Highlights of JLab Parity Violation Electron Scattering Results from the Past Year

Xiaochao Zheng (Univ. of Virginia)

July, 2012

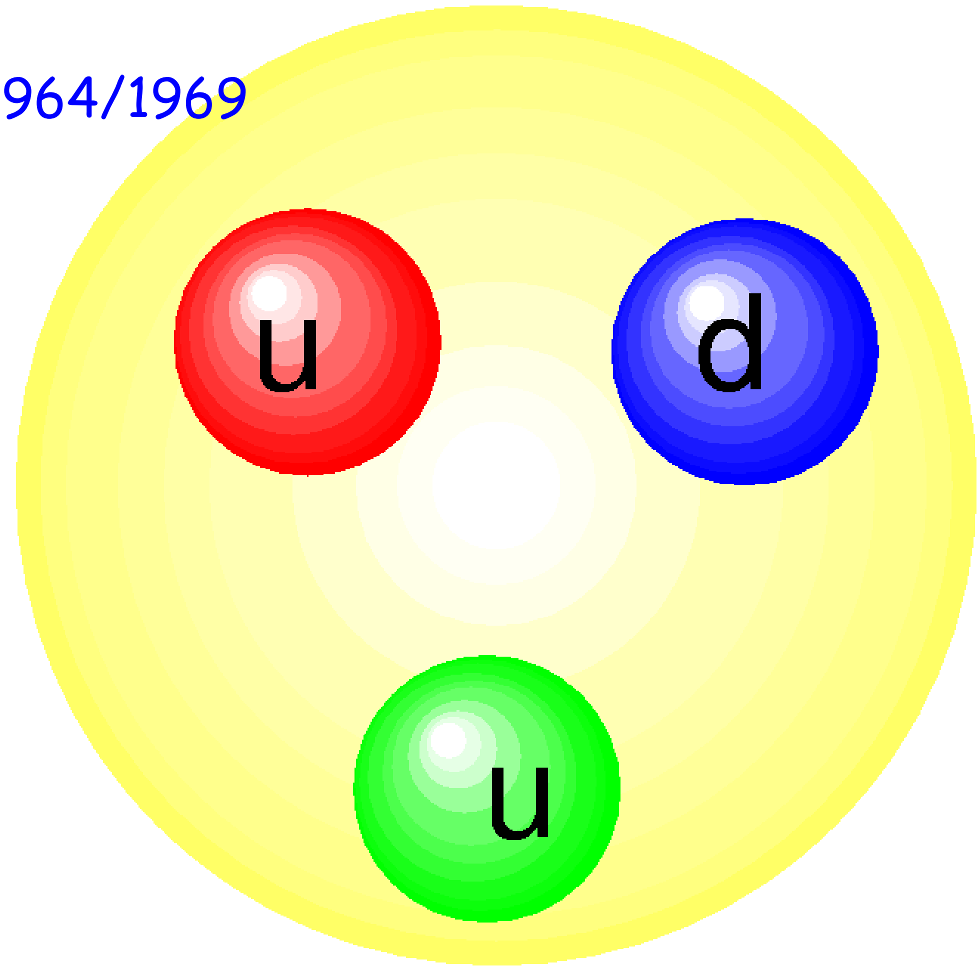
- What the photons can't tell us, Z^0 can!
- PVDIS and Electroweak Neutral Couplings
- Outlook for the 12 GeV Program – SoLID, Moller...

Jefferson Lab

What is the Nucleon Made of?

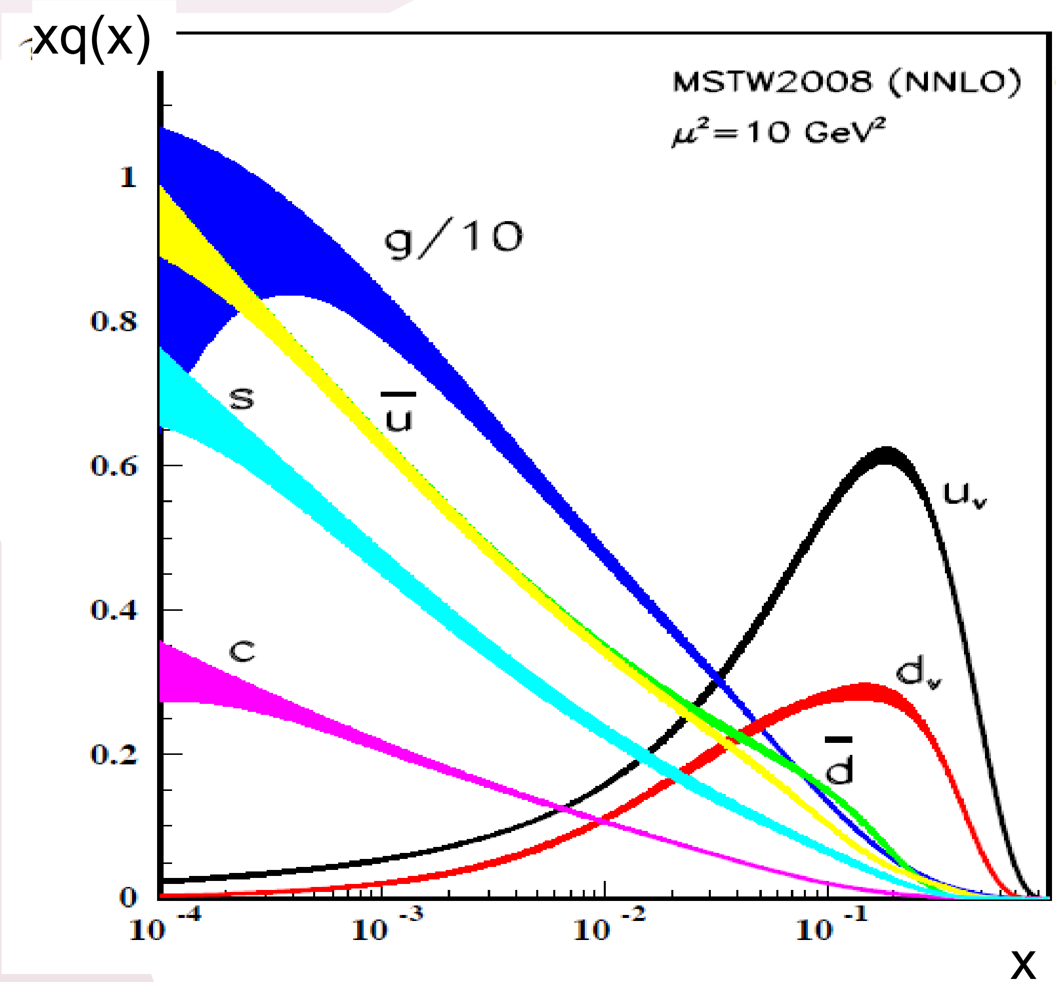
The simple quark model of hadrons

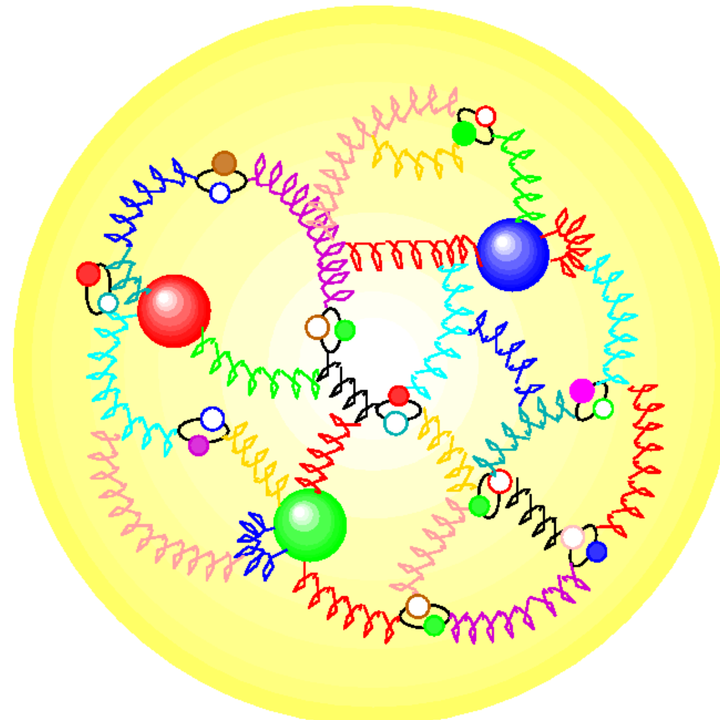
Gell-Mann (Nishijima) 1961-1964/1969



We Learned A Lot In the Past 40 Years !

A.D. Martin et al, Eur. Phys. J. C63, 189 (2009)

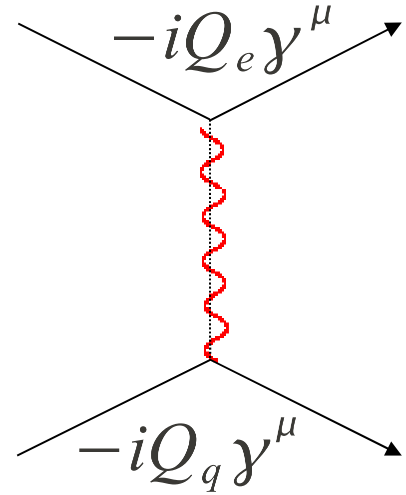




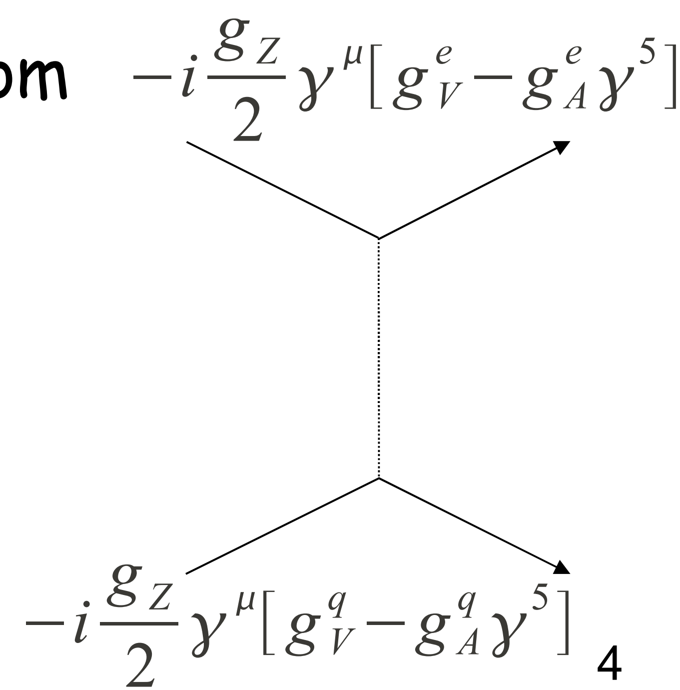
- Fit to data from DIS, Drell-Yan, Collider etc.

High Energy Virtual Photons Told Us A Lot, but They Are Not Perfect:

- Virtual photon cross sections can't tell quarks from anti-quarks – sensitive to $q+\bar{q}$, never $q-\bar{q}$!
- They don't "see" neutral particles such as the neutron !



We need a "second opinion", perhaps from a less talkative friend – the Z^0.



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

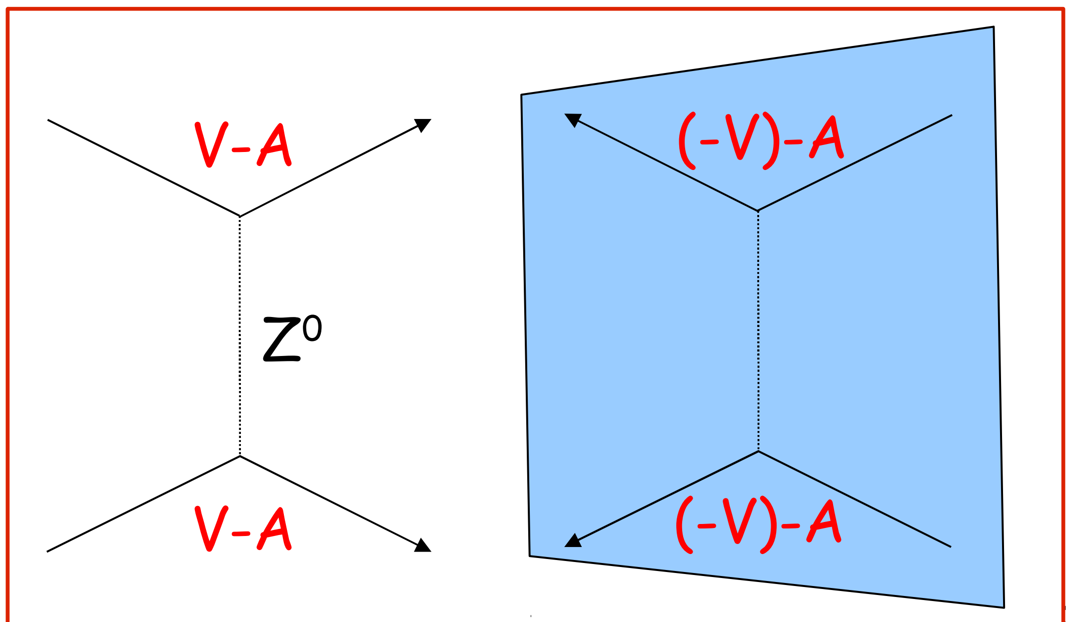
- In the Standard Model,

  weak interaction current =
  V(vector) minus A(axial-vector)

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	$-\frac{1}{2}$	$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W$

- Parity violation is from the cross products V x A:

$$\boxed{\begin{aligned} C_{1q} &\equiv 2\, g_A^e\, g_V^q \\ C_{2q} &\equiv 2\, g_V^e\, g_A^q \end{aligned}}$$



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Parity Violation in DIS

(Z_0 sees the quarks)

Parity Violation – Signature of Weak Interaction And Z^0 Exchange

- In the Standard Model,

  weak interaction current = V(vector) minus A(axial-vector)

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	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
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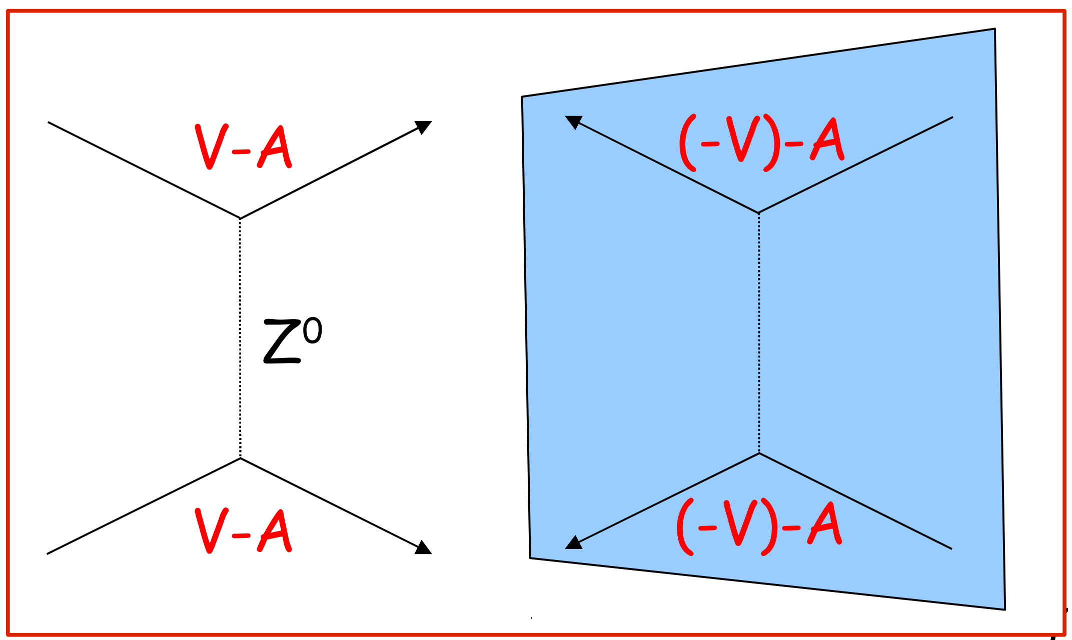
- Parity violation is from the cross products V x A:

$$\boxed{\begin{aligned} C_{1q} &\equiv 2 g_A^e g_V^q \\ C_{2q} &\equiv 2 g_V^e g_A^q \end{aligned}}$$

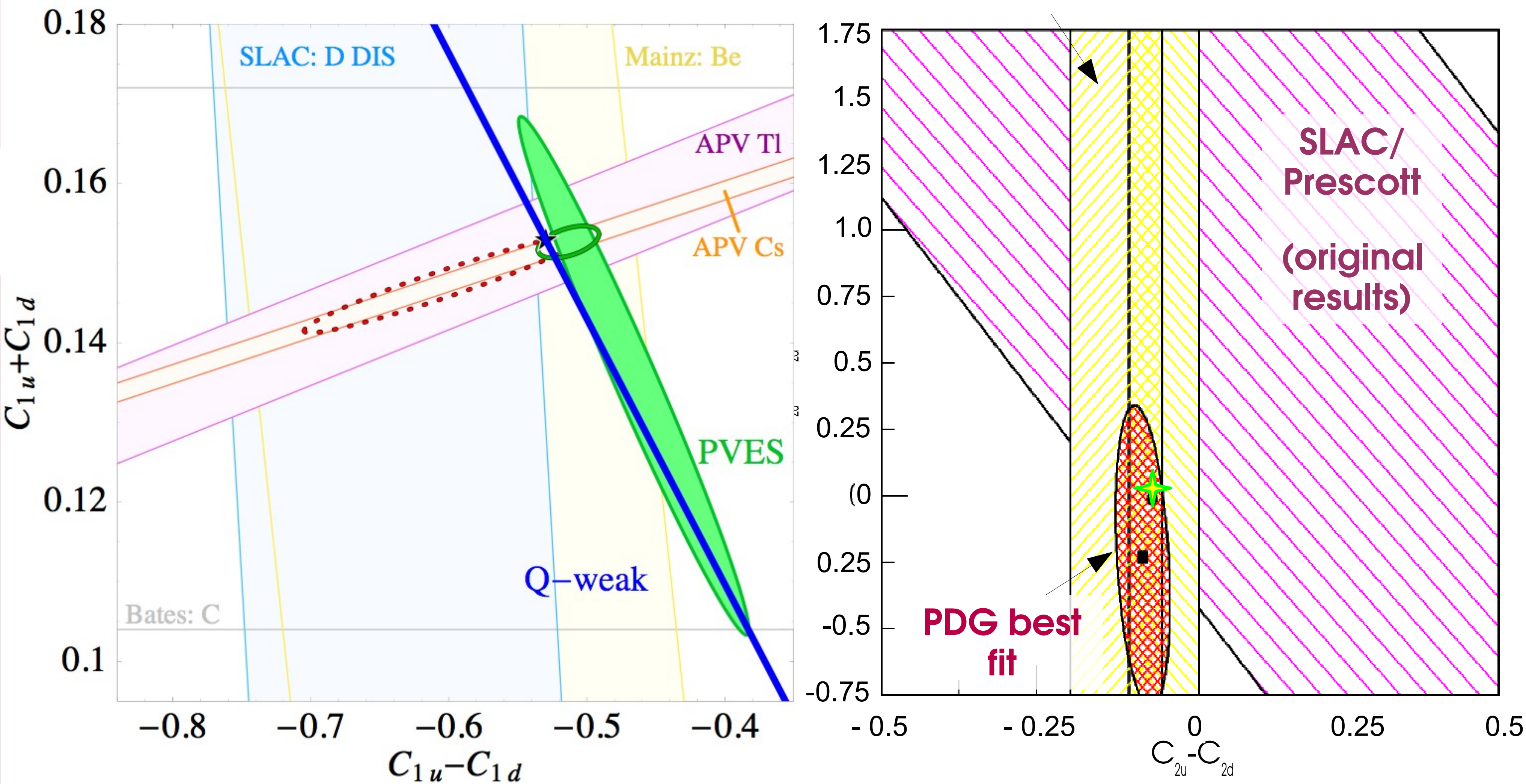
Both have potential in new physics search



Weak Vector and Axial Charges of Quarks

all are 1 σ limit

with recent PVES data and Qweak (projected) **without JLab data**



Qweak in Hall C (2010-May 2012): $\boxed{{}^1H + \vec{e} \rightarrow e' + p}$ **factor of 5 improvement** in $Q^p_W=-2(2C_{1u}+C_{1d})$, New Physics scale from 0.9 to 2 TeV

Parity Violation in Deep Inelastic Scattering

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

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

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

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

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

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

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

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

0

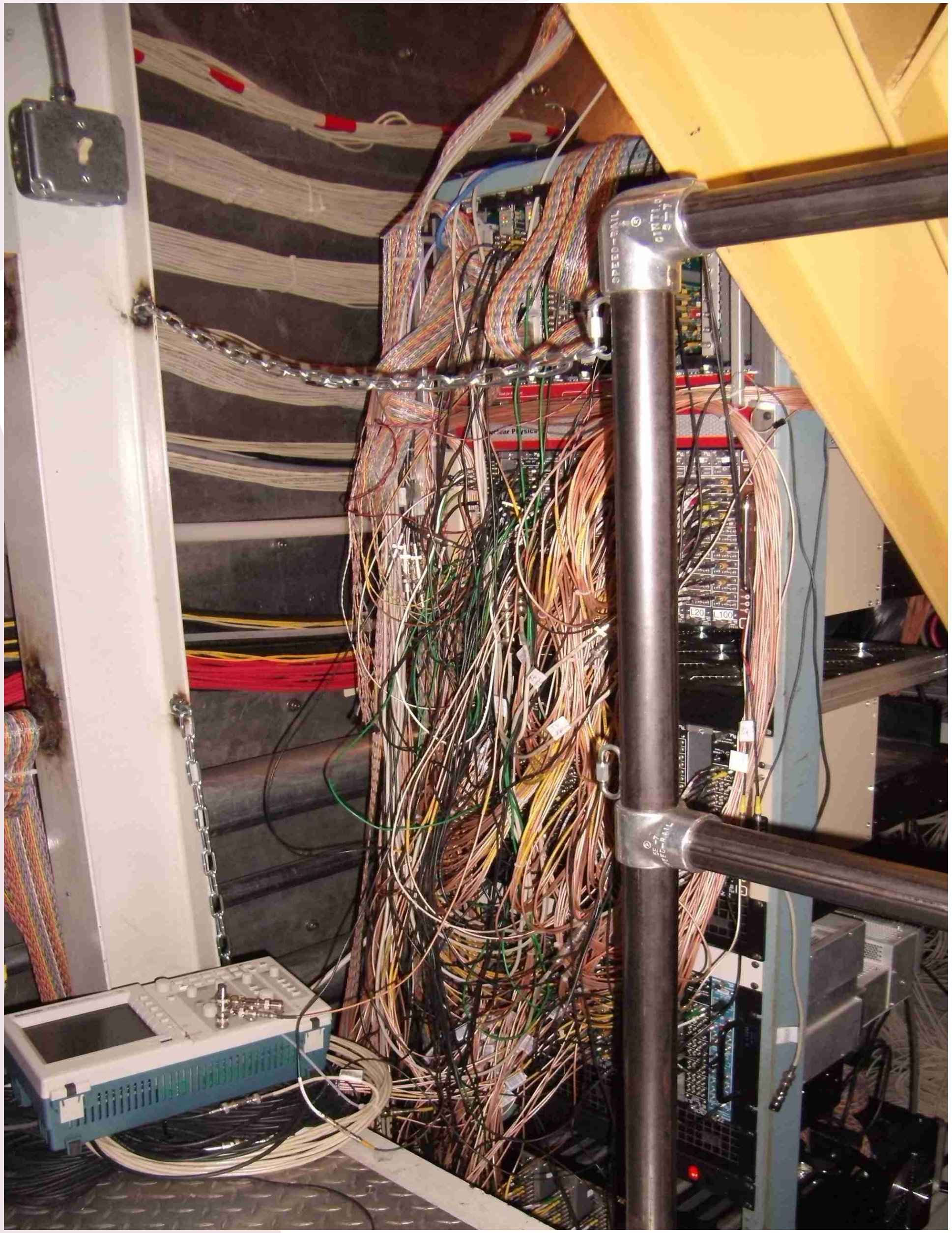
$$b(x) = \frac{3}{10}\left(2C_{2u} - C_{2d}\right)\left(\frac{u_V + d_V}{u^+ + d^+}\right)$$

1

PVDIS: Only way to measure C_{2q}

at high x

PVDIS at 6 GeV (JLab E08-011)



- Ran in Oct-Dec 2009, 100uA, 90% pol beam, 20-cm LD2 target
- Q^2=1.1 and 1.9 GeV^2.
- Scaler-based fast counting DAQ ($100k) specifically built to accommodate the 500kHz DIS rate with 10^4 pion rejection

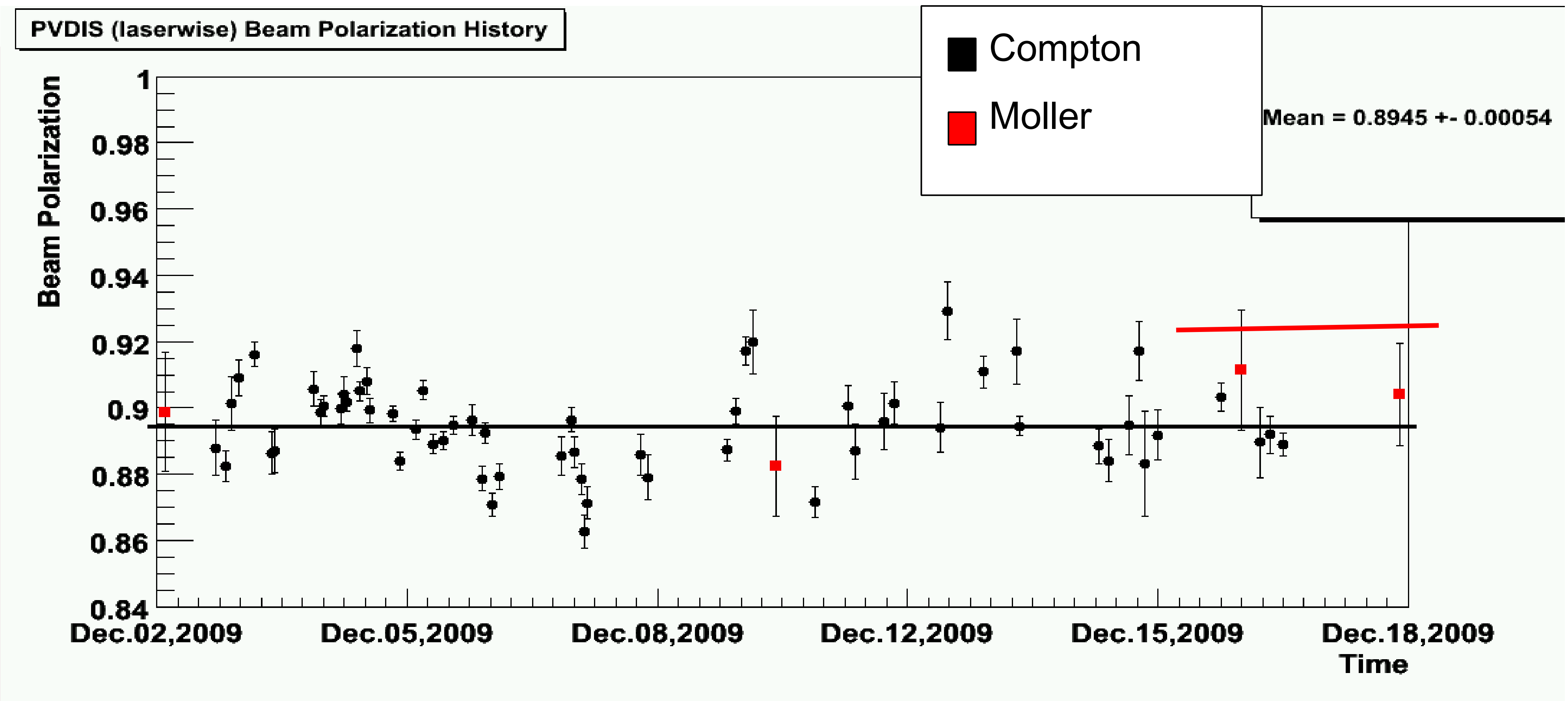
- Postdoc: Ramesh Subedi
- Graduate Students: Xiaoyan Deng (UVa), Huaibo Ding (China), Kai Pan (MIT), Diancheng Wang (UVa),

Beam Polarization (Compton/Moller)

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

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

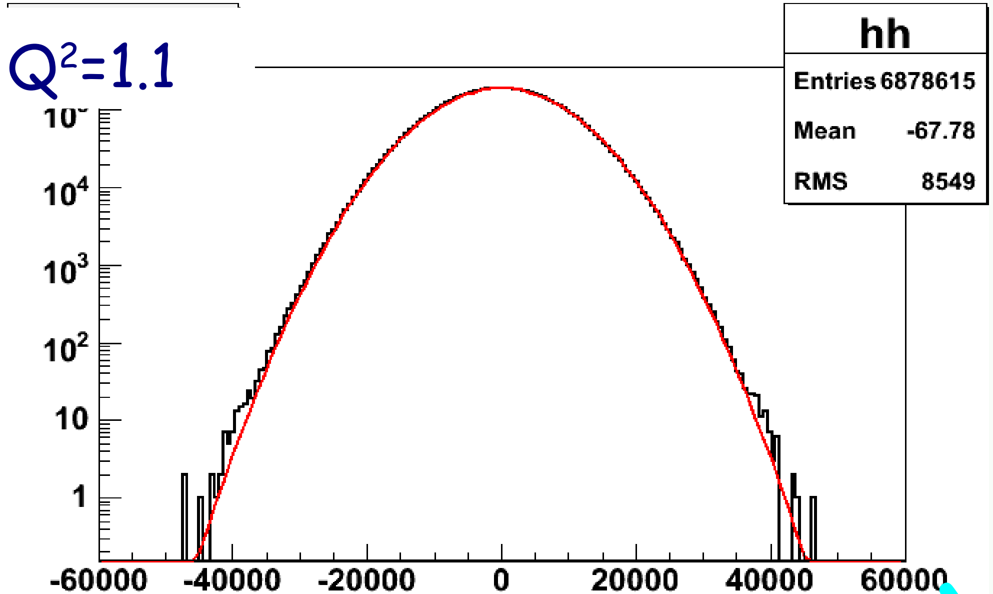
Compton: 89.45% +/- 1.92% (syst, rel)

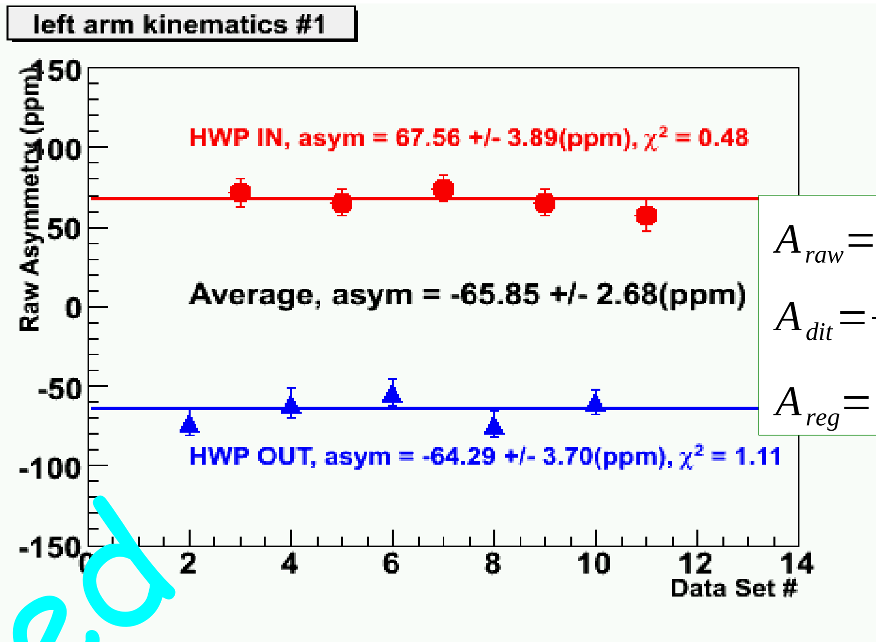


Quality of Asymmetry Measurement

(blinded pair-wise asymmetry):

Q^2=1.1



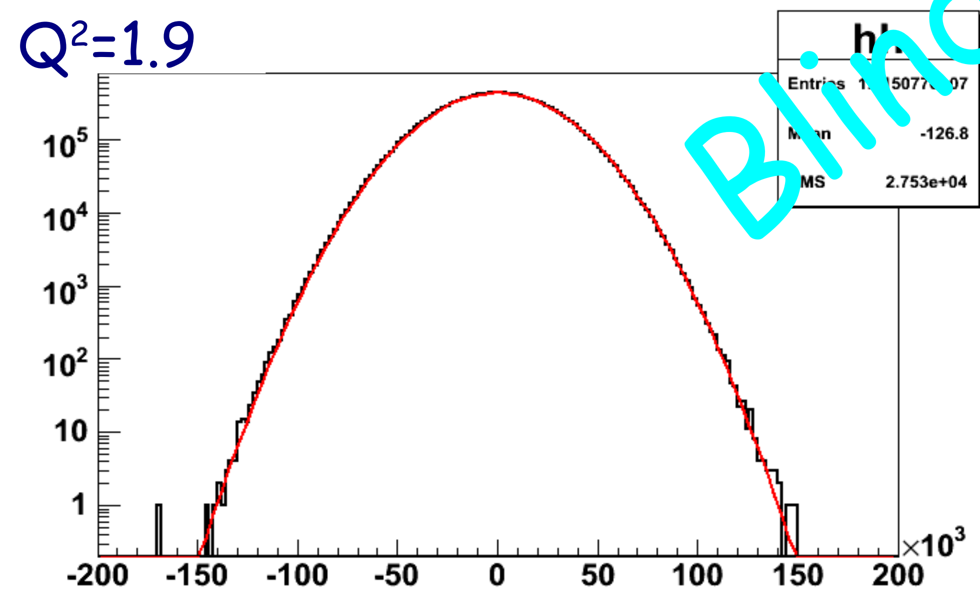


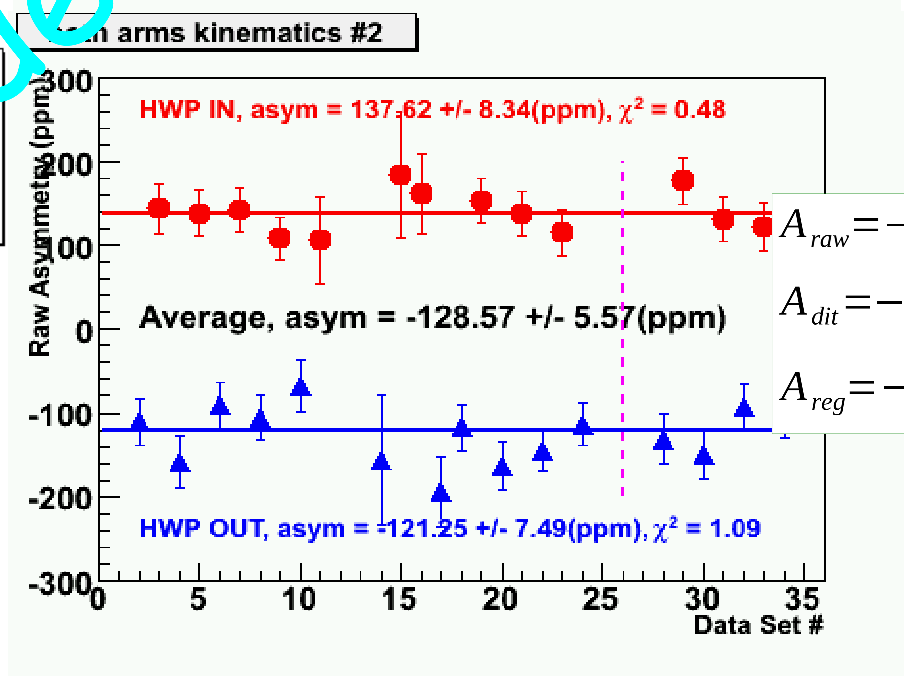
$A_{raw} = -65.85\text{ppm}$

$A_{dit} = -65.85\text{ppm}$

$A_{reg} = -65.93\text{ppm}$

Q^2=1.9





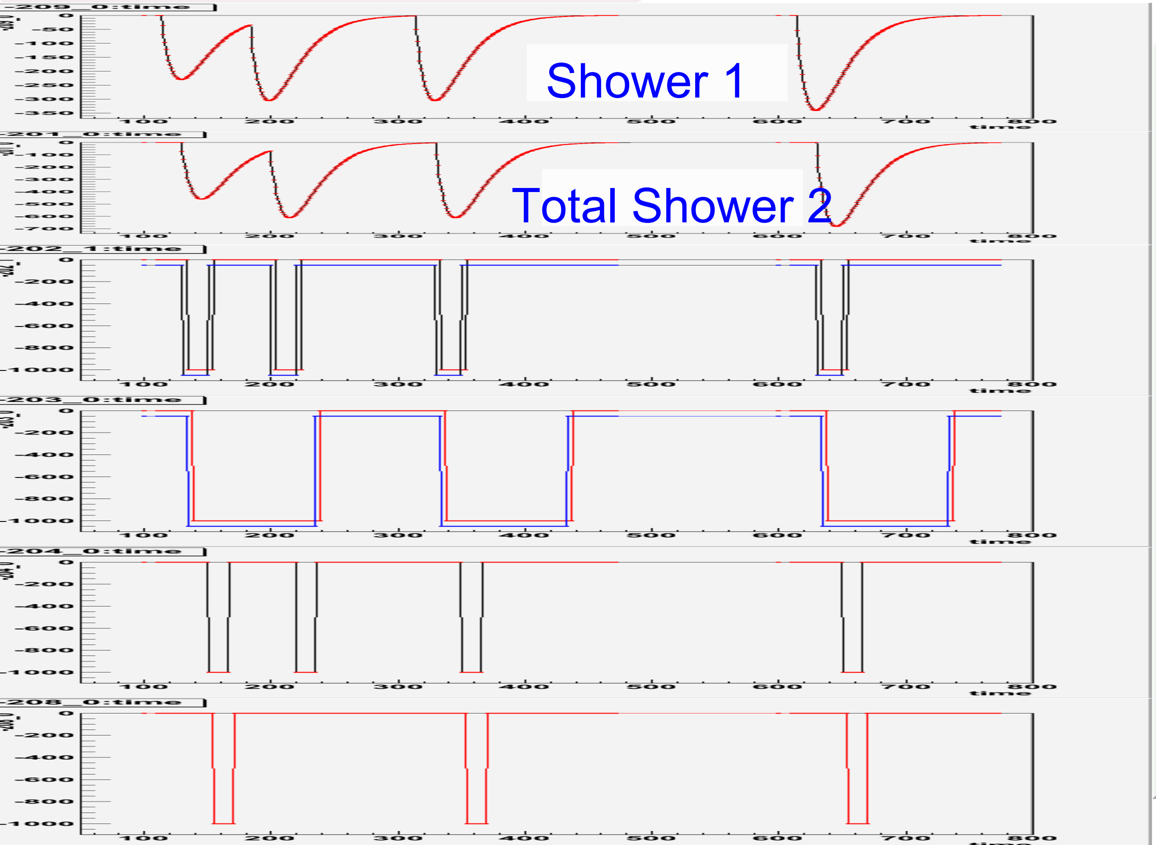
$A_{raw} = -128.57\text{ppm}$

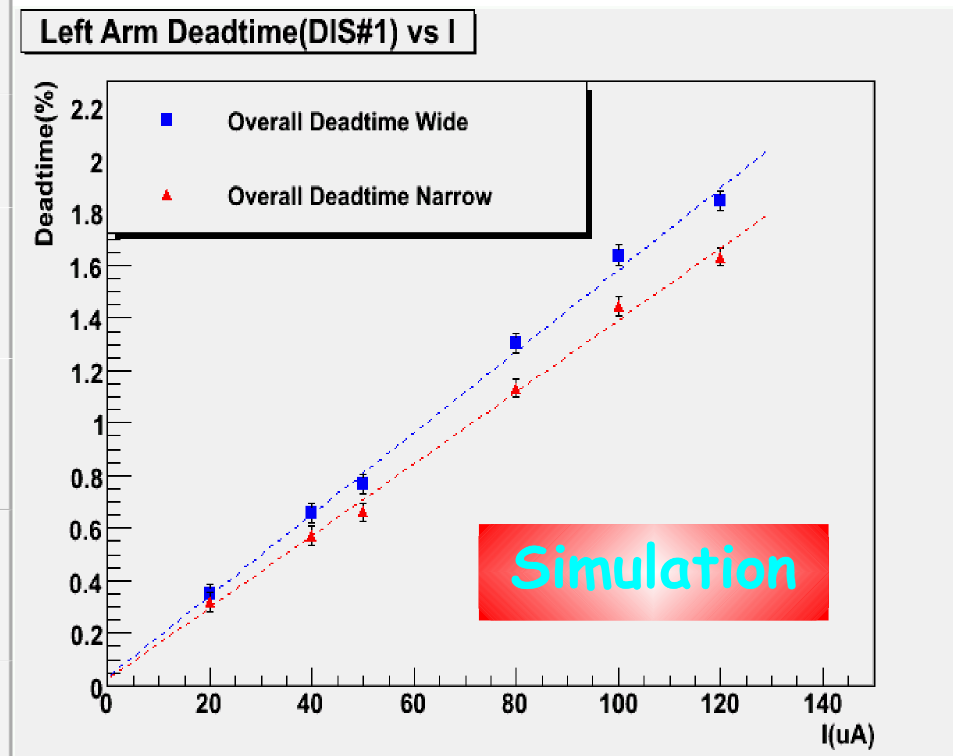
$A_{dit} = -128.52\text{ppm}$

$A_{reg} = -128.87\text{ppm}$

Blinded

DAQ Deadtime Correction from Timing Simulation





@100uA	RES #3	RES #4	RES #5	RES #7	DIS #1	DIS #2
Narrow	1.48%	2.22%	2.06%	0.73%	1.45%	0.89%
Wide	1.68%	2.62%	2.36%	0.80%	1.64%	0.93%

Timing simulation checked with FADC, TDC, pulser…

Uncertainty: take 30% relative

Correction Due to Pion Contamination

(work of K. Pan and D. Wang)

Pion asymmetry is observed to be non-zero:

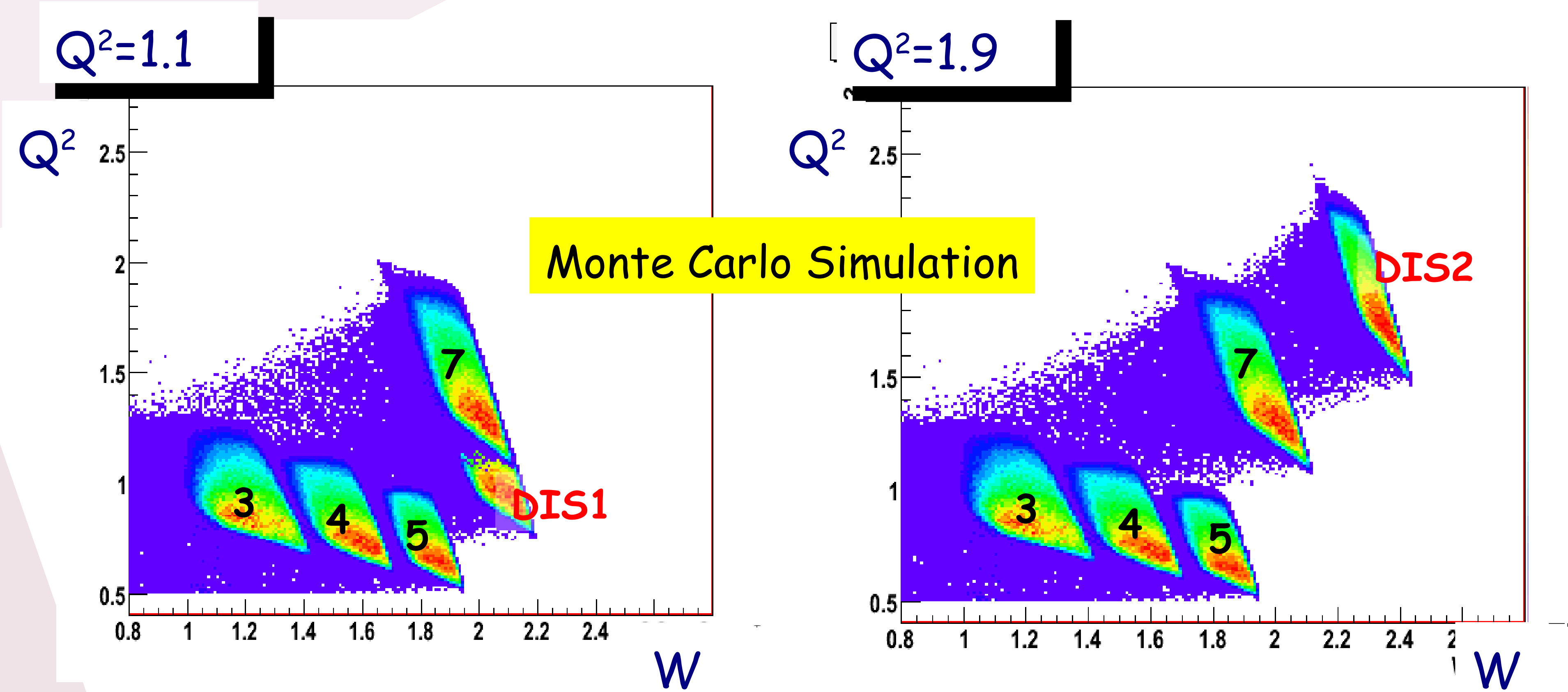
	Left Kine#1	Left Kine#2	Right Kine#2
$A\pi$ narrow (ppm)	-48.01(7.54)	-14.00(14.89)	-9.51(4.22)
electron fraction	0.56 (0.16)	0.04(0.04)	0.011(0.001)
$A\pi$ corrected (ppm)	-30.85(12.84)	-8.91(16.31)	-8.04(4.27)

Pion correction uncertainty is the combination of:

$$\frac{\Delta A_e}{A_e} = \Delta f \oplus f \frac{\Delta A_\pi}{A_e}$$

	Kine#1	Kine#2
Correction to Ae	1.00019(0.00014)	1.00024(0.00003)

Corrections for Resonance Background



- Implemented in MC: ionization loss, internal+ext. brem
- Measured resonance PV asymmetries (10-15% stat.) to constrain inputs of two resonance PV models: Delta agree at 2σ, 2^{nd} and 3^{rd} resonances agree within 1σ.
- Corrections to A DIS: ~(2±2)% (1.1 GeV^2); (2±0.4)% (1.9 GeV^2)

Corrections and Uncertainties, Kine #1

blinding factor = -12.00665ppm

		Correction	Uncertainty
	Raw (Dithering) A_d (ppm)	-66.43	2.68
Run-by-Run	$\Delta P_b/P_b$	13.4%	2.0%
	Deadtime correction	1.49%	0.44%
	PID efficiency	0.048%	0.008%
Global	Radiative Correction	2.1%	2.0%
	Q^2	N/A	0.725%
	Transverse Asymmetry	N/A	0.55%
	Target Endcap	0.017%	0.003%
	False Asymmetry	N/A	0.16%
	Pair Production	0.025%	0.005%
	Pion Dilution	0.019%	0.014%
	Statistical (ppm)	3.15	
	Systematics	3.01%	

Corrections and Uncertainties, Left Kine #2

blinding factor = -12.00665ppm

		Correction	Uncertainty
	Raw (Dithering) A_d (ppm)	-128.48	10.43
Run-by-Run	$\Delta P_b/P_b$	12.0%	1.33%
	Deadtime correction	0.84%	0.25%
	PID efficiency	0.091%	0.013%
Global	Radiative Correction	1.9%	0.43%
	Q^2	N/A	0.575%
	Transverse Asymmetry	N/A	0.56%
	Target Endcap	0.023%	0.005%
	False Asymmetry	N/A	0.1%
	Pair Production	0.52%	0.052%
	Pion Dilution	0.025%	0.004%
	Statistical (ppm)	12.08	
	Systematics	1.64%	

Corrections and Uncertainties, Right Kine #2

blinding factor = -12.00665ppm

		Correction	Uncertainty
	Raw (Dithering) A_d (ppm)	-128.56	6.58
Run-by-Run	$\Delta P_b/P_b$	12.7%	1.69%
	Deadtime correction	0.86%	0.25%
	PID efficiency	0.161%	0.018%
Global	Radiative Correction	1.9%	0.43%
	Q^2	N/A	0.640%
	Transverse Asymmetry	N/A	0.56%
	Target Endcap	0.023%	0.005%
	False Asymmetry	N/A	0.03%
	Pair Production	0.48%	0.048%
	Pion Dilution	0.024%	0.002%
	Statistical (ppm)	7.67	
	Systematics	1.96%	

Preliminary Asymmetries Compared with Calculation

x_{bj}=0.241, Q^2=1.085 GeV^2: Ad=-92.27 ±3.15 (stat.) ± 2.77 (syst) ppm

x_{bj}=0.295, Q^2=1.901 GeV^2: Ad=-163.60 ± 6.48 (stat.) ± 3.05 (syst) ppm

Still missing: γ-Z box corrections (1% for E158)

Preliminary

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

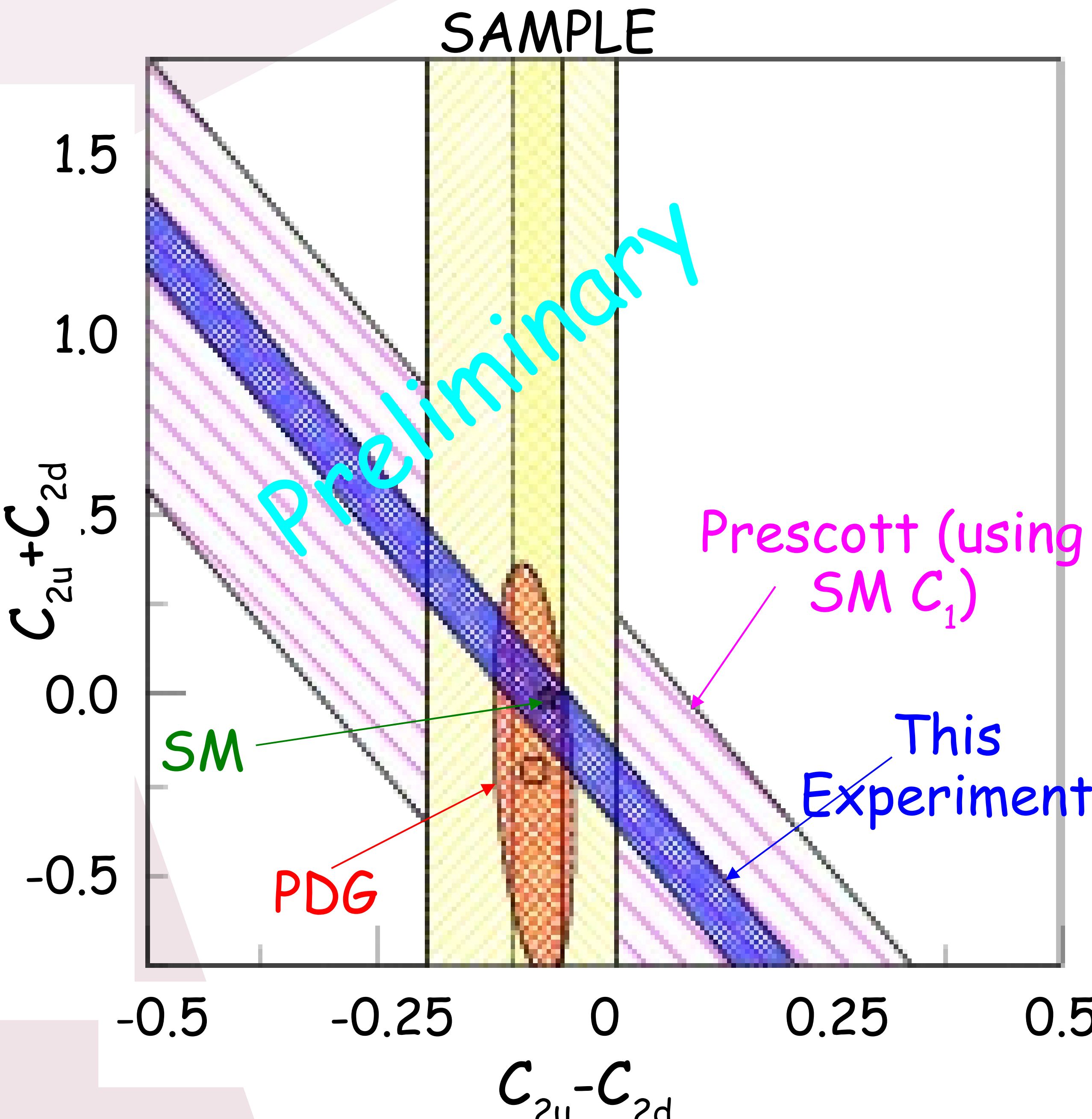
Q^2=1.085	x=0.241				
F_2^{γ}, $F_2^{\gamma Z}$, $F_3^{\gamma Z}$	"static (quark model) limit"	CTEQ/ JLab (NLO)	MSTW2008 LO+QPM	**MSTW2008 NLO+QPM**	MSTW2008 NNLO+QPM
A(C_1 term)	-83.15	NA	-83.69	**-84.32**	-84.35
A(C_2 term)	-5.58	NA	-4.60	**-4.74**	-4.78

Q^2=1.901	x=0.295				
F_2^{γ}, $F_2^{\gamma Z}$, $F_3^{\gamma Z}$	"static (quark model) limit"	CTEQ/ JLab (NLO)	MSTW2008 LO+QPM	**MSTW2008 NLO+QPM**	MSTW2008 NNLO+QPM
A(C_1 term)	-145.65	-147.74	-146.58	**-147.09**	-147.05
A(C_2 term)	-14.59	-13.62	-13.12	**-13.41**	-13.50

Current Extraction Method

- Use MSTW2008 NLO, 3-flavor PDF to construct F_2^{γ} and $F_{1,3}^{\gamma Z}$ in the quark-parton model. Different methods differ by no more than 0.5% in the a_1 term and 2% in the a_3 term.
- Use $C_{1,2}$ from J. Erler: evaluated at measured Q^2, preliminary γ-Z box correction included.
- run α(EM) to measured Q^2 to account for vacuum pol.
- HT correction to a_3 is estimated but not applied.
- Corrections not done: γ-γ box (denominator), interference between Z and γ-γ box (numerator). This correction is about 1% for E158. Using 1% for PVDIS for now.
- Subtract the calculated a_1 term from the measured asymmetry, and compare the rest with the calculate a_3 term.

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



Using SM C_1 term
(if 1σ 4% from Qweak, ~2σ here)

Assuming no HT

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

(compared to PDG ±0.24 → factor of 4.6153846)

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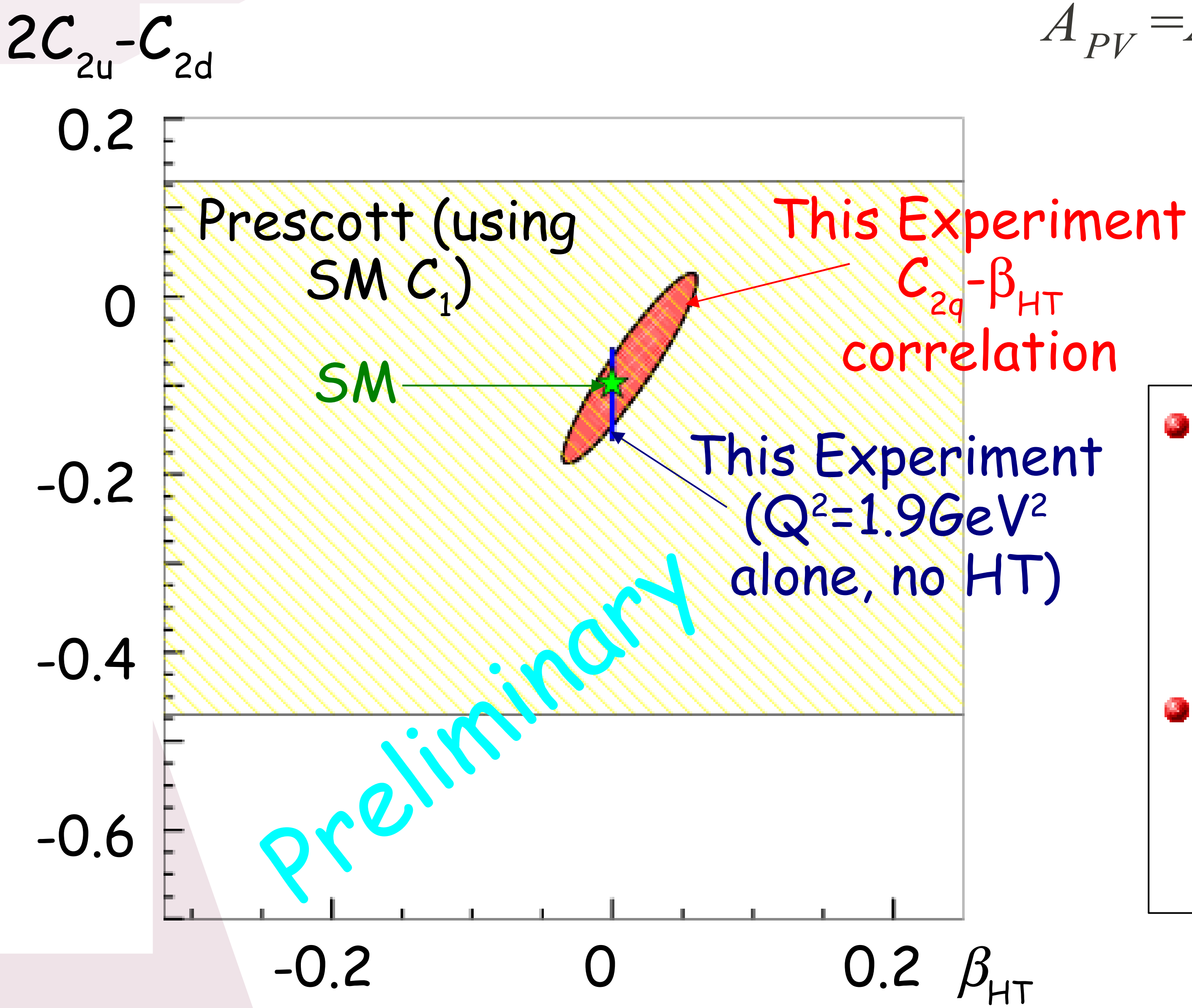
Preliminary C_{2q}- β_{HT} Correlation from Q^2=1.1 and 1.9 GeV^2 Combined

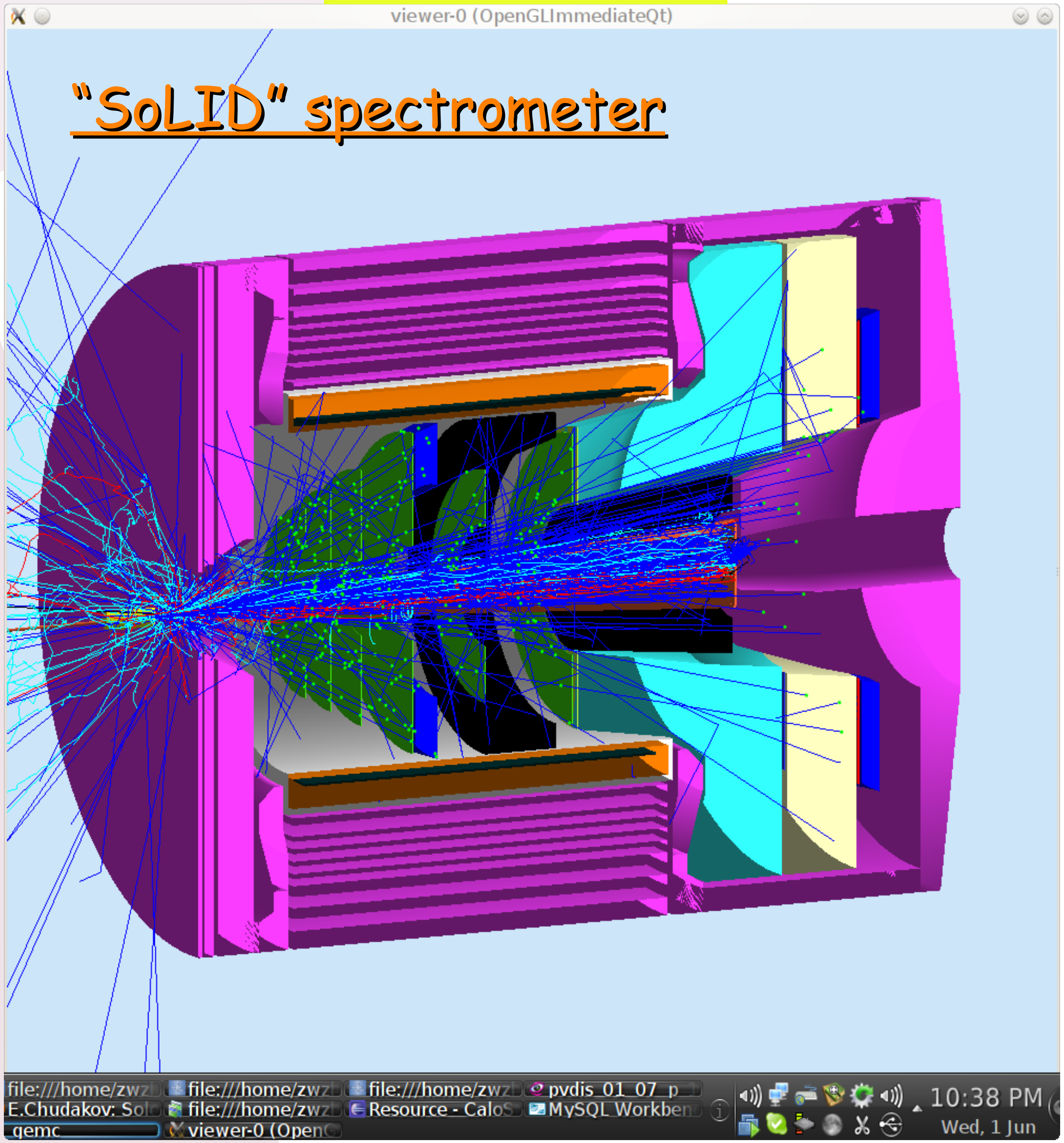
$$A_{PV} = A_{PV}^{EW}\left(1+\frac{\beta_{HT}}{(1-x)^3 Q^2}\right)$$

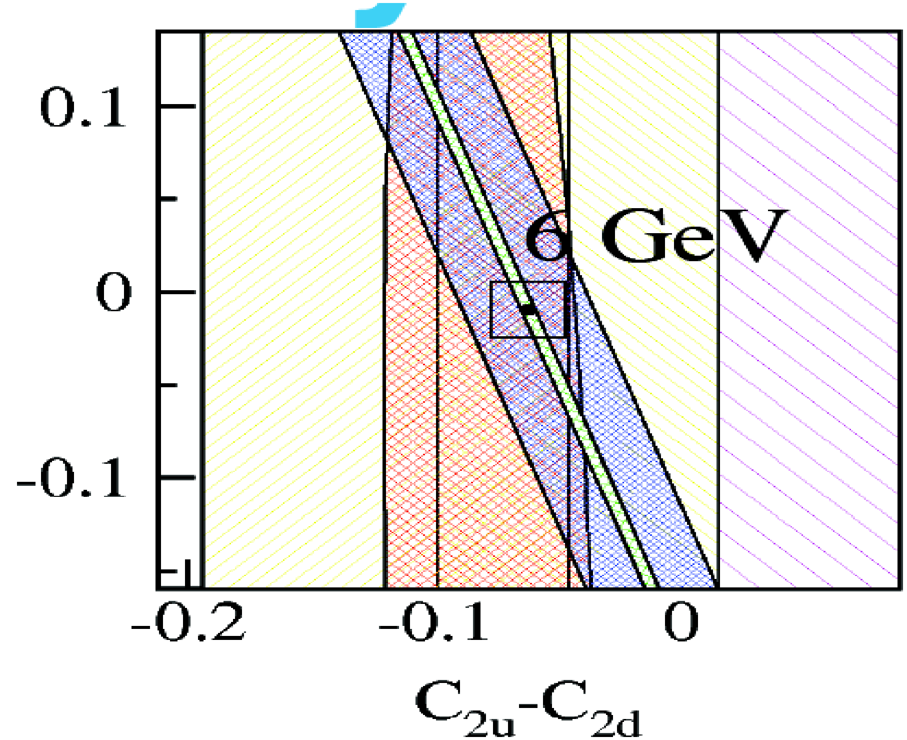


- No obvious Q^2 dependence (HT) at the 6 GeV precision.
- If using 1.1 GeV^2 point to extract $C_2 \rightarrow$ 10% better.

Coherent PVDIS Program with SoLID @ 11 GeV

A 20M$ device



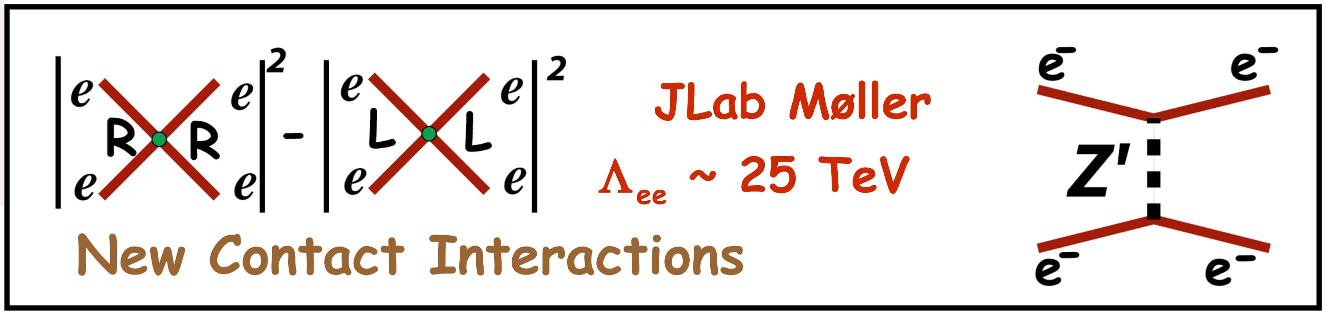


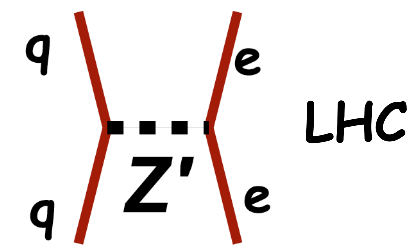
SoLID Physics topics:

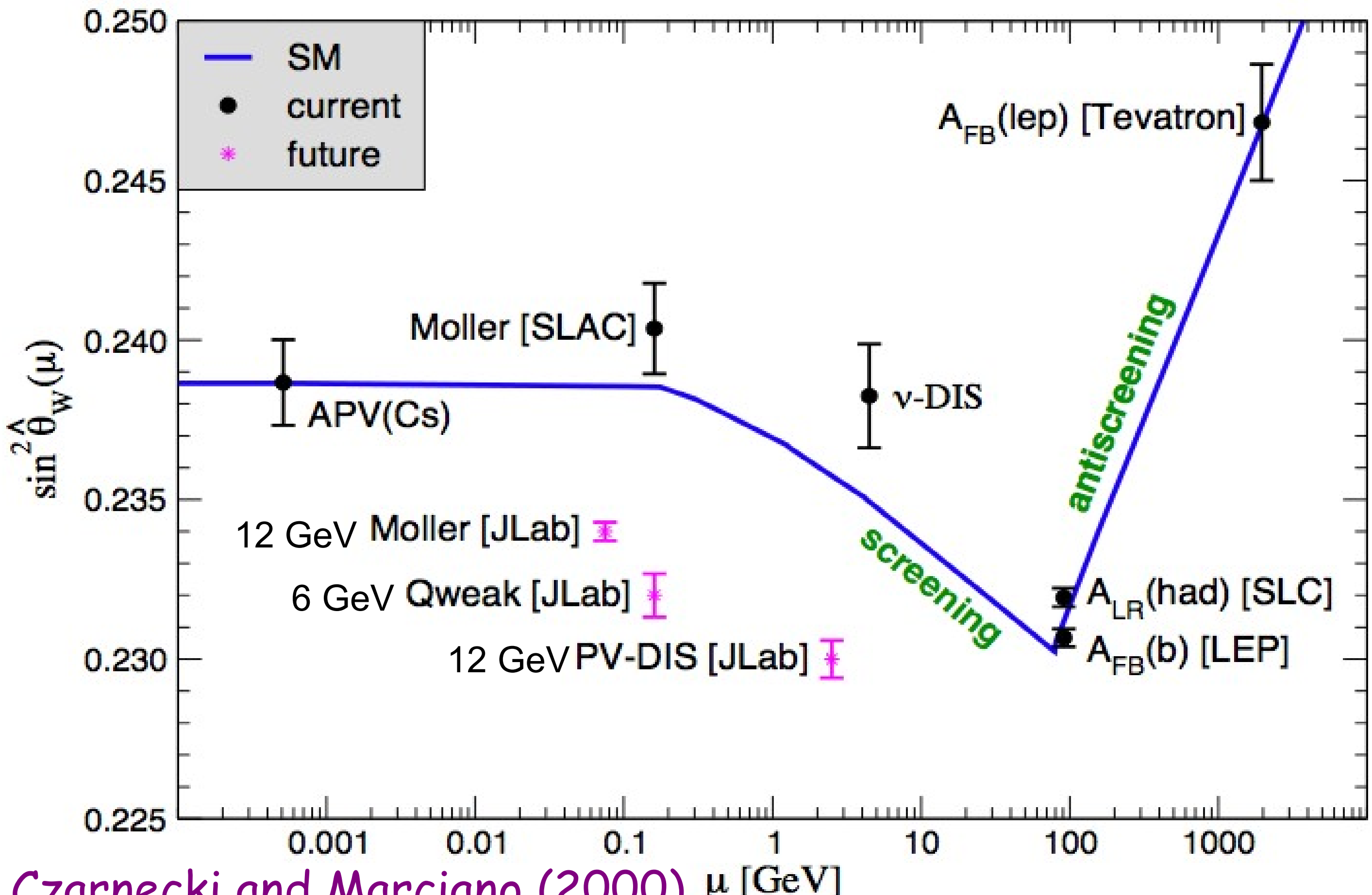
- PVDIS deuteron (180 days) – C_2, $\sin^2\theta_W$, CSV, diquarks,
- PVDIS proton (90 days) – d/u
- PV with $^3\vec{He}$ (LOI)
- SIDIS – transversity, TMD, A1(?): $^3\vec{He}$ (125 days), $\vec{NH_3}$ (Cond.)

Møller Parity-Violating Experiment: New Physics Reach

(a large installation experiment with 11 GeV beam energy)







Czarnecki and Marciano (2000)
Erler and Ramsey-Musolf (2004)

- Expected precision comparable to the two most precise measurements from colliders, but at lower energy.
- No other experiment with comparable precision in the forseeable future!

Summary and Perspectives

Preliminary Results:

- C_{2q} seems to agree with the SM, and non-zero by 3 sigma;
- higher order radiative corrections still need to be applied.

"New construction" experiments at JLab 12 GeV:

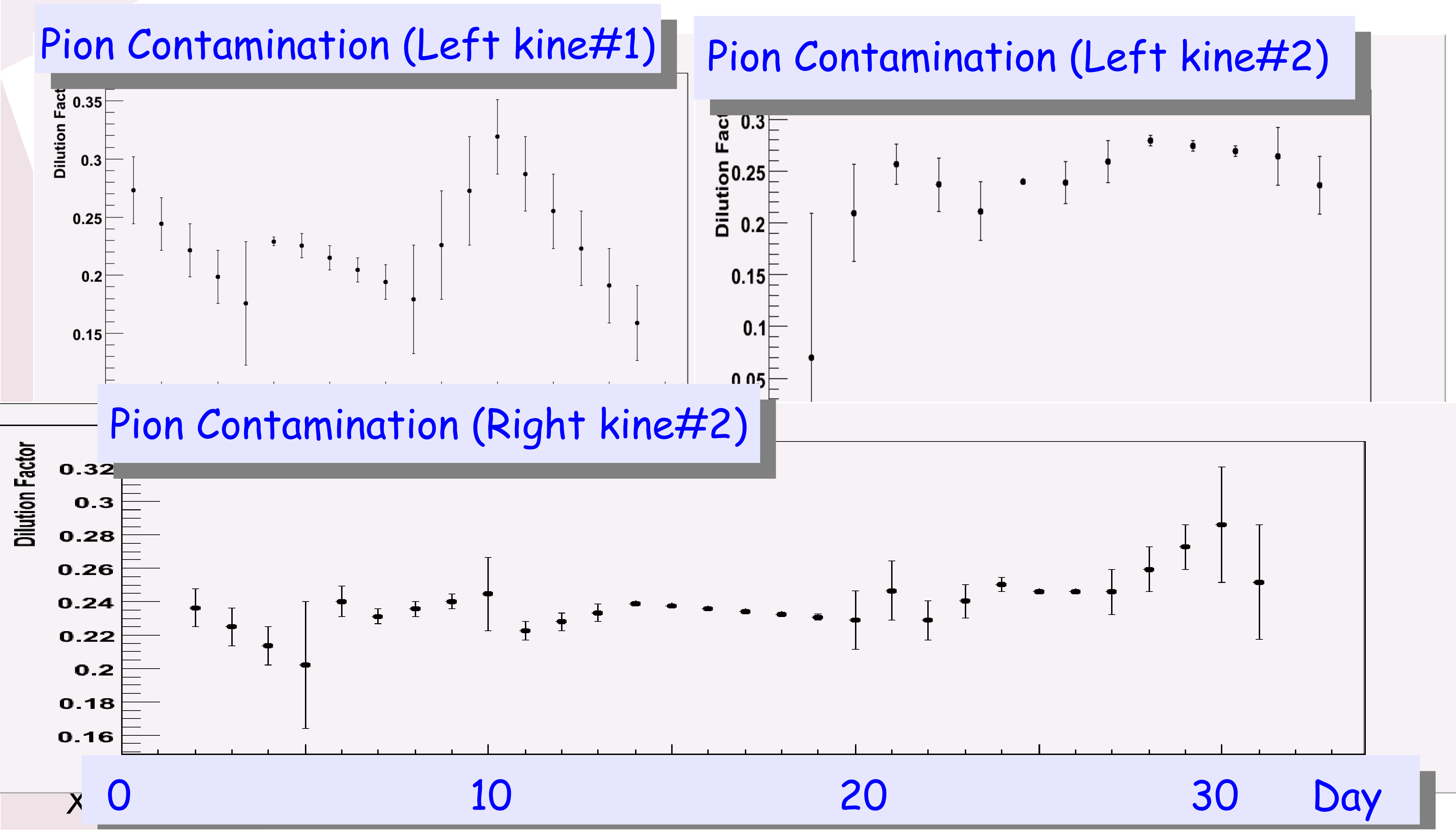
- PVDIS @ 11 GeV (SoLID)
- Moller @ 11 GeV

- Thanks to our postdocs and graduate students for their hard work.
- And our theorists friends for useful discussions.

Run-by-Run PID Analysis

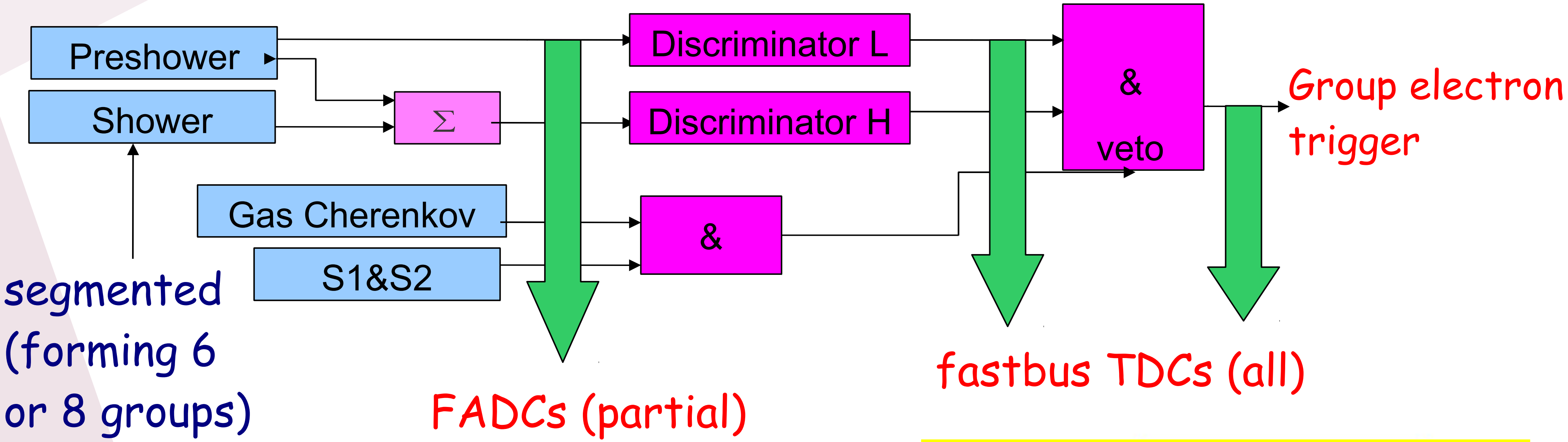
(work of K. Pan)

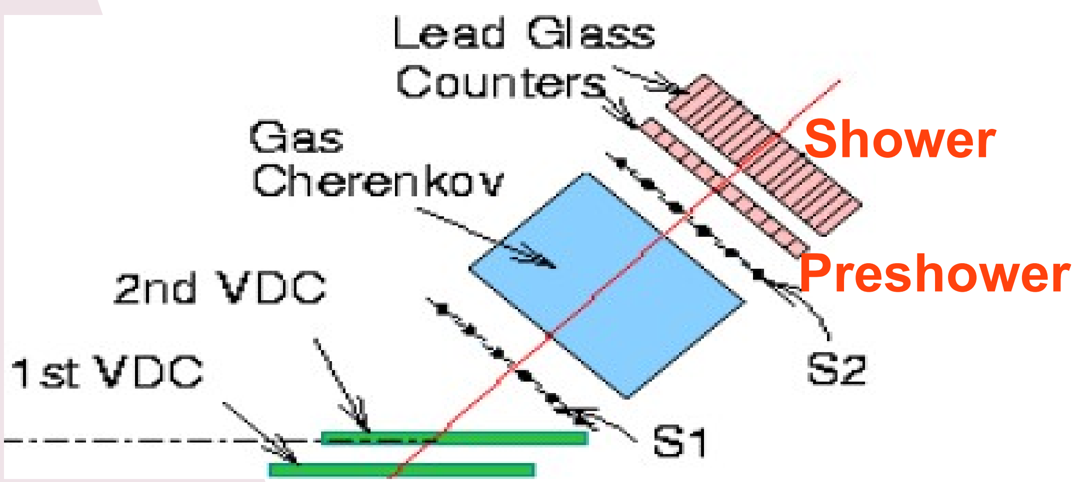
$$f=\left(\frac{\pi}{e}\right)_{e\ \ counter}=\frac{R_{\pi}\eta_{rej}^{\pi\ \ triggers\ \ e\ \ counter}+R_e\times T_{VETO}\times\eta_{eff}^{e\ \ triggers\ \ GC}\times R_{\pi}\eta_{eff}^{\pi\ \ triggers\ \ LG}}{R_e\eta_{eff}^{e\ \ triggers\ \ e\ \ counter}}$$

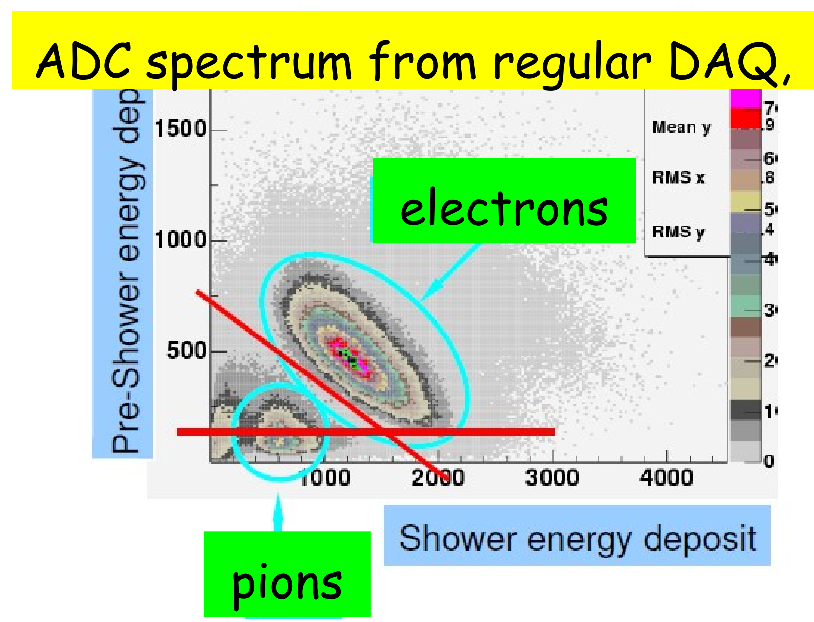


Scaler-Based Counting DAQ with online (hardware) PID

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







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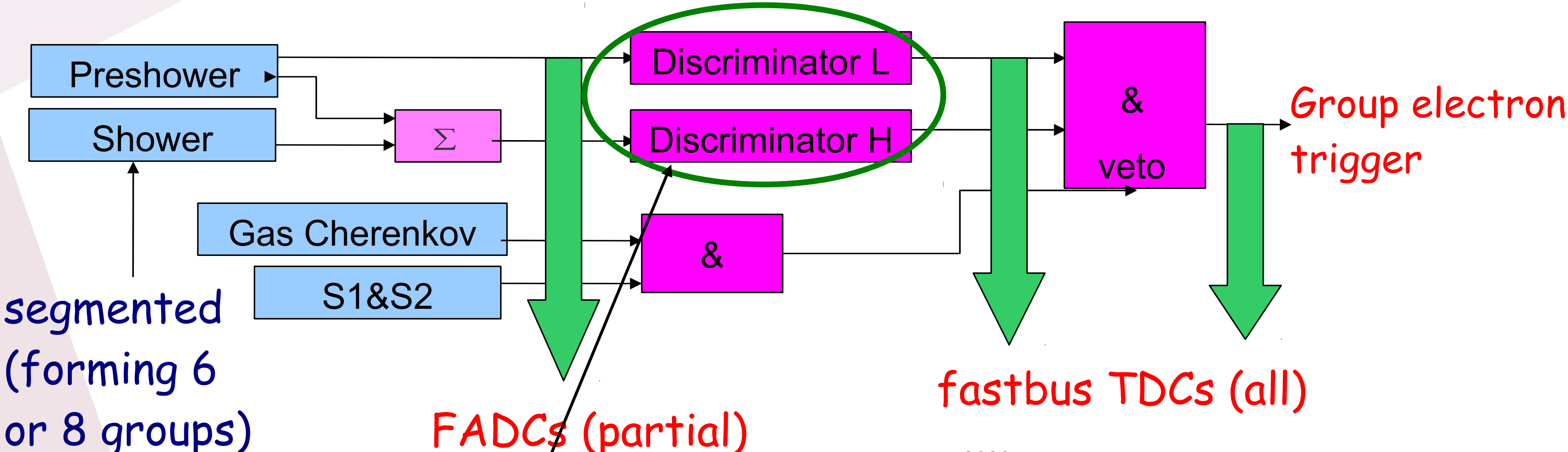
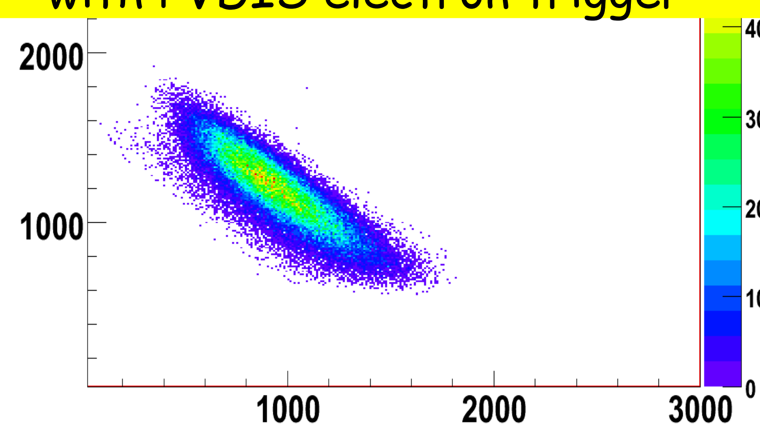


Two identical DAQ paths with known discriminator width (30ns, 100ns), for deadtime study

ADC spectrum from regular DAQ, with PVDIS electron trigger



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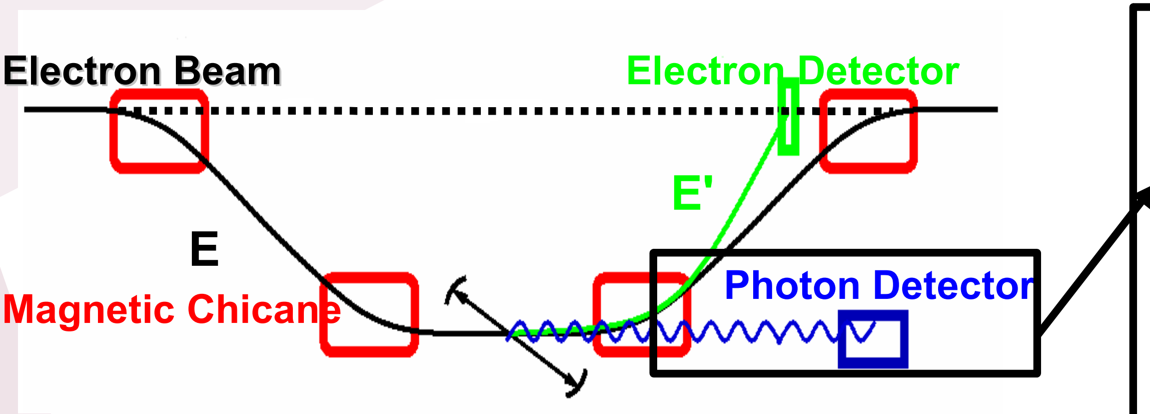
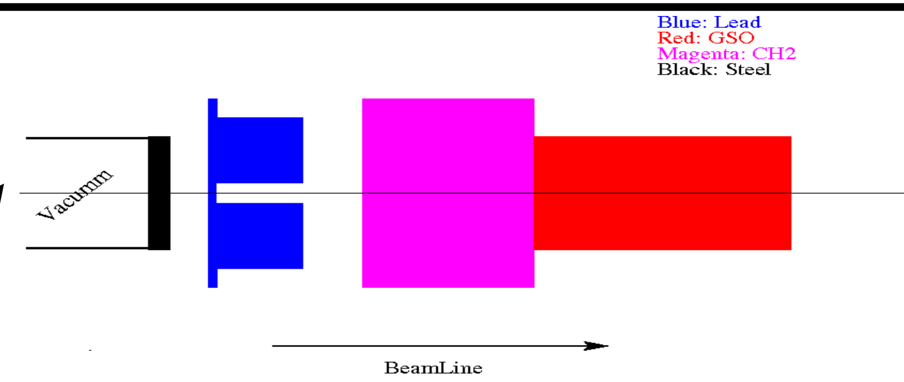
Compton Analyzing Power (work of D. Wang)





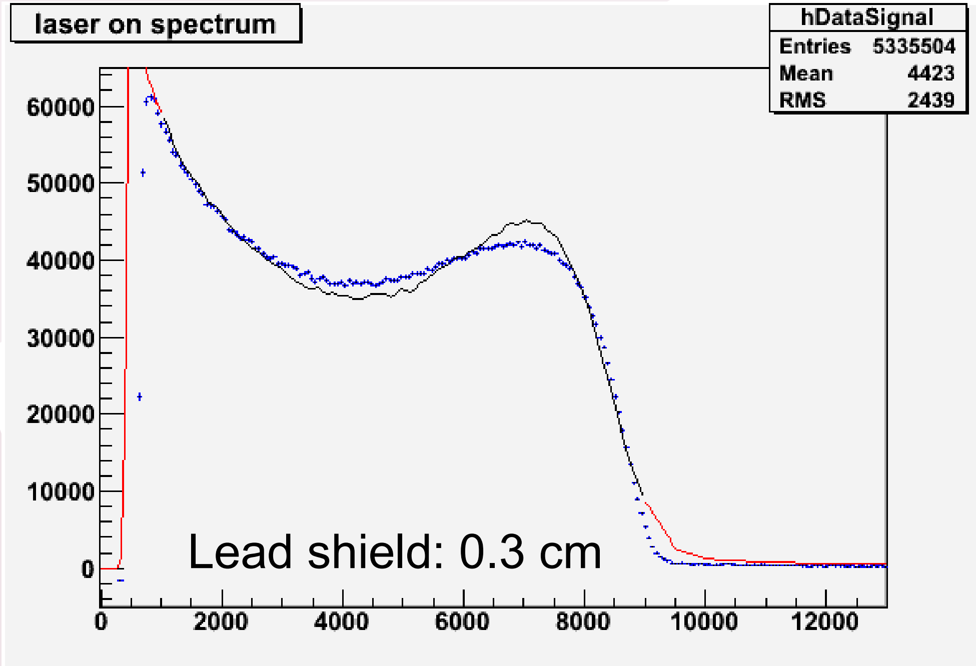
Vacuum End Cap(steel): 0.05cm
Lead shielding thickness: 0.3 cm
Collimator: inner radius 0.5cm
outer radius 4.0 cm, length 5.0 cm
CH2: radius 5.0 cm, length 10.2 cm
GSO: radius 3.0 cm, length 15.0 cm

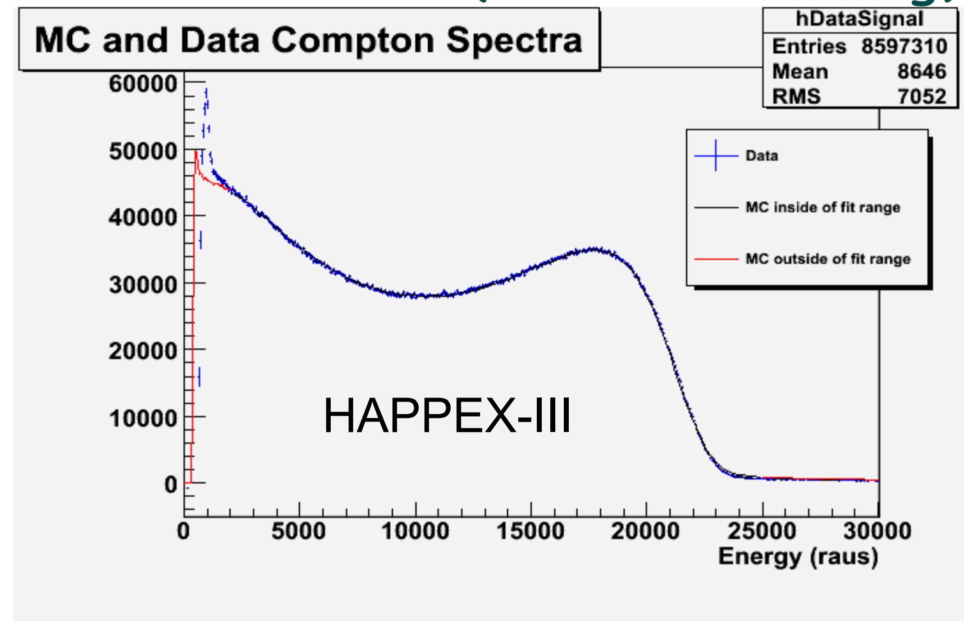
GEANT4 MC to calculate A_{th}

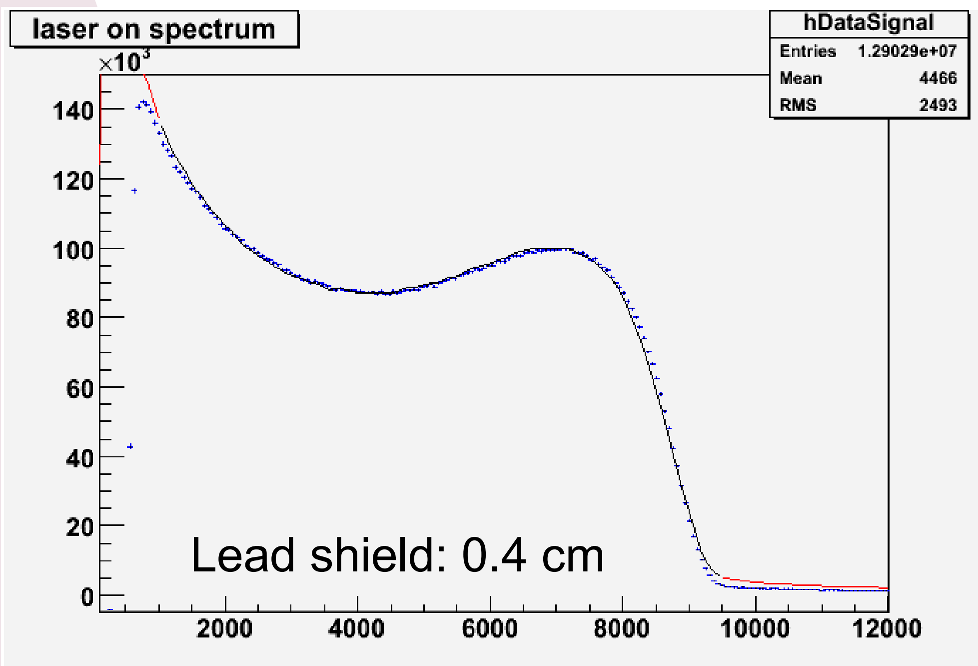
Inputs to the simulation:

- The experimental setup:
  - →Shielding, alignment.....
  - →Thickness of the lead shielding
  - → Radius of the hole of the collimator
- Detector resolution, smearing
- Pileup Effect
- PMT nonlinearity

Compton Analyzing Power (work of D. Wang)







Blue: data

Red, black: simulation

0.3cm: <Ath> = 0.04883

0.4cm: <Ath> = 0.04970

So Δ<Ath> = ±1.75% (relative)

DAQ Deadtime Correction

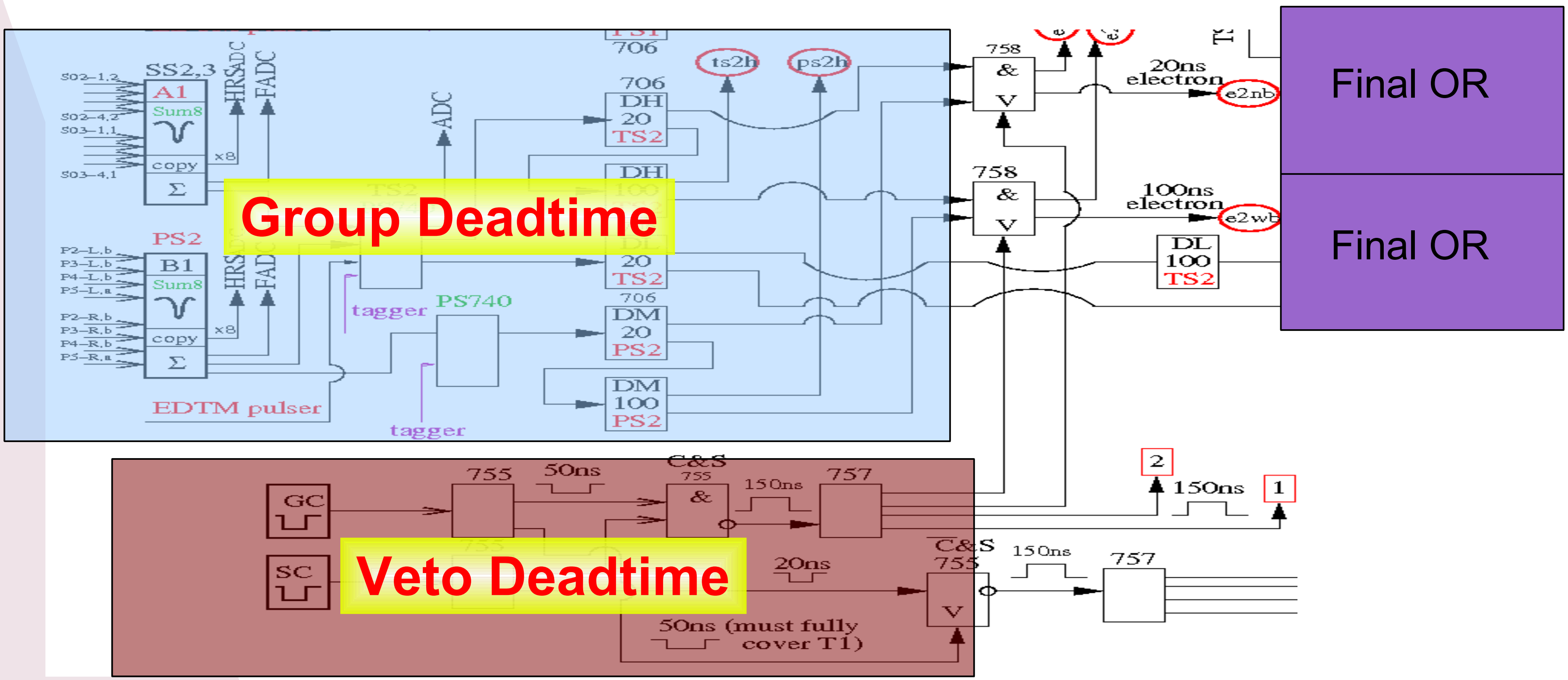
(work of D. Wang)

Deadtime correction to asymmetry:

$A_{measured} = A_{phys}$ (1 – deadtime loss)

Deadtime Decomposition:

- Group Deadtime: proportional to group rate; narrow/wide.
- Veto Deadtime: T1/GC rate; the same for all groups.
- Final OR.
- Overall Deadtime: Veto DT + Group DT + Final OR DT



DAQ Timing Simulation (HATS)

(work of D. Wang)

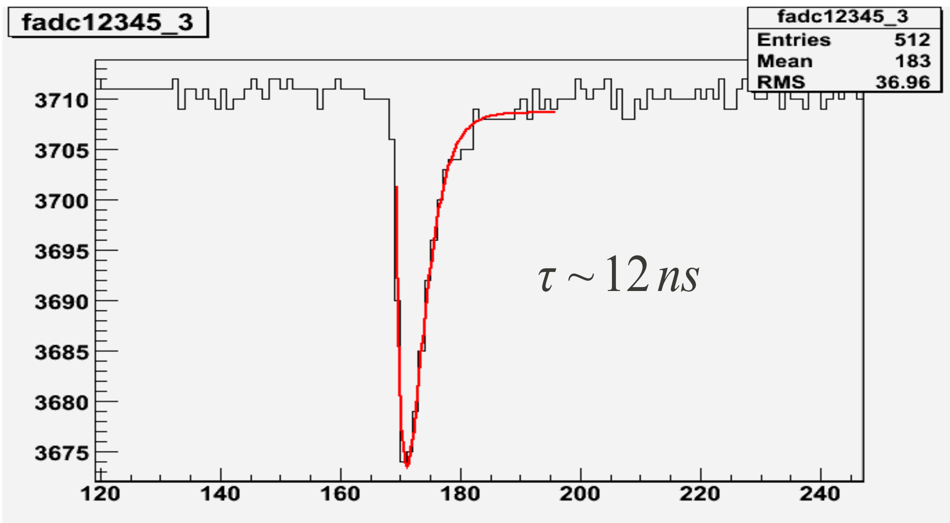
Inputs:

1) Signal amplitude and shape (from data)

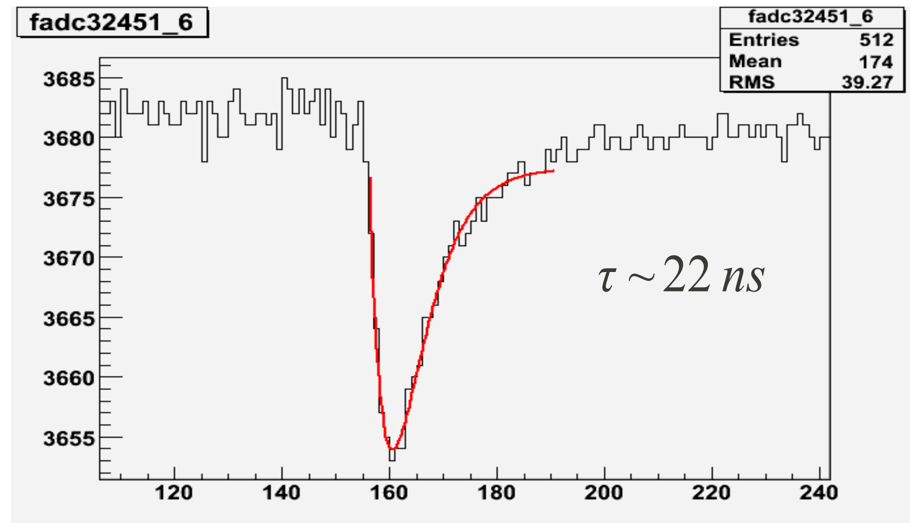
2) Rates and position-dependence (from data)

3) DAQ electronic diagram, model spec., cable delays... ...

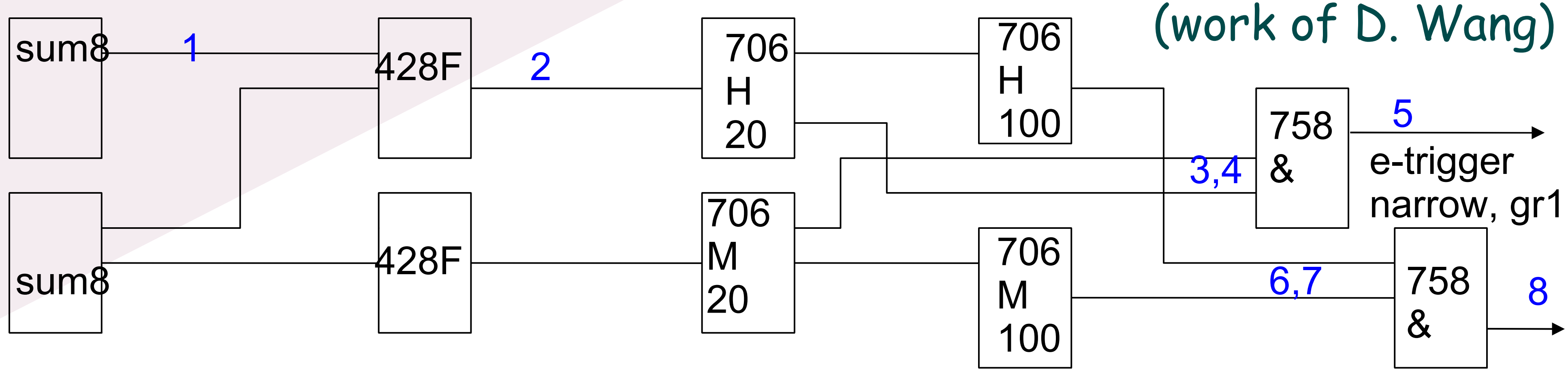
Right arm preshower PMTs:

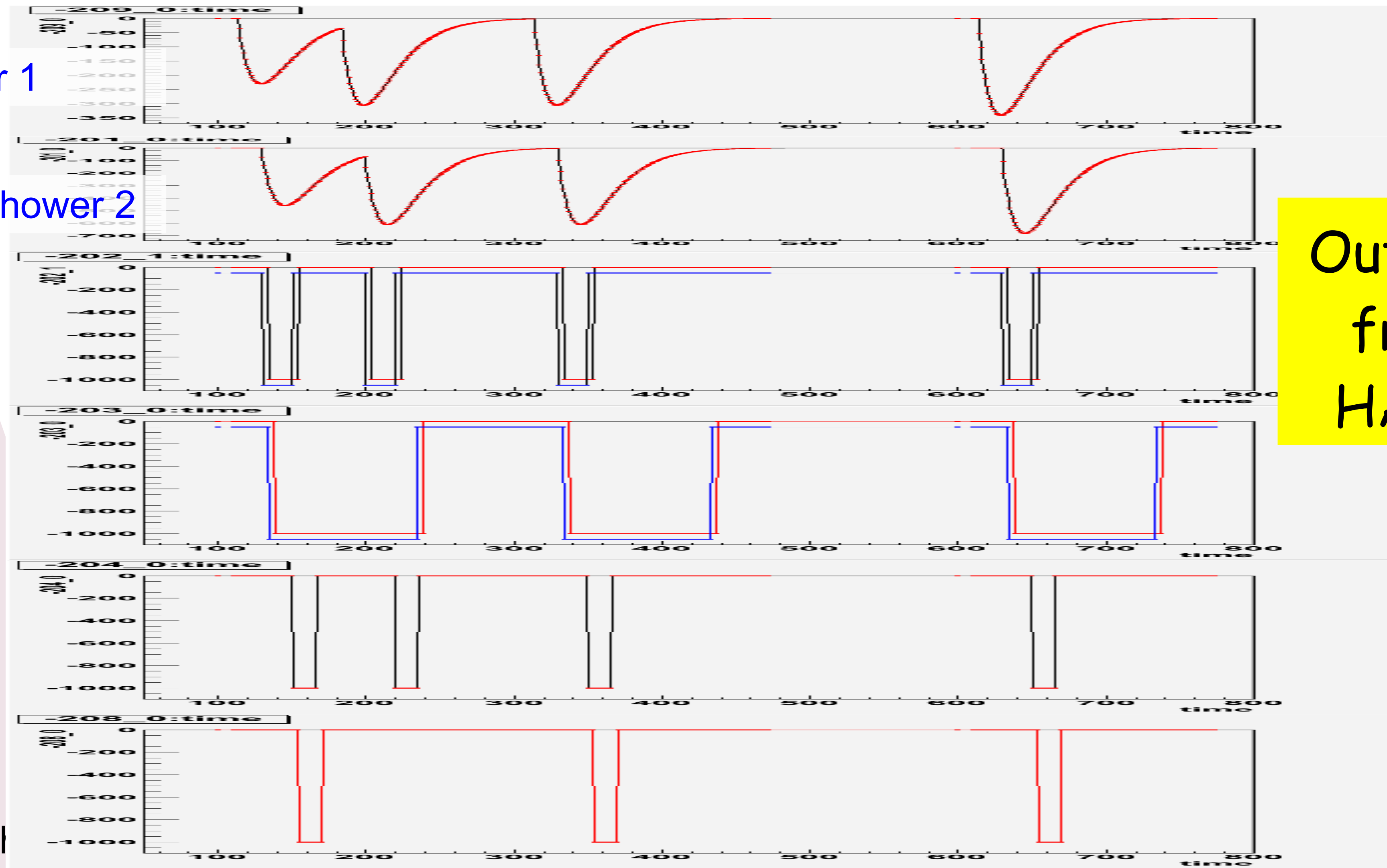


All Other Leadglass PMTs:



(work of D. Wang)





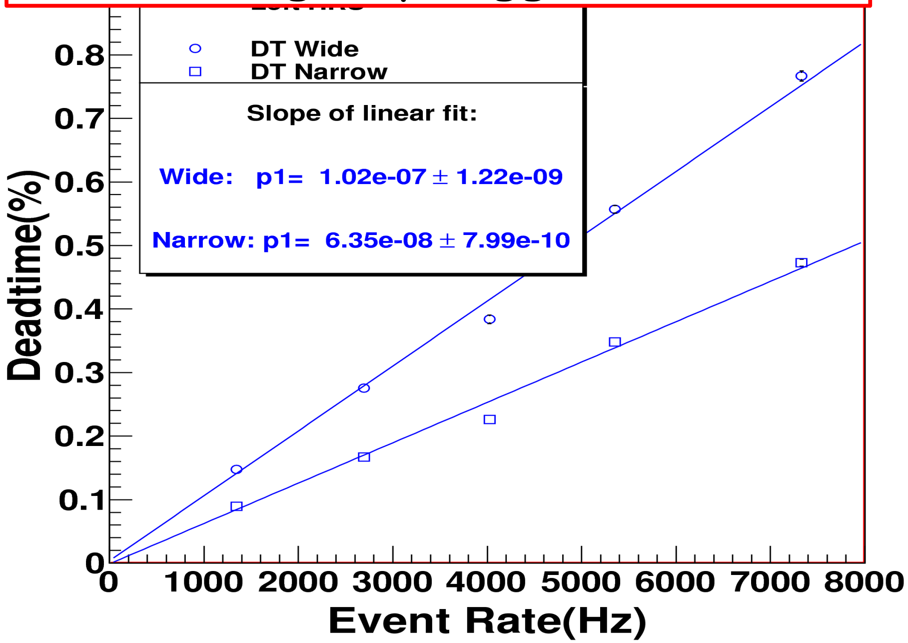
Outputs from HATS

(work of D. Wang)

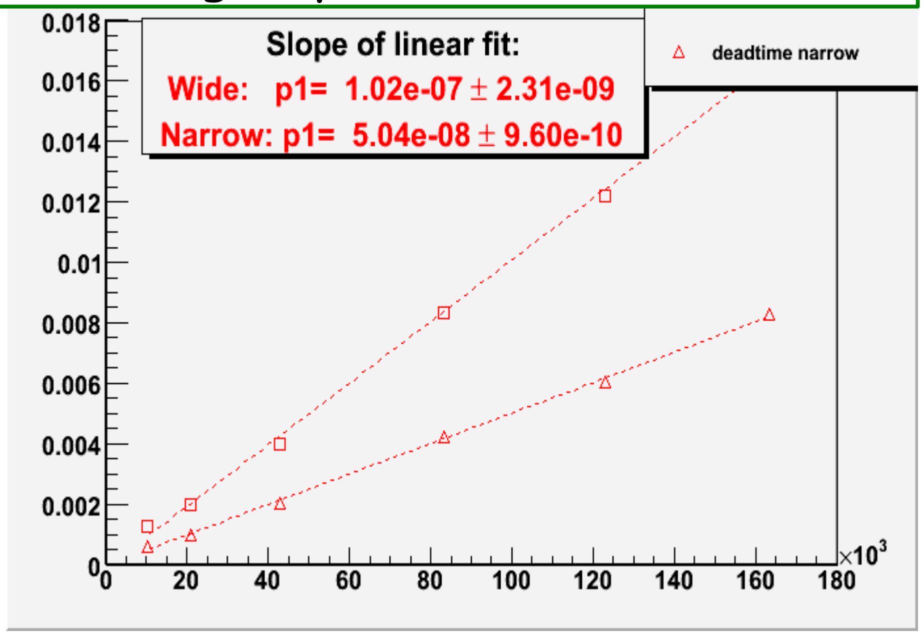
Deadtime Decomposition:

- Group DT: measured by "tagger" data

HRS group tagger data



HRS group HATS (simulation)

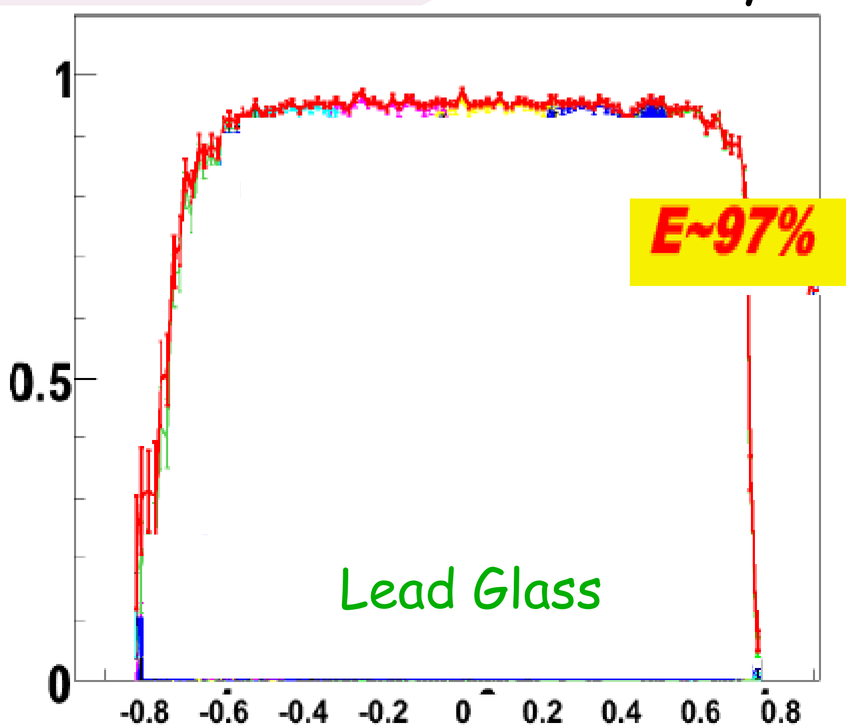


- Veto DT: Using FADC data as input/proof;
- OR (final) DT: no direct data, but can estimate in theory reliably.

PID Performance – Single Run

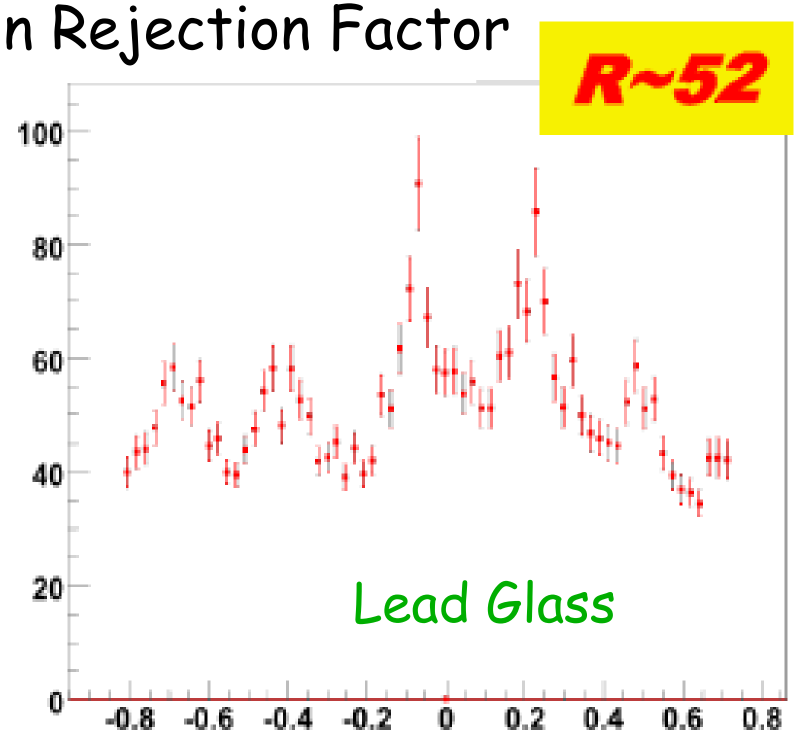
(work of K. Pan)

Electron Detection Efficiency



Vertical hit position [m]

Pion Rejection Factor



Vertical hit position [m]

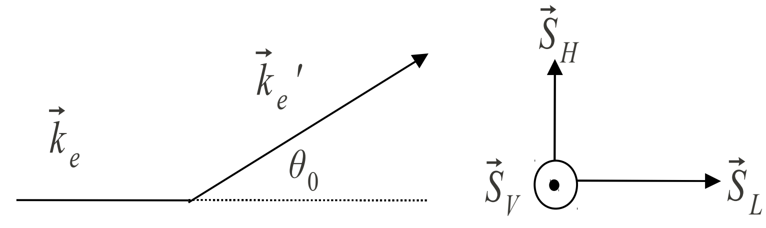
Affects measured asymmetry (Q^2) if it varies over the acceptance or if there are "holes"

<u>We extract detector efficiencies from VDC-on runs, which were taken daily</u>

Transverse Asymmetry Background

(work of K. Pan and D. Wang)

- Transverse Asymmetry:



$\vec{S}_e \cdot [\vec{k}_e \times \vec{k}_e{}']$

Correction to Ad:

$A_T^{pure\ \ transverse}$

$$\frac{A_T}{\sin\theta_0} \cdot \left[S_H \cdot \sin\theta_{tr} - S_v \cdot \sin\theta_0 \cdot \cos\theta_{tr} \right]$$

- Measured: -24.15 +/- 15.05 ppm (Kine #1)
  23.49 +/- 44.91 ppm (Kine #2)

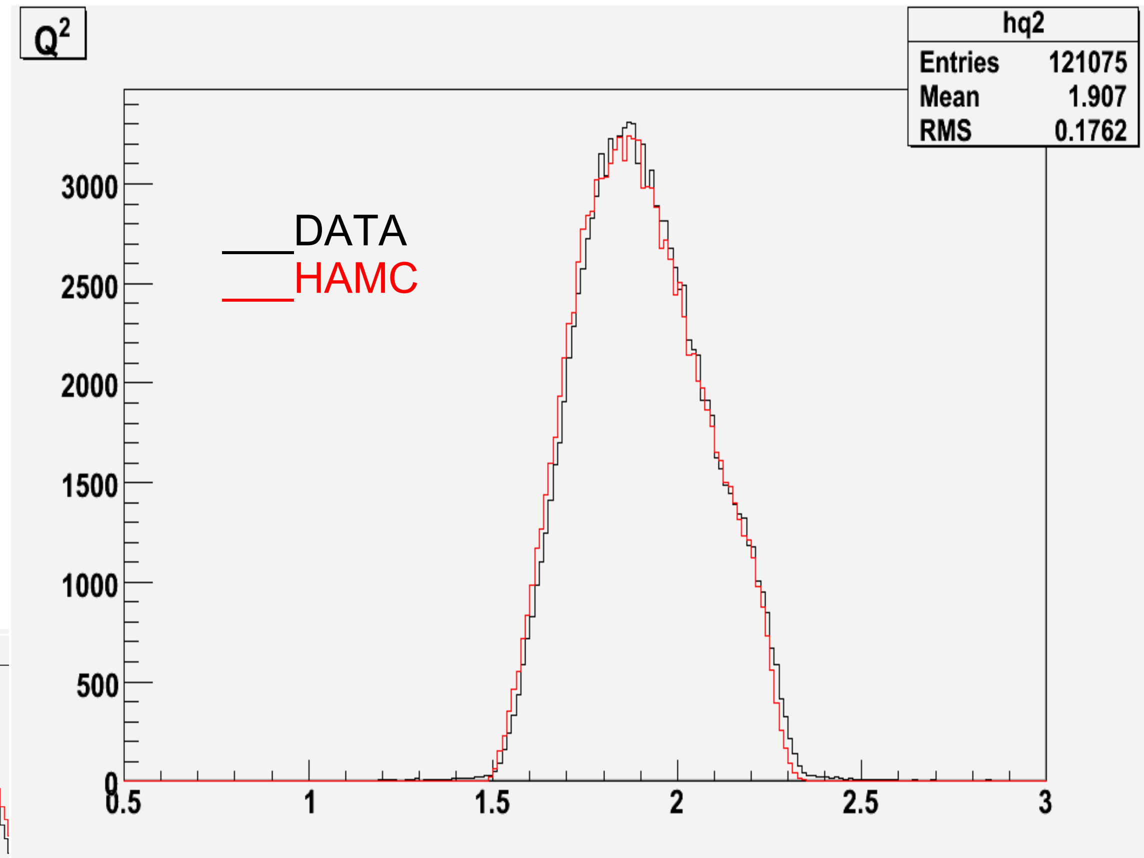
θ_{tr} very small, $S_V < 2\%$, $S_H < 20\%$

Systematic Error due to Transverse Asymmetry:

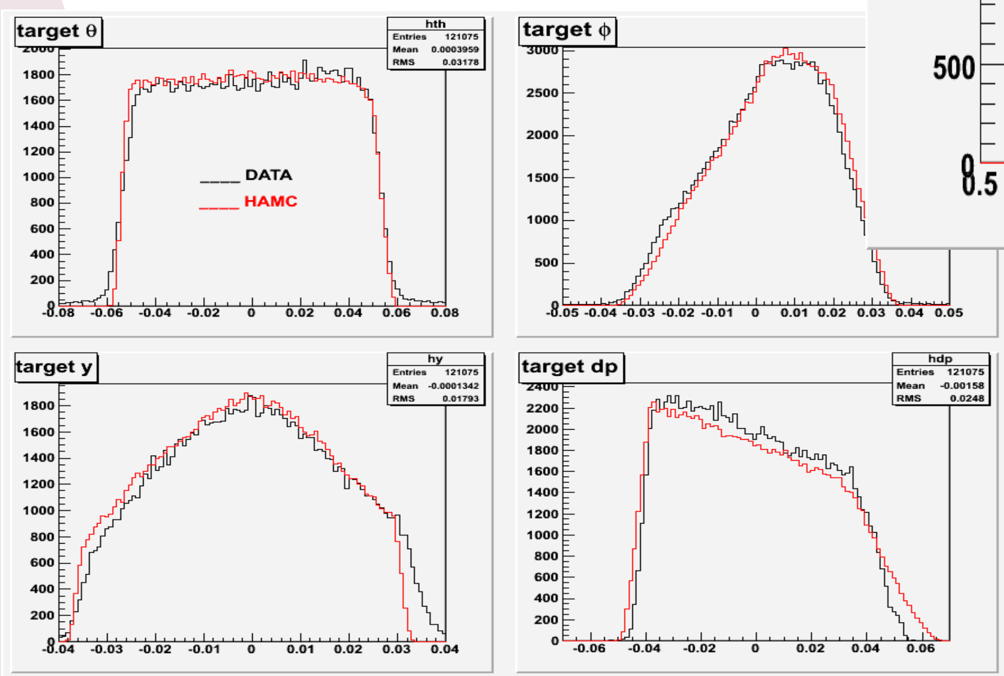
0.55% (Kine #1)
0.56% (Kine #2)

Hall A Monte Carlo

(work of D. Wang)



Basic checks of HAMC:



$$Q^{2}{}_{data} = 1.907$$

$$Q^{2}{}_{hamc} = 1.896$$

EM Radiative Corrections

(work of D. Wang)

Two theory calculations for Apv in the resonance:

- Lee/Sato: Delta(1232) only
  - Current: D=n+p
  - On-going: with wavefunctions – for separate publication
- M. Gorshteyn (Indiana)
  - whole resonance
  - isospin rotation p -> n
- Toy Model:

Latest Hall C RES fit

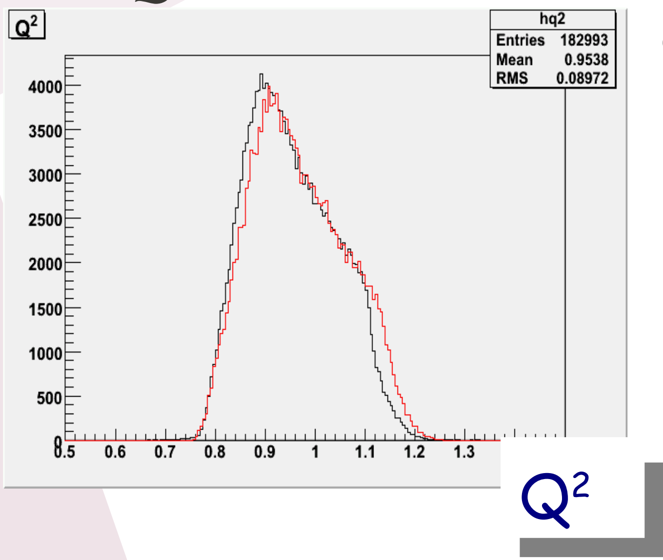
$$A^{RES} = A^{DIS\ \ formula} \frac{\sigma^{RES}}{\sigma^{DIS\ \ formula}}$$

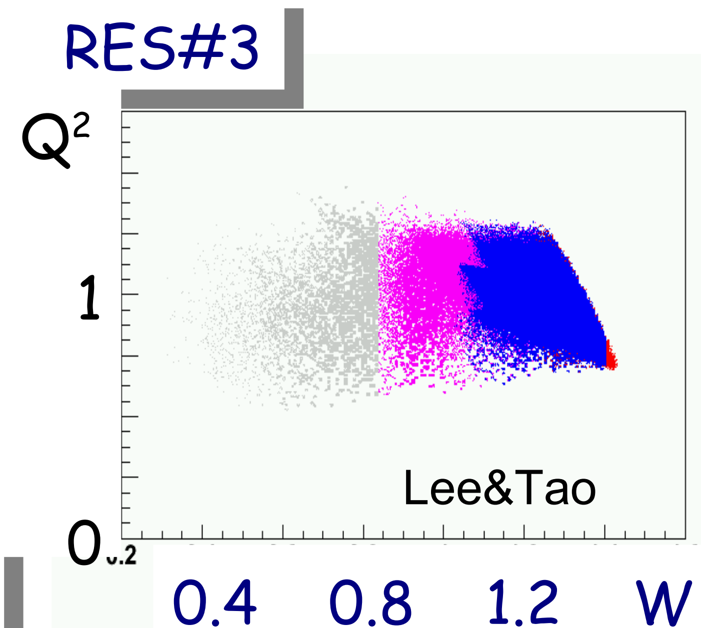
Res #3 - Delta (1232) (work of D. Wang)

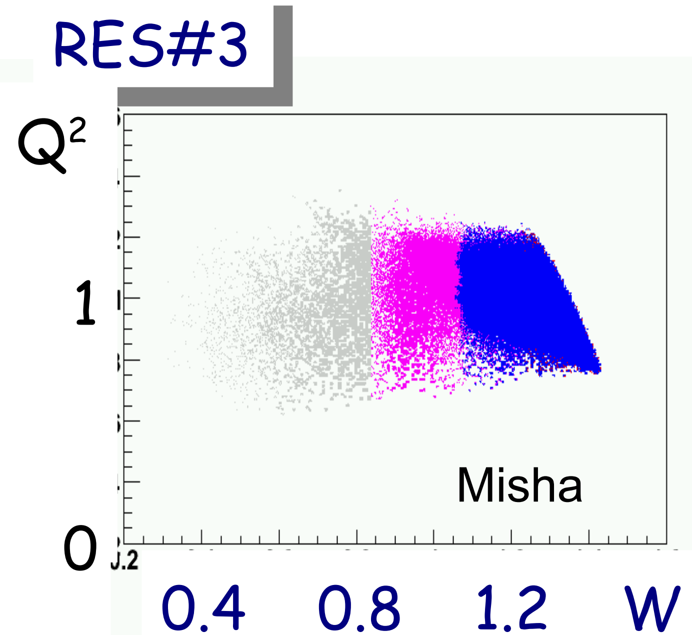
(Magnets Mistuned)

$Q^{2}{}_{data} = 0.954$

$Q^{2}{}_{hamc} = 0.968$



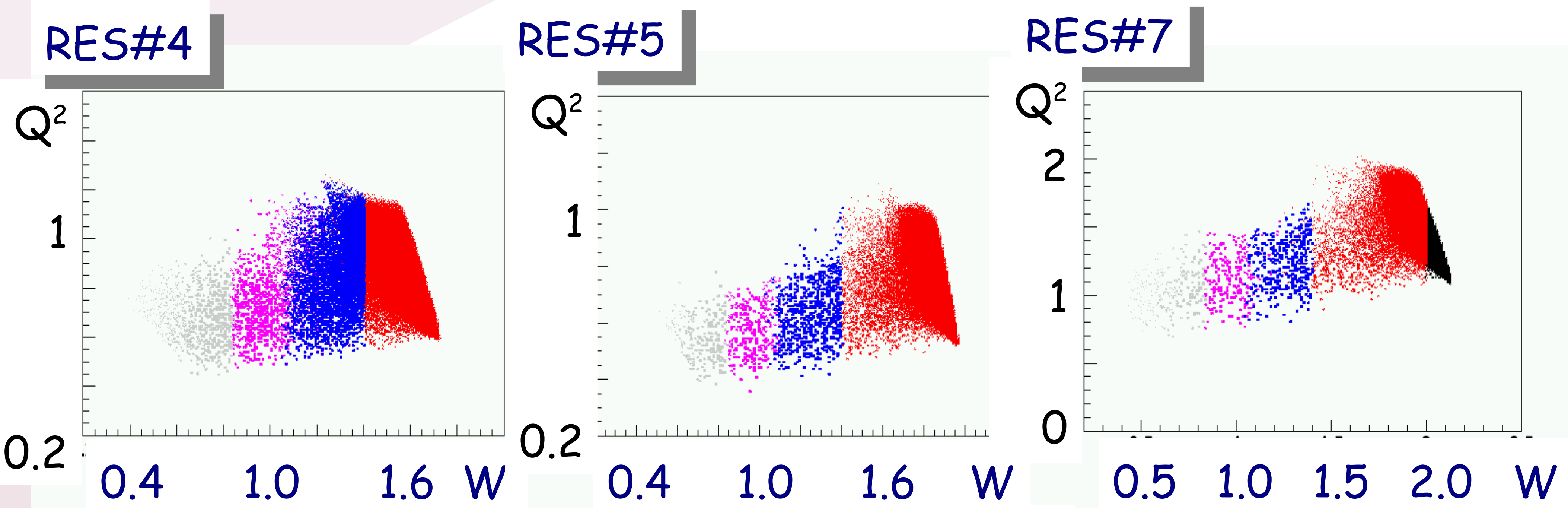




	Elastic	QE	Model	DIS	Toy	<Asym> HAMC (ppm)	Data (ppm)
Lee&Tao	79.2 (0.14%)	-45.5 (11.9%)	-88.5 (86.5%)	0	-49.7 (1.5%)	-82.61	-66.258 ±7.768
Misha	79.2 (0.14%)	-45.5 (11.2%)	-88.1 (88.7%)	0	0	-83.13	

Resonance #4,5,7 / Lee&Tao

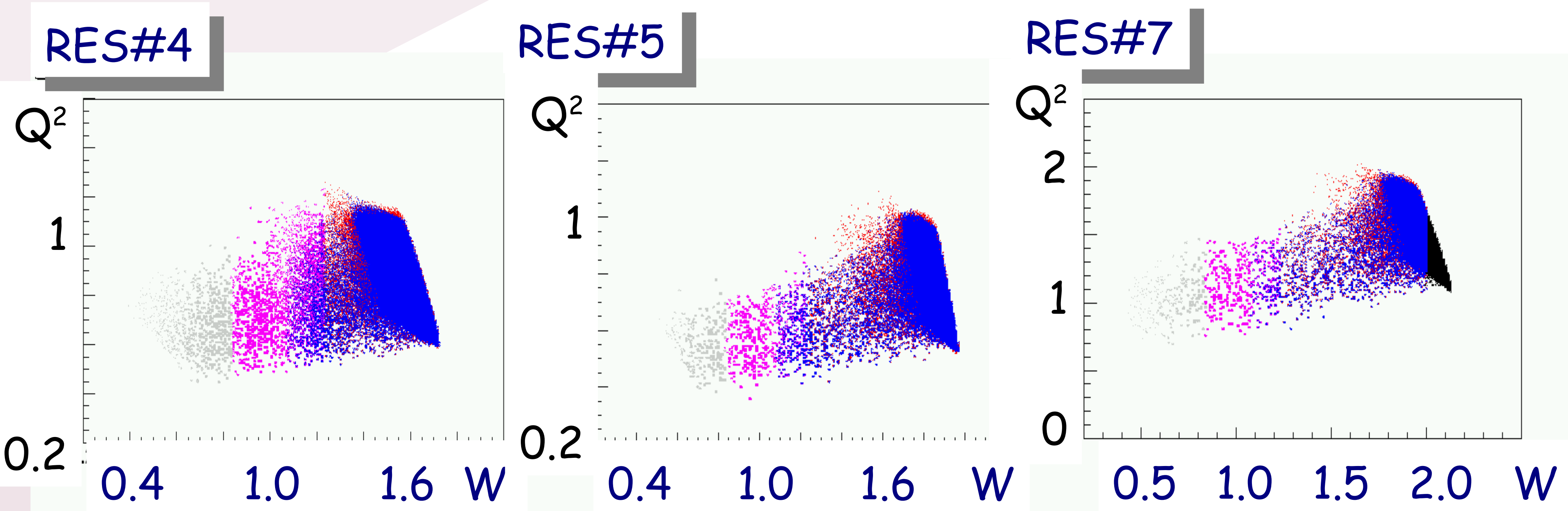
(work of D. Wang)



	Elastic	Quasi	Delta	DIS	Toy	<Asym> HAMC (ppm)	Data (ppm)
Res #4	53.9 (0.03%)	-25.4 (1.5%)	-75.9 (5.26%)	0	-65.0 (93.2%)	-65.0	-73.4 ± 6.9
Res #5	42.8 (0.02%)	-18.0 (1.5%)	-55.3 (1.6%)	0	-59.9 (96.8%)	-59.1	-60.9 ± 5.15
Res #7	81.4 (0.04%)	-44.1 (0.89%)	-98.5 (0.99%)	-108.8 (31.3%)	-122.4 (66.8%)	-117.1	-118.8 ± 16.9

Resonance #4,5,7 (Misha)

(work of D. Wang)



	Elastic	Quasi	Table	DIS	Toy	<Asym> HAMC (ppm)	Data (ppm)
Res #4	53.9 (0.03%)	-27.1 (1.8%)	-69.5 (94.0%)	0	-57.7 (4.2%)	-68.2	-73.4 ± 6.9
Res #5	42.8 (0.02%)	-18.2 (1.6%)	-62.4 (91.9%)	0	-65.6 (6.5%)	-61.9	-60.9 ± 5.15
Res #7	81.4 (0.04%)	-44.2 (0.9%)	-127.6 (62.1%)	-108.8 (31.3%)	-125.9 (5.7%)	-120.8	-118.8 ± 16.9

DIS Radiative Corrections

(work of D. Wang)

Lee,Tao

	Elastic	QE	Delta	Dis	Toy	<Asym> HAMC	A_<Q2>	Correction Factor
Dis #1	56.0 (0.03%)	-26.5 (1.3%)	-70.7 (1.2%)	-86.1 (74.4%)	-93.3 (23.2%)	-86.8 (ppm)	-88.6 (ppm)	1.021
Dis #2	79.7 (0.03%)	-45.8 (0.95%)	-107.7 (0.83%)	-159.3 (95.5%)	-118.1 (2.7%)	-156.6 (ppm)	-159.6 (ppm)	1.019

Misha

	Elastic	QE	Table	Dis	Toy	<Asym> HAMC	A_<Q2>	Correction Factor
Dis #1	56.0 (0.03%)	-26.5 (1.3%)	-97.4 (19.1%)	-86.1 (74.4%)	-92.7 (5.3%)	-87.8 (ppm)	-88.6 (ppm)	1.009
Dis #2	79.7 (0.03%)	-45.8 (0.95%)	-117.7 (3.4%)	-159.3 (95.5%)	-147.8 (0.1%)	-156.7 (ppm)	-159.6 (ppm)	1.019

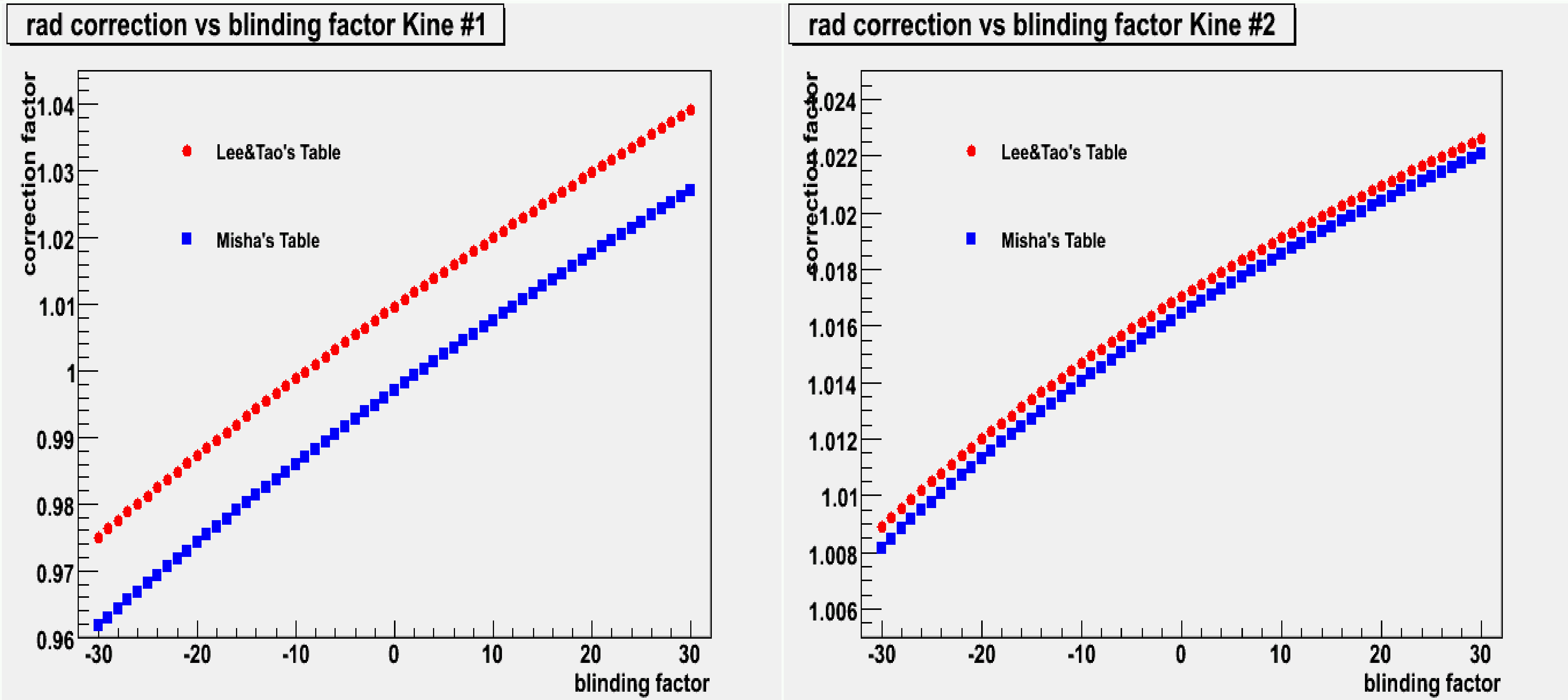
Uncertainty is estimated using

$$\Sigma f_i \times (uncertainty \quad of \quad the \quad model)_i$$

max(error of the data, discrepancy between data and model)

Iteration of Radiative Corrections

- Correction depends on the value of C_{2q} used in DIS formula;
- We calculated rad. corr. for different $C_{2q;}$
- No more than 2 iterations was necessary.



PVDIS Asymmetry in Full Generality

$$A_{PV} = -\left(\frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\right)\left[g_A^e Y_1 \frac{F_1^{\gamma Z}}{F_1^\gamma} + \frac{g_V^e}{2} Y_3 \frac{F_3^{\gamma Z}}{F_1^\gamma}\right] = -\left(\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\right)\left[a_1 Y_1 + a_3 Y_3\right]$$

$g_{A,V}$ follow PDG

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

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

$$a_1 = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^\gamma} = 2\frac{\sum C_{1q} Q_q\left[q(x)+\bar{q}(x)\right]}{\sum Q_q^2\left[q(x)+\bar{q}(x)\right]}$$

$$a_3 = 2\frac{g_V^e}{2}\frac{F_3^{\gamma Z}}{F_1^\gamma} = 2\frac{\sum C_{2q} Q_q\left[q(x)-\bar{q}(x)\right]}{\sum Q_q^2\left[q(x)+\bar{q}(x)\right]}$$

for deuteron:

$$a_1 = \frac{6\left[2C_{1u}(1+R_c) - C_{1d}(1+R_s)\right]}{5+R_s+4R_c}$$

$$a_3 = \frac{6\left[(2C_{2u} - C_{2d})R_V\right]}{5+R_s+4R_c}$$

"no structure"
(PDG Eq.10.21)

$$a_1 = \frac{6}{5}\left[2C_{1u} - C_{1d}\right] \qquad a_3 = \frac{6}{5}\left[(2C_{2u} - C_{2d})\right]$$

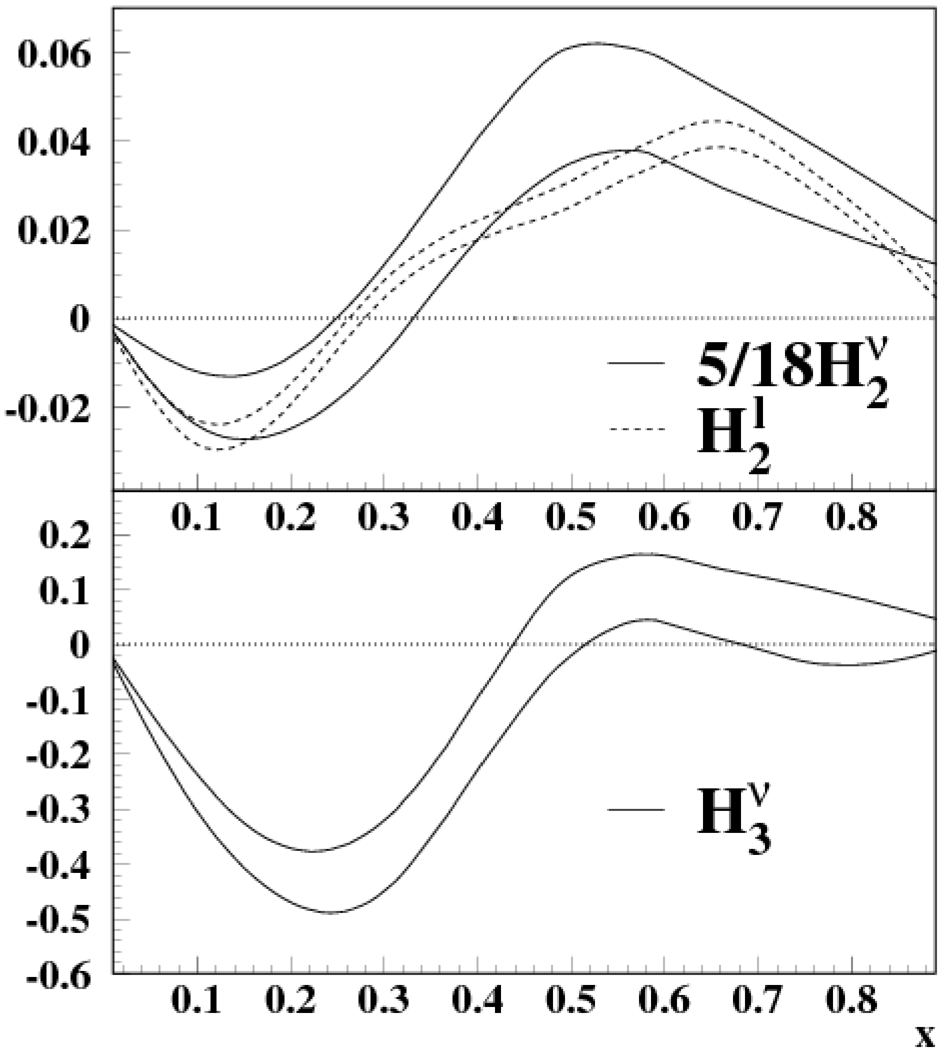
X. Zheng, July 2012

Estimation of HT on the a_3 term

We could use HT results on $F_3^{\gamma Z}$ from neutrino data in 0710.0124(hep-ph) to correct the a_3 term:

$$F_{2,T,3}\left(x,Q^2\right)=F^{\tau=2}_{2,T,3}\left(x,Q^2\right)+\frac{H^{\tau=4}_{2,T,3}(x)}{Q^2}+\frac{H^{\tau=6}_{2,T,3}(x)}{Q^4}+\ldots\ldots$$

isoscalar target



for F_2^ν and F_2^l

for xF_3^ν

(not F_3^ν)

for any target

$$F_3^\nu=2\left[d+s-\bar{u}-c\right]$$

for deuteron

$$F_3^\nu=2\left[u_V+d_V+2s-2\bar{c}\right]$$

Coherent PVDIS Program with SoLID @ 11 GeV

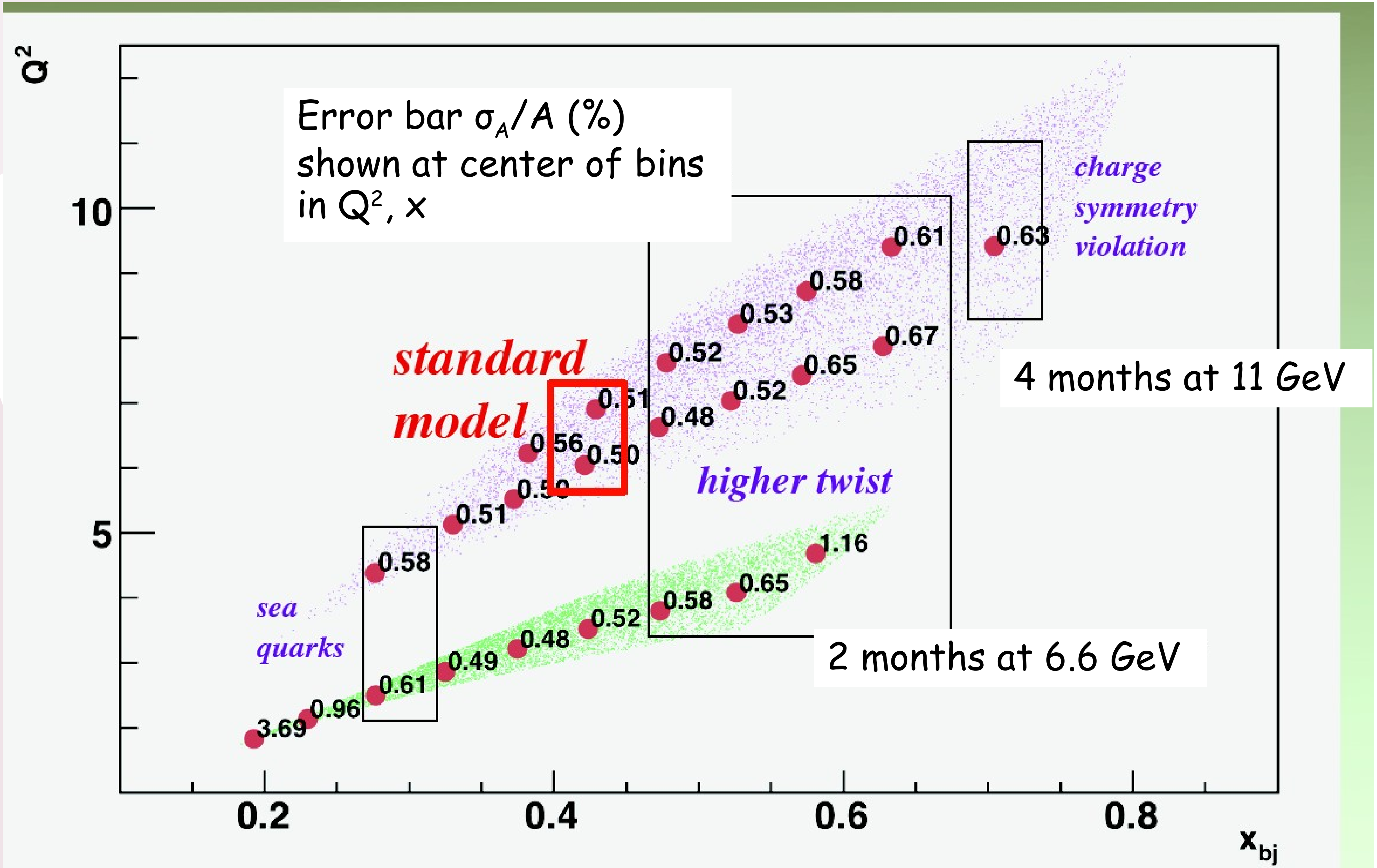
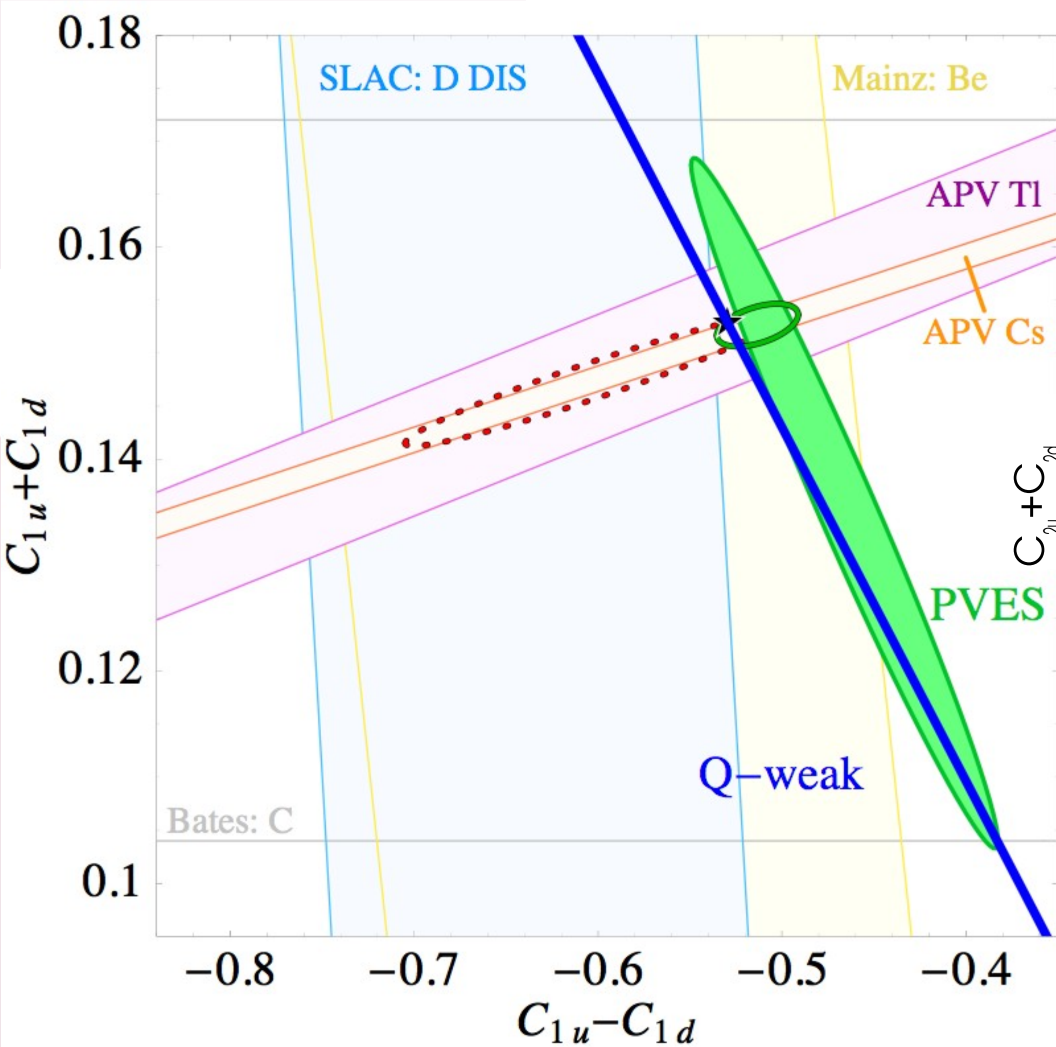
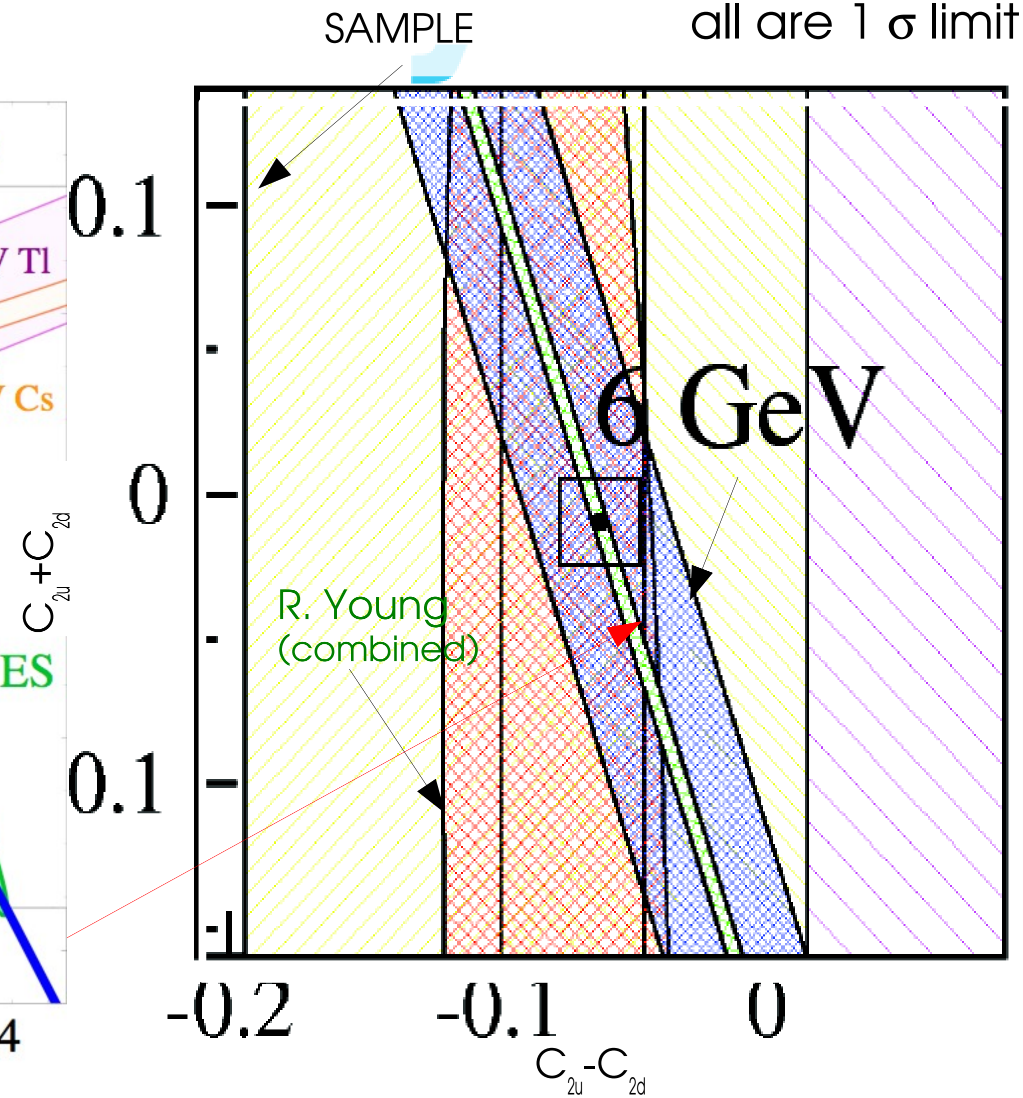


figure from K. Kumar, Seattle 2009 EIC Workshop EW talks

Knowledge on $C_{1,2q}$ with Projected JLab 12 GeV Results

all are 1 σ limit





PVDIS@11 GeV with SoLID: potential to improve C_{2q} knowledge by another order of magnitude and better separation from hadronic effects.