The Qweak Experiment

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for the Qweak Collaboration

QCD for New Physics at the Precision Frontier
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Jefferson Lab
Thomas Jefferson National Accelerator Facility

Office of Nuclear Physics
Department of Energy

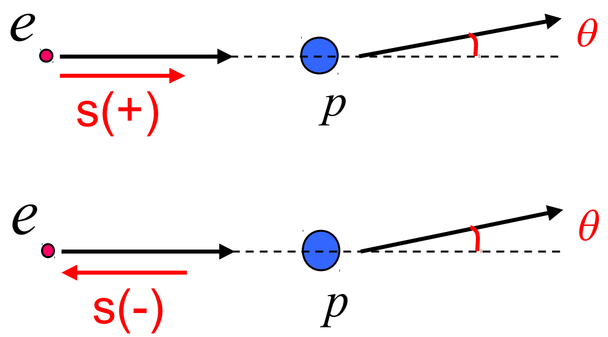
National Science Foundation

NSERC
CRSNG

Overview

- Qweak is a measurement of parity-violation in elastic scattering of ~1 GeV electrons from the proton at forward angles (asymmetry of ~300 ppb) in order to extract $Q_W(p)$ and $\sin^2\theta_W$ at a Q^2 of 0.025 GeV^2
  - A deviation from the SM predictions would be a sign of new PV physics at TeV mass scale
- Qweak ran in Hall C of Jefferson Lab May 2010-May 2012, with about a year of beam-on-target
  - Commissioning run (about 4% of total data set) was published Oct 2013; PRL 111, 141803.
  - Analysis of remainder is continuing, results expected in a year
    - Experimental apparatus described in NIM **A781**, 105 (2015)
- Several ancillary measurements were taken to determine or constrain background processes or corrections

Parity-Violating Electron Scattering



Electromagnetic (PC) + Neutral-weak (PV)

$$\mathcal{M}^{EM} \propto \frac{1}{Q^2} \qquad \mathcal{M}^{NC}_{PV} \propto \frac{1}{M_Z^2 + Q^2}$$

$$\sigma \propto |\mathcal{M}^{EM}|^2 + 2\mathcal{M}^{EM}\mathcal{M}^{NC}_{PV} + |\mathcal{M}^{NC}_{PV}|^2$$

Parity violated in the weak interaction: form an asymmetry

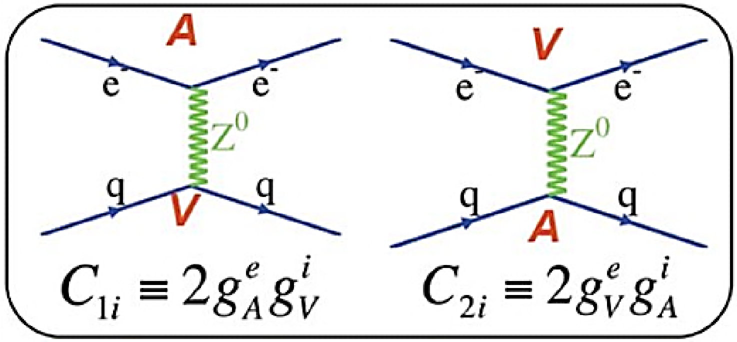
$$A_{PV}(p) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}^{NC}_{PV}}{\mathcal{M}^{EM}} \propto \frac{Q^2}{M_Z^2} \quad \text{when } Q^2 \ll M_Z^2$$

Weak Charges

Electron-quark scattering, four-fermion contact interaction

$$\mathcal{L}_{eq}^{PV} = -\frac{G_F}{\sqrt{2}} \sum_i \left[C_{1i}\bar{e}\gamma_\mu\gamma_5 e\bar{q}\gamma^\mu q + C_{2q}\bar{e}\gamma_\mu e\bar{q}\gamma^\mu\gamma^5 q \right] + \mathcal{L}_{new}^{PV}$$

Particle	Electric charge	Weak vector charge ($\sin^2\theta_W \approx \frac{1}{4}$)
e	-1	$Q_W^e = -1 + 4\sin^2\theta_W \approx 0$
u	$+\frac{2}{3}$	$-2C_{1u} = +1 - \frac{8}{3}\sin^2\theta_W \approx +\frac{1}{3}$
d	$-\frac{1}{3}$	$-2C_{1d} = -1 + \frac{4}{3}\sin^2\theta_W \approx -\frac{2}{3}$
p(uud)	$+1$	$Q_W^p = 1 - 4\sin^2\theta_W \approx 0.07$
n(udd)	0	$Q_W^n = -1$



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

Small scattering angles $\qquad$ Large scattering angles

For an arbitrary nucleus, $Q_w(Z,N) = -2\{C_{1u}(2Z + N) + C_{1d}(Z + 2N)\}$

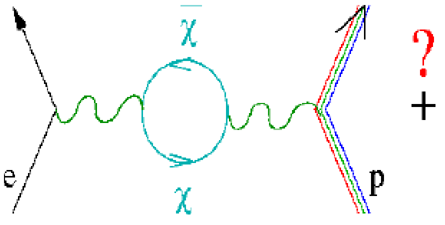
- Ex: $Q_w(p) = -2(2C_{1u} + C_{1d})$ (this experiment)
  - Uses higher Q^2 PVES data to constrain hadronic corrections (about 20%)
- Ex: $Q_w(^{133}Cs) = -2(188C_{1u} + 211C_{1d})$ (APV)
  - Latest atomic corrections from PRL 109, 203003 (2012)
- Combining $Q_w(p)$ and $Q_w(^{133}Cs)$ → C_{1u} & C_{1d}, $Q_w(n)$

Sensitivity to new physics

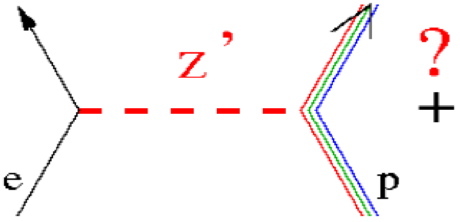
- Suppose some new physics adds a contact term to the PV electron-quark Lagrangian, with coupling constant, *g*, and mass, Λ: **Erler et al. PRD 68, 016006 (2003)**

$$\begin{aligned}\mathcal{L}^{PV}_{e-q} &= \mathcal{L}^{PV}_{SM} + \mathcal{L}^{PV}_{New} \\ &= -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e\sum_q C_{1q}\bar{q}\gamma^\mu q + \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e\sum_q h^q_V\bar{q}\gamma^\mu q\end{aligned}$$

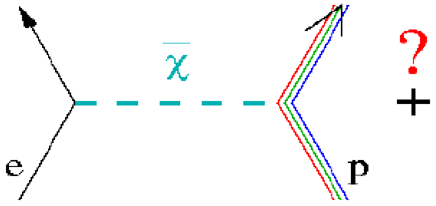
$$\frac{\Lambda}{g}\sim\left(\sqrt{2}\,G_F\,\Delta Q^p_W\right)^{-\frac{1}{2}}\sim O\left(TeV\right)$$



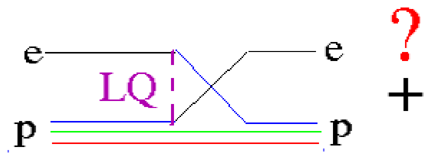
RPC SUSY



Generic Z'



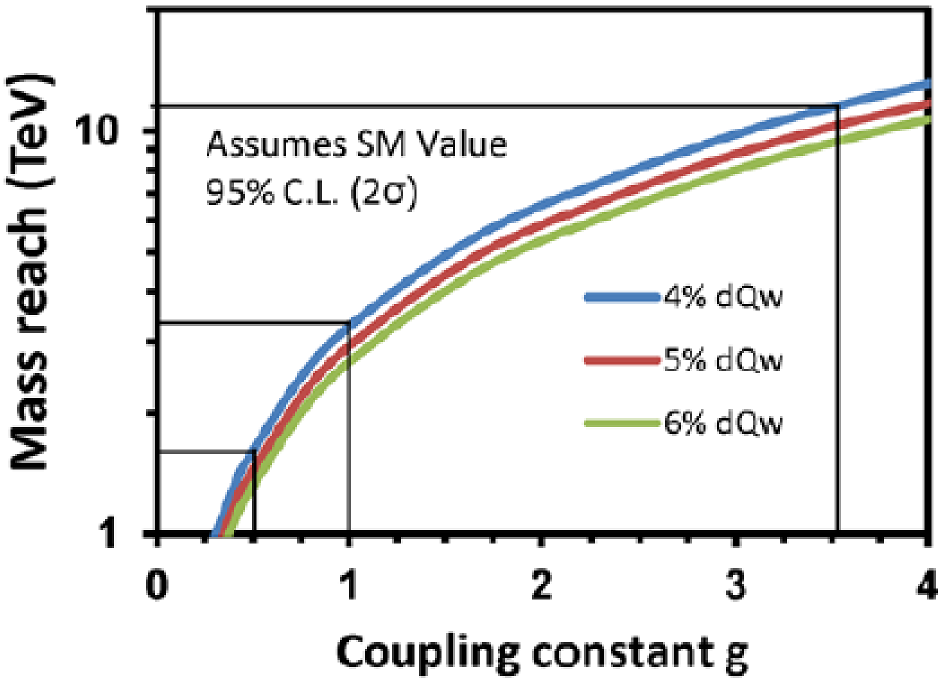
RPV SUSY



Leptoquarks

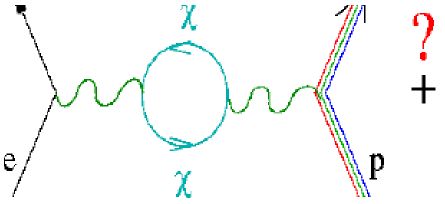
Sensitivity to new physics

- Suppose some new physics adds a contact term to the PV electron-quark Lagrangian, with coupling constant, *g*, and mass, Λ: **Erler et al. PRD 68, 016006 (2003)**

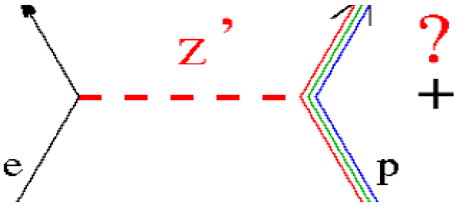


$$\frac{\Lambda}{g} \sim \left(\sqrt{2}\, G_F\, \Delta Q_W^p\right)^{-\frac{1}{2}} \sim O\left(TeV\right)$$

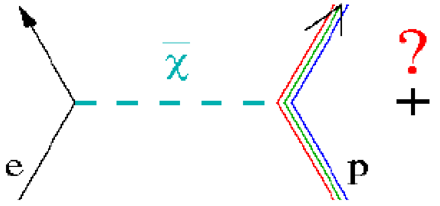
The proposal goal of $\Delta Q_W/Q_W = 4.2\%$ would give $\Lambda/g \sim 3.2$ TeV.



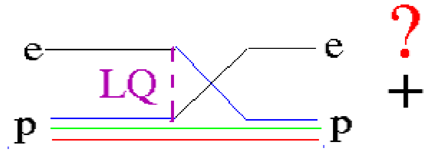
RPC SUSY



Generic Z'



RPV SUSY



Leptoquarks

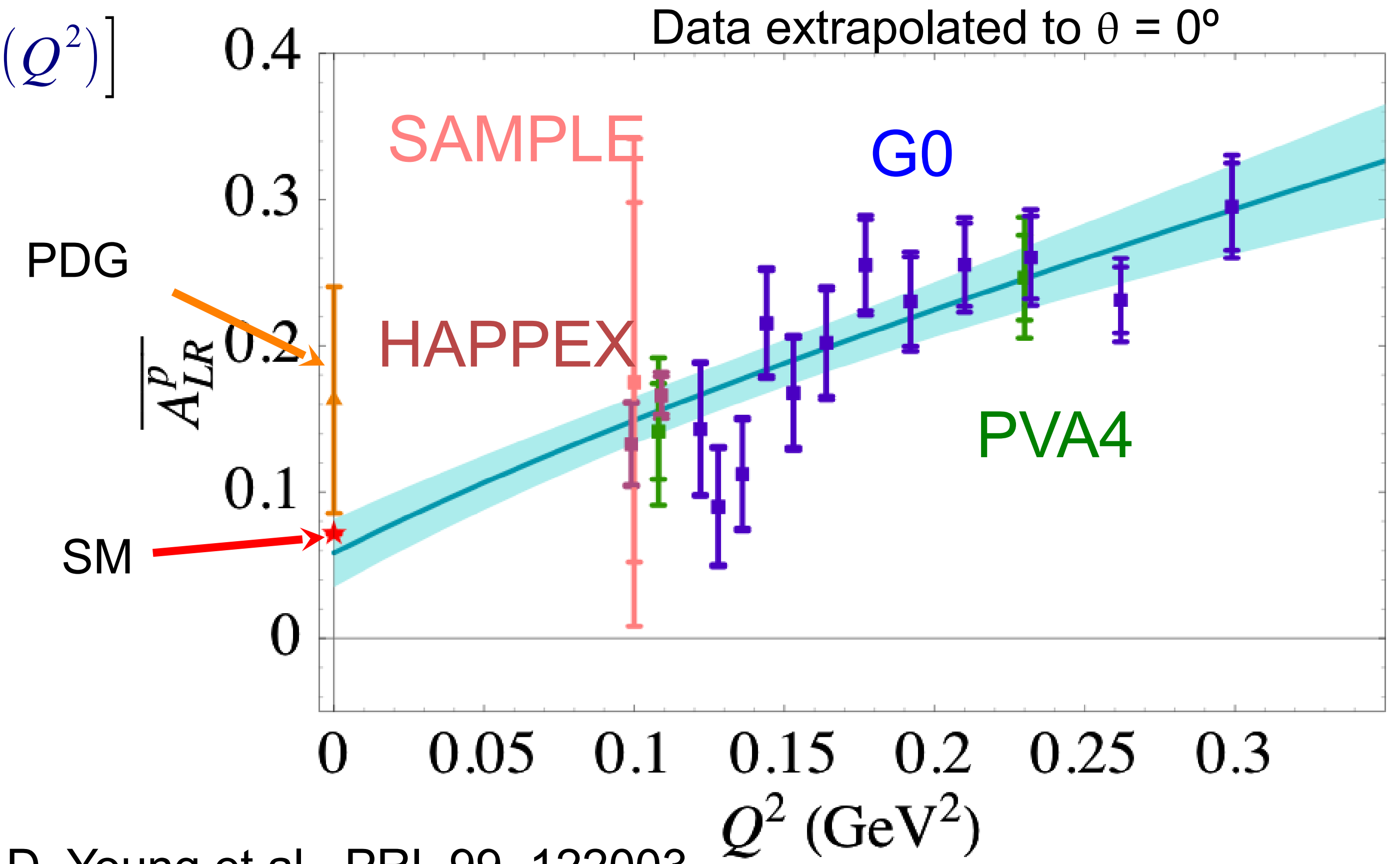
PVES asymmetry

$$A_{LR}=\frac{-G_\mu\ Q^2}{4\pi\alpha\sqrt{2}}\left[\frac{\varepsilon G_E^\gamma G_E^Z+\tau G_M^\gamma G_M^Z-(1-4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^e}{\varepsilon(G_E^\gamma)^2+\tau(G_M^\gamma)^2}\right]$$

$$A_{LR}=\frac{-G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left[Q_{weak}^p+Q^2 B(Q^2)\right]$$

$$\overline{A_{LR}^p}\equiv\frac{A_{LR}^p}{-(G_\mu/4\pi\alpha\sqrt{2})Q^2}$$

$$\overline{A_{LR}^p}=Q_{weak}^p+Q^2 B(Q^2)$$

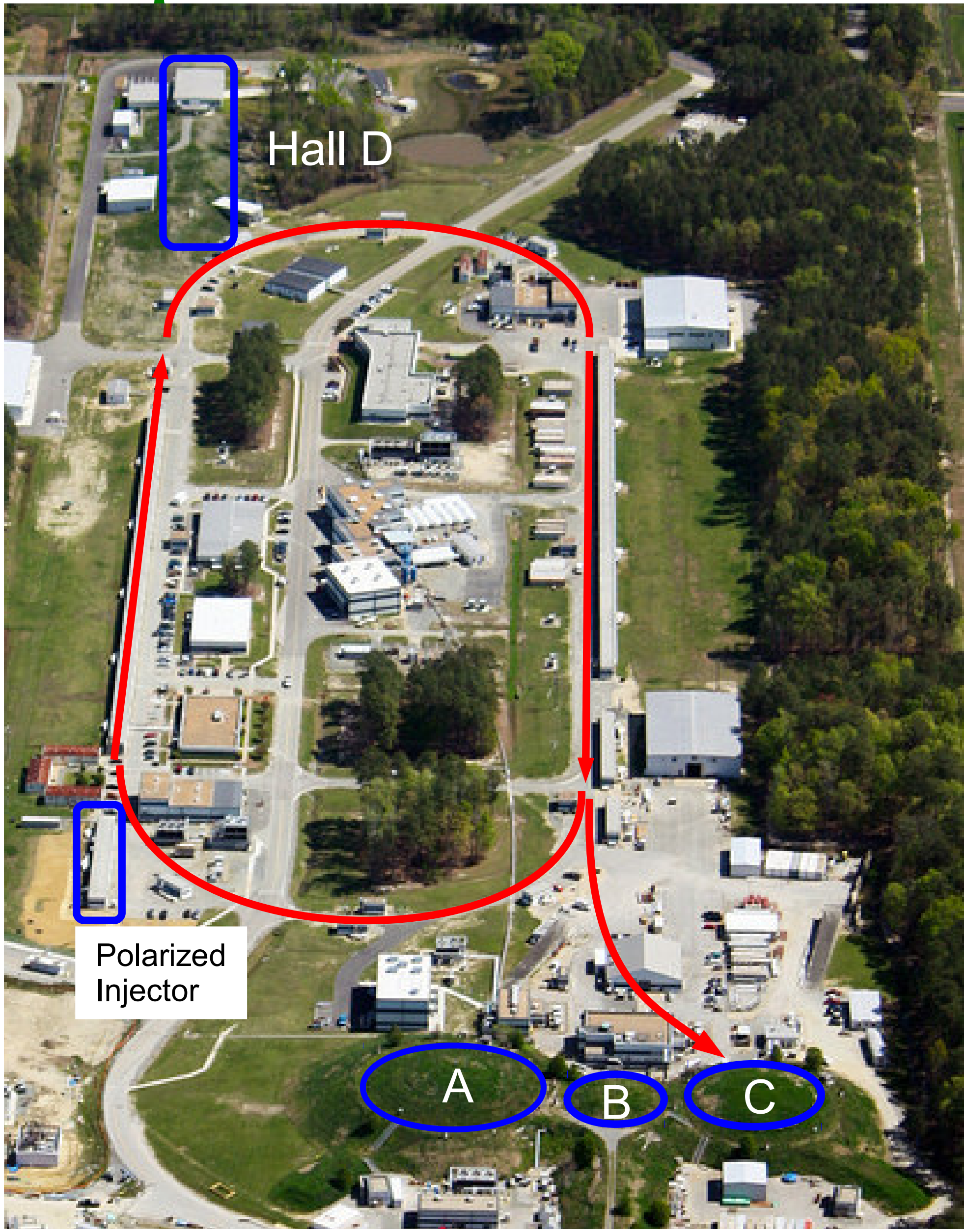


R.D. Young et al. PRL 99, 122003

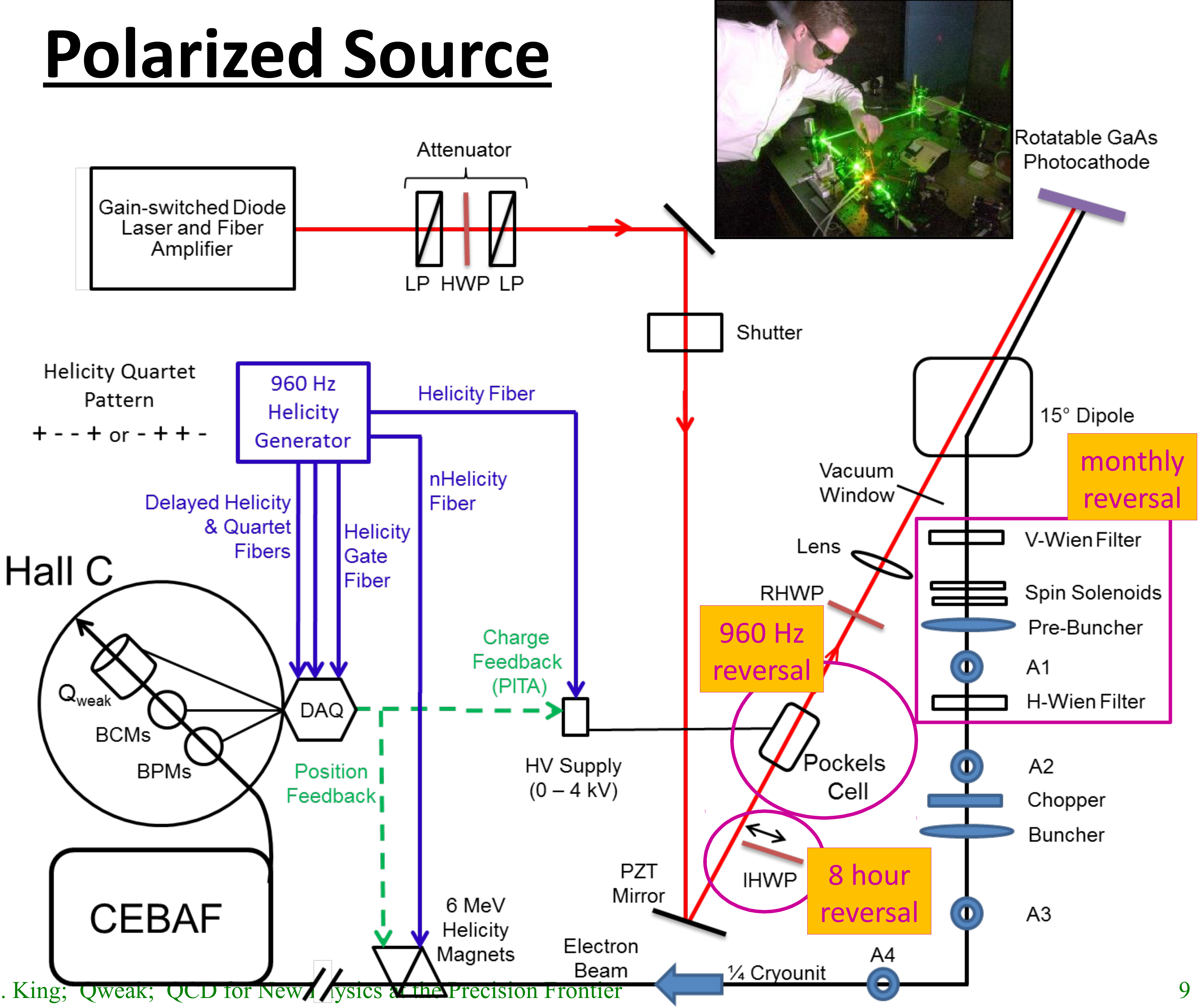
Role of QWEAK: A single precise value at low Q^2 to constrain the intercept

The Qweak Experiment

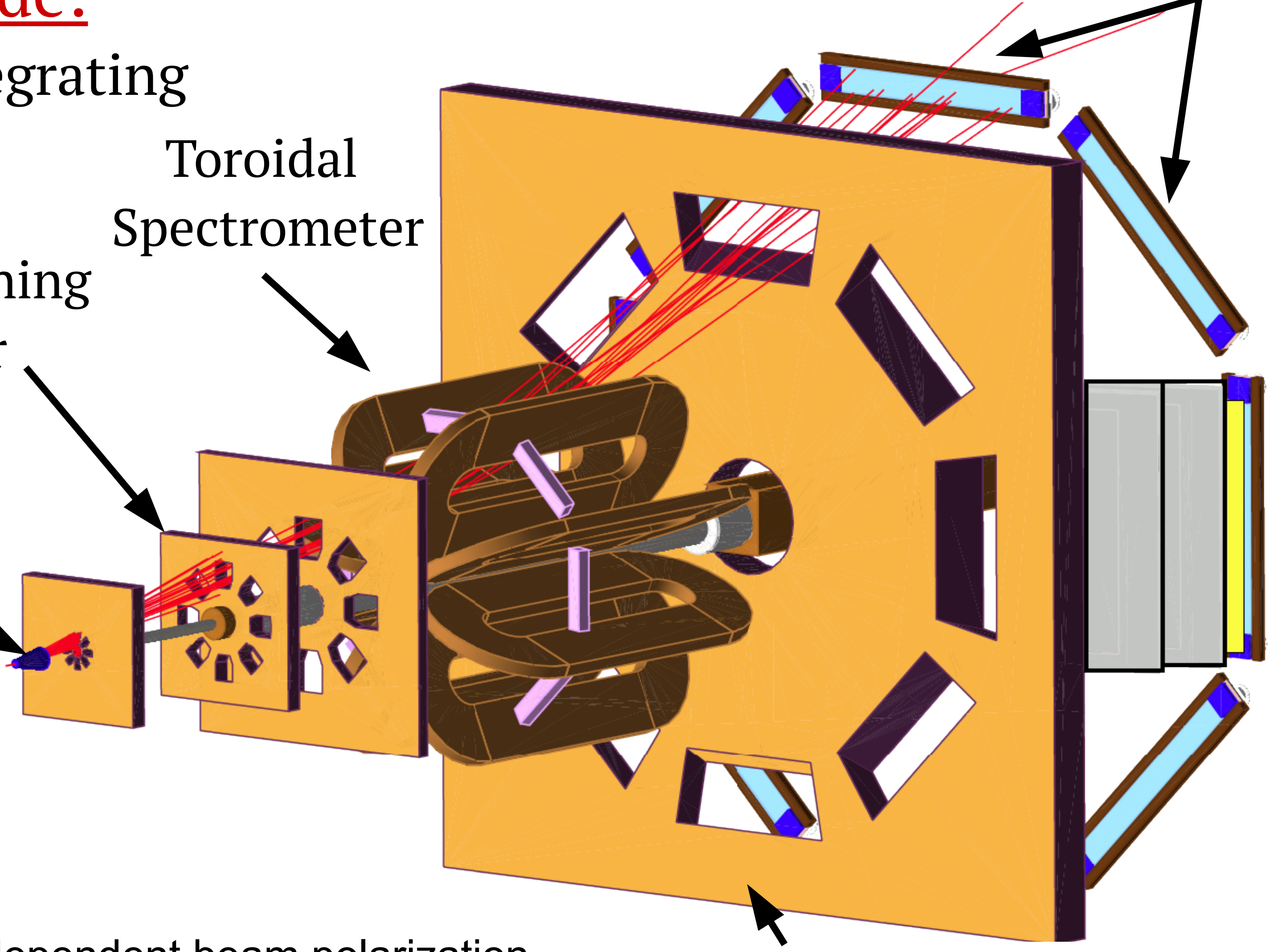
- Qweak ran in Hall C at Jefferson Lab, Newport News, VA
- Qweak ran before the 12 GeV upgrade, May 2010- May 2012
  - Commisioning: Jan - Feb 2011
  - Run1: Feb - May 2011
  - Run2: Nov 2011-May 2012
- Beam energy was 1.16 GeV
  - Most at 1-pass, with some running at 2-pass (extra spin reversal by precession)



Polarized Source



Qweak Apparatus



Production Mode:

145 - 180 μA, Integrating

Quartz Bar Detectors
~800 MHz rate/bar

Toroidal
Spectrometer

Acceptance-defining
Pb collimator

35 cm LH_2 target
3 kW cooling power

e- beam

E = 1.16 GeV
I = 145- 180 μA
P = 89%

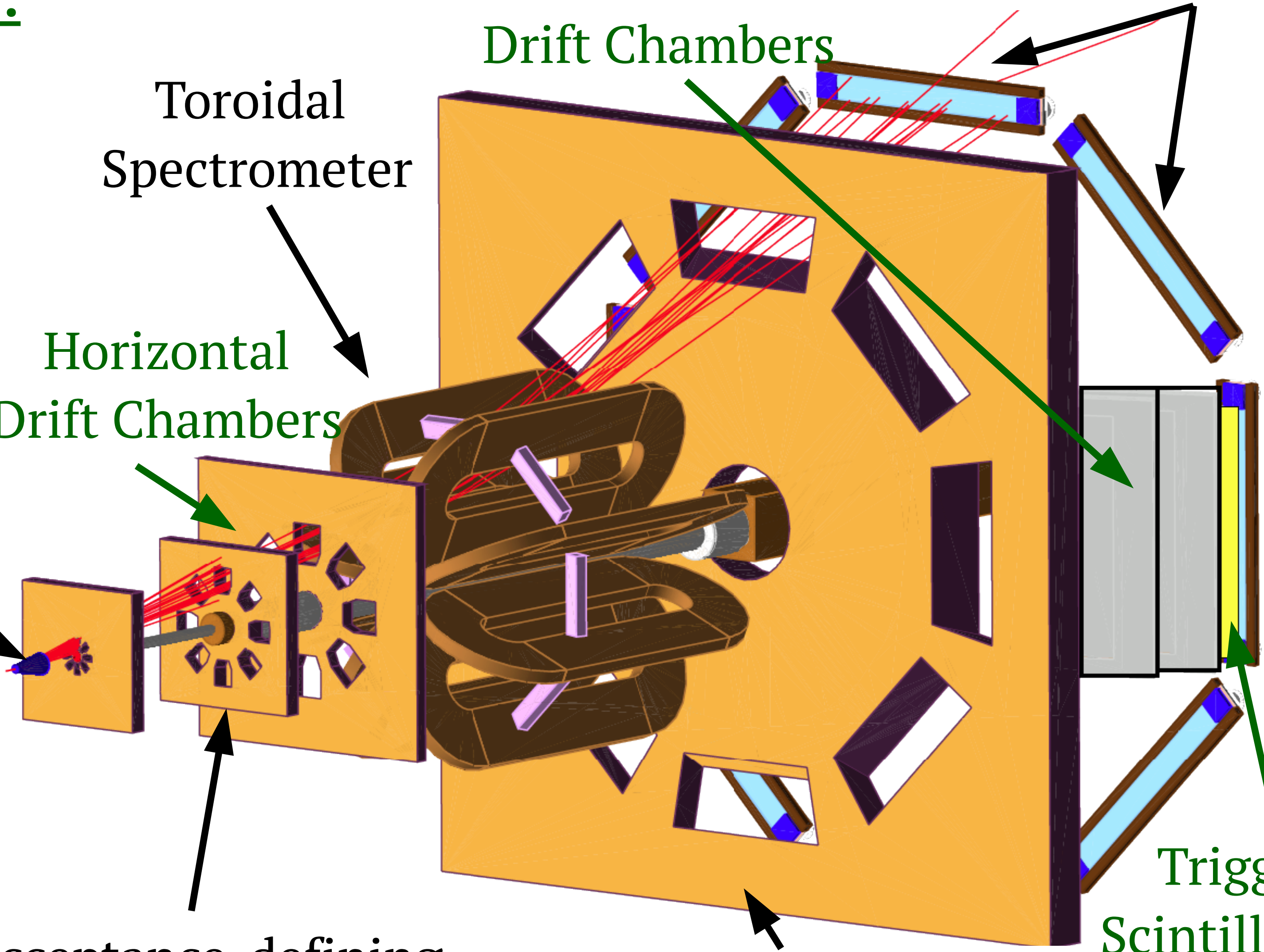
Two independent beam polarization measurements:
Moller polarimeter &Compton polarimeter

High-density concrete
shielding wall

Qweak Apparatus

Tracking Mode:

Down to 50 pA,
Counting
(Q^2 Systematics)



Quartz Bar Detectors
~100 Hz - few kHz

Vertical
Drift Chambers

Toroidal
Spectrometer

Horizontal
Drift Chambers

35 cm LH_2 target

e- beam

E = 1.16 GeV

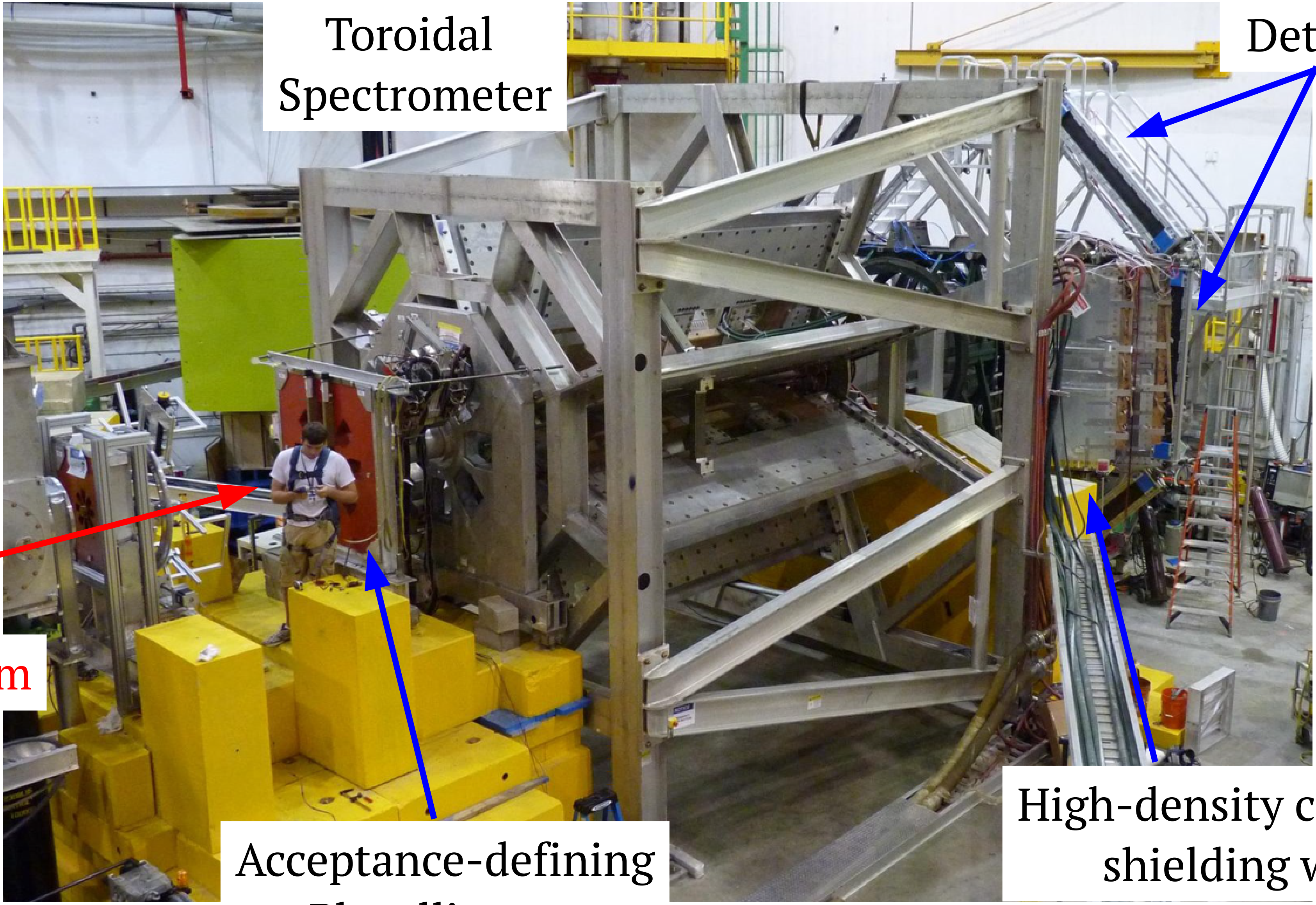
P = 88%

Acceptance-defining
Pb collimator

High-density concrete
shielding wall

Trigger
Scintillators

Qweak During Installation



Toroidal Spectrometer

Quartz Bar Detectors

e- beam

Acceptance-defining Pb collimator

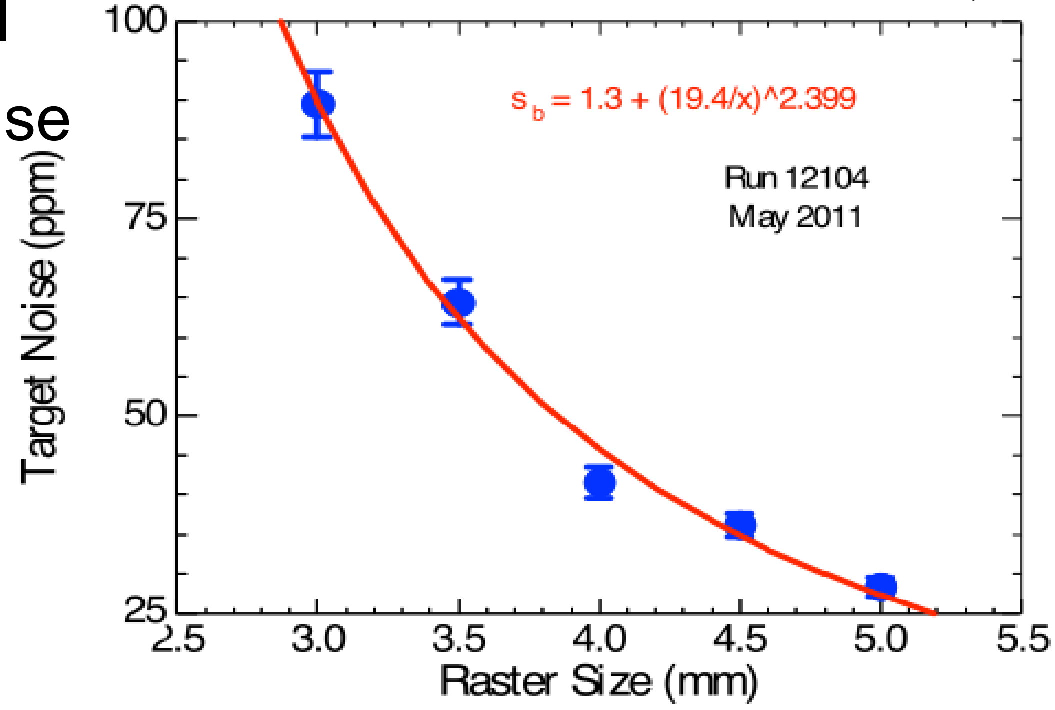
High-density concrete shielding wall

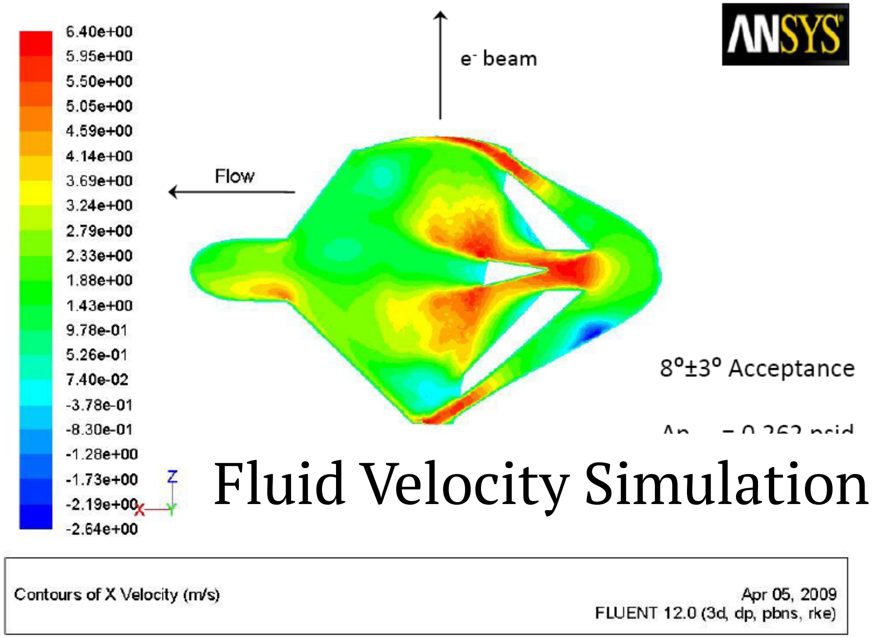
Target Design and Performance

- 35 cm LH_2 (4% X_0)
  - 20K, 30-35 psia
  - ~3 kW power
- Designed using computational fluid dynamics to minimize noise from density fluctuations

Target “Boiling” Noise:
target density fluctuations

Beam Raster Size Scan @ 182 μA





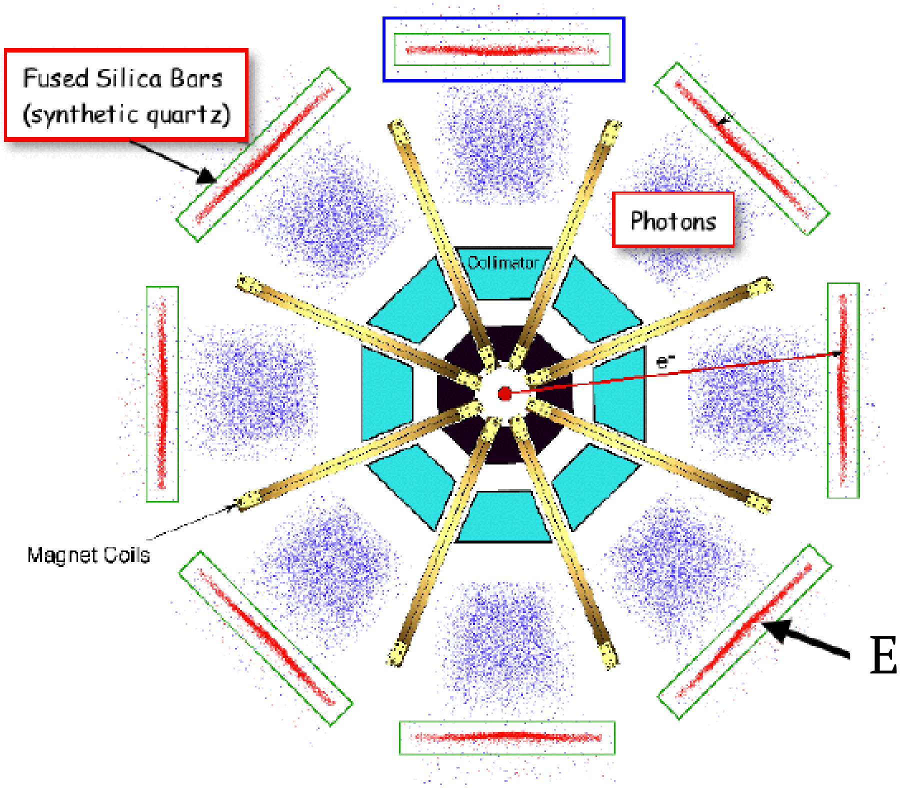
Fluid Velocity Simulation

47 ppm/quartet small contribution to asymmetry width

Main Detectors

- Eight 2m long radiation-hard fused silica Čerenkov detectors

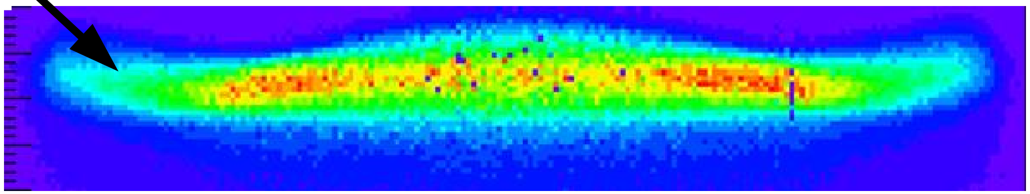
Azimuthal Symmetry



Elastic
ep

Installed 2cm lead pre-radiators

Measured profile in 6 o'clock octant

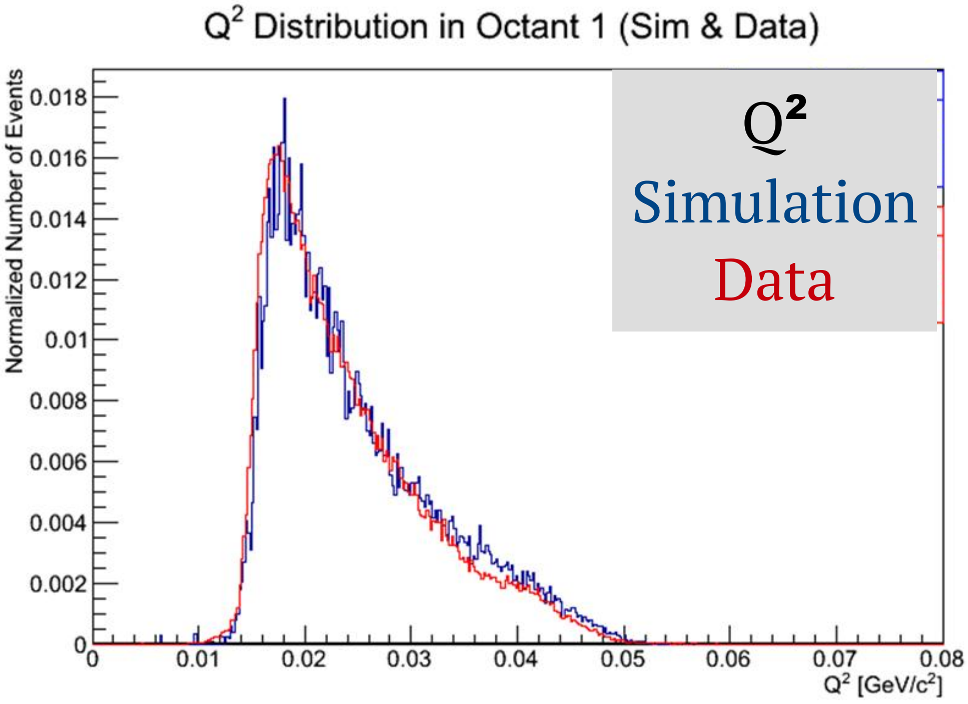


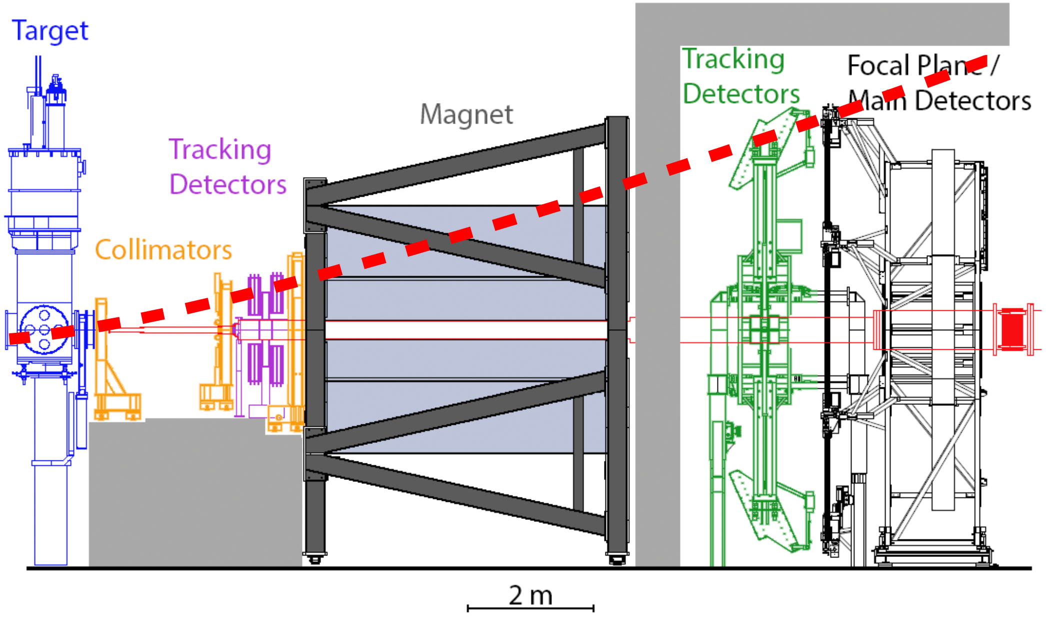
Electrons focused on detectors by QTOR

Photons show collimator aperture shape

Kinematics Determination

- Drift chambers before and after magnetic field
- Low current, reconstruct individual events
- Systematic studies


Q^2 Distribution in Octant 1 (Sim & Data)



Measure light-weighted acceptance

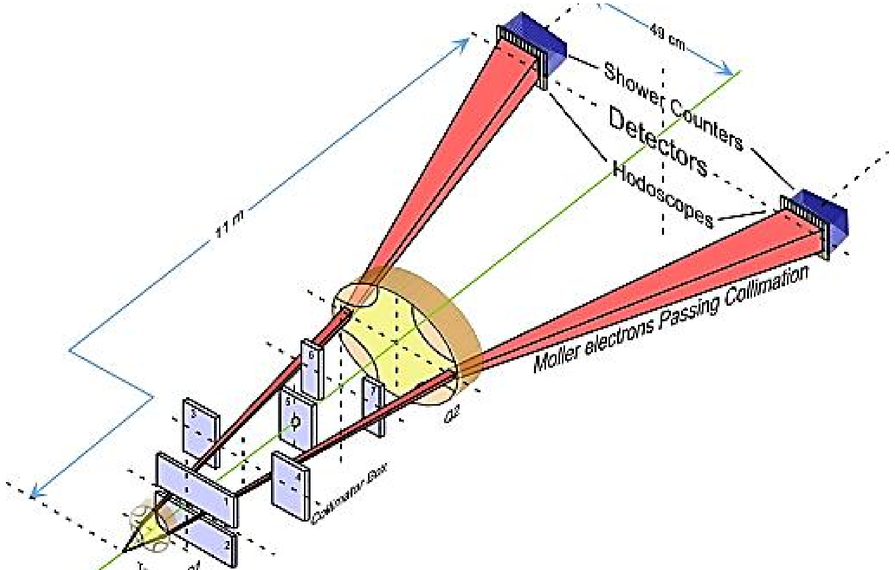
(Q^2 varies by factor of 2 over acceptance)

Precision Polarimetry

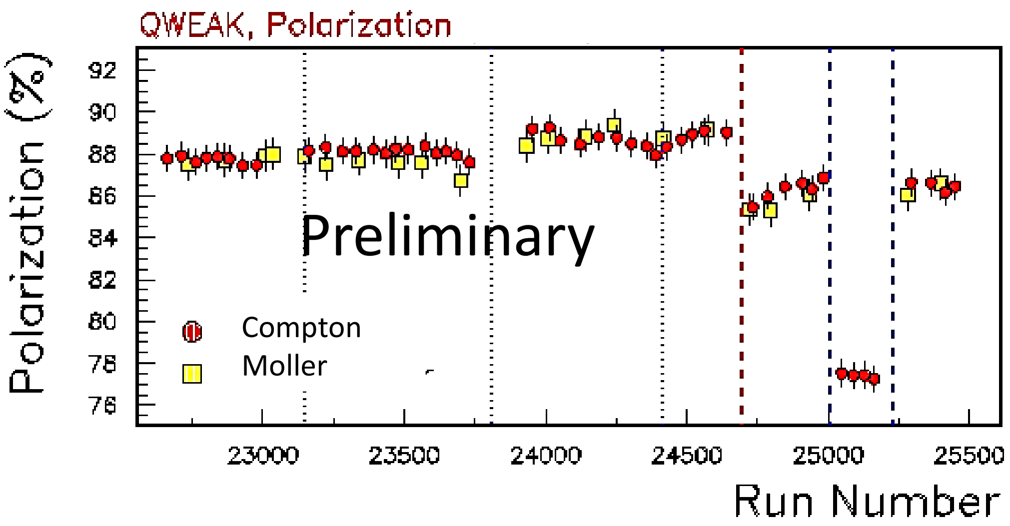
- Two independent devices for <1% polarization

Møller

- low current only, invasive

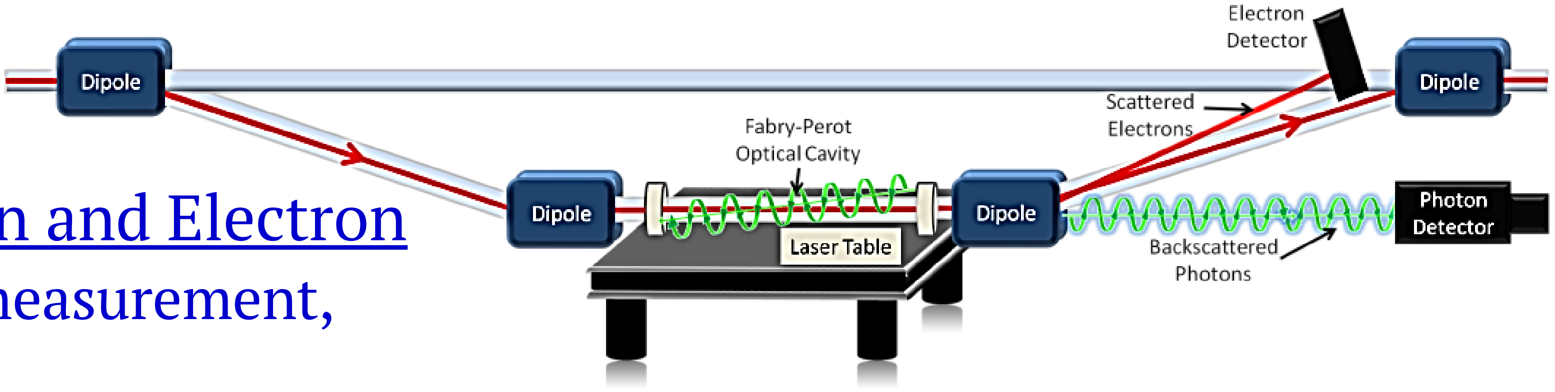


PRELIMINARY Polarization – Run 2



Compton: Photon and Electron

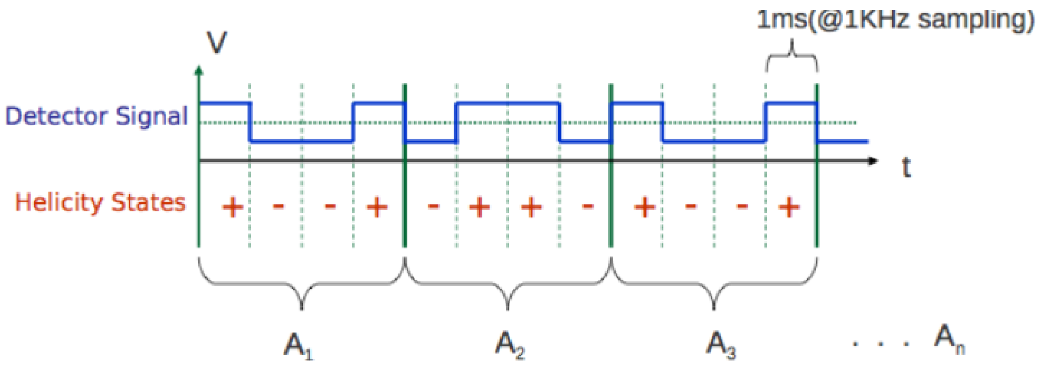
- continuous measurement, high current

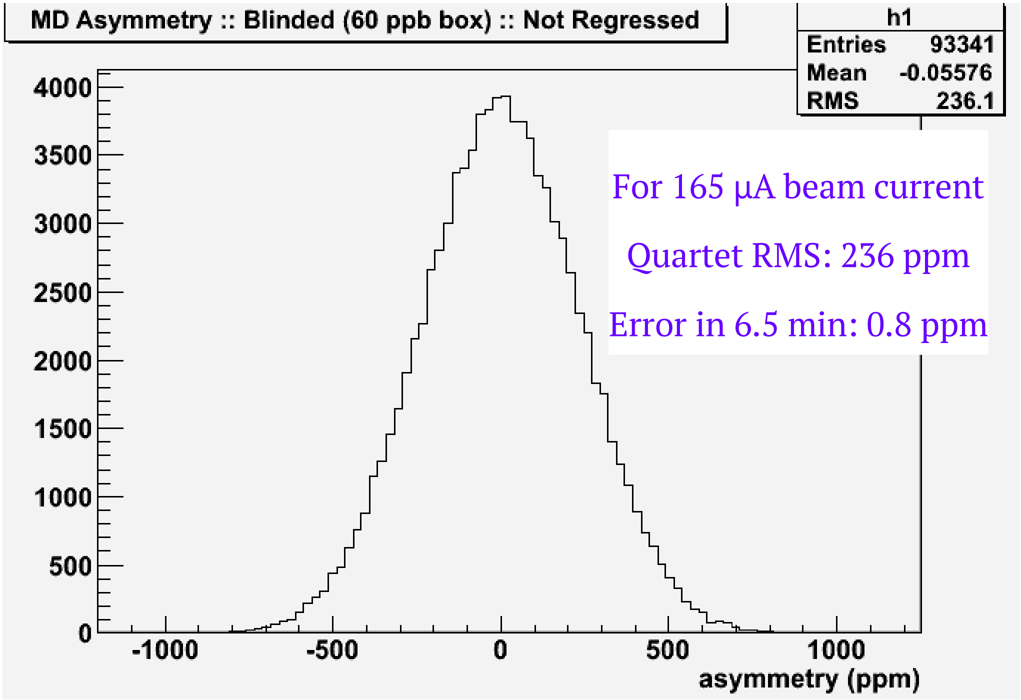


Measurement process

- "Helicity windows" occur at about 960 Hz
  - Groups of four windows have helicity pattern +--+ or -++- chosen pseudorandomly
  - Helicity reporting is delayed
- Detector and beam monitor signals are integrated over the window
- Asymmetries are constructed for each pattern

$$A=\frac{Y_{+}-Y_{-}}{Y_{+}+Y_{-}}$$





For 165 μA beam current

Quartet RMS: 236 ppm

Error in 6.5 min: 0.8 ppm

Constructing the asymmetry

- Detector & beam monitor yields are integrated over 1/960 s helicity windows, grouped in quartet patterns with helicities +--+ or -++-

$$\boxed{A_{msr} = A_{raw} + A_T + A_L + A_{reg}}$$

A_{raw} = (Y+ - Y-)/(Y+ + Y-)
Asymmetry calculated from charge normalized yields
A_T = remnant transverse asymmetry
A_L = potential non-linearity in PMT
A_{reg} = helicity-correlated false asymmetry from beam parameter variations

$$\boxed{A_{ep} = R_{tot} \frac{A_{msr}/P - \sum_{i=1}^{4} f_i A_i}{1 - f_{tot}}}$$

R_{tot} = includes radiative corrections (following Mo-Tsai prescription) and correction for light-variation
Background corrections: Al windows, neutrals, scattering from beamline, inelastic scattering
f = background fraction
A = background asymmetry

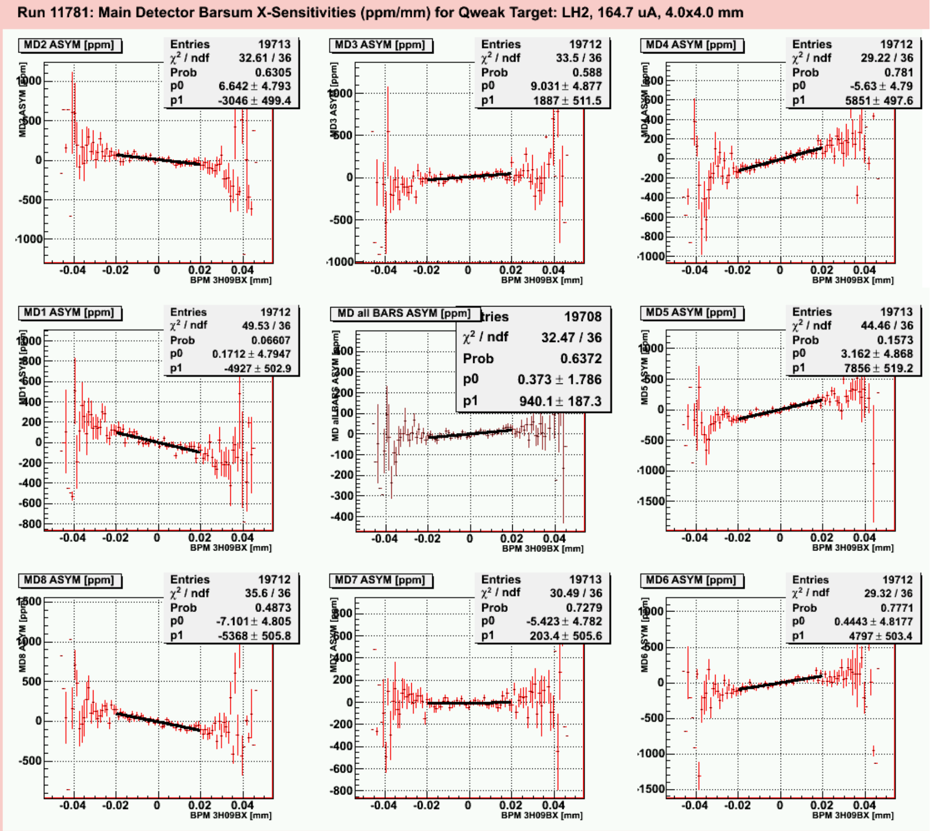
Beam Parameter Corrections

- Helicity correlated beam parameter variations can produce an asymmetry in the detectors
  - Symmetric detectors give partial cancellation
  - Large HC beam variations can be reduced by retuning
  - Measured detector-beam correlations can provide a correction

$$A_{corr} = \sum_{i=1}^{5} \left(\frac{\partial A}{\partial x_i} \right) \Delta x_i$$

$$(x, x', y, y', E)$$

Example: Detector Sensitivity to X position variation

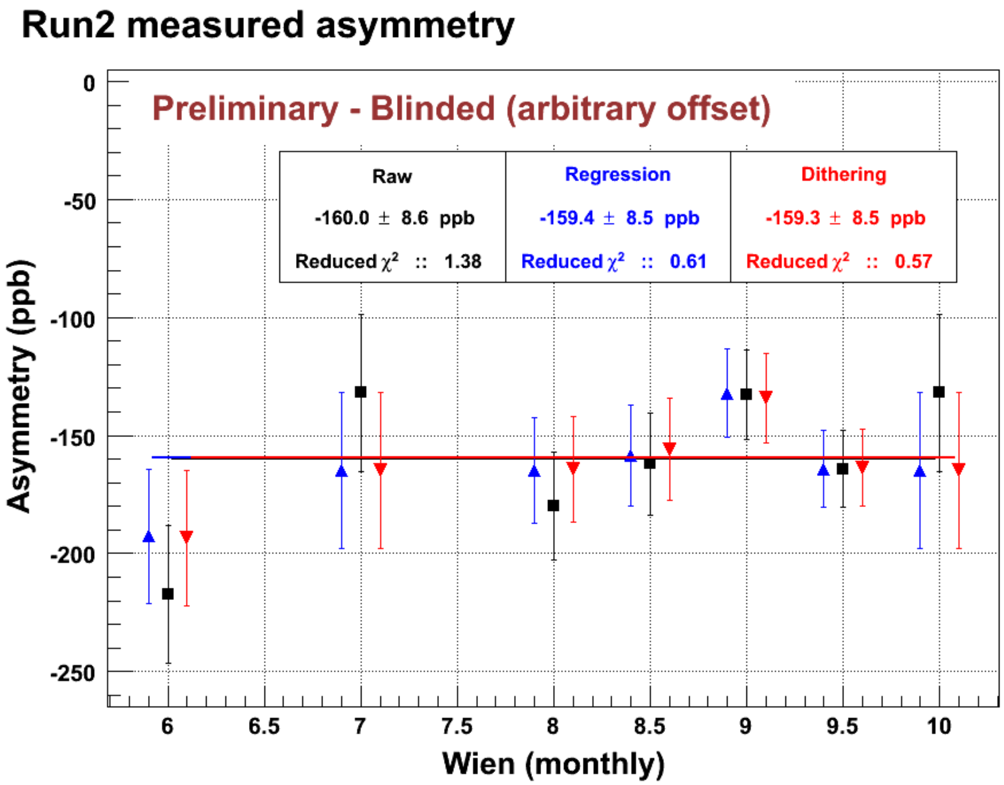


Regression Correction from Qweak "Wien0"

(PRL 111, 141803): A_{corr} = -35 ± 11 ppb

Beam Parameter Corrections

- Two ways to determine sensitivity of the detector asymmetries to beam parameter variations
  - Regression: Natural jitter of beam parameters
  - Dithering: Occasional "large" driven variation of each beam parameter
- Corrections based on the two methods are in excellent agreement for this subset of our data where both are available



- About 77% of the run2 data-set
- Asymmetries have no corrections other than beam parameter correction

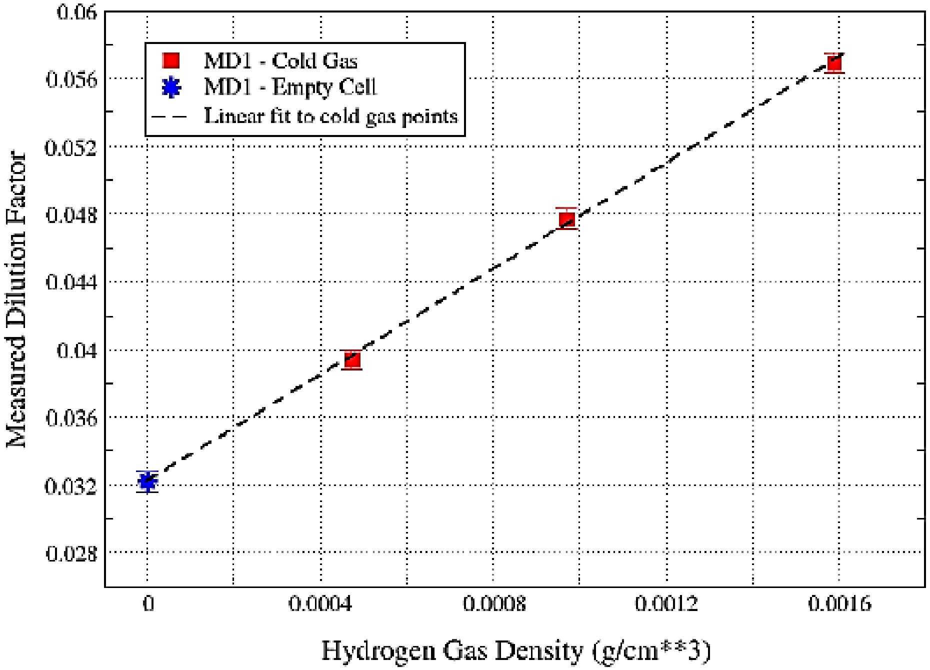
Aluminum background

Largest correction

Dilution from windows measured with empty target

$f_{Al} = 3.2 \pm 0.2$ %

Corrected for effect of using simulation and data driven models of elastic and QE scattering



Asymmetry measured from thick Al targets

Measured asymmetry agrees with expectations from scaling

$A_{Al} = 1.76 \pm 0.26$ ppm

$C_{Al} = f_{Al} * A_{Al} = -64 \pm 10$ ppb

$$A_{PV}({}^{N}_{Z}X) = \left[\frac{-Q^2 G_F}{4\pi\alpha\sqrt{2}}\right]\left[Q_W^p + \left(\frac{N}{Z}\right) Q_W^n\right]$$

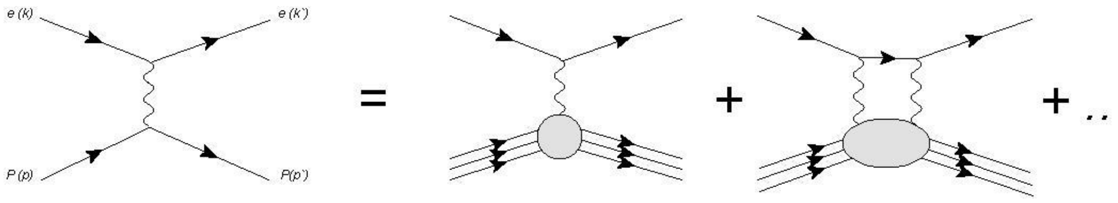
Ancillary Measurements

Many additional measurements under analysis:

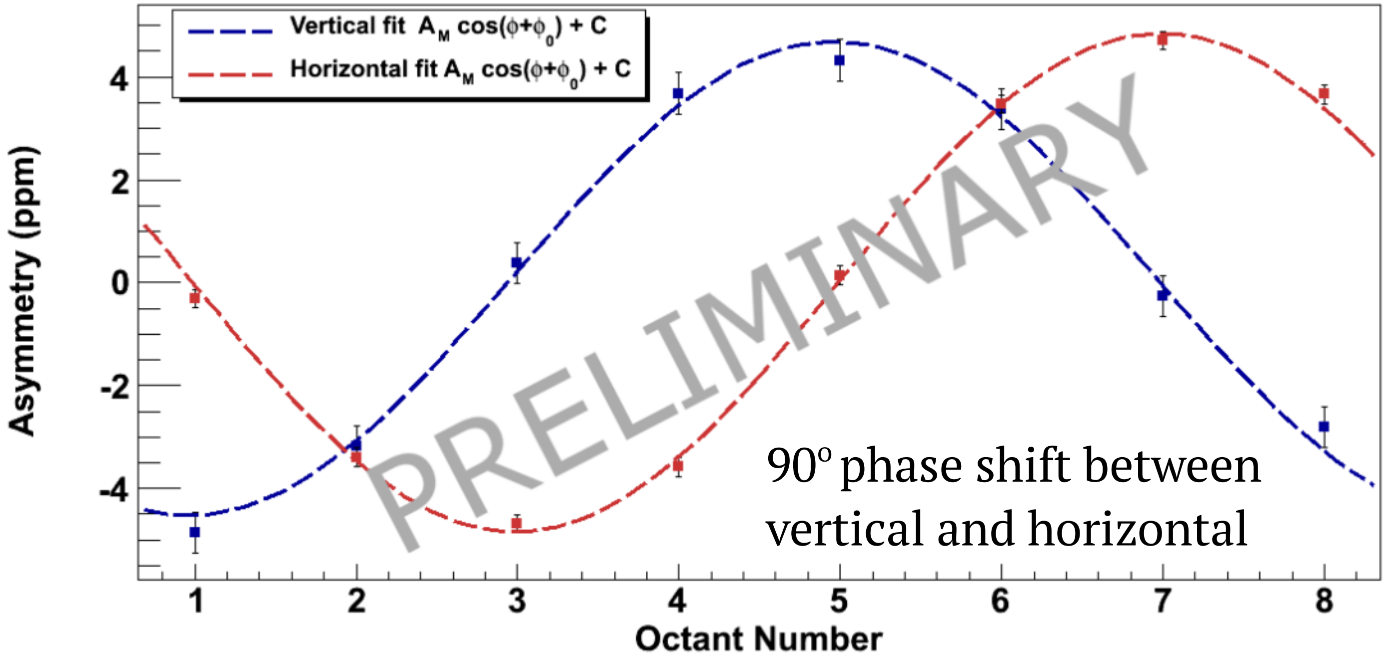
- Parity violating asymmetry:
  - elastic ^{27}Al
  - N → Δ
    (E = 1.16 GeV, 0.877 GeV)
  - Near W = 2.5 GeV
    (related to γZ box)
  - Pion photoproduction
    (E = 3.3 GeV)
- Parity conserving transverse asymmetry:
  - elastic ep
  - elastic ^{27}Al, Carbon
  - N → Δ
  - Møller
  - Near W = 2.5 GeV
  - Pion photoproduction
    (E = 3.3 GeV)

Beam Normal Single Spin Asymmetry

- PC asymmetry; zero in OPE, but contributions from 2γ exchange
  - Sensitive to all allowed virtual excitations of the proton up to E_{cm} = 1.7 GeV



- Dedicated measurement with fully transverse beam on LH2, Al, C



90° phase shift between vertical and horizontal

Transverse asymmetry from LH2

- Kinematics:
  - Q^2 = 0.0250 ± 0.006 $(\mathrm{GeV/c})^2$
  - E = 1.155 ± 0.003 GeV
  - Scattering angle = 7.9° ± 0.3°
- Preliminary results

  A_n = -5.30 ± 0.07 ± 0.15 ppm
  - No radiative corrections
  - Results from B. Waidyawansa Ph.D.thesis; being prepared for publication

Corrections and uncertainties

UNITS: parts per billion (ppb)

$$A_{msr} = A_{raw} + A_T + A_L - A_{reg}$$

$$A_{msr} = -204 \quad \pm 31\,(stat) \quad \pm 13\,(sys)$$

$$\left.\begin{array}{lcrl} A_T & = & 0 & \pm\ 4 \\ A_L & = & 0 & \pm\ 3 \\ A_{reg} & = & -35 & \pm\ 11 \end{array}\right\}$$

~ 1σ correction to A_{raw}

$$A_{ep} = \left(\frac{R_{tot}}{P\,(1 - f_{tot})} \right) \times \left(A_{msr} - P \sum_{i=1}^{4} f_i A_i \right)$$

f_i : fraction of light from background i

$f_{tot} = \Sigma f_i = 3.6\%$

R: product of factors ~ unity:

(Rad. corr, kinematics, detector response)

$$\boxed{A_{ep} = -279 \quad \pm\ 35\,(stat) \quad \pm\ 31\,(sys)}$$

← Published commissioning result from 4% of total data collected

$$R_{TOT} / (P\,(1 - f_{tot})) \quad = \quad 1.139$$

$$\left. P\, f_i\, A_i = -51 + 11 + 0 + 1 = -39 \right\}$$

~ 1σ correction

(Al windows + beamline bgd. + soft neutrals + inelastic)

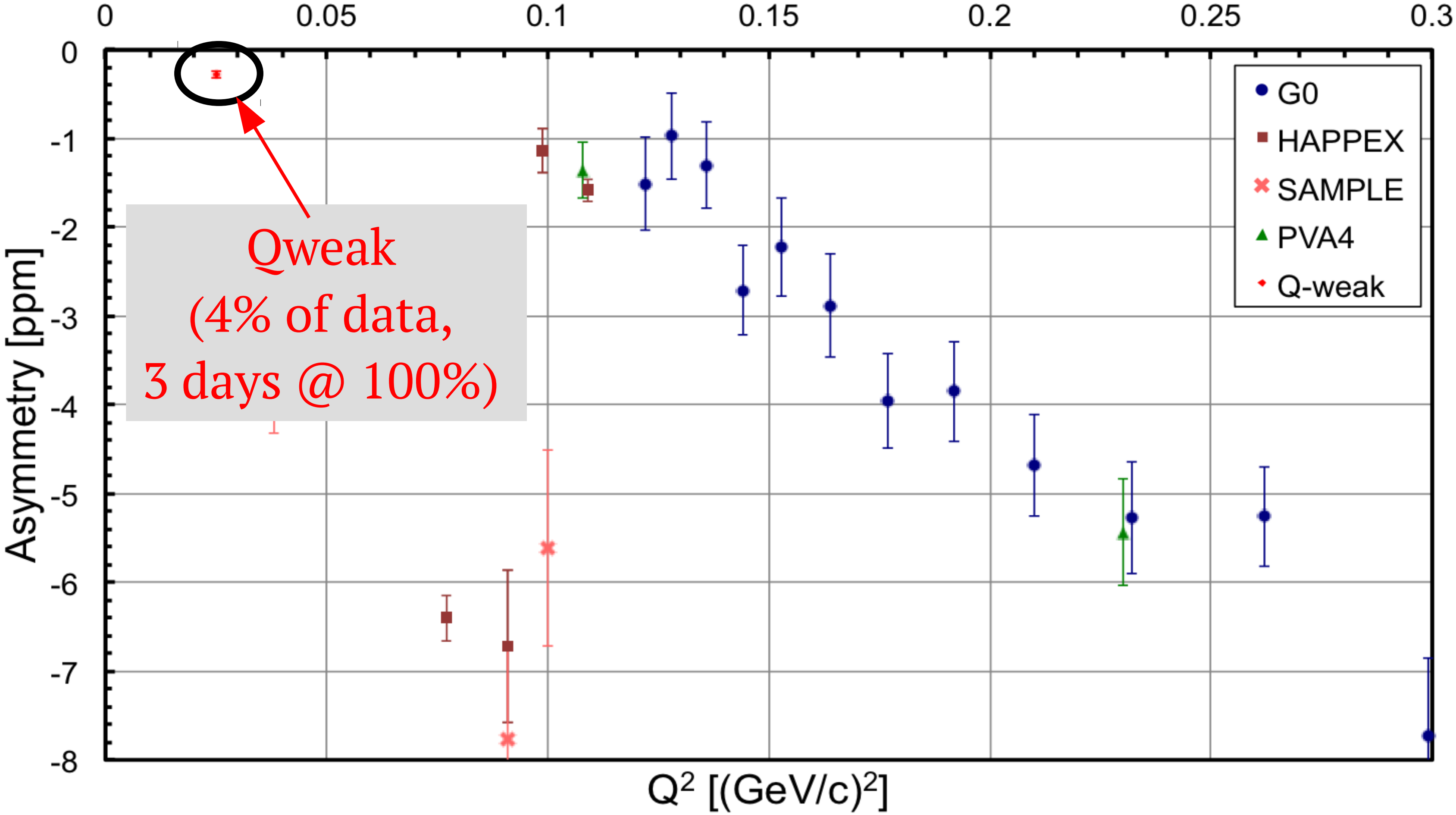
Published 10/2/2013: PRL **111,**141803 (2013)

First Results: Asymmetry

- Run 0 Results
  (1/25th of total dataset)

Kinematics: $\langle Q^2 \rangle = 0.0250 \pm 0.0006 \text{ GeV}^2$
$\langle E_{beam} \rangle = 1.155 \pm 0.003 \text{ GeV}$

$$\boxed{A_{ep} = -279 \pm 35 \text{ (stat) } \pm 31 \text{ (syst) ppb}}$$



Qweak
(4% of data,
3 days @ 100%)

Electroweak Corrections

$$Q_W^p = [1+\Delta\rho+\Delta_e]\left[(1-4\sin^2\theta_W(0))+\Delta_{e'}\right] + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

- Most of these well known and precisely calculated – except for γZ-box
- γZ-box: significant energy-dependent correction first identified by Gorchtein & Horowitz
- Hall *et al* model dependence constrained by JLab PVDIS data

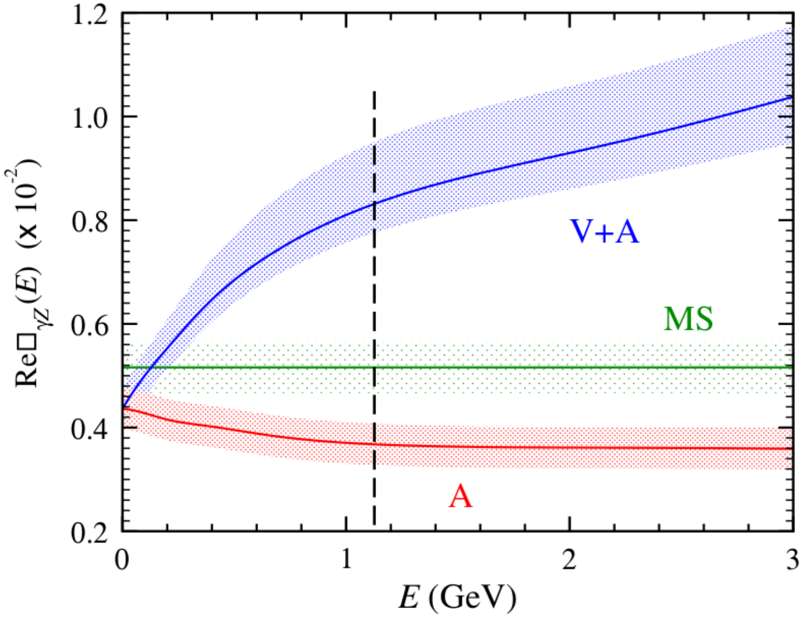
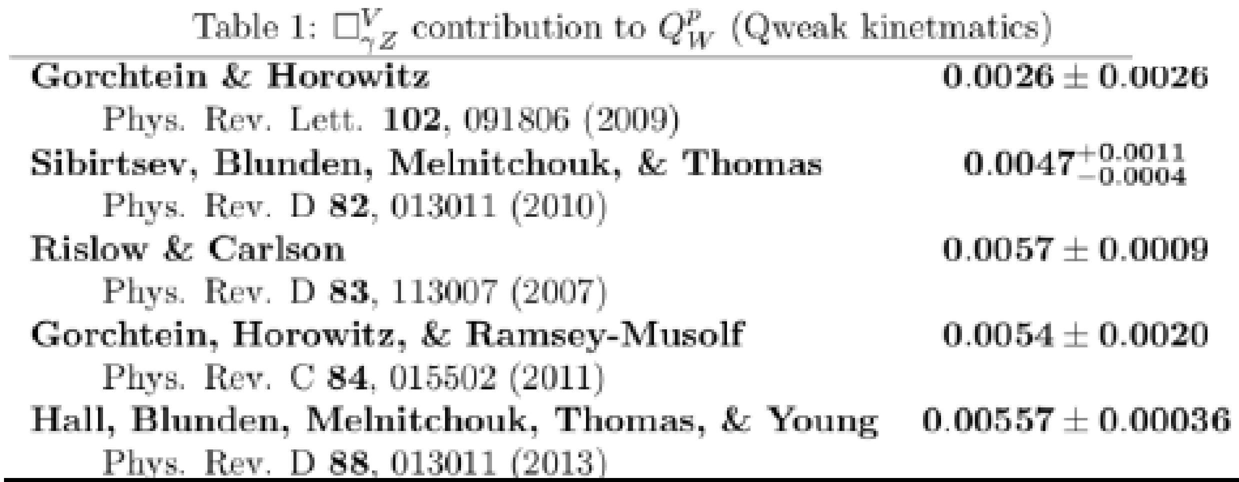
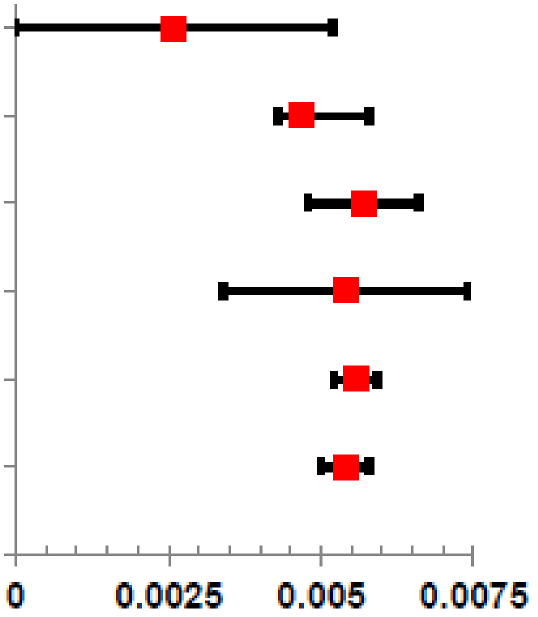


Table 1: $\Box^V_{\gamma Z}$ contribution to Q_W^p (Qweak kinetmatics)



Gorchtein & Horowitz Phys. Rev. Lett. **102**, 091806 (2009)	0.0026 ± 0.0026
Sibirtsev, Blunden, Melnitchouk, & Thomas Phys. Rev. D **82**, 013011 (2010)	$0.0047^{+0.0011}_{-0.0004}$
Rislow & Carlson Phys. Rev. D **83**, 113007 (2007)	0.0057 ± 0.0009
Gorchtein, Horowitz, & Ramsey-Musolf Phys. Rev. C **84**, 015502 (2011)	0.0054 ± 0.0020
Hall, Blunden, Melnitchouk, Thomas, & Young Phys. Rev. D **88**, 013011 (2013)	0.00557 ± 0.00036

Hall, Blunden, Melnitchouk, Thomas & Young 0.0054 ± 0.0004
arXiv:1504.03973 (2015)



Extracting the Weak Charge

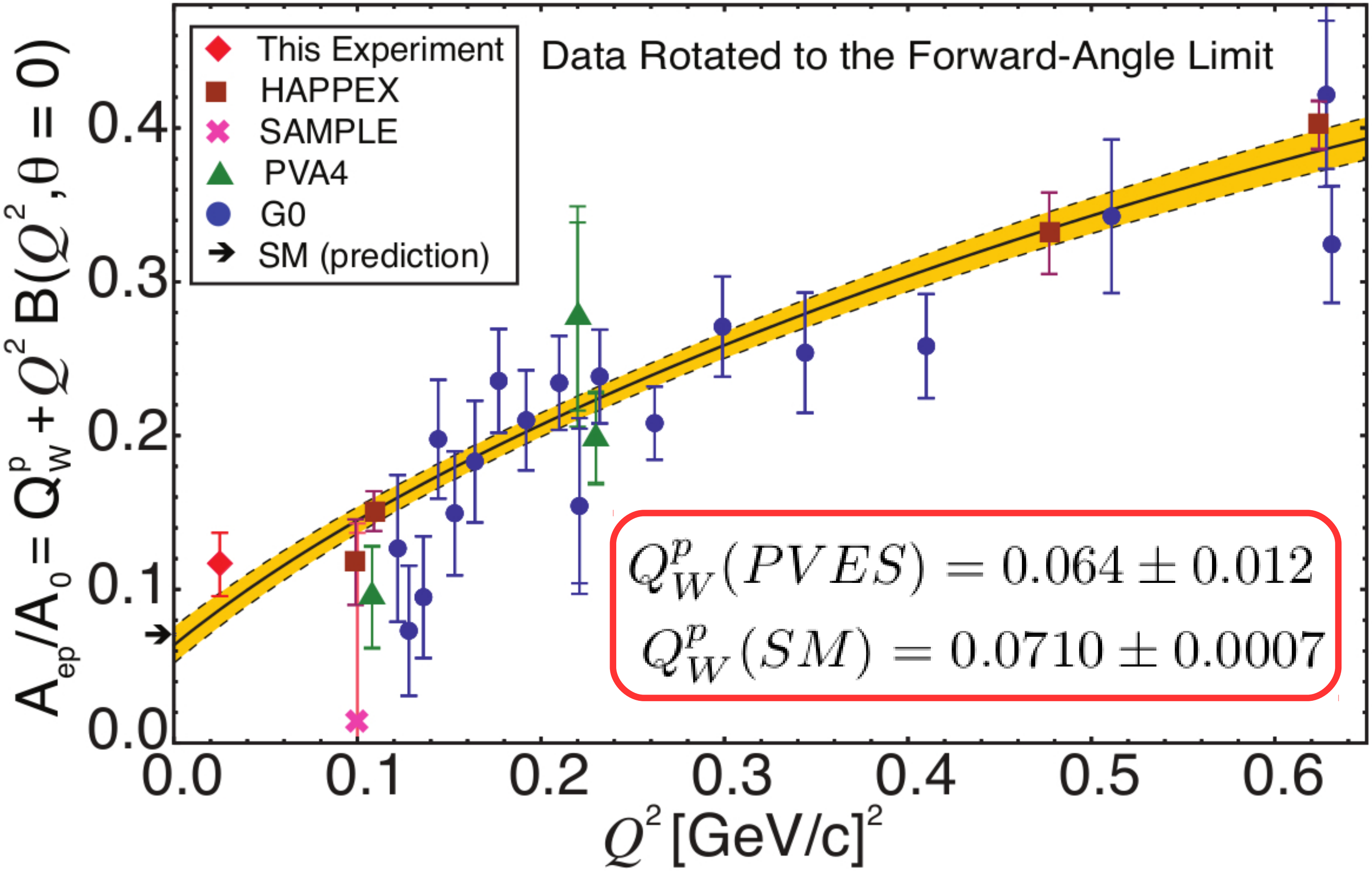
Global fit in Q^2 and θ to the reduced asymmetry

$$A_{LR}/A_0 = Q^p_{weak} + Q^2 B(Q^2) \qquad A_0 = -(G_\mu / 4\pi\alpha\sqrt{2})Q^2$$

- Using 5 free parameters: C_{1u}, C_{1d}, ρ_s, μ_s, & the isovector part of G_A^Z
  - G_E^S, G_M^S, and G_A^Z use a dipole, $(1+Q^2/\lambda^2)^{-2}$, with λ = 1 GeV/c
- Employs all PVES data up to $Q^2 = 0.63\ (\mathrm{GeV}/c)^2$
  - On p, d, & ^{4}He targets, forward and back-angle data
    - SAMPLE, HAPPEX, G0, PVA4
- Uses constraints on isoscalar part of G_A^Z
  - Zhu, et al., PRD 62, 033008 (2000)
- All ep data corrected for E & Q^2 dependence of γZ-box

First Results: Weak Charge

$$A_{ep}/A_0 = Q^p_W + Q^2 B(Q^2, \theta = 0)\ , \qquad A_0 = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}$$



$$Q^p_W(PVES) = 0.064 \pm 0.012$$
$$Q^p_W(SM) = 0.0710 \pm 0.0007$$

Global fit of world PVES data up to $Q^2 = 0.63$ GeV^2

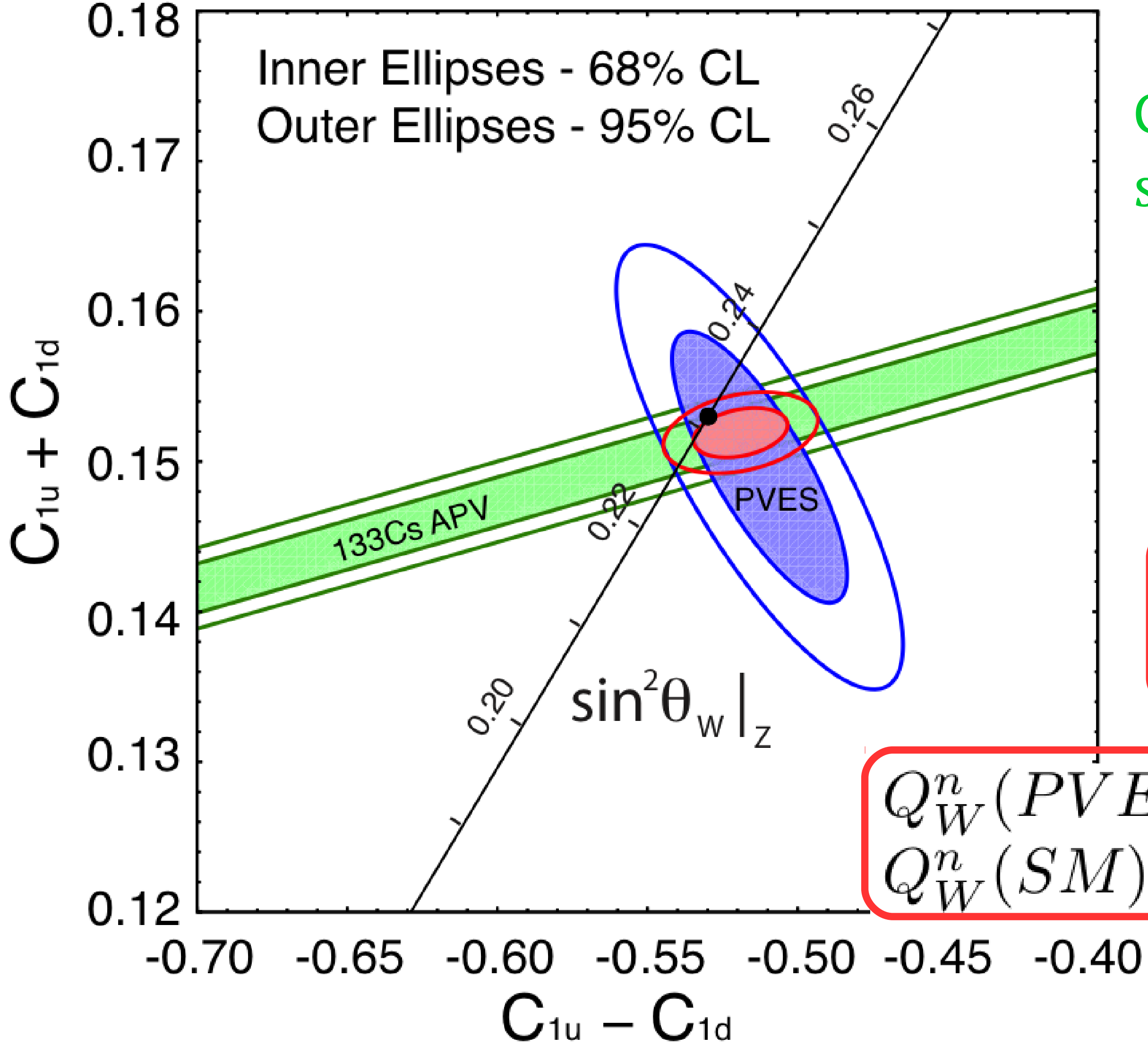
Data rotated to forward-angle for plotting

Remove energy- & Q^2 -dependence of γZ-box

4% of Qweak Data

Published 10/2/2013: PRL **111,**141803 (2013)

First Results: Quark Couplings



Black dot is SM value

Green band is Cesium APV – more sensitive to isoscalar combination

(Dzuba et al., PRL 109, 203003 (2012))

Blue ellipse is combined PVES (now with Qweak)

Red is combined APV+PVES fit

$$C_{1u} = -0.1835 \pm 0.0054$$
$$C_{1d} = 0.3355 \pm 0.0050$$

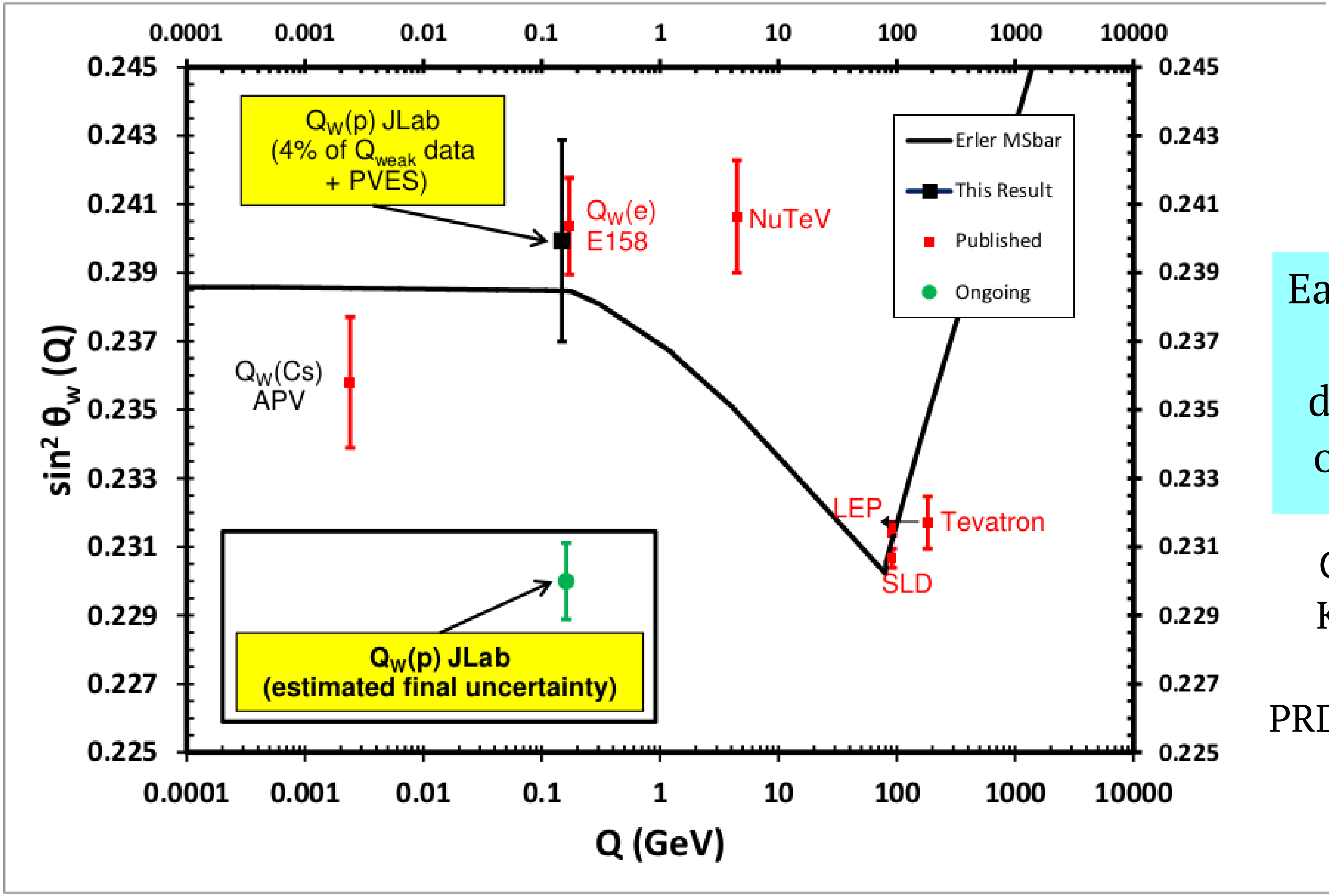
$$Q_W^n(PVES + APV) = -0.975 \pm 0.010$$
$$Q_W^n(SM) = -0.9890 \pm 0.0007$$

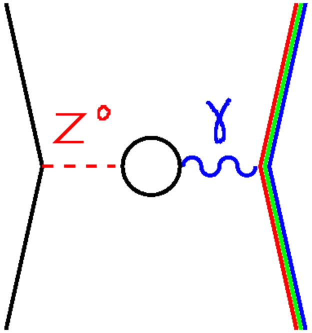
Published 10/2/2013: PRL **111,**141803 (2013)

4% of Qweak Data

First Results: Weak Mixing Angle

At tree level: $Q^p_W = 1 - 4\sin^2\theta_W$



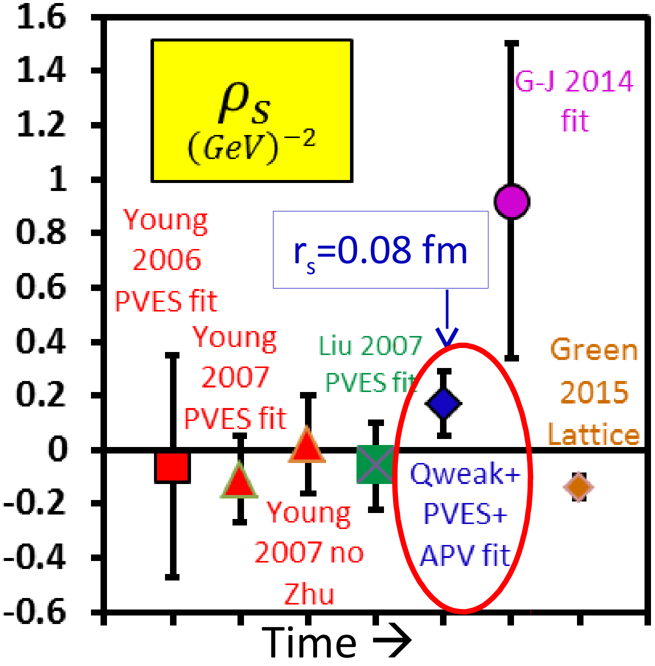


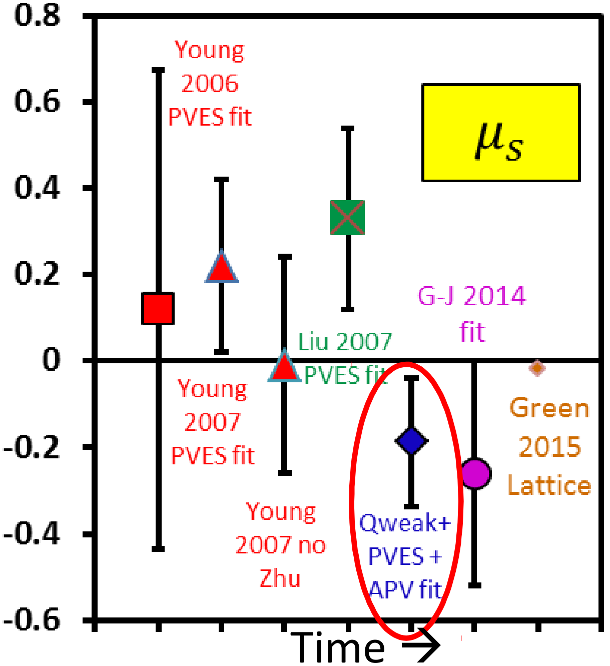
Each experiment sensitive to different types of new physics

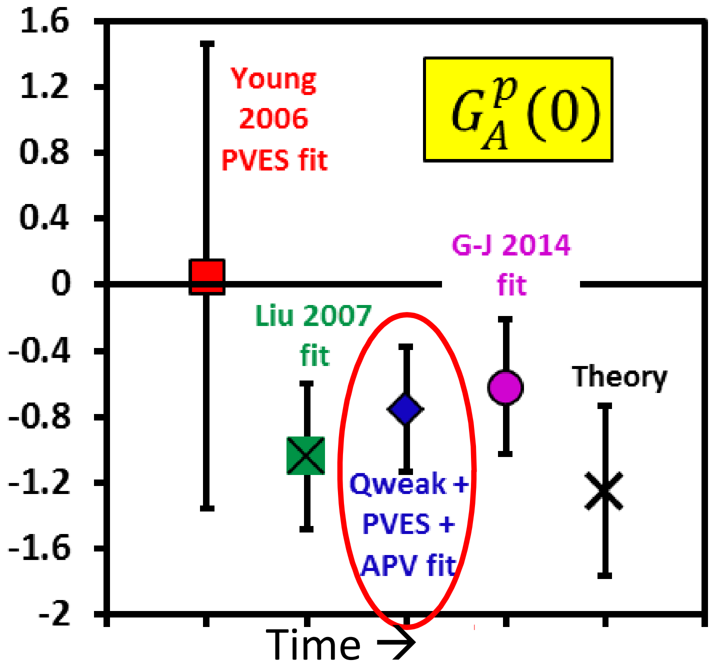
Curve from Erler, Kurylov, Ramsey-Musolf,
PRD **68**, 016006 (2003)

4% of Qweak Data

Global fit results for ρ_s, μ_s, & G_A







- Consistency of our fitted ρ_s, μ_s, & G_A^p with other fits gives us confidence in our published $Q_W(p)$ result.
- Physics statements about ρ_s, μ_s, & G_A^p will be made after careful systematic studies of our fit with the final $Q_W(p)$ data point included.

Q_{weak} +PVES fit: Androic, et al, PRL 111, 141803 (2013)
(only 4% of expt's total data)

Young 2006 fit: Young, et al, PRL 97, 102002 (2006)
Young 2007 fit: Young, et al, PRL 99, 122003 (2007)

G-J 2014 fit: Gonzalez-Jimenez, et al, PRD 90, 033002 (2014)
Green Lattice QCD: arXiv 1505.01803 (2015)

Liu fit: Liu, et al, PRC76, 025202 (2007)

Theory: See ref's in 2006 Young paper: $$G_A^p = \frac{\xi_A^{T=1} G_A \tau_3 + \xi_A^{T=0} a_8 + \xi_A^0 a_s + A_{ana}^{T=1}\tau_3 + A_{ana}^{T=0}}{\left(1+{Q^2}/{\lambda^2}\right)^2}$$

Usually fixed to Zhu, et al, PRD62, 033008 (2000)

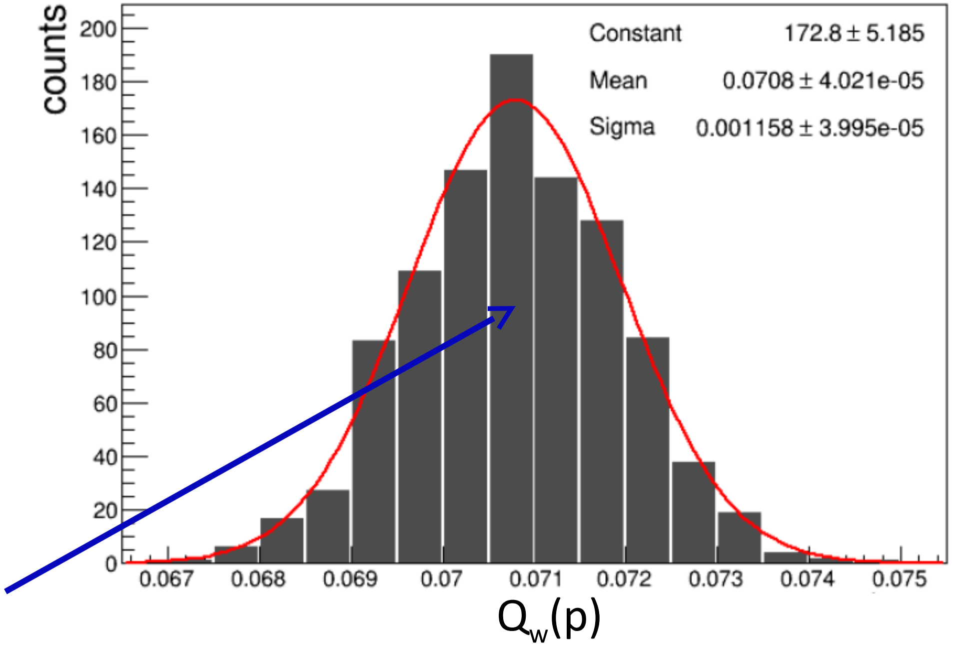
Constrained by other expt's

Always floated in the fits

Sensitivity to EM FFs

- Use "theory point" of A = −213.9 ± 4.1 ppb at our kinematics
  - Perform $Q_w(p)$ PVES fits for each of 4 EMFF fits:
  - No difference
- Next study impact of uncertainties in the EMFFs
  - Use Arrington & Sick EMFF fit
    - Low Q^2, 2γ, careful treatment of correlations, more recent…
  - Do $Q_w(p)$ PVES fit 1000 times, varying EMFFs within their errors, using the "theory point"
  - Width of distribution only 1.6%

EMFF Fit	Q^p_w	dQ^p_w
Arrington & Sick	0.0705	0.0023
Kelly	0.0702	0.0023
Simple Dipole	0.0702	0.0022
Friedrich & Walcher	0.0683	0.0022

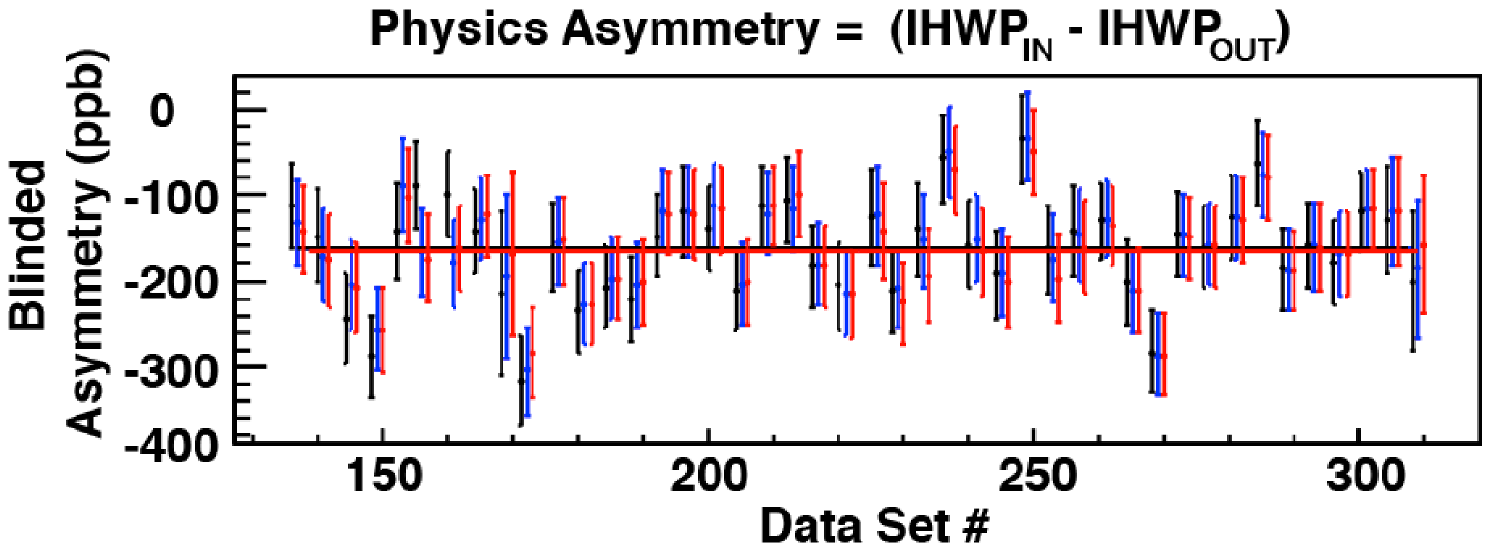


J. Friedrich and Th. Walcher. EPJ A 17(4):607–623, 2003.
J. Kelly. Phys. Rev. C, 70:068202, 2004
John Arrington and Ingo Sick. Phys. Rev. C, 76:035201, 2007.

Analysis is progressing...

Qweak Run 2 - Blinded Asymmetries

(statistics only - not corrected for beam polarization, Al target windows, ΔQ^2, etc.)


Physics Asymmetry = $(IHWP_{IN} - IHWP_{OUT})$

Raw = -161.8 ± 7.6

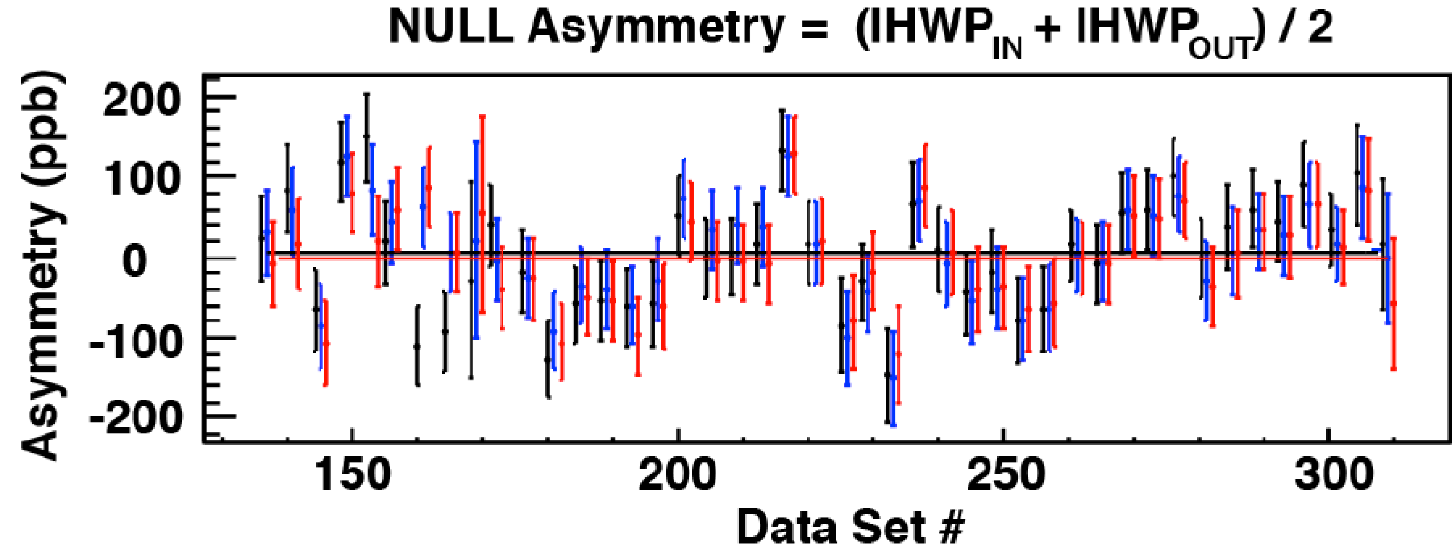
(χ^2/ NDF = 1.40, Prob = 0.043)

Regressed = -160.9 ± 7.6

(χ^2/ NDF = 1.19, Prob = 0.18)

Beamline
Bkgd Corrected = -164.5 ± 7.6

(χ^2/ NDF = 1.08, Prob = 0.33)


NULL Asymmetry = $(IHWP_{IN} + IHWP_{OUT}) / 2$

Raw = 4.7 ± 7.7

(χ^2/ NDF = 1.84, Prob = 0.001)

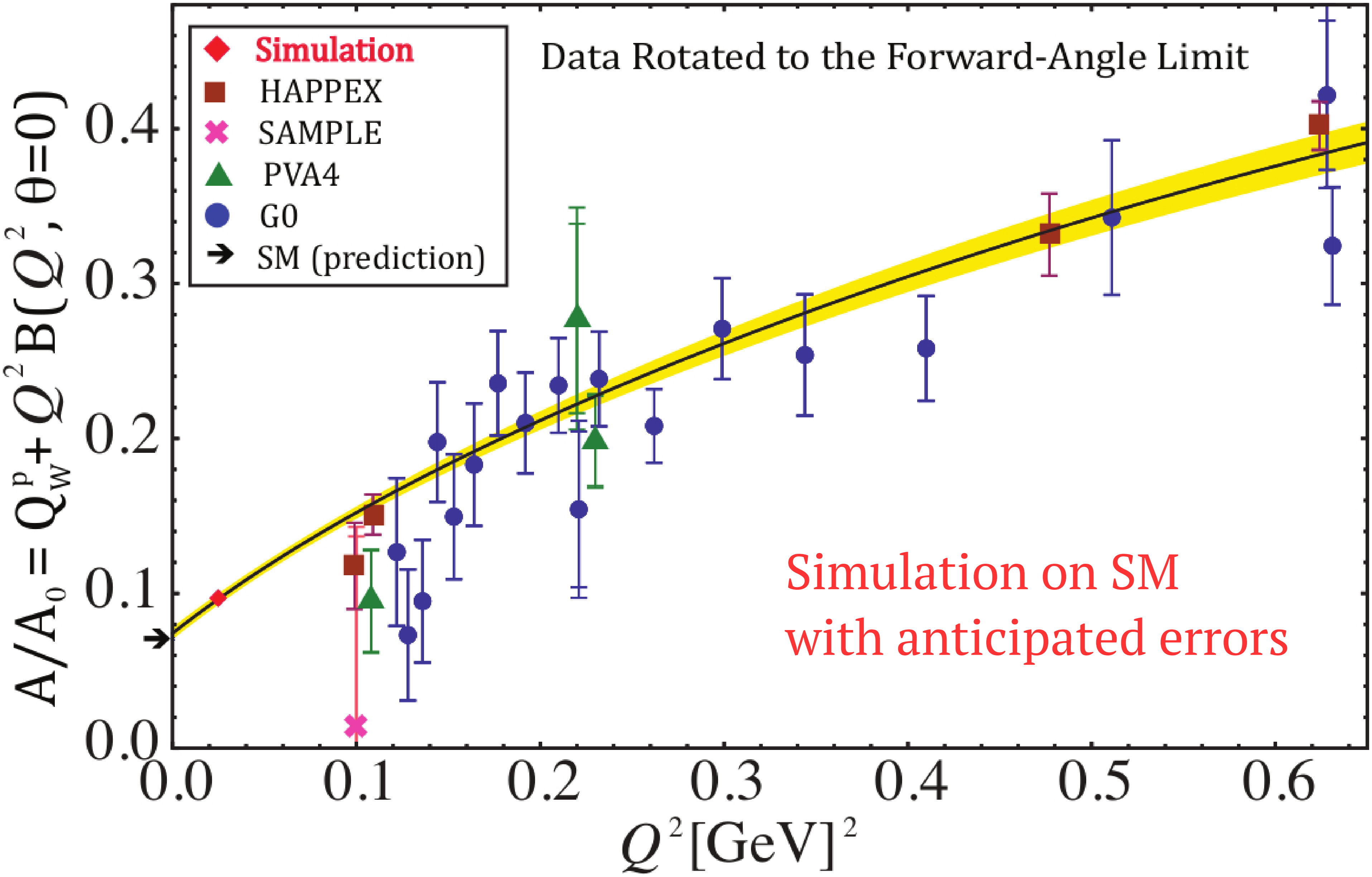
Regressed = 7.9 ± 7.7

(χ^2/ NDF = 1.38, Prob = 0.048)

Beamline
Bkgd Corrected = -1.4 ± 7.7

(χ^2/ NDF = 1.29, Prob = 0.097)

“Teaser” with anticipated final errors



Summary

- First published result from the Qweak experiment

$$A_{ep} = -279 \pm 35\ (\mathrm{stat})\ \pm 31\ (\mathrm{syst})\ \mathrm{ppb}$$

4% of
Qweak
Data

  - Determination of the proton and neutron weak charge

$$Q^p_W(PVES) = 0.064 \pm 0.012$$
$$Q^p_W(SM) = 0.0710 \pm 0.0007$$

$$Q^n_W(PVES + APV) = -0.975 \pm 0.010$$
$$Q^n_W(SM) = -0.9890 \pm 0.0007$$

In agreement with Standard Model predictions

- Final result expected in a year
  - Statistical error 5 times smaller, with reduced systematics
  - Additionally, many ancillary results under analysis

The Qweak Collaboration

97 collaborators 23 grad students
10 post docs 23 institutions

Institutions:

[1] University of Zagreb
[2] College of William and Mary
[3] A. I. Alikhanyan National Science Laboratory
[4] Massachusetts Institute of Technology
[5] Thomas Jefferson National Accelerator Facility
[6] Ohio University
[7] Christopher Newport University
[8] University of Manitoba,
[9] University of Virginia
[10] TRIUMF
[11] Hampton University
[12] Mississippi State University
[13] Virginia Polytechnic Institute & State Univ
[14] Southern University at New Orleans
[15] Idaho State University
[16] Louisiana Tech University
[17] University of Connecticut
[18] University of Northern British Columbia
[19] University of Winnipeg
[20] George Washington University
[21] University of New Hampshire
[22] Hendrix College, Conway
[23] University of Adelaide

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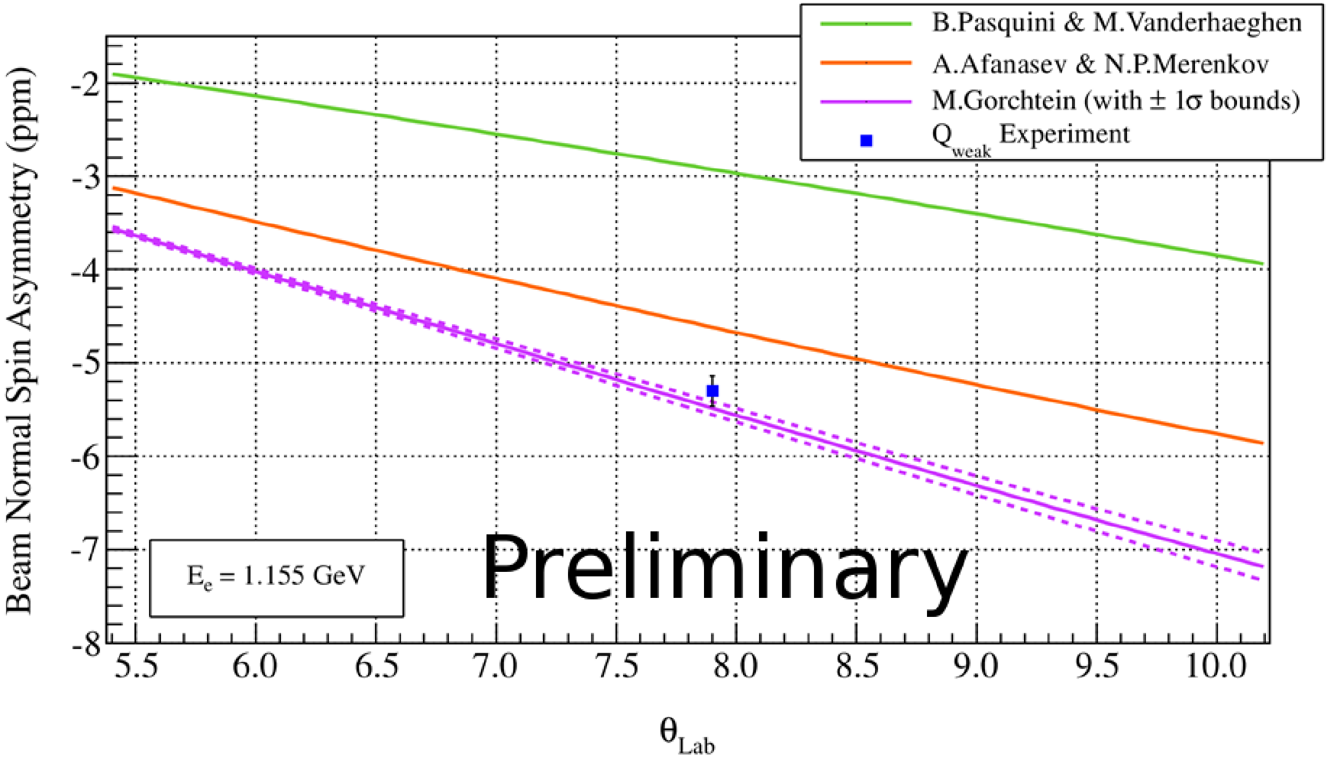
Spokespersons Project Manager Grad Students

e-p transverse asymmetry

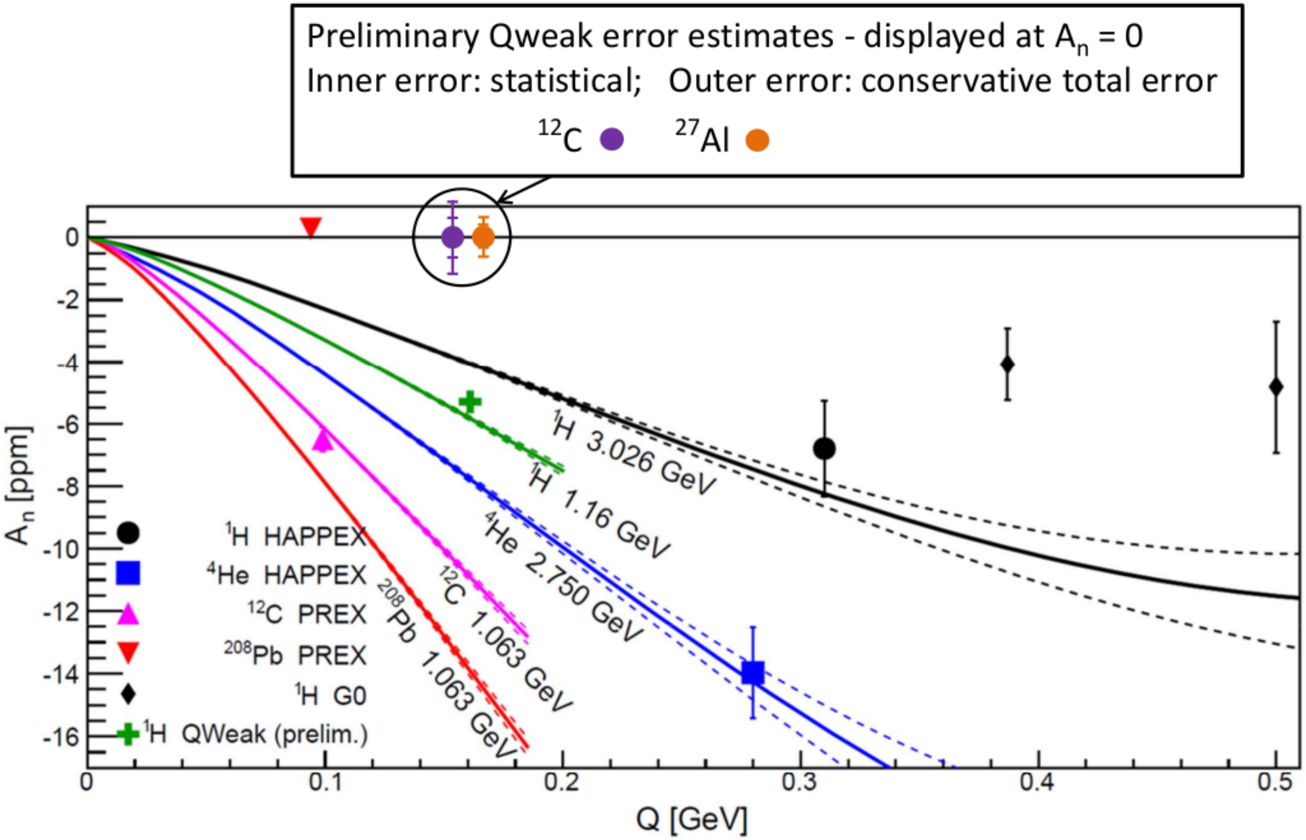
- Pasquini/Vanderhaeghen Model
  - Includes intermediate states: proton (elastic) and πN (inelastic)
  - Computed via N → πN electroproduction amplitudes from MAID
- Afanasev/Merenkov and Gorchtein Models
  - Optical theorem: relates forward Compton amplitude to total photoproduction cross section
  - Effectively includes both πN and ππN states
- For all models, inelastic dominates over elastic

- Kinematics:
  - Q2 = 0.0250 ± 0.006 (GeV/c)2
  - E = 1.155 ± 0.003 GeV
  - Scattering angle = 7.9° ± 0.3°
- Preliminary
  A_n = -5.30 ± 0.07 ± 0.15 ppm
  - No radiative corrections
  - Results from B. Waidyawansa Ph.D.thesis; being prepared for publication



Transverse asymmetry on nuclei

- Calculations with inelastic intermediate hadronic states agree with experimental data up to A = 12, but fail to describe Pb (A = 208)
- No calculation includes both Coulomb distortion and a full range of excited intermediate states.
- Adding data between A=12 and A=208 (such as Al, A=27) will shed light on this issue



Preliminary Qweak error estimates - displayed at $A_n = 0$
Inner error: statistical; Outer error: conservative total error
^{12}C ● ^{27}Al ●

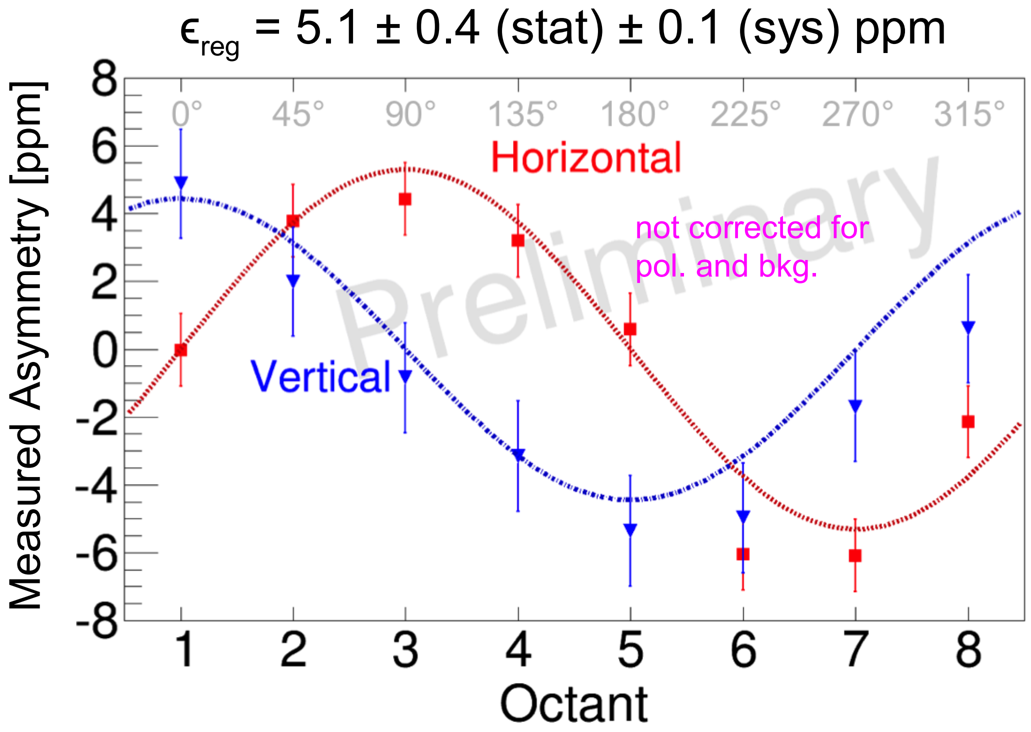
Figure adapted from PREX collaboration;
PRL 109, 192501 (2012)

Calulations by M. Gorchtein and C. J. Horowitz,
Phys. Rev. C 77, 044606 (2008).

Beam Normal Single Spin Asymmetry in Δ Resonance

Q-weak has measured Beam Normal Single Spin Asymmetry (B_n) in the N-to-Δ transition on H_2

$$B_n = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = \frac{2T_{1\gamma} \times \mathrm{Im}\, T_{2\gamma}}{|T_{1\gamma}|}$$

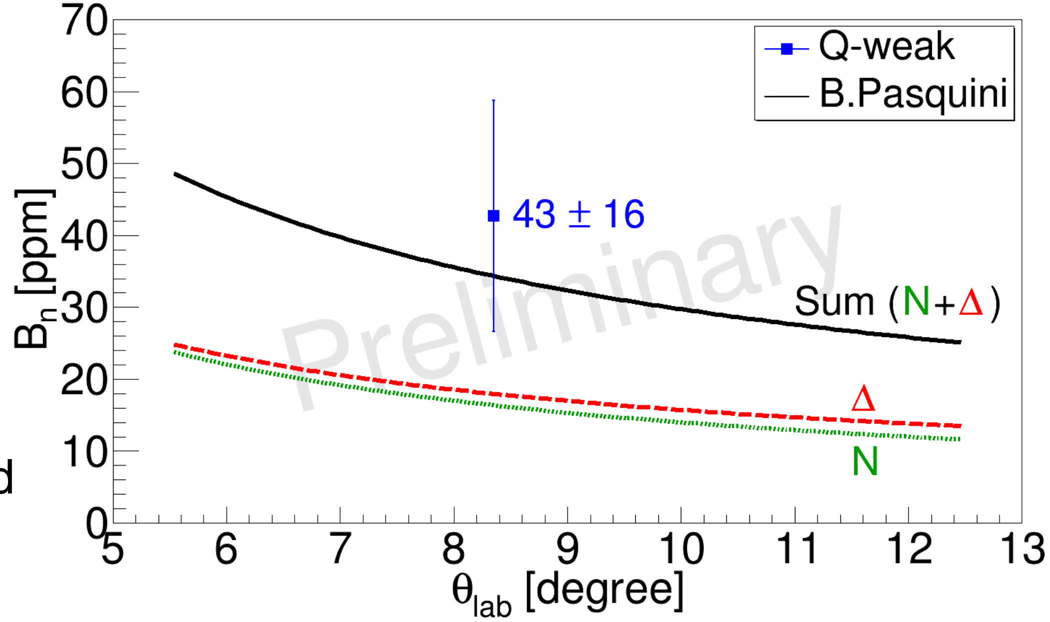


After correcting for polarization and backgrounds

$$B_n = 43 \pm 16 \text{ ppm}$$

at kinematics

- $\langle E \rangle$ = 1.16 GeV
- $\langle W \rangle$ = 1.2 GeV
- $\langle \theta \rangle$ = 8.3°
- $\langle Q^2 \rangle$ = 0.021 GeV^2



- Unique tool to study $\gamma^*\Delta\Delta$ form factors
- Q-weak along with world data has potential to constrain models and study charge radius and magnetic moment of Δ