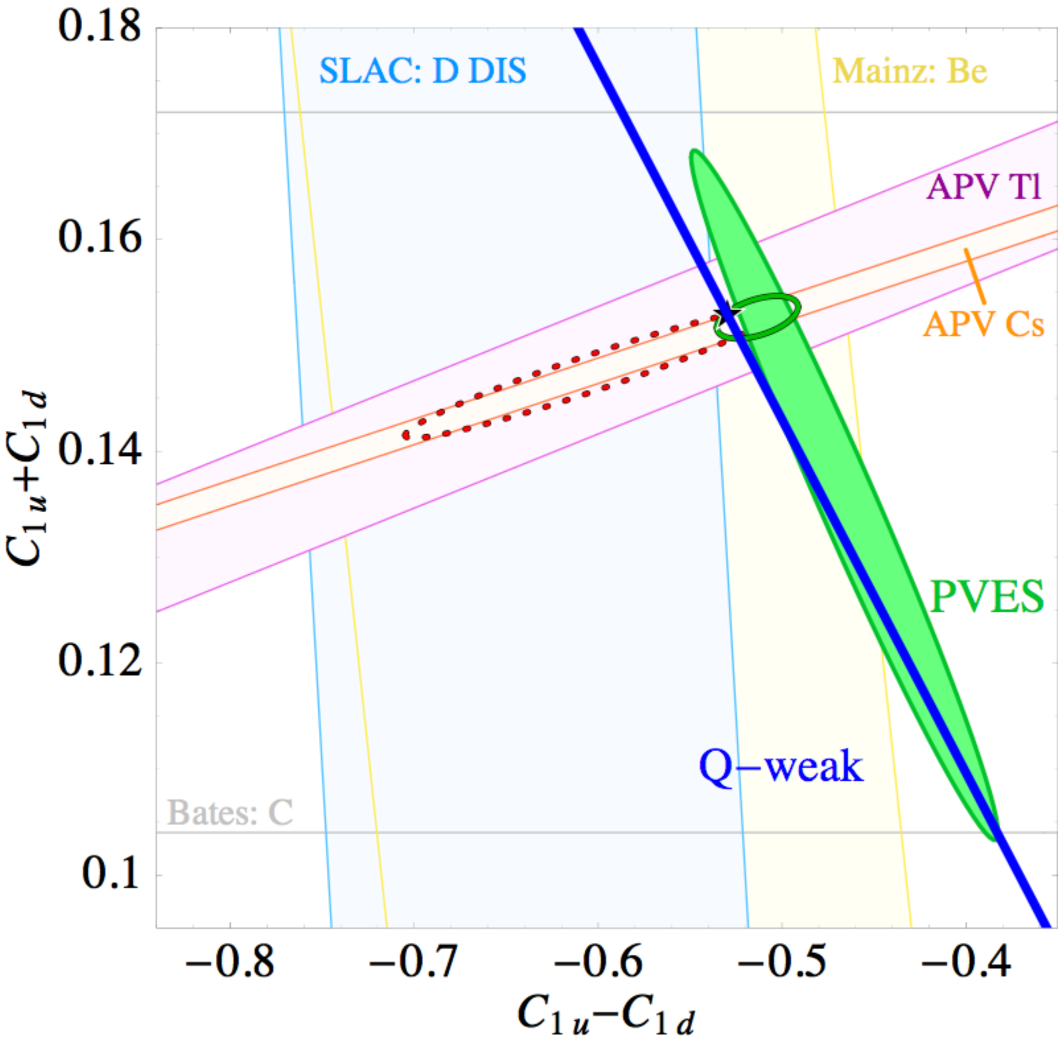
- *PVDIS (JLab)*

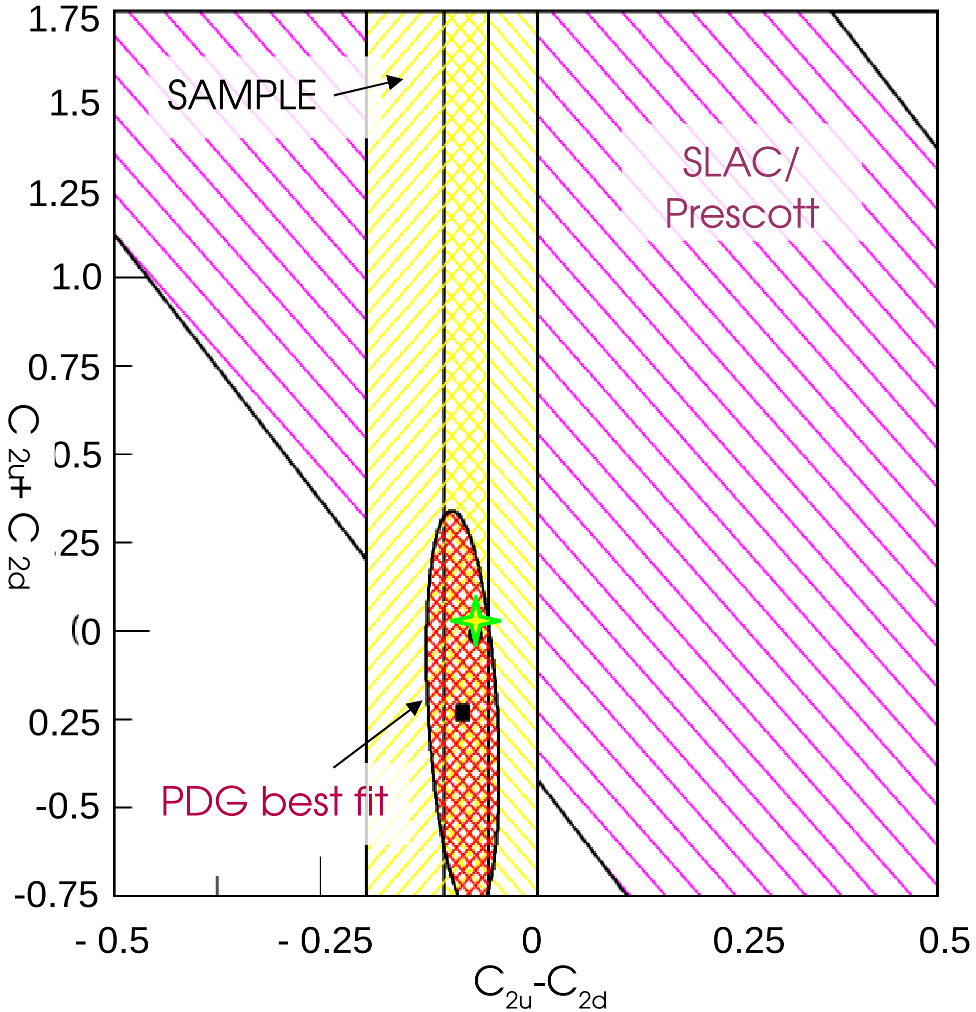


  - $(2C_{1u}-C_{1d})+Y(2C_{2u}-C_{2d})$
  - Isoscalar quark scattering

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

all are 1 σ limit

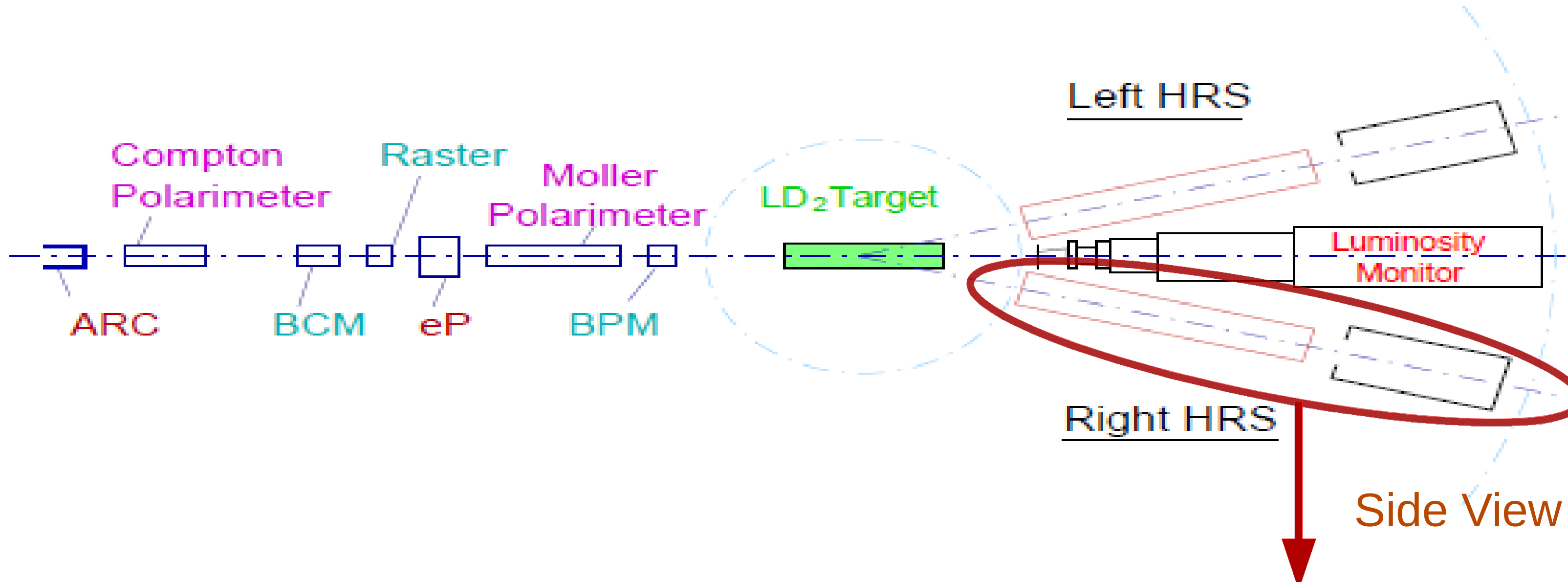




SLAC E122 vs. JLab E08-011

	SLAC E122 (1978)	JLab E08-011 (2009)
Beam	37%, 16.2-22.2 GeV	90%, 6.0674 GeV,100uA
Target	30-cm LD2, LH2	20-cm LD2
Spectrometer	4^o	12.9^o and 20^o
Q^2	1-1.9 GeV^2	1.1 and 1.9 GeV^2
Data Collection	Integrating gas Cerenkov and lead glass detectors, independently	Counting DAQ using both GC and lead glass for PID at the hardware level
Deuteron results $\sin^2\theta_W=0.20\pm0.03$	(two highest energies only) $A/Q^2=(-9.5\pm1.6)\times10^{-5}\ (GeV/c)^{-2}$ $\pm0.86\times10^{-5}$(stat)$\pm$5%(Pb) $\pm$3.3%(beam) $\pm$2%(pion contamination) $\pm$3%(radiative corrections)	$\pm$(3-4)%(stat) $\pm$syst.
Proton results	$A/Q^2=(-9.7\pm2.7)\times10^{-5}\ (GeV/c)^{-2}$	

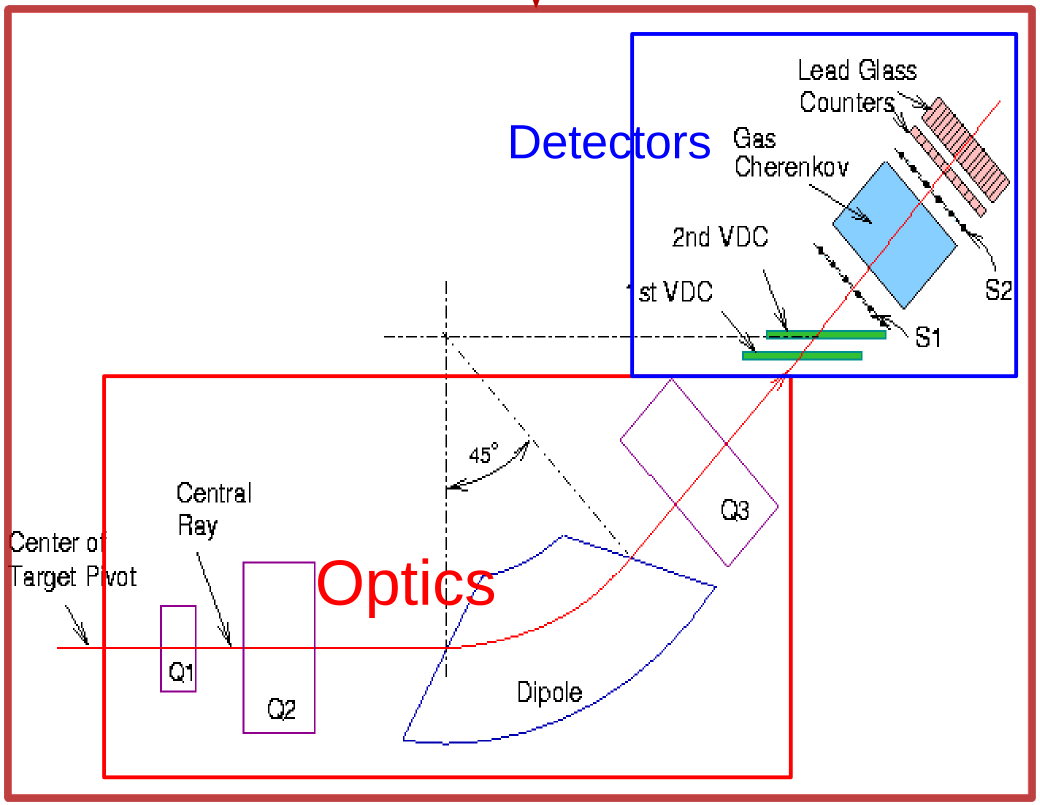
JLab Hall A Experimental Setup



- High Resolution Spectrometer (HRS)
- Beam Energy 6.067 GeV
- 20 cm long liquid deuterium (LD_2) target
- 100 uA polarized beam with 90% beam polarization
- Two DIS kinematics

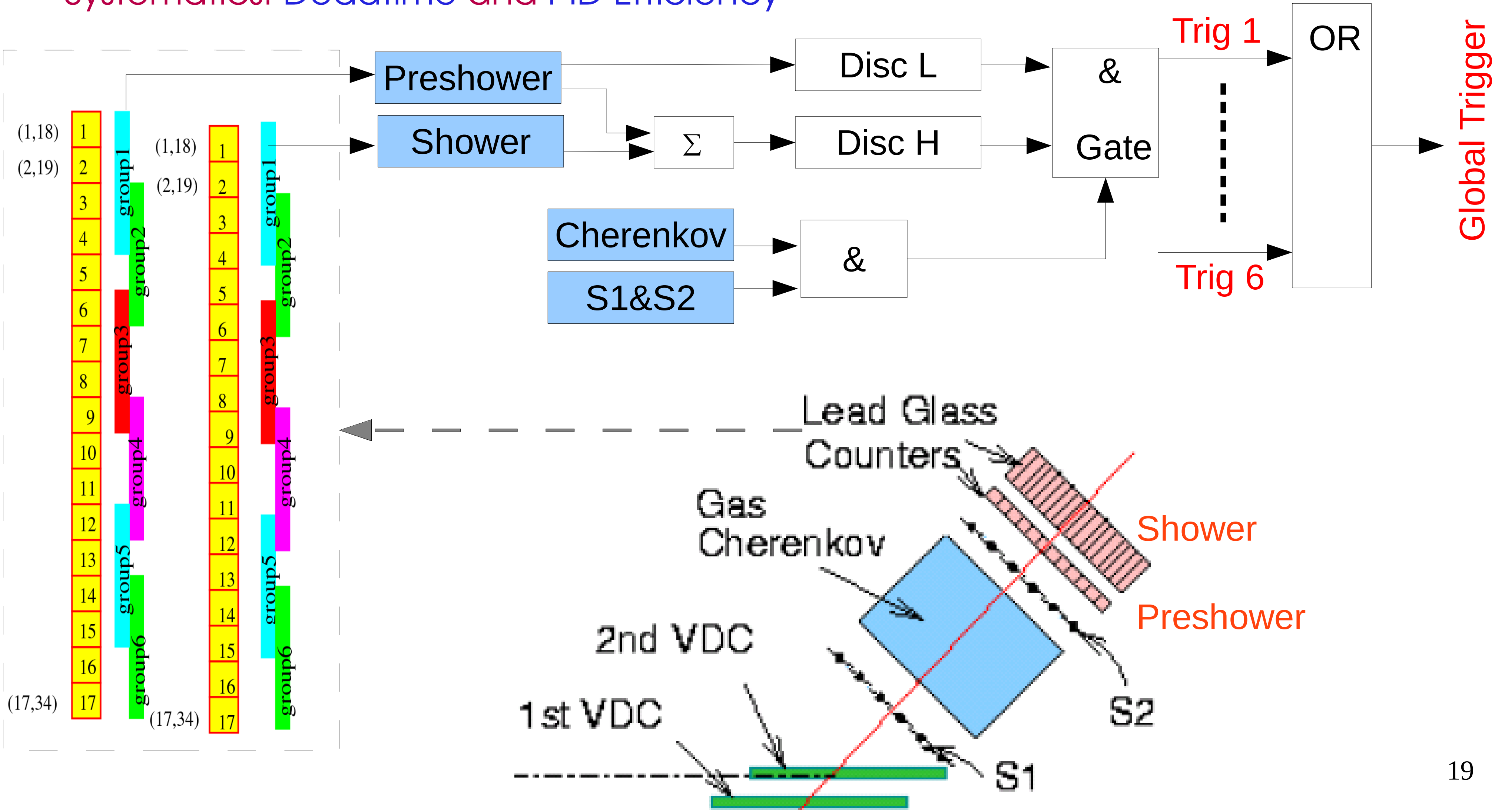
  #1: Q^2=1.1$(GeV)^2$; xbj= 0.24; 12.90°

  #2: Q^2=1.9$(GeV)^2$; xbj= 0.30; 20.00°
- Four Resonance kinematics



Online (Hardware) Particle Identification
Scaler Based Counting DAQ

- DIS region, pions contaminate, can't use integrating DAQ.
- High event rate (~500KHz), exceeds Hall A regular DAQ's Limit.
- Systematics: Deadtime and PID Efficiency



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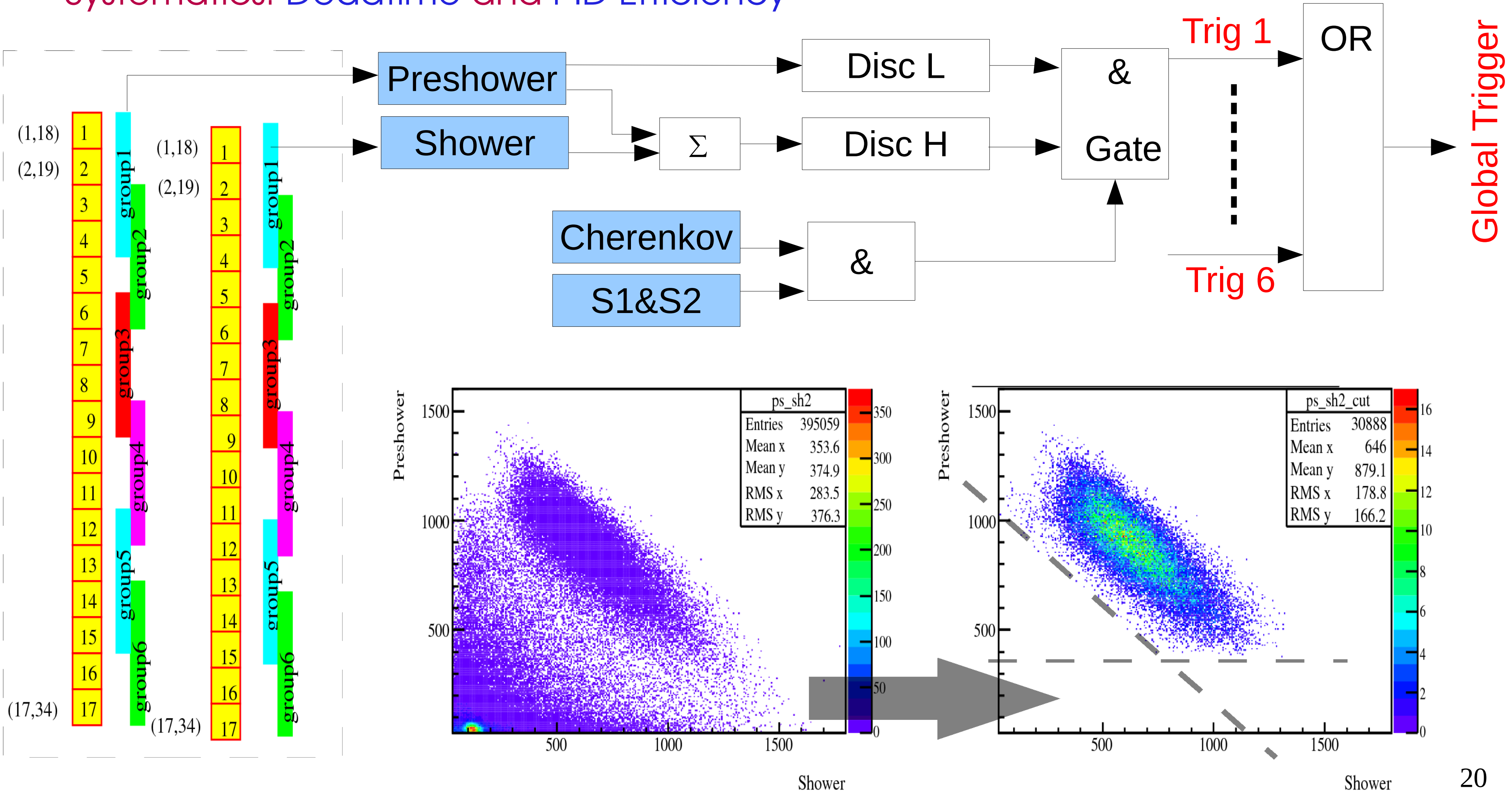
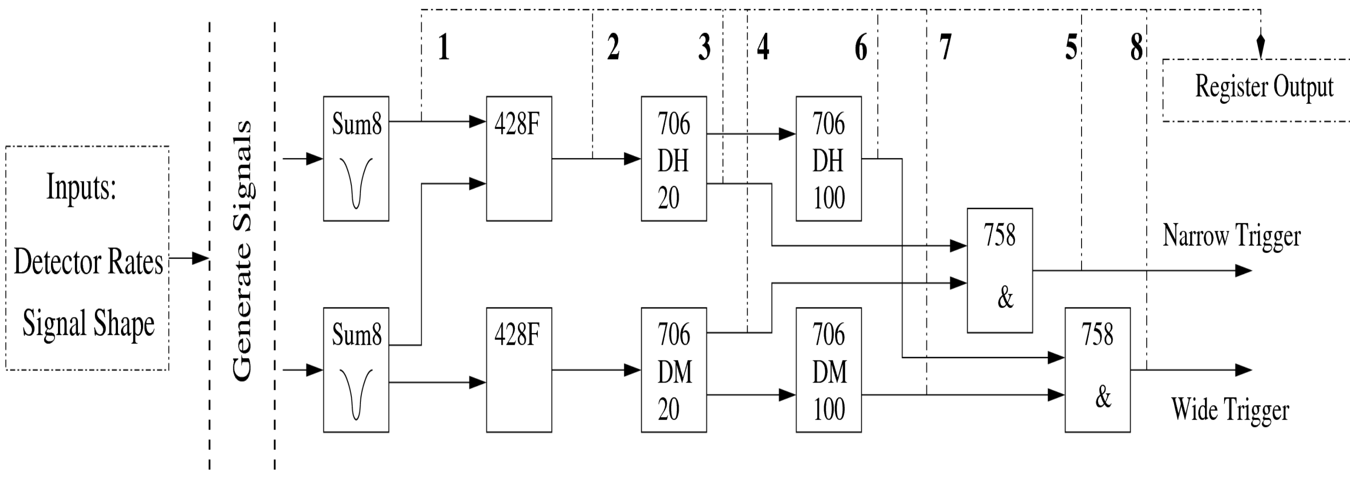
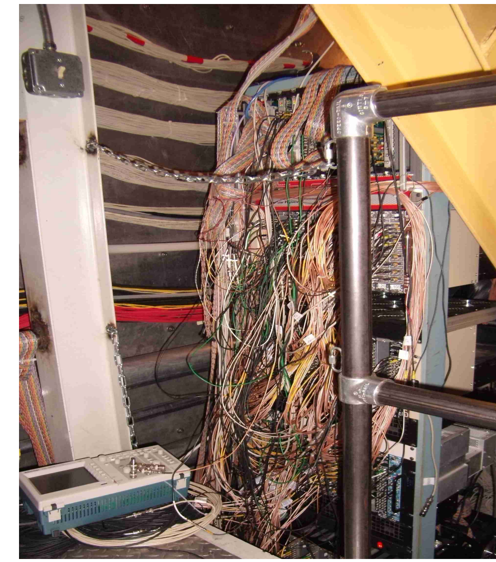
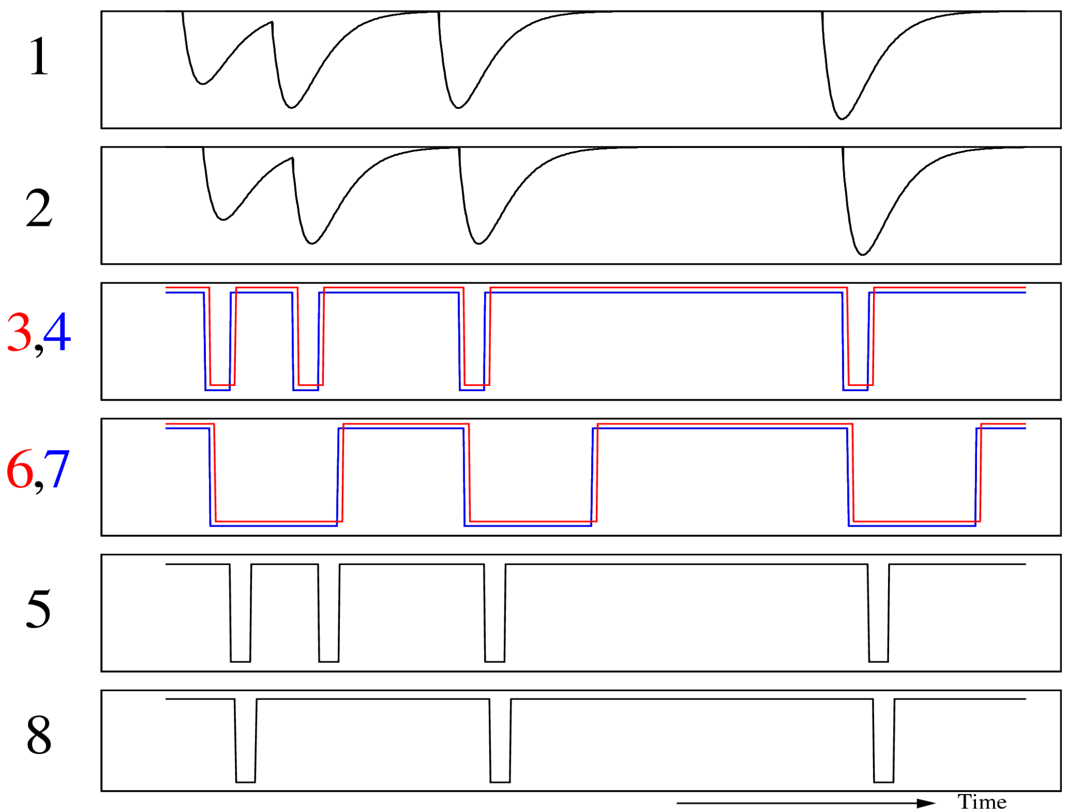
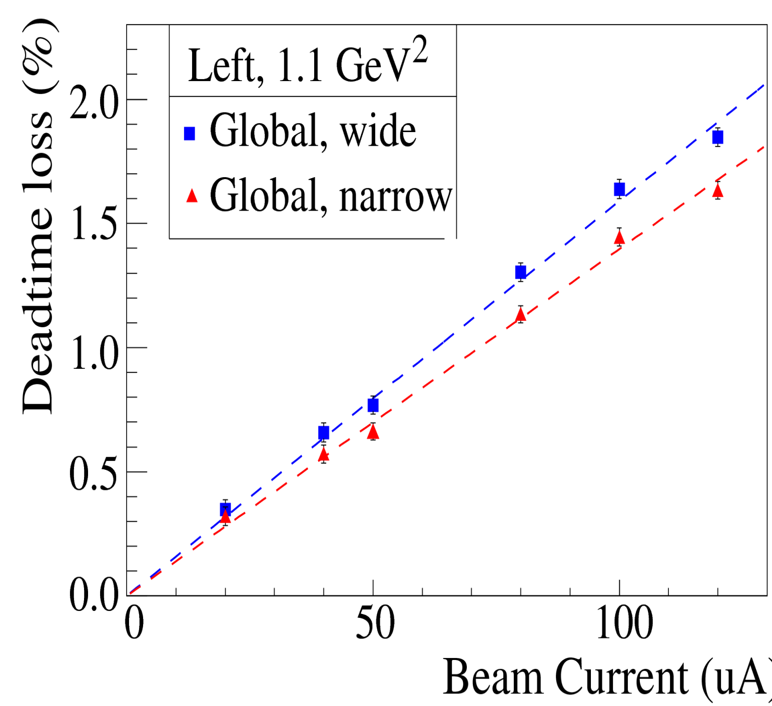


Deadtime Study / Trigger Simulation



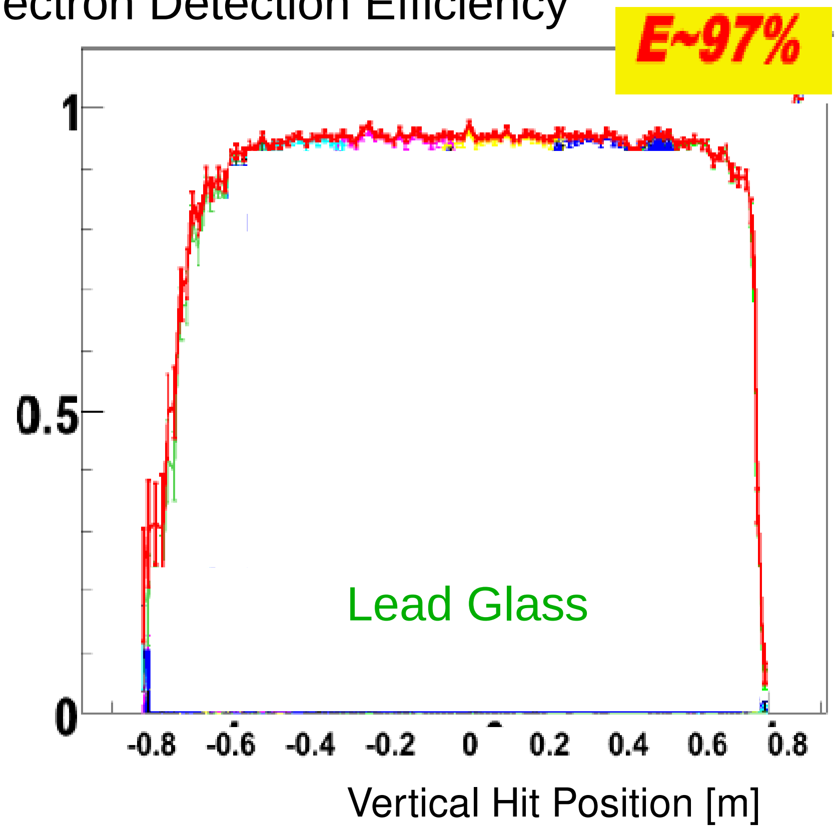




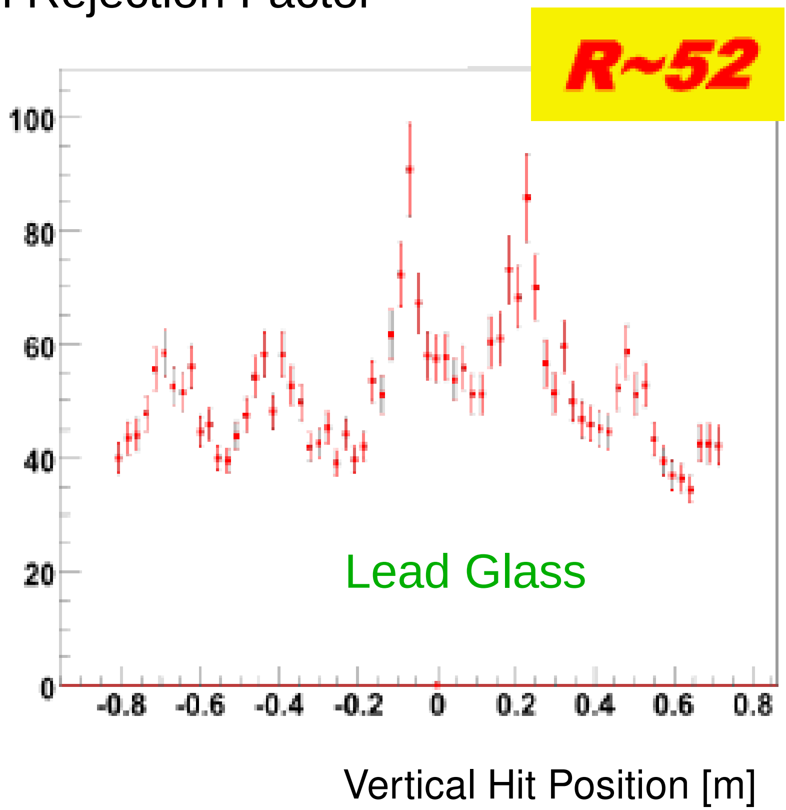


Particle Identification Performance

Electron Detection Efficiency



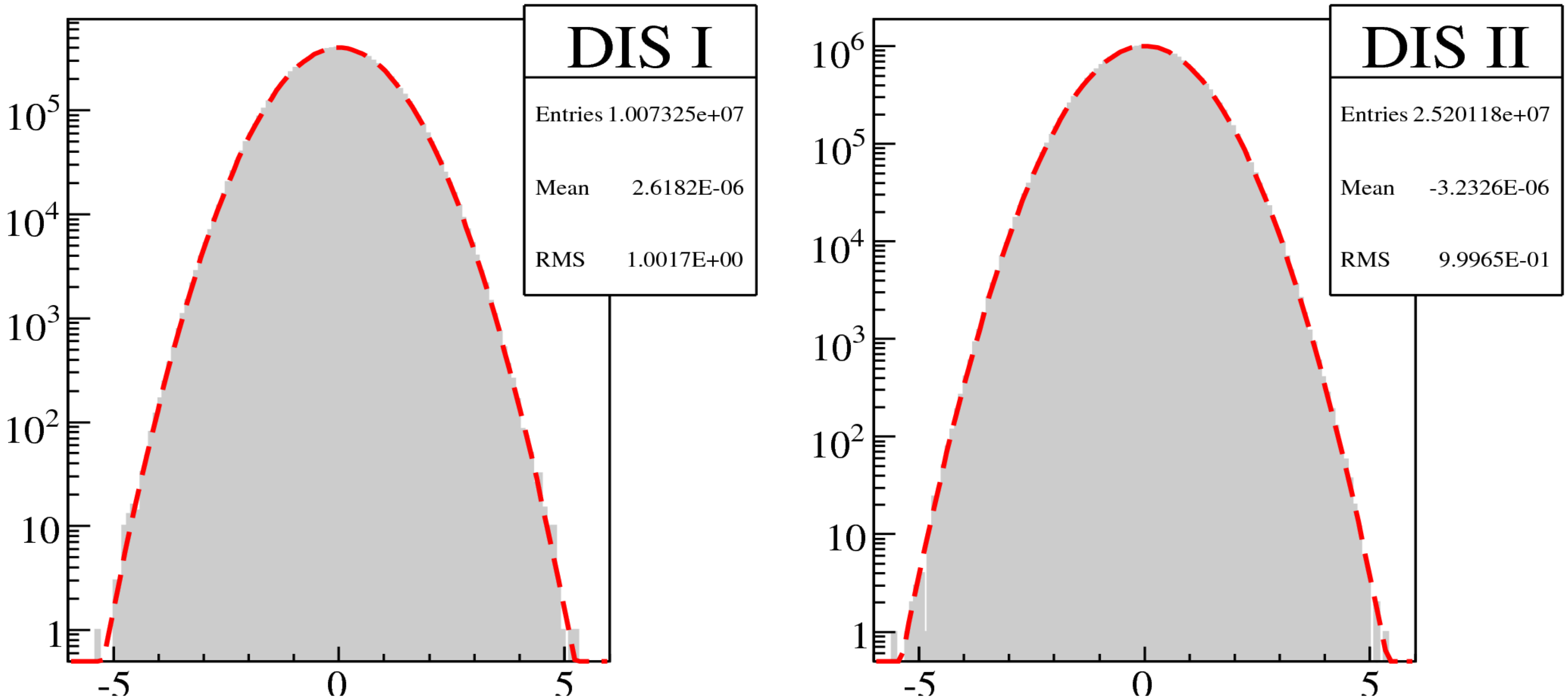
Pion Rejection Factor



Affects measured asymmetry (Q^2) if it varies over the acceptance or if there are "holes"

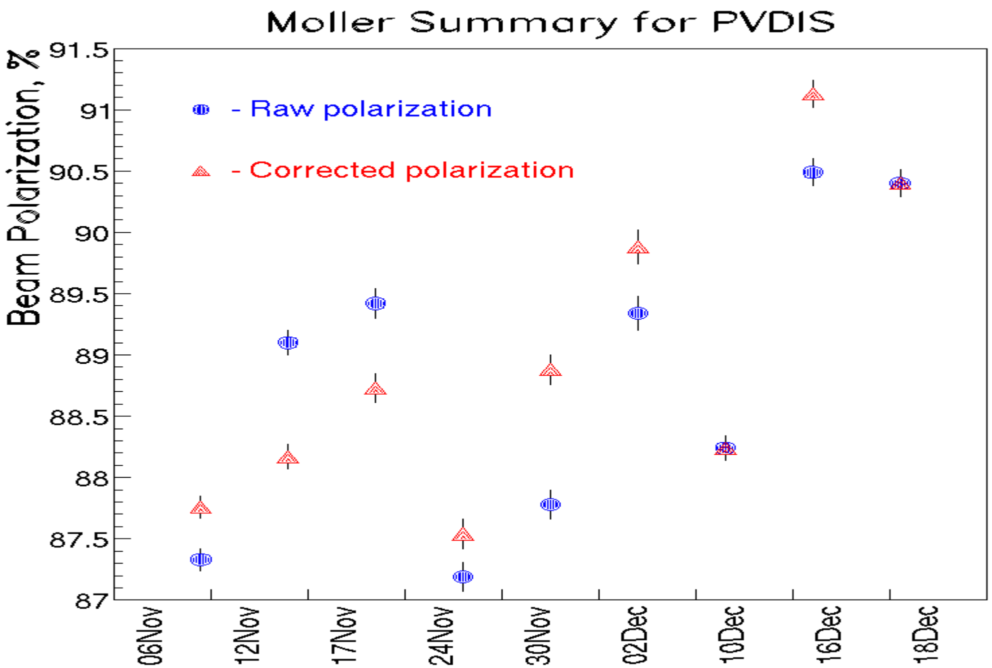
	Lead Glass	Gas Cherenkov	Overall
Electron Efficiency	97%	96%	95%
Pion Rejection Factor	52	200	10e4

Data Quality



Pairwise Pull Plot $\frac{A_i - \bar{A}}{\sigma_i}$

Beam Polarization (Compton/Moller)



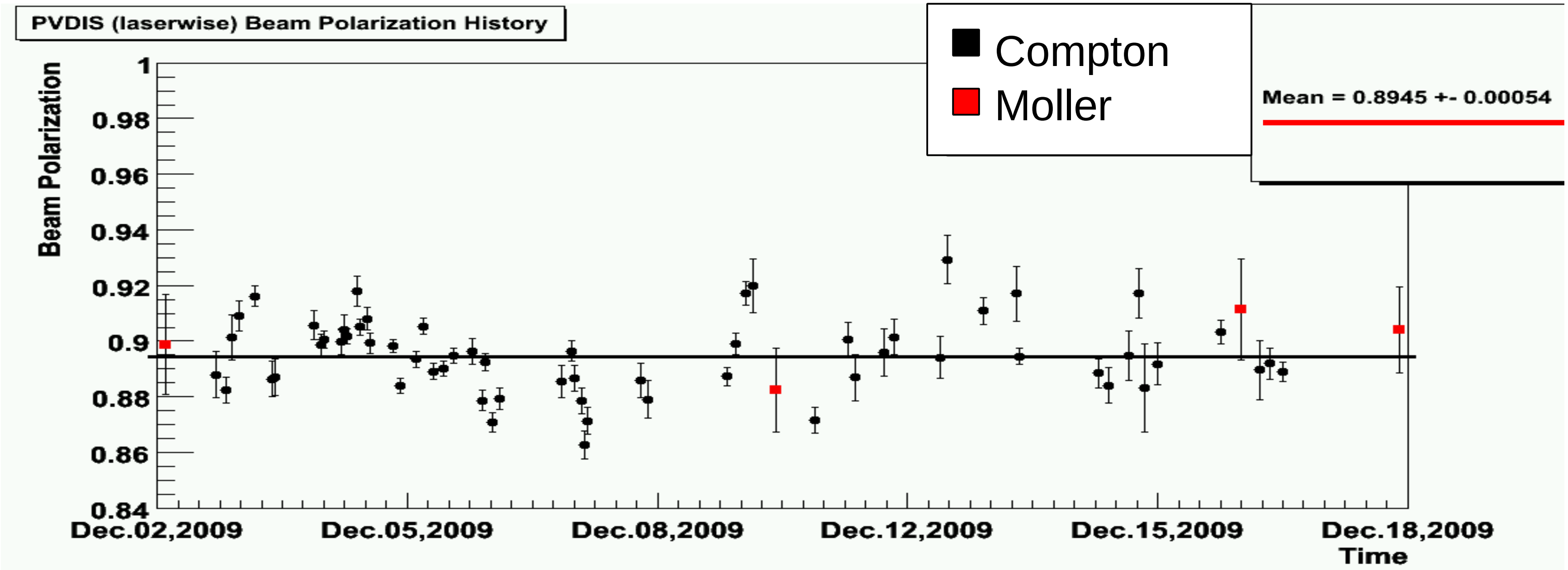
Moller: 88.47% +/- 2.0% (syst, relative) (6.0GeV)

90.4% +/- 1.7% (syst, relative) (4.8GeV)

Compton: 89.45% +/- 1.92% (syst, relative)

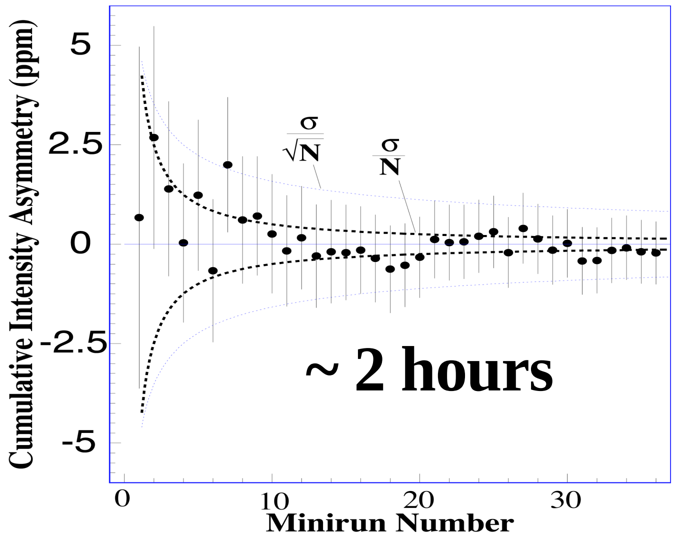
Systematic mainly from A_{th}

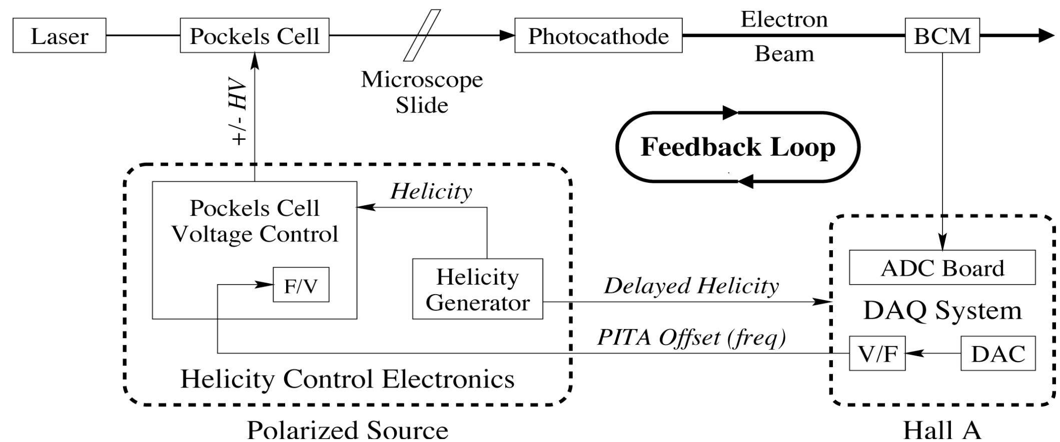
$(A_{exp} = P_\gamma \times P_e \times A_{th})$



False Asymmetries

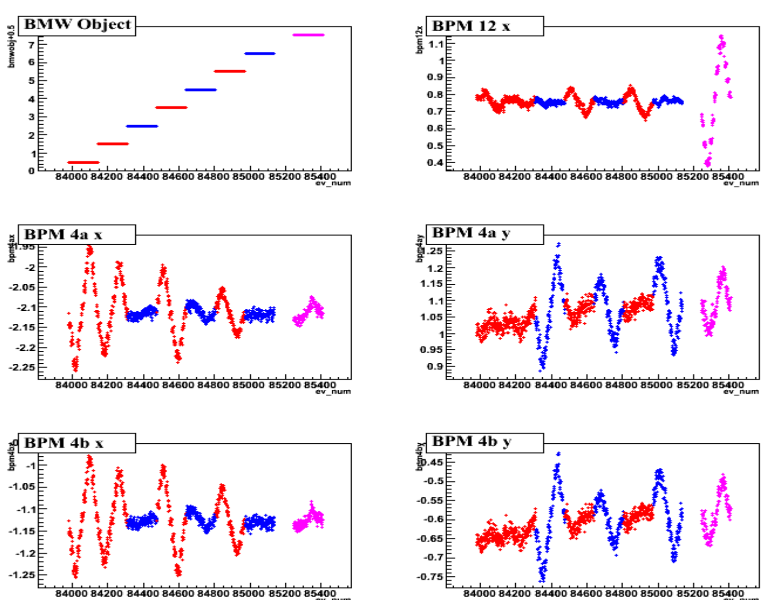
Charge Asymmetry: Intensity Feedback

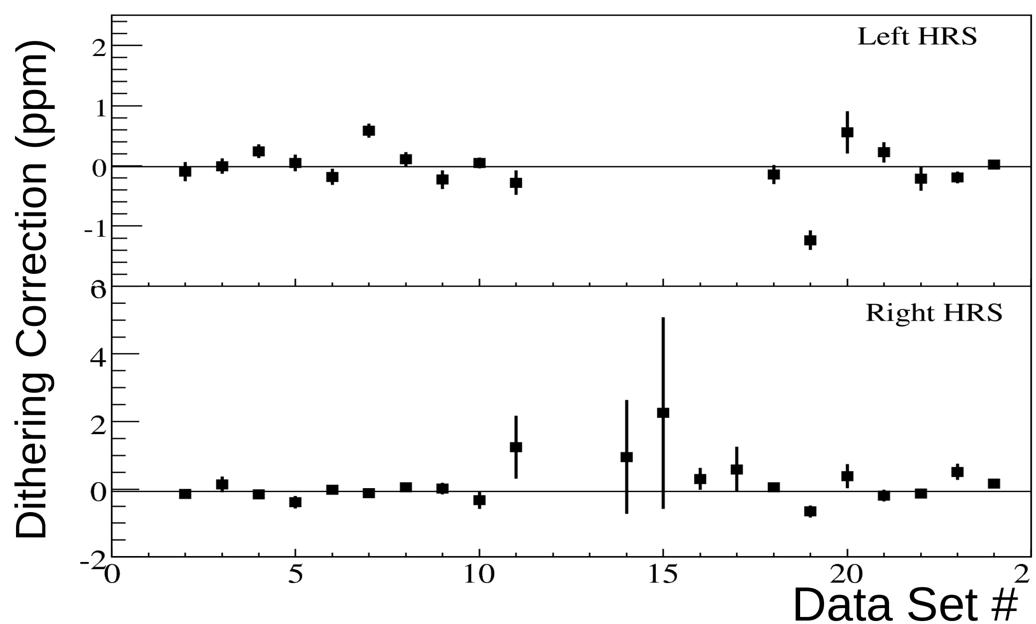




Low jitter and high accuracy allows sub-ppm Cumulative charge asymmetry in ~ 1 hour

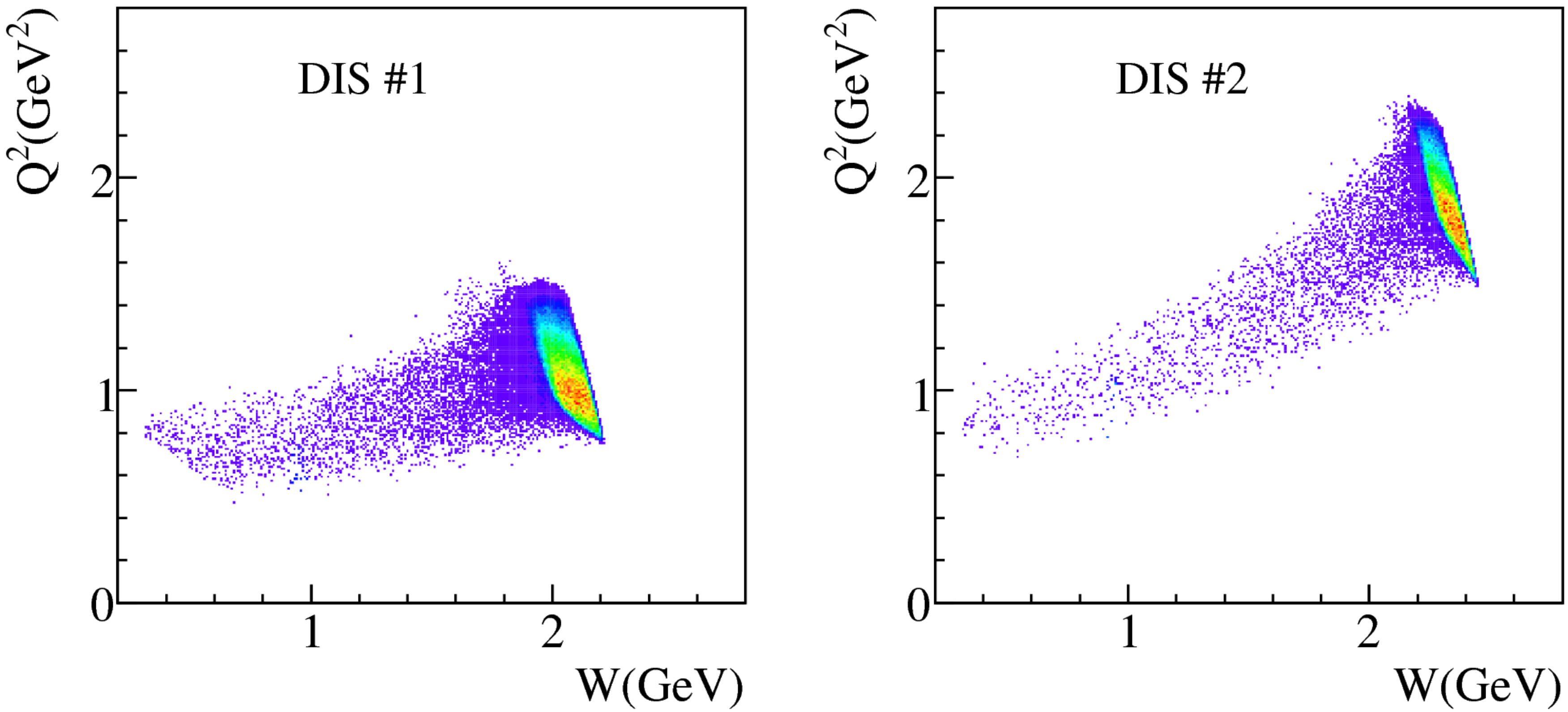
Beam Movement: Dithering / Regression





EM Radiative Corrections

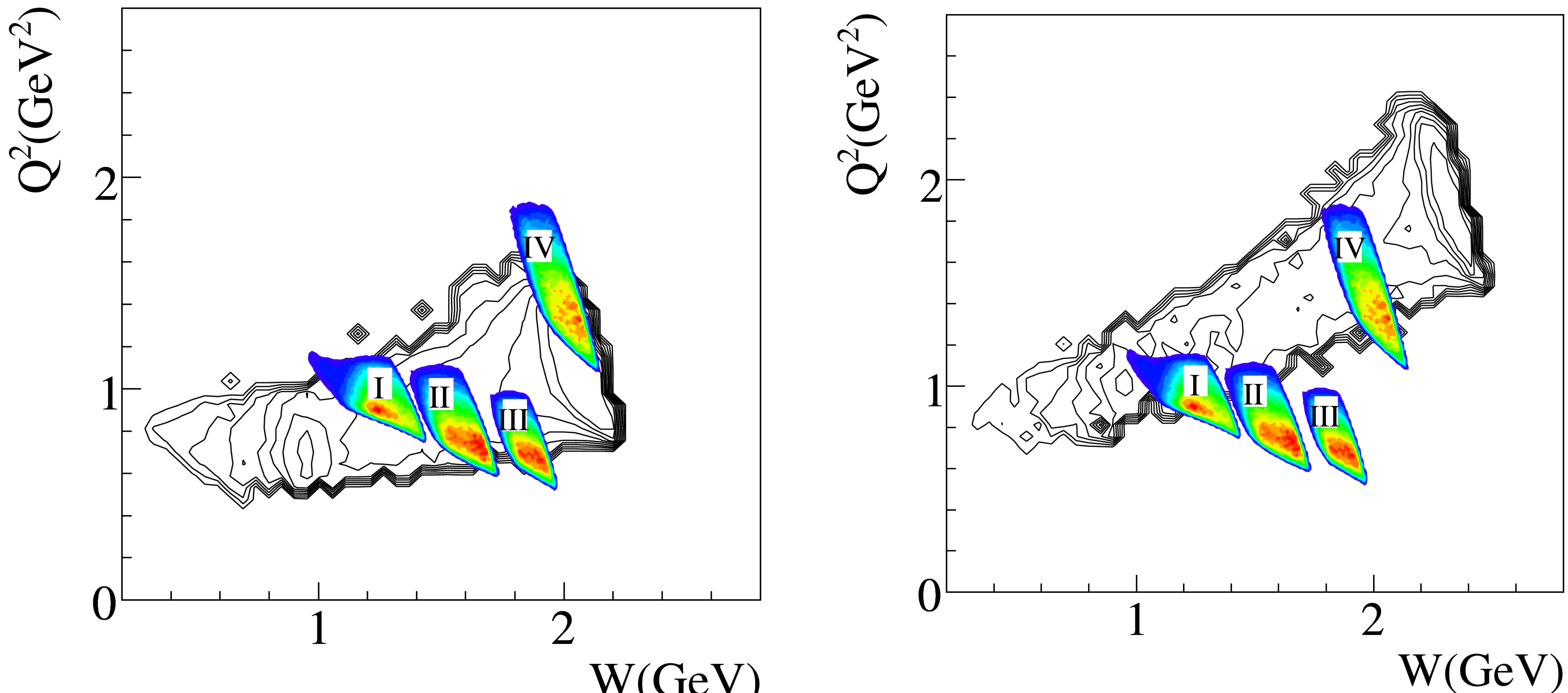
Monte Carlo Simulation



- No previous measurements of Apv in the resonance region
- Two Theory Calculations for Apv in the resonance, and "Toy Model"
- Measured resonance Apv (10-15% stat.) to constrain inputs of resonance PV models

EM Radiative Corrections

Monte Carlo Simulation



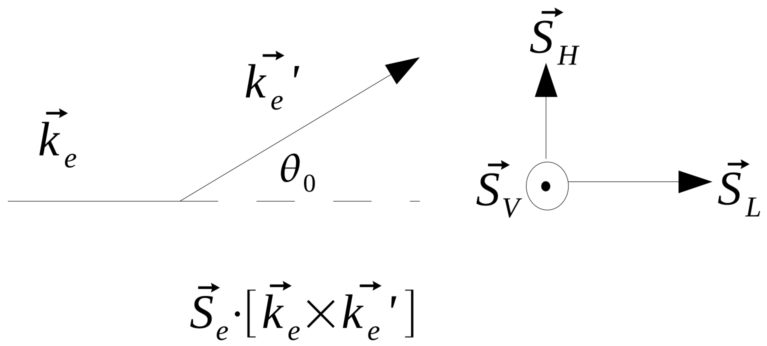
- No previous measurements of Apv in the resonance region
- Two Theory Calculations for Apv in the resonance, and "Toy Model"
- Measured resonance Apv (10-15% stat.) to constrain inputs of resonance PV models
- Radiative Corrections: 2.1%+/-2.0% (Kine #1); 1.9%+/-0.43% (Kine #2)

Backgrounds

- Transverse Asymmetry:

$$Correction\ to\ A_d:\ \frac{A_T}{\sin\theta_0}\cdot[S_H\cdot\sin\theta_{tr} - S_v\cdot\sin\theta_0\cdot\cos\theta_{tr}]$$

$$where\ |\theta_{tr}|\ very\ small,\ S_V < 2\%,\ S_H < 20\%$$



	Kine #1	Kine #2
A_T (ppm)	-24.15 ± 15.05	23.49 ± 44.91
Uncertainty to A_d	0.55%	0.56%

- Pair Production (Dilution): Positron asymmetry measured, consistent with zero

	Kine #1	Kine #2
A_{e+} (ppm)	723.2 ± 1154.7	1216 ± 1304.5
Correction to A_d	0.03% ± 0.003%	0.48% ± 0.048%

- Pion Contamination: Pion asymmetries observed to be non-zero

	Kine #1	Kine #2
A_π (ppm)	-30.85 ± 12.84	-8.10 ± 4.13
Correction to A_d	0.019% ± 0.014%	0.024% ± 0.003%

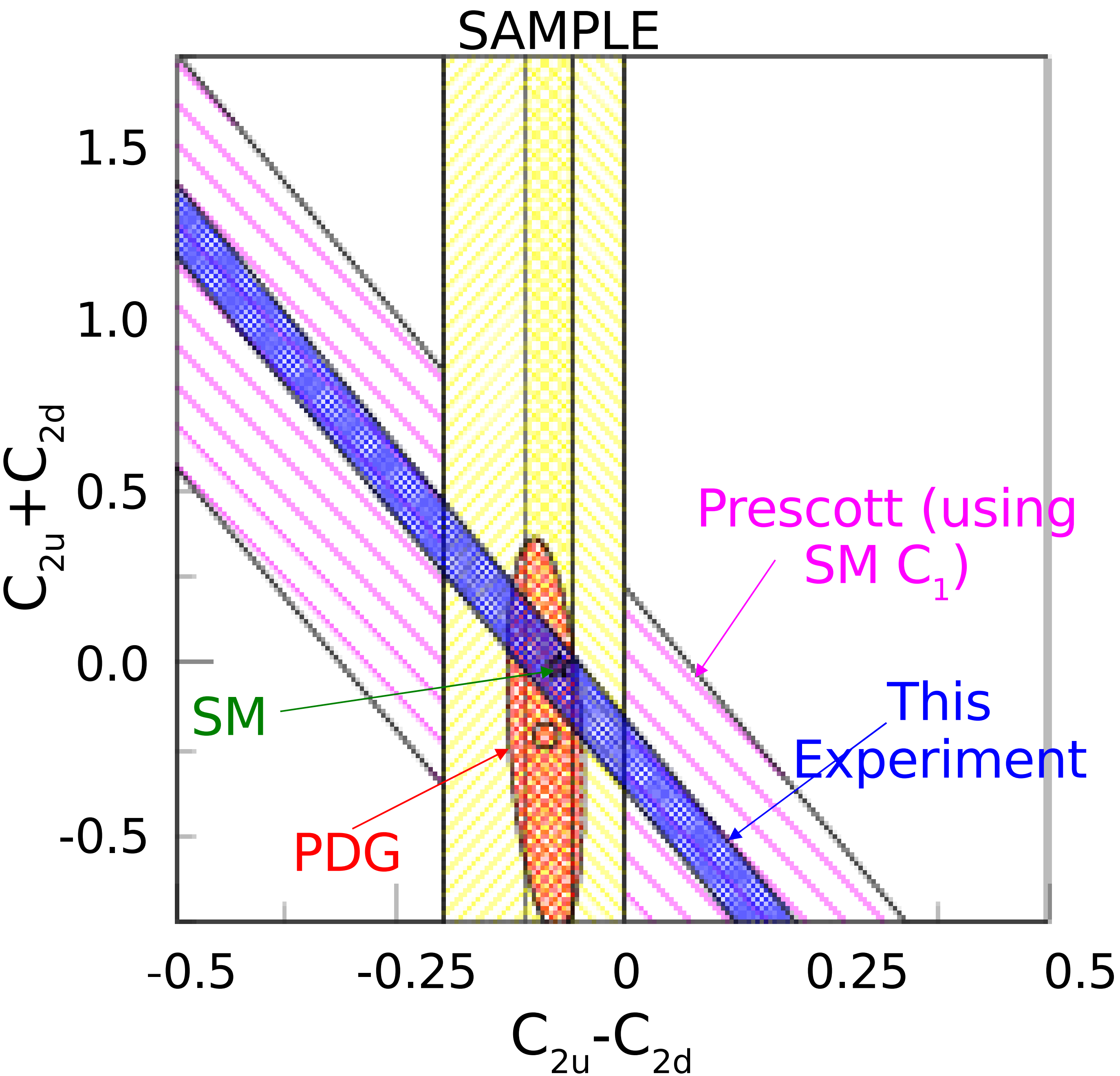
- Aluminum endcap from target cell: Estimated using SM calculated values

	Kine #1	Kine #2
$A_{Al} - A_d$ (ppm)	-0.75	-1.79
Correction to A_d	0.017% ± 0.0034%	0.023% ± 0.0046%

Uncertainties

Source \ $\Delta A_d/A_d$	Kine #1	Kine #2
$\Delta P_b/P_b$	2.00%	1.59%
Radiative Correction	2.00%	0.43%
Q^2	0.73%	0.62%
Transverse Asymmetry	0.55%	0.56%
Deadtime Correction	0.44%	0.25%
False Asymmetry	0.16%	0.05%
Pair Production	0.01%	0.05%
PID Efficiency	0.01%	0.02%
Pion Dilution	0.01%	0.01%
Target Endcap	0.01%	0.01%
Systematics	3.01%	1.87%
Statistical	3.41%	3.96%
Total	4.55%	4.38%

C_{2q} from Q^2=1.9 GeV^2 Point

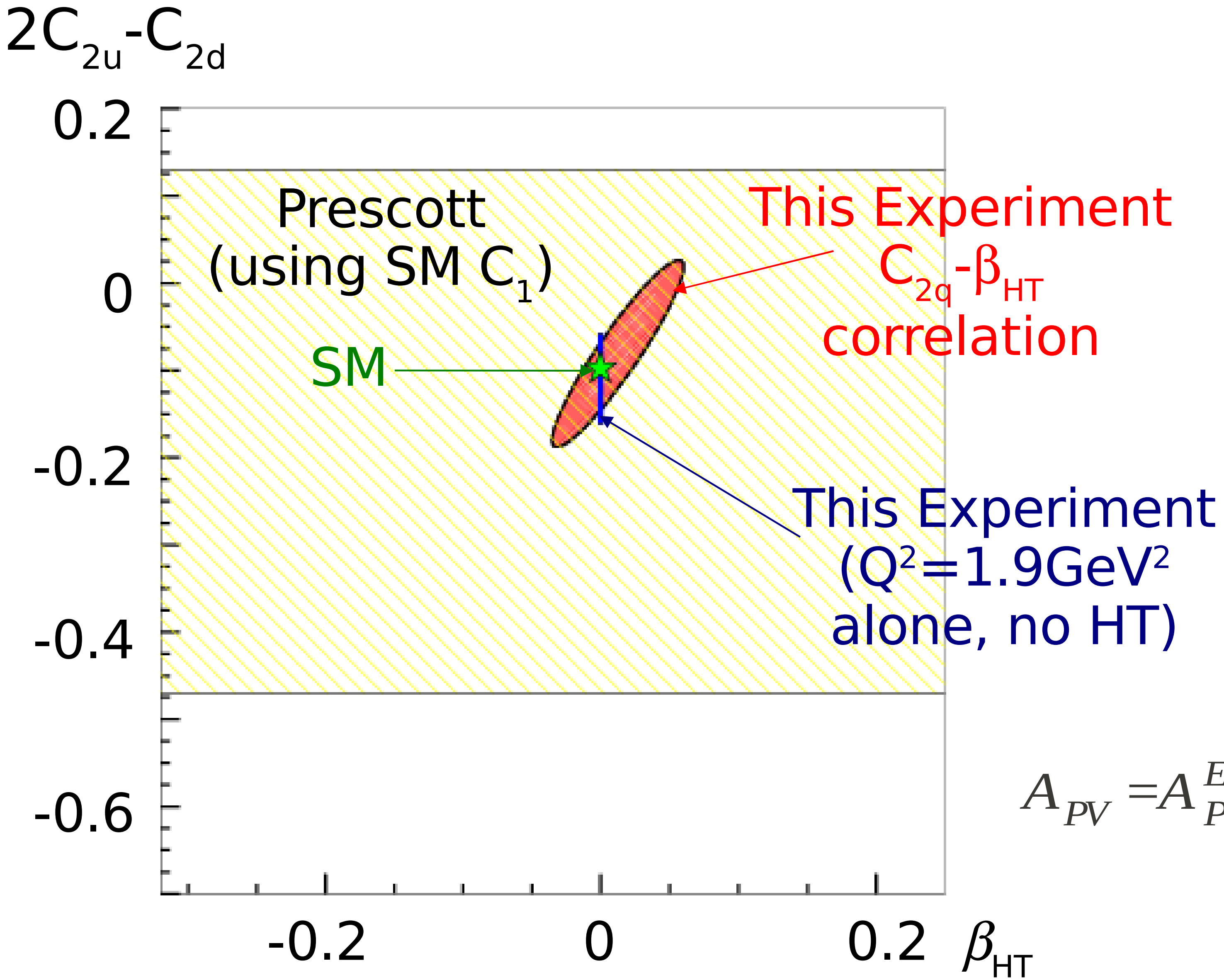


Assuming no HT

Preliminary
$\Delta(2C_{2u}-C_{2d})$=0.052
(expt. error only)

(compared to PDG ±0.24 → factor of 4.6153846)

C_{2q}- β_{HT} Correlation from Q^2=1.1 and 1.9 GeV^2 Combined



- No obvious Q^2 dependence (HT) at the 6 GeV precision.

$$A_{PV} = A_{PV}^{EW}\left(1 + \frac{\beta_{HT}}{(1-x)^3 Q^2}\right)$$

A_{pv} in the Resonance Region

Motivation:

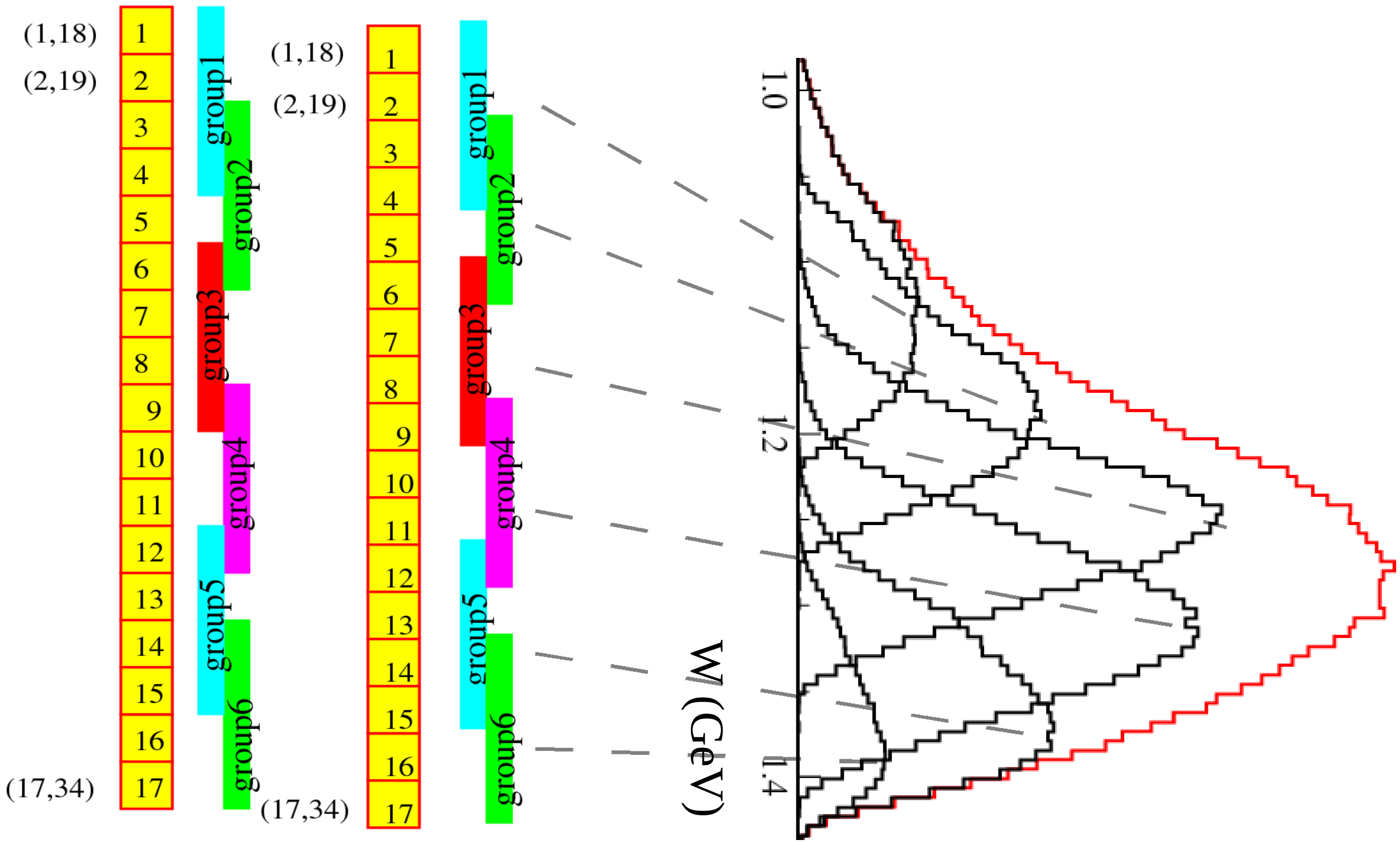
- Real Motivation: Radiative Correction for DIS
- After-the-Experiment Motivation:
  - Apv in the resonance region has never been measured (G0 Δ)
  - Provides inputs for calculating γZ box diagram corrections to elastic PVES
  - Check theoretical calculations
  - Quark-Hadron Duality

Methods and Data:

- Exactly the same experimental setup as DIS
- About 1~2 days of beam time for each kinematics
- Data analysis follows the same procedure as DIS, except using group triggers.

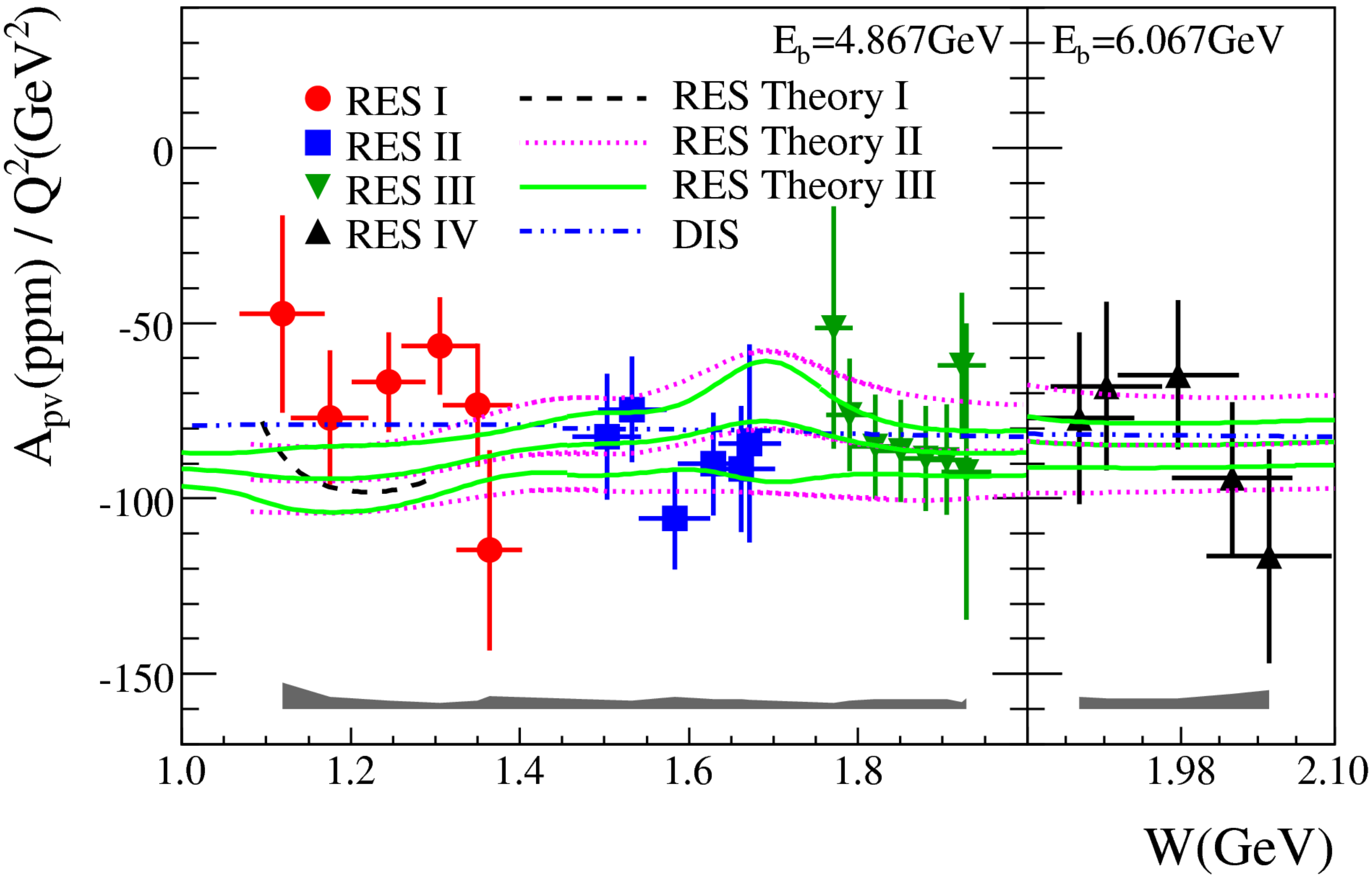
Using Group Triggers

Unlike DIS, Group Triggers are used for resonance data analysis



- Group triggers are naturally separated in W
- In resonance region, expect strong dependence of Apv on W
- 4 resonance kinematics ⟶ 26 data points

Resonance A_{pv} Results



Theoretical Calculations:

- I: T.-S.H. Lee et.al, Phys. Rev. C72, 025204
- II: M. Gorchtein et.al, Phys. Rev. C84, 015502
- III: N. Hall, W. Melnitchouk, private communication

Summary

- DIS results and extraction of C_{2q}
  - PVDIS asymmetry is measured with high statistical precision and well controlled systematics;
  - from Q^2=1.9 GeV^2 point assuming no higher twist is consistent with the Standard Model value and factor of five improvement over previous data;
  - simultaneous fit to both Q^2=1.1 and 1.9 GeV^2 points indicate the HT to be small;
- Resonance Results
  - First Measurement of A_{pv} throughout the resonance region;
  - Measurement generally agrees with theory models
  - Quark-Hadron Duality holds