Qweak Report and Technology Application at Lower Energies

Mark Pitt* Virginia Tech

Workshop to Explore Physics Opportunities with Intense, Polarized Electron Beams up to 300 MeV
Cambridge, MA March 14-16, 2013

Qweak uses parity-violating elastic electron-proton scattering to measure the proton's neutral weak charge at Jefferson Lab

- Precision Standard Model test
- tests "running of $\sin^2\theta_W$" from M^2_Z to low Q^2
- sensitive to new TeV scale physics

A brief status report on the experiment will be given with a focus on existing instrumentation and demonstrated methodology for application to lower beam energy realizations of PV measurements.

* Work partially supported by the National Science Foundation

A SEARCH FOR NEW PHYSICS

Qweak

The Collaboration

Funded by DOE, NSF, NSERC

D. Androic, D.S. Armstrong, A. Asaturyan, T. Averett, J. Balewski, J. Beaufait, R. Beminiwattha, J. Benesch, F. Benmokhtar, J. Birchall, **R.D. Carlini[1] (Principal Investigator)**, J.C. Cornejo, S. Covrig, M. Dalton, C. A. Davis, W. Deconinck, J. Diefenbach, K. Dow, J. Dowd, J. Dunne, D. Dutta, W.S. Duvall, M. Elassar, W. Falk, **J.M. Finn[1]***, T.A. Forest, D. Gaskell, M. Gericke, J. Grames, V.. Gray, K. Grimm, F. Guo, J.R. Hoskins, K. Johnston, D. Jones, M. Jones, R. Jones, E. Kargiantoulakis, P. King, E. Korkmaz, **S. Kowalski[1]**, J. Leacock, J.P. Leckey, A. Lee, J.H. Lee, L. Lee, S. MacEwan, D. Mack, J. Magee, R. Mahurin, J. Mammei, J. Martin, M. McHugh, D. Meekins, J. Mei, R. Michaels, A. Micherdzinska, K.E. Myers, A. Mkrtchyan, H. Mkrtchyan, A. Narayan, L. Ndukum, V. Nelyubin, Nuruzzaman, A.K. Opper, **S.A. Page[1]**, J. Pan, K. Paschke, S.K. Phillips, M. Pitt, B.M. Poelker, J.F. Rajotte, W.D. Ramsay, J. Roche, B. Sawatzky, T. Seva, M. Shabestari, R. Silwal, N. Simicevic, **G. Smith[2]**, P. Solvignon, D. Spayde, A. Subedi, R. Subedi, R. Suleiman, V. TAdevosyan, W. Tobias, V. Tvaskis, W.T.H. van Oers, B. Waidyawansa, P. Wang, S. Wells, S.A. Wood, S. Yang, R.D. Young, S. Zhamkochyan, D. Zou

[1]Spokespersons *deceased [2]Project Manager

The Q_{weak} Experiment:
A Search for New Physics at the TeV Scale Via a
Measurement of the Proton's Weak Charge

December 3, 2001

D. Armstrong[1], T. Averett[1], J.D. Bowman[5], R. Carlini[9] (contact person), C.A. Davis[11] J. Erler[3], R. Ent[9], M. Finn[1], T.A. Forest[6], K. Johnston[6], R. Jones[2], S. Kowalski[8], L. Lee[7], A. Lung[9], D. Mack[9], S.A. Page[7], S. Penttila[5], M. Pitt[10], M. Poelker[9], W.D. Ramsay[7], M. Ramsey-Musolf[2,4], J. Roche[1,9], N. Simicevic[6], G. Smith[9], R. Suleiman[8], S. Taylor[8], W.T.H. van Oers[7], S. Wells[6], S. Wilburn[5], S.A. Wood[9]

Timeline

- Proposal 2001
- Design/Construction 2003 – 2010
- Data-taking 2010 - 2012
- Analysis 2012 - 2014
- Now ~ 100 collaborators; 22 students

Outline

- Motivation and Interpretation
- Qweak apparatus and performance highlights with emphasis on aspects useful for lower energy PVES experiments
- Results from "25% Commissioning Dataset"
  – First Direct Measurement of the Proton's Weak Charge
- Thoughts about reusing Qweak apparatus at lower energies

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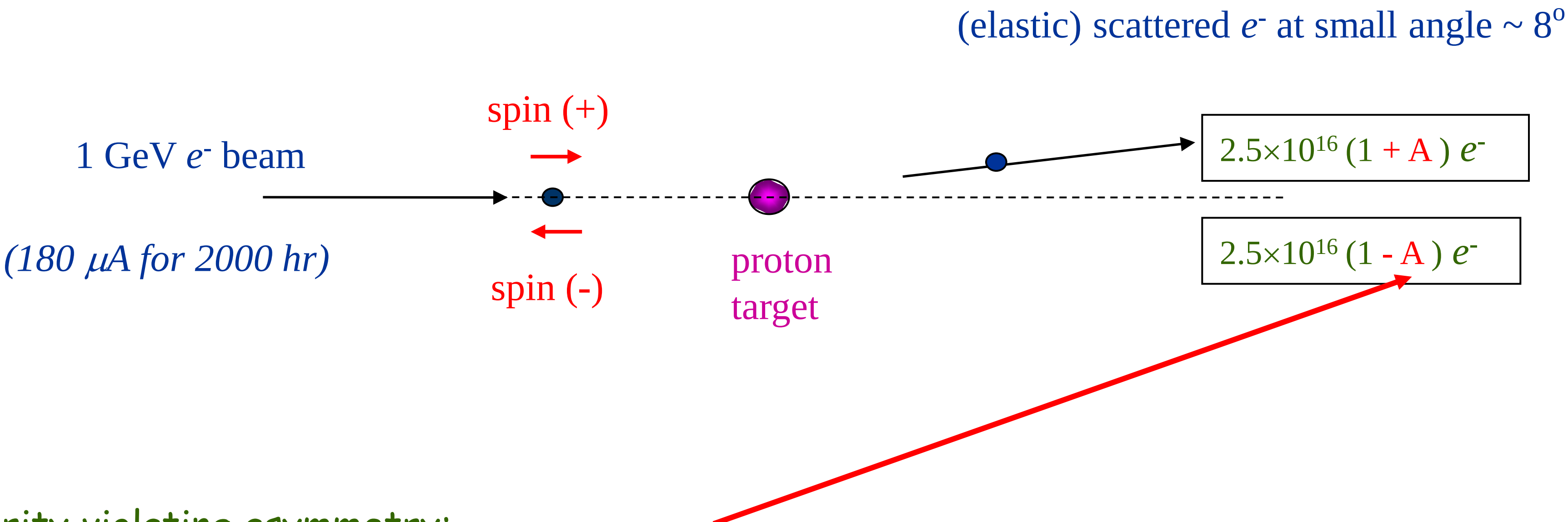
The Qweak Experiment: Essentials

Elastic scattering of longitudinally polarized electrons on protons

$$\vec{e}^- + p \rightarrow e^- + p$$



Parity violating asymmetry:

$A \sim$ -230 ppb (parts per billion) at low $Q^2 \sim 0.025\ (\mathrm{GeV}/c)^2$

→ Measurement of this small asymmetry requires:

- high statistics (high beam current, high polarization, high power liquid H_2 target)
- careful attention to systematic errors (false asymmetries, backgrounds, polarization)

Goal: Measure proton's weak charge – Q^p_W with ~ 4% precision

→ corresponds to a 0.3% precision measurement of $\sin^2\theta_W$

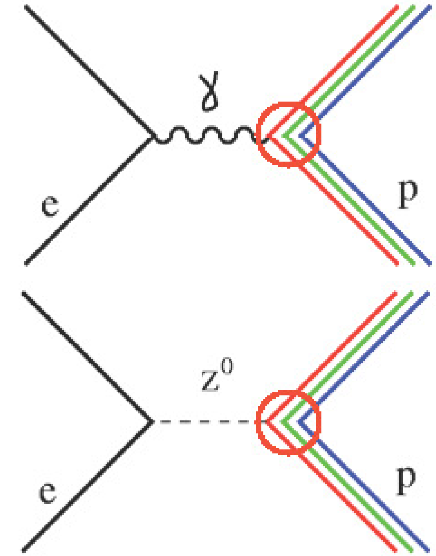
~ sensitivity to New Physics due to suppression of Q^p_W in Standard Model

$$Q^p_{weak} = 1 - 4\sin^2\theta_W$$

Accessing Neutral Weak Sector

Electron scattering proceeds via exchange of gamma or Z bosons.

$$\sigma \propto |M_\gamma + M_{\rm weak}|^2 \sim |M_\gamma|^2 + 2M_\gamma M^*_{\rm weak}$$



Asymmetry is proportional to interference

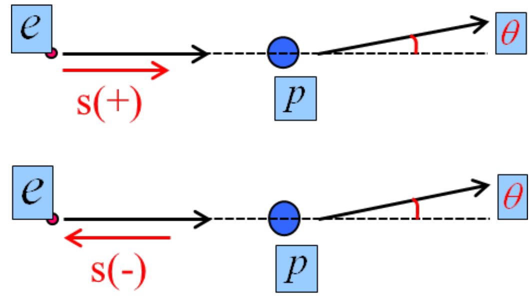
$$A_{\rm PV} \sim \frac{|M^{\rm PV}_{\rm weak}|}{|M_{\rm EM}|}$$

Tree level electric and weak charges

	$Q_{\rm EM}$	$Q_{\rm weak}$
q_u	$+\frac{2}{3}$	$+1 - \frac{8}{3}\sin^2\theta_W \approx 0.38$
q_d	$-\frac{1}{3}$	$-1 + \frac{4}{3}\sin^2\theta_W \approx -0.69$
p	$+1$	$+1 - 4\sin^2\theta_W \approx 0.07$
n	0	-1

← suppression

Parity-Violating Asymmetry for the Q_{weak} Experiment



The Qweak experiment at JLAB determines the proton's weak charge by measuring the parity-violating asymmetry in elastic scattering of longitudinally polarized electrons on proton.

$$A_{PV} = \frac{2M_{NC}}{M_{EM}} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right]\left[\frac{\varepsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1-4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^Z}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2}\right]$$

At forward scattering angles and low 4-momentum transfer:

$$A \equiv \frac{d\sigma_+ - d\sigma_-}{d\sigma_+ + d\sigma_-} \xrightarrow[\theta\to 0]{Q^2\to 0} \left[\frac{-G_F}{4\pi\alpha\sqrt{2}}\right]\left[Q^2 Q^p_{weak} + Q^4 B(Q^2)\right]$$

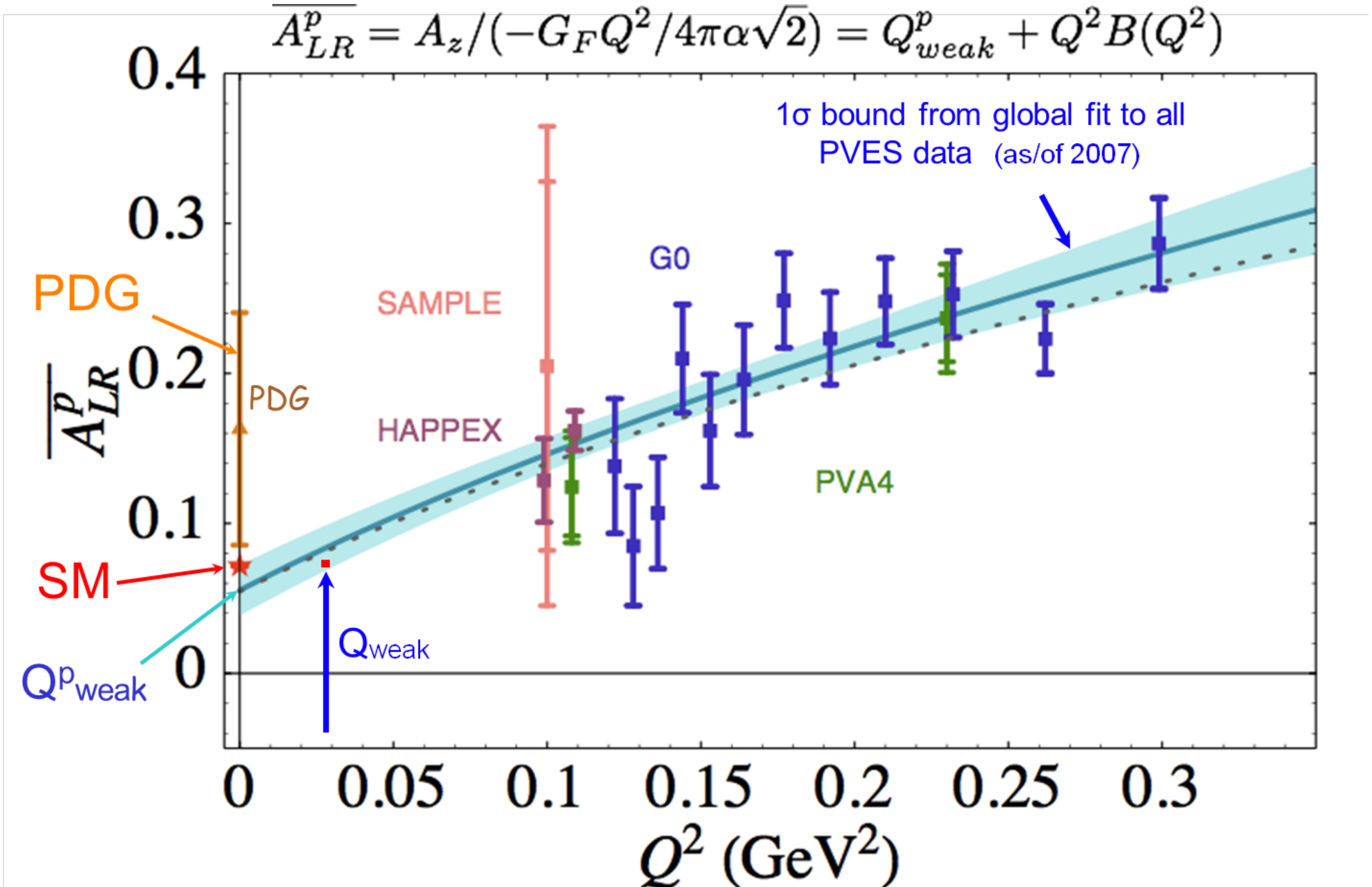
$$Q^p_{weak} = \xrightarrow{Q^2\to 0, E\to 0} \frac{A}{\left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right]}$$

proton's weak charge:
$Q^p_{weak} = 1 - 4\sin^2\theta_W$ at tree level

"Form factor" term due to finite proton size - hadronic structure (~ 30% for Qweak)

By running at a small value of Q^2 (small beam energy, small scattering angle) we minimize our sensitivity to the effects of the proton's detailed spatial structure.

Existing PV e-p Data - Use To Determine Hadronic Term $B(Q^2)$



Ref: (R.D. Young, R.D. Carlini, A.W. Thomas, and J. Roche, PRL 99, 122003 (2007))

Existing elastic electron-proton parity-violating asymmetry data at higher Q^2 is adequate to constrain the hadronic structure term - $B(Q^2)$ - for a 4% measurement of Q_{weak}

Energy Dependent Electroweak Radiative Corrections

After removing hadronic term, need to correct for energy dependent radiative corrections

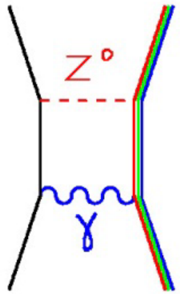
Two-photon Exchange (J.A. Tjon, P.G. Blunden, and W. Melnitchouk, PRC 79, 055201 (2009))

Total correction found to be ~ 0.13%

γ-Z Box Diagram

$\Box_{\gamma Z}$ contribution to Q_W^p (Qweak kinematics)

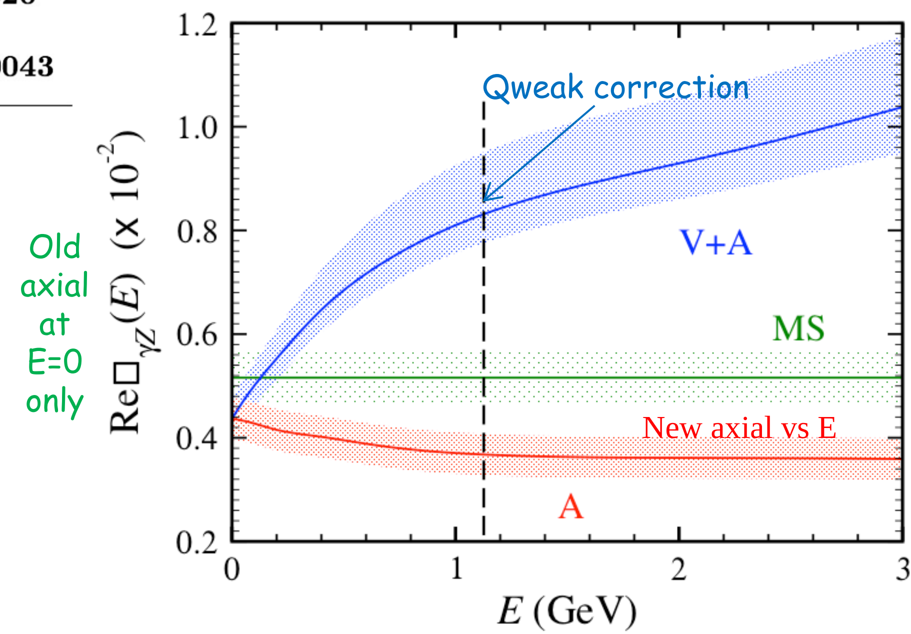
Gorchtein & Horowitz *PRL 102, 091806 (2009)*	$\mathbf{0.0026 \pm 0.0026}$
Sibirtsev, Blunden & Melnitchouk, Thomas *PRD 82, 013011 (2010)*	$\mathbf{0.0047^{+0.0011}_{-0.0004}}$
Rislow & Carlson *arXiv:1011.2397 (2010)*	$\mathbf{0.0057 \pm 0.0009}$
Gorchtein, Horowitz & Ramsey-Muslof *arXiv:1102.3910 (2011)*	$\mathbf{0.0054 \pm 0.0020}$
Hall, Blunden, Melnitchouk, Thomas & Young *Private communication (2012)*	$\mathbf{0.0052 \pm 0.00043}$



Example: latter correction is ~ 7.3 ± 0.6%

Calculations are primarily dispersion theory type; error estimates can be firmed up with PVDIS data

More detail in next two talks in PS1:
W. Melnitchouk
B. Rislow



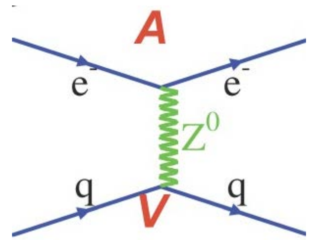
Standard Model Test

The resulting "static" proton weak charge $Q^{p}_{weak} \xrightarrow{Q^2\to 0, E\to 0} \dfrac{A}{\left[\dfrac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right]}$ can be used for SM test

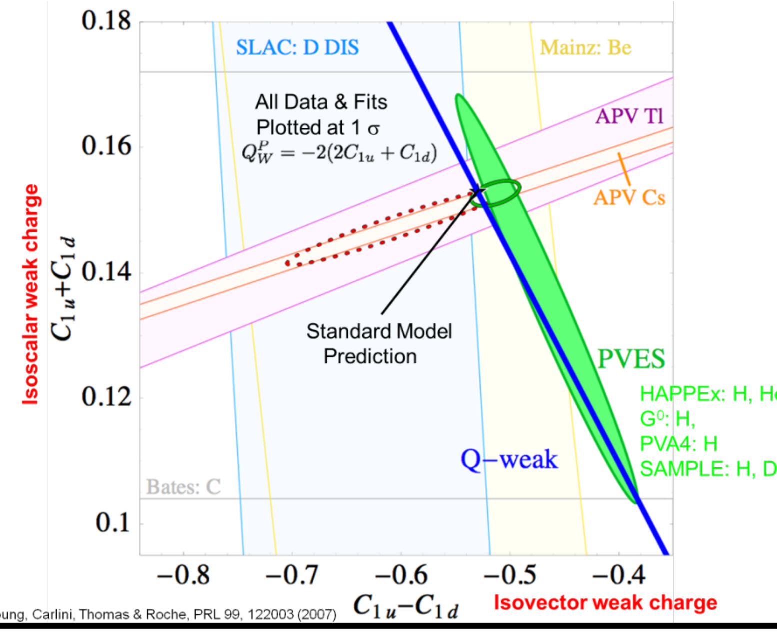
Quark Vector Couplings

$$L^{PV}_{e\text{-}q} = -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e\sum_q C_{1q}\bar{q}\gamma^\mu q$$

$$Q^p_W = -2(2C_{1u} + C_{1d})$$



$$C_{1i} \equiv 2g^e_A g^i_V$$

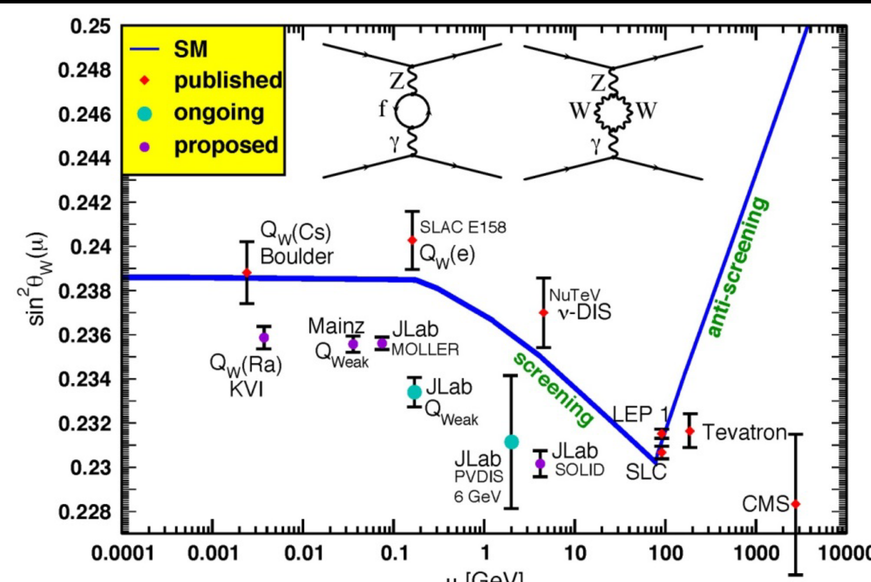


"Running" of the weak mixing angle - $\sin^2\theta_W$

Extract $\sin^2\theta_W$ for comparison with other probes

$$Q_W(p) = [\rho_{NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_W(0) + \Delta'_e]$$
$$+ \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

(see Kumar, Mantry, Marciano, Souder, arXiV:1302.6263 for recent review)



Sensitivity to New Physics at TeV Scales

Parameterize new physics with a new contact interaction in the Lagrangian:

$$\mathcal{L}_{NP}^{PV} = -\frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e \sum_q h_V^q \bar{q}\gamma^\mu q$$

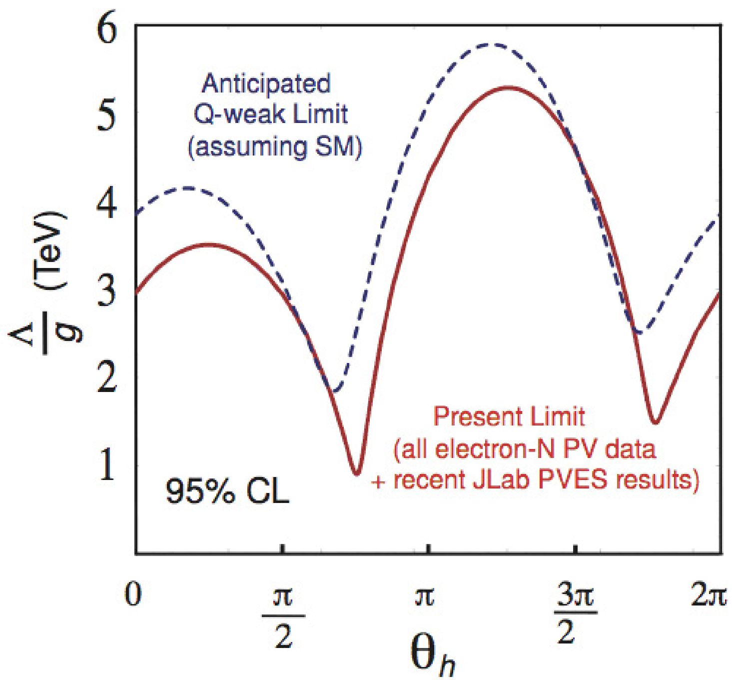
g=coupling
Λ=mass scale

Arbitrary quark flavor dependence of new physics:

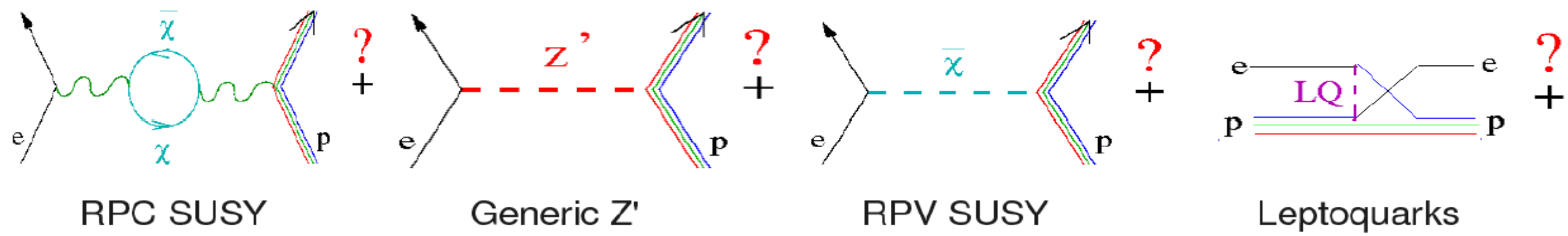
$$h_V^u = \cos\theta_h \qquad h_V^d = \sin\theta_h$$

Qweak constrains new PV physics to beyond 2 TeV

Young, Carlini, Thomas & Roche, PRL 99, 122003 (2007)



Possible New Physics Scenarios:



Ramsey-Musolf, Phys. Rev. C 60, 015501 (1999), Erler, et al. Phys. Rev. D 68, 016006 (2003)

New Physics Scenarios - Some Recent Examples

Low Energy PV and Tevatron Top A_{FB} Anomaly

Gresham, Kim, Tulin, Zurek,, Phys. Rev. D86, 034029 (2012)

Tevatron CDF and D0 see excess in $t - \bar{t}$ forward backward asymmetry
Possible explanation of new, relatively light scalar or vector particle ruled out by low energy PV constraints

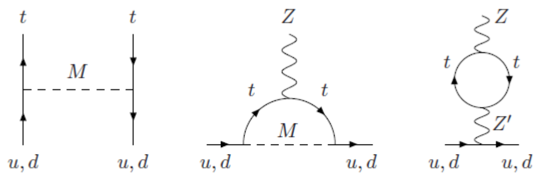
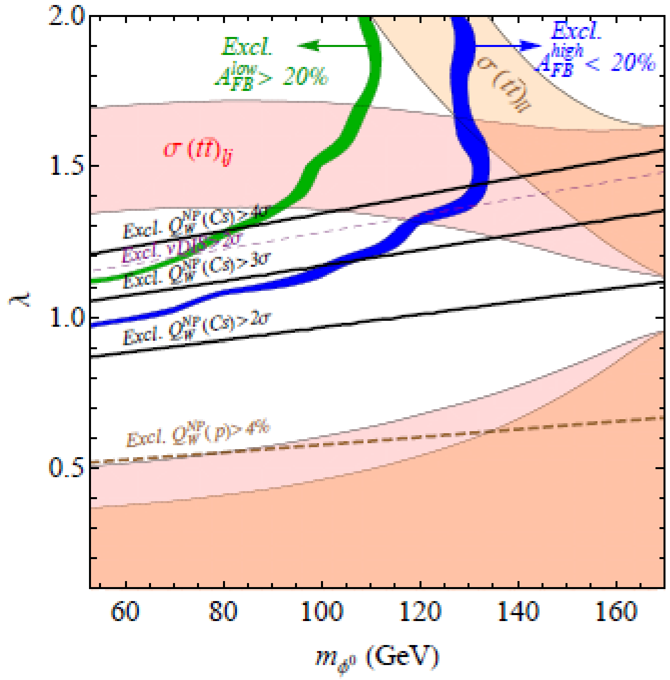


FIG. 1: A_{FB} from t-channel exchange of M (left). Anomalous coupling of Z to u, d at one-loop is generated by M (center) and by flavor-conserving Z' associated with certain vector M models.



Muon Anomaly and "Dark" Parity Violation

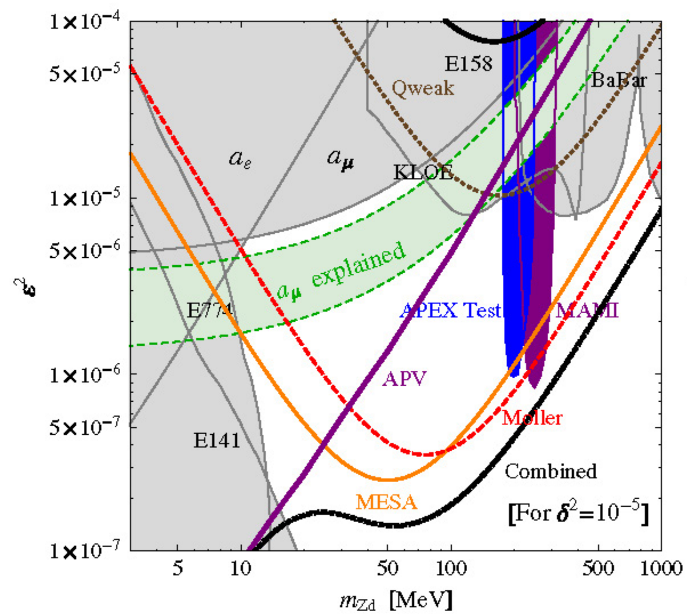
Davoudiasl, Lee, Marciano, PRL 109, 031802 (2012)

Possible mass mixing between Z boson and "dark heavy photons"

→ Introduces new source of low energy parity violation with observable consequences

→ complementary to direct searches for heavy dark photons at JLAB

$$\epsilon_Z = \frac{m_{Z_d}}{M_Z}\delta$$



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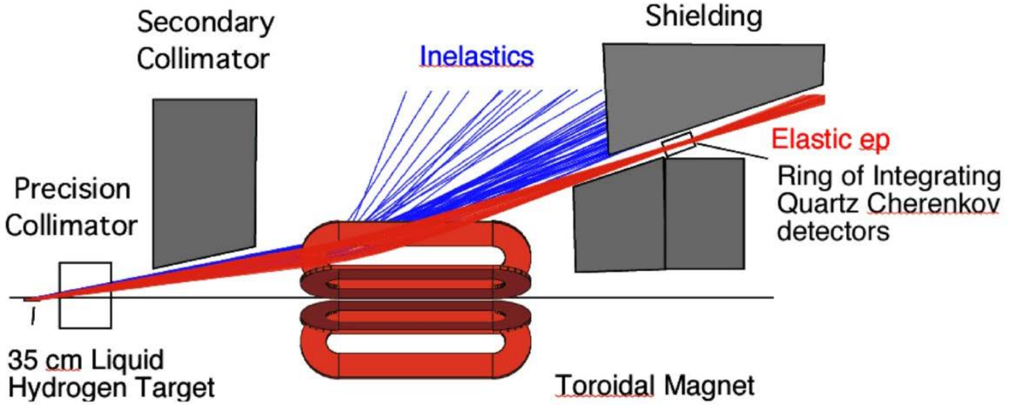
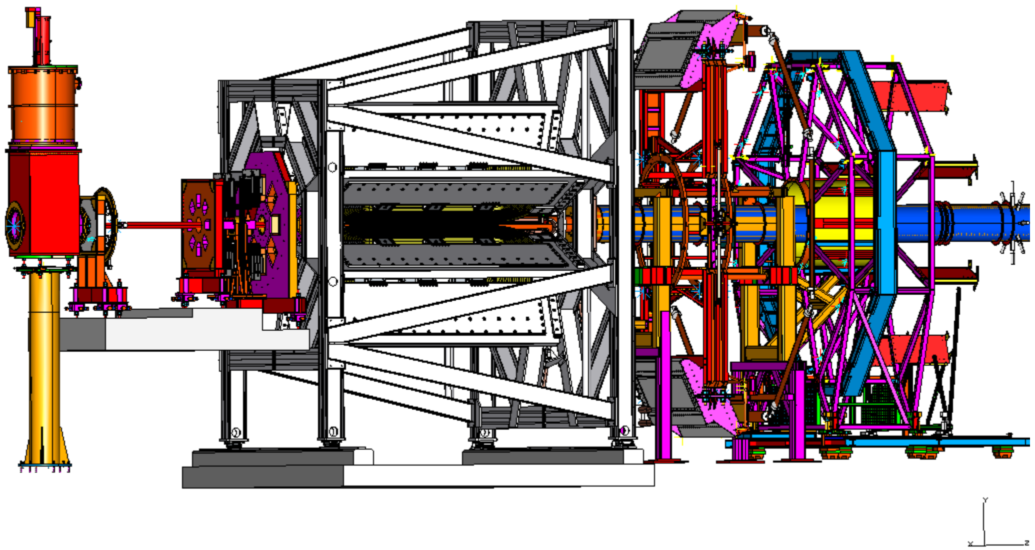
The Qweak Experiment: Apparatus and Concept

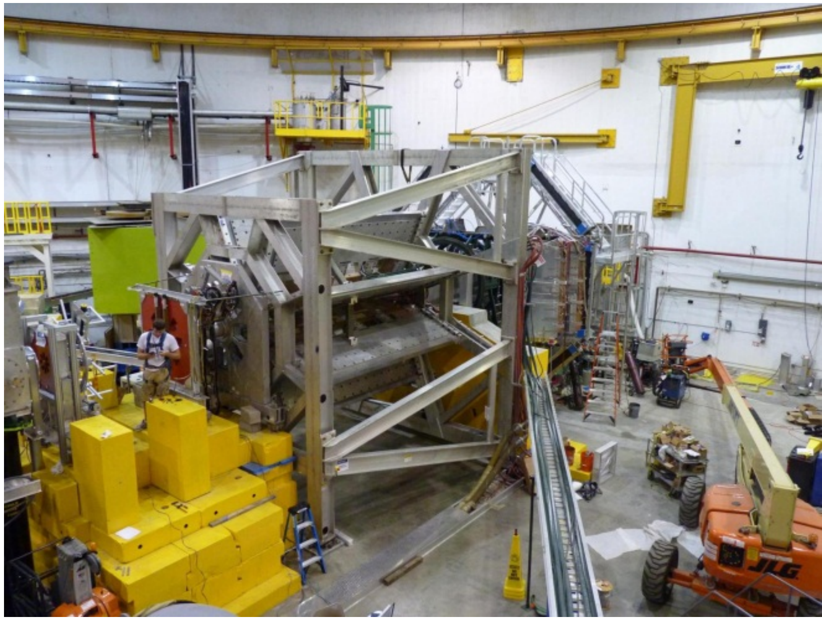
- Elastic $\vec{e}$-p scattering: 180 μA 1.1 GeV electron beam on liquid hydrogen target in Hall C
- Toroidal magnet provides large acceptance focusing of forward scattered elastic electrons – contributions from inelastic and neutral backgrounds < 1%
- World's highest power liquid hydrogen target (35 cm long, 2.5 kW power deposit)

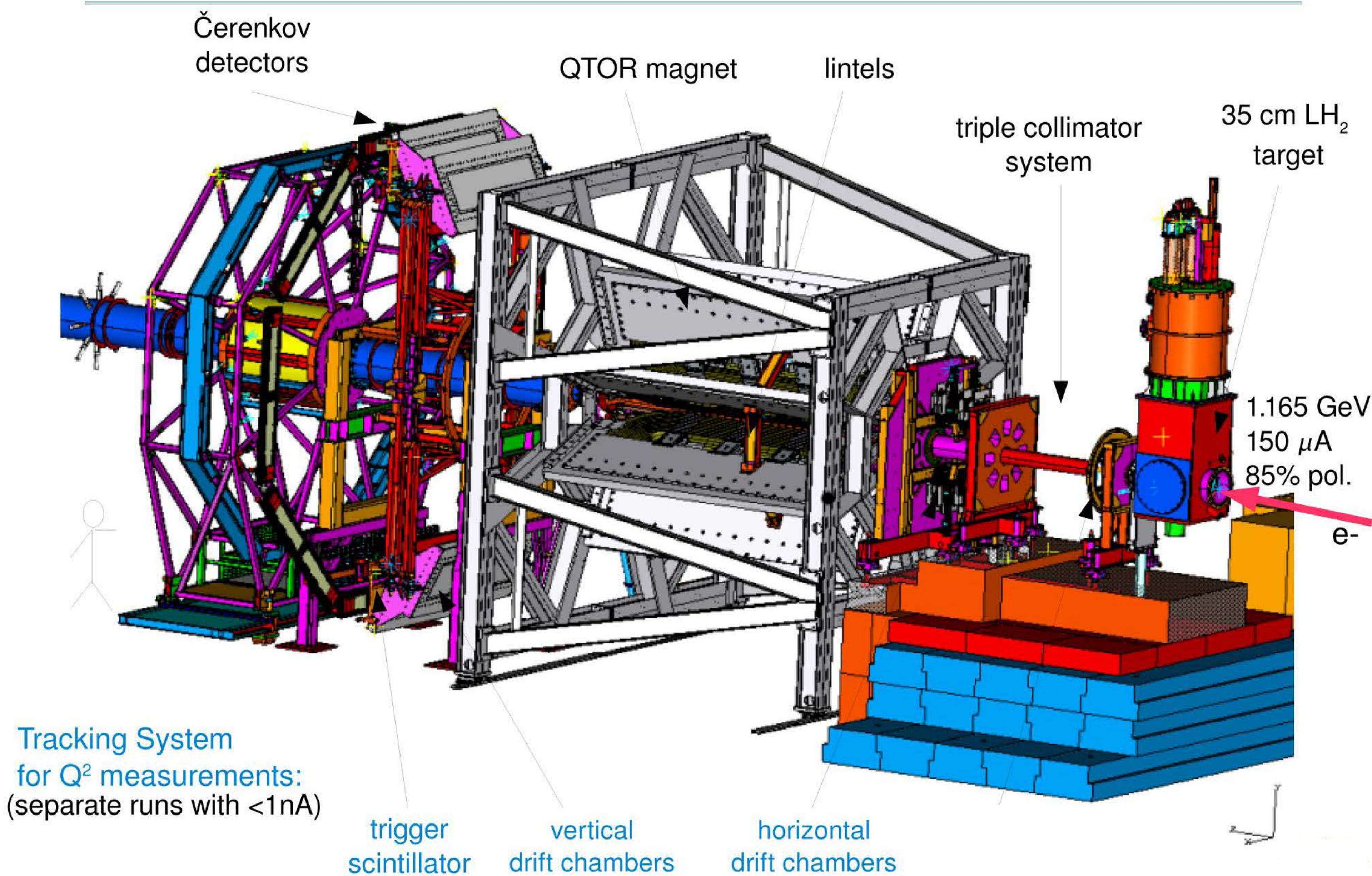
Status:

- Data-taking completed in May 2012
- Analysis is in progress



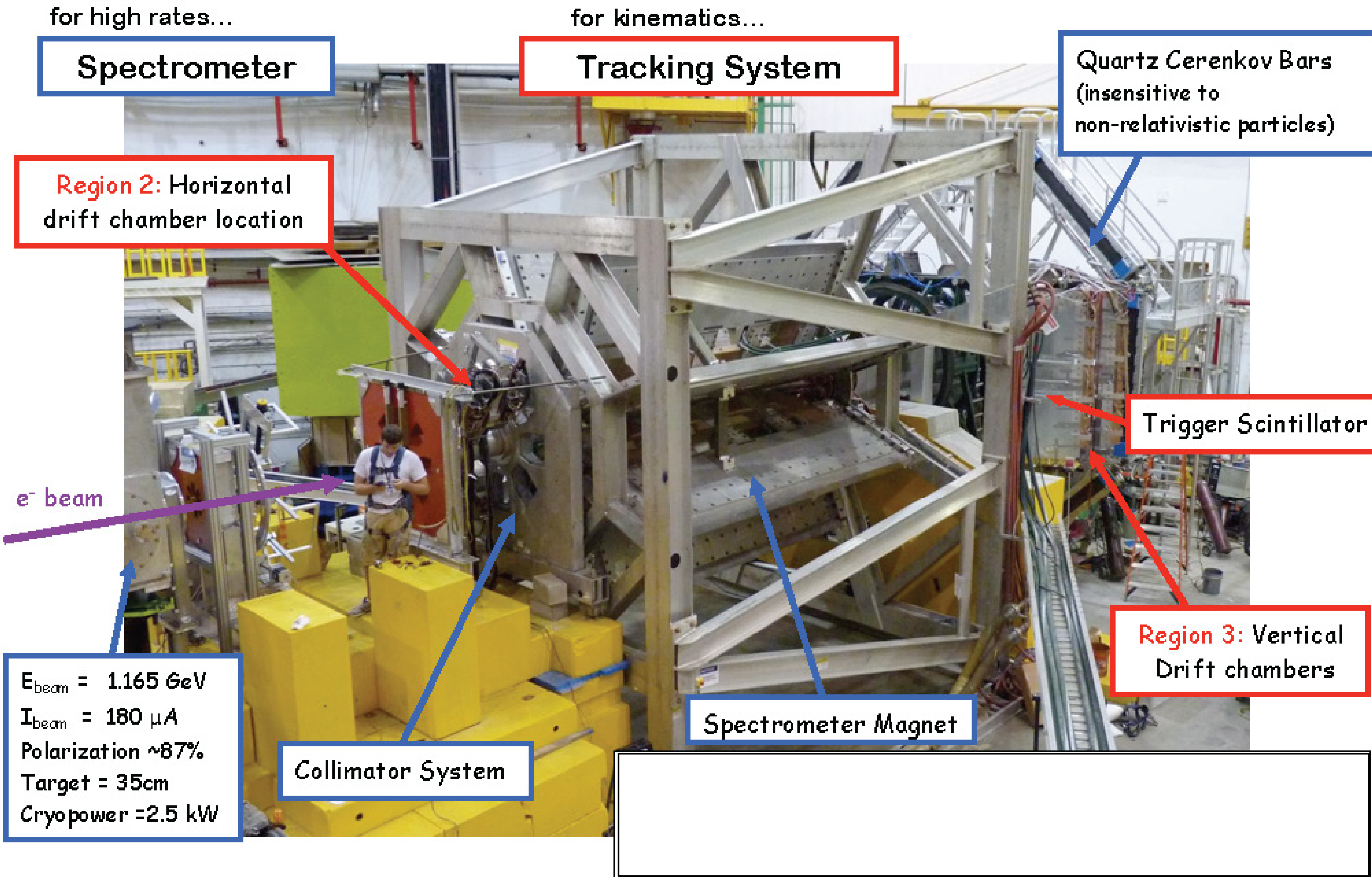




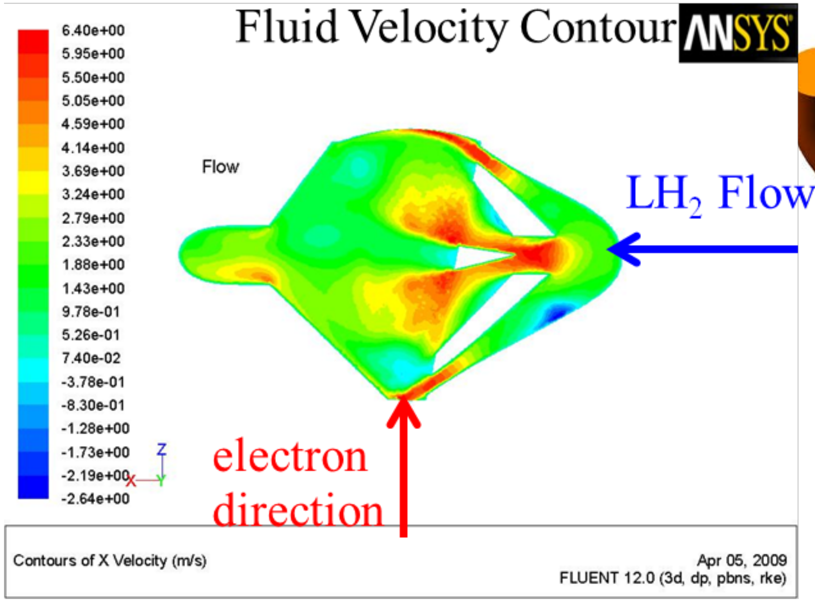


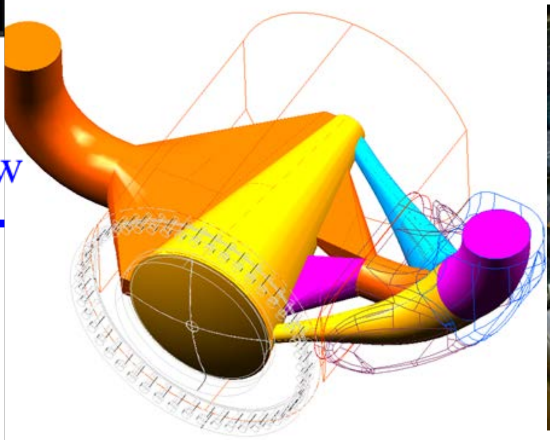
Qweak runs in two modes

- "Current mode" – I ~ 165 – 180 μA, integrate detector PMT signals for ~ 1 msec
- "Event mode" – I ~ 50 pA – 100 nA, insert tracking system, count individual pulses


for high rates…
Spectrometer
for kinematics…
Tracking System
Quartz Cerenkov Bars
(insensitive to
non-relativistic particles)
Region 2: Horizontal
drift chamber location
Trigger Scintillator
e⁻ beam
Region 3: Vertical
Drift chambers
E_beam = 1.165 GeV
I_beam = 180 μA
Polarization ~87%
Target = 35cm
Cryopower =2.5 kW
Collimator System
Spectrometer Magnet

Qweak Target – World's Highest Power Liquid Hydrogen Target



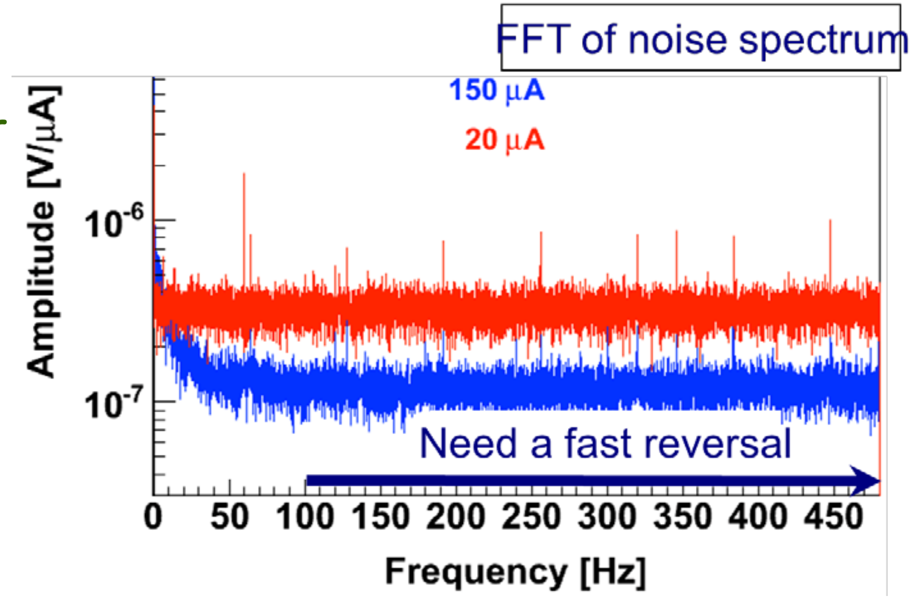


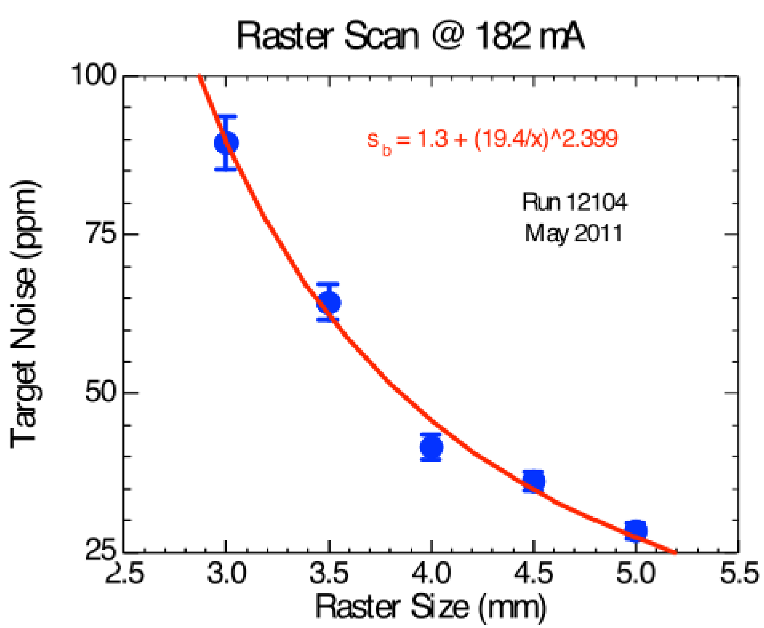
- Target has power capacity of 2500 W – adequate for 180 μA electron beam on 35 cm target
- First target of this type to use computational fluid dynamics (CFD) in its design
- Designed to minimize contribution to random noise from target density fluctuations – "boiling"

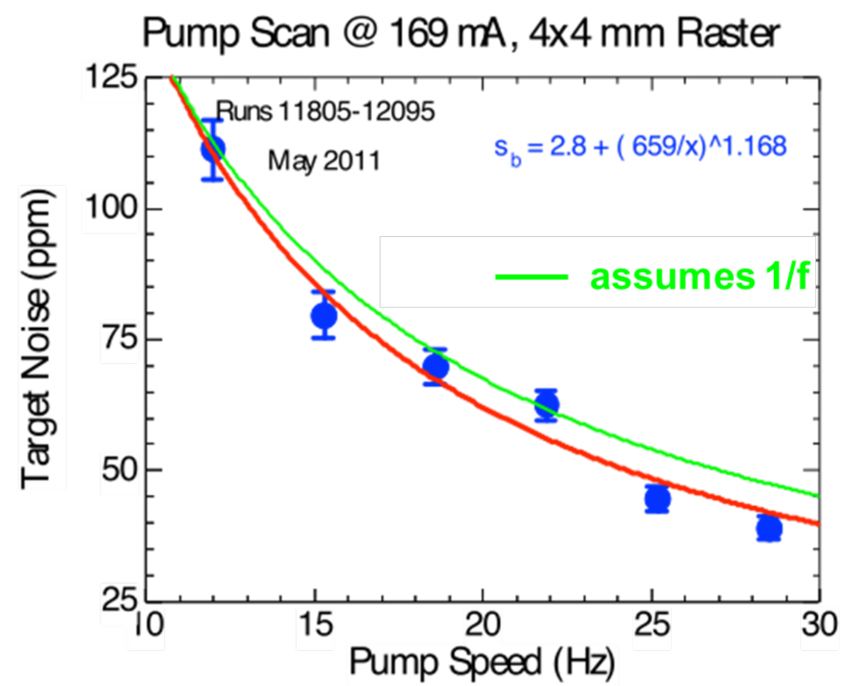
See talk: "Designing High Power Targets with Computational Fluid Dynamics (CFD), Silviu Covrig (PS5C)

Target Density Fluctuations

Critical that target density fluctuations at our data rate (960 Hz) be kept less than counting statistics fluctuations ~ 236 ppm (achieved!   contribution < 46 ppm)

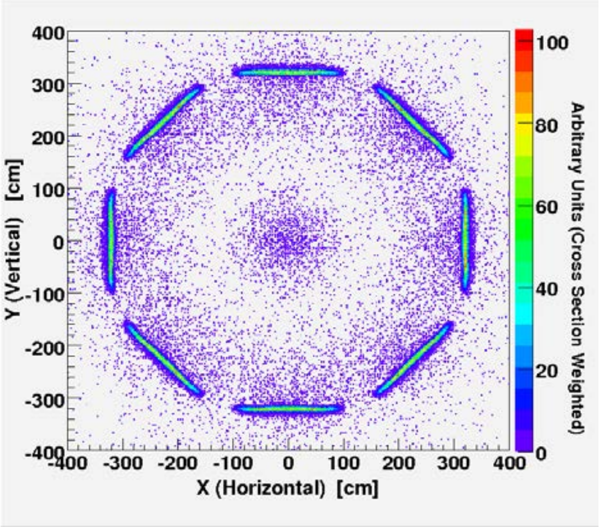






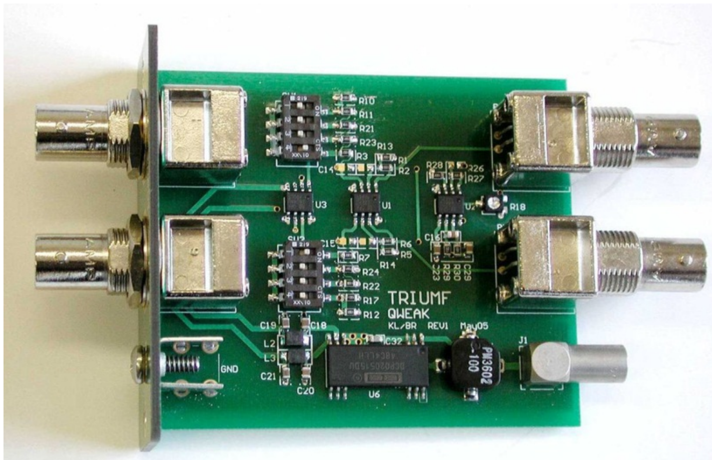
Qweak Main Detector

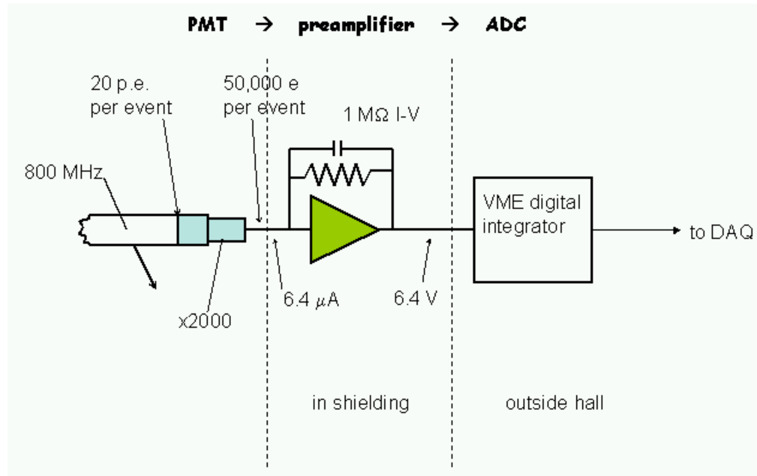
- Main detector: Large array of eight Cerenkov radiator bars (each 200 x 18 x 1.25 cm^3)
- artificial fused silica for UV transmission, polished to 25Angstroms (rms)
- **Spectrosil 2000: rad-hard, non-scintillating, low-luminescence**
- Two 5" PMTs per bar, S20 cathodes for high light levels
- Yield 100 pe's/track with 2cm Pb pre-radiators

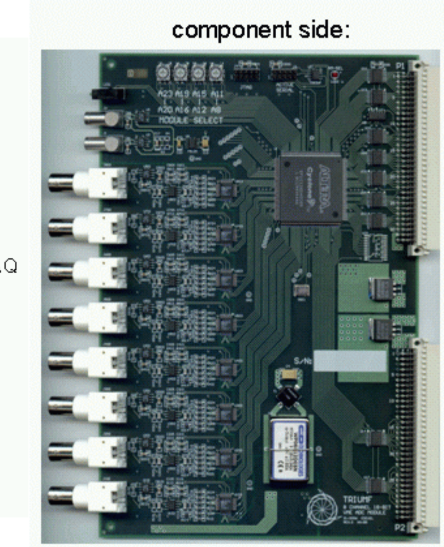


Qweak Electronics (current mode)

Current mode experiments require low noise amplifiers and high resolution digitization; Qweak relied on custom made (at TRIUMF) low noise I-to-V preamps and high resolution integrators/ADCs





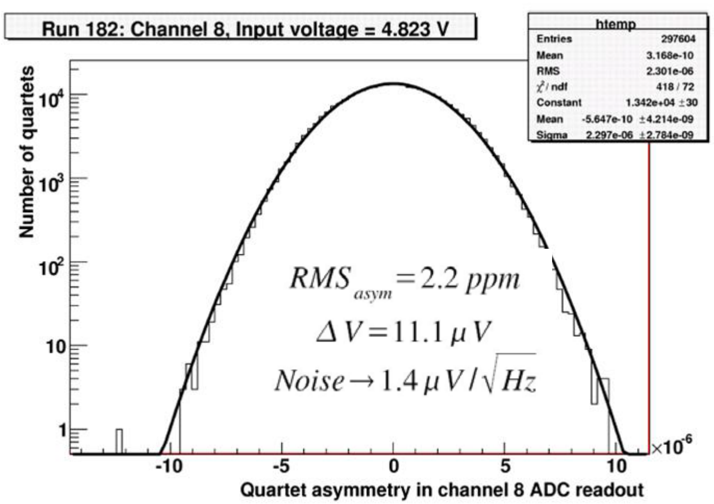


VME integrator –

18 bit ADC sampling at 500 kHz

FPGA sums 500 samples into one data word

same resolution as a 26 bit ADC

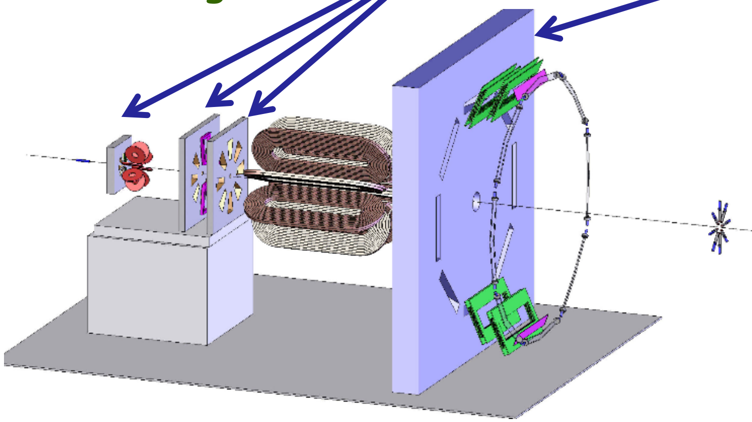


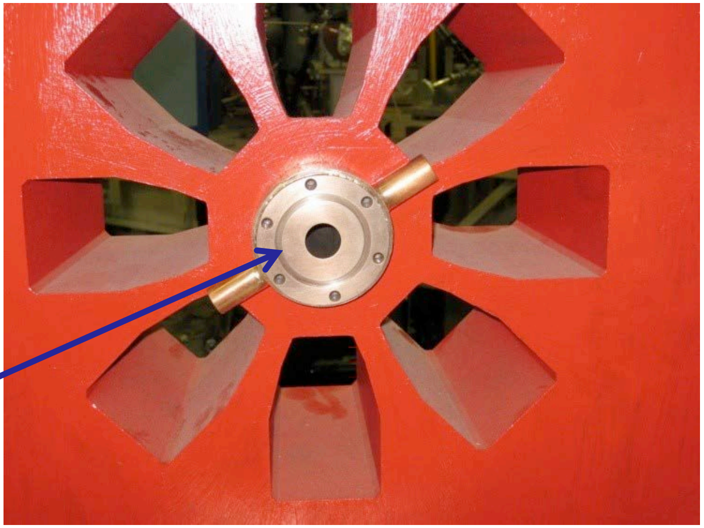
Γ_{elec} ~ 2 ppm << Γ_{count} ~ 236 ppm

→ from test on bench with battery; actual noise as installed in hall ~ 10 ppm

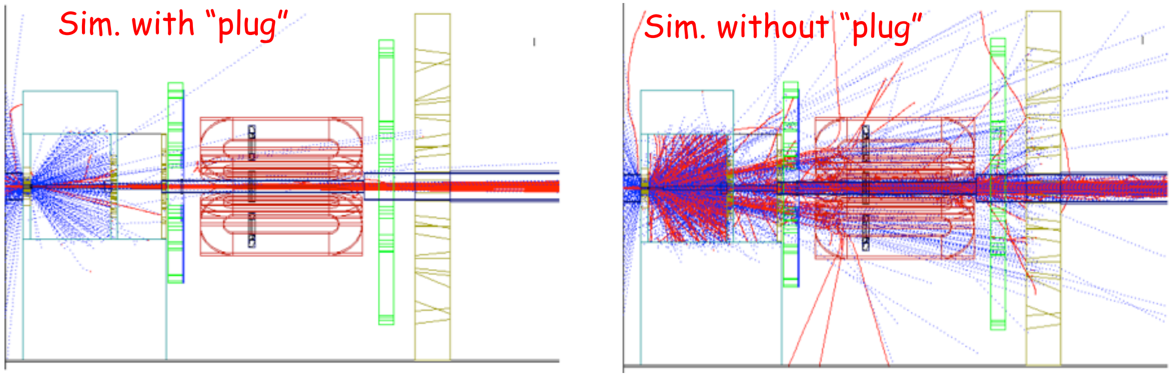
Collimation and Shielding – Reduction of Backgrounds

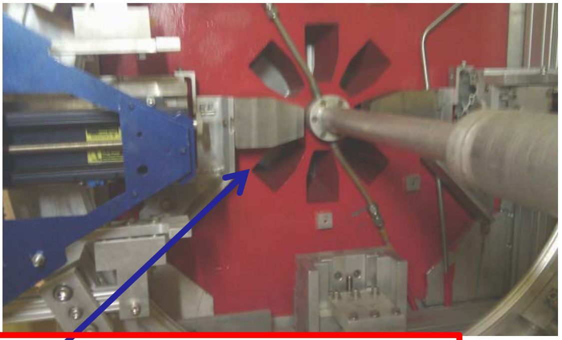
Three layers of lead collimation and concrete shield wall to control background





Small aperture tungsten collimator plug placed in collimator 1 to block low angle scattered particles from interacting with downstream beampipe





Diffuse backgrounds directly demonstrated with measurements

- Beamline background (direct measurement) : "tungsten shutters" ~ 0.19 ± 0.06%
- Event mode (Cerenkov/scintillator anti-coincidence) neutral background ~ 0.38 ± .14%

Q^p_{weak} Uncertainty Goals for Full Data Set

	$\Delta A_{phys}/A_{phys}$	$\Delta Q^p_{weak}/Q^p_{weak}$
Statistical (~2500 hours production)	2.1%	3.2%
Systematic:		
Helicity-correlated Beam Properties	0.5%	0.7%
Beam polarimetry	1.0%	1.5%
Backgrounds	0.5%	0.7%
Absolute Q^2 determination	0.5%	1.0%
Hadronic structure uncertainties	--	1.5%
Total	**2.5%**	**4.2%**

$$A_{ep} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \left[\frac{-G_F}{4\pi\alpha\sqrt{2}}\right]\left[Q^2\, Q^p_{weak} + Q^4 B(Q^2)\right]$$

Other important subsystems that contribute to this goal (not covered here):

- Tracking system (low current running; Q^2 and background measurements)
- Background and luminosity monitor detectors
- Beam property modulation system and feedback for reduction of helicity-correlated beam properties
- Precison Beam Polarimetry (Compton and Moller) see Dave Gaskell talk, "Electron Polarimetry at Low Energies in Hall C at Jefferson Lab", (PS5B)

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Details of Qweak Dataset

Qweak data was taken in three running periods - each with its own "blinding factor"

Running periods:

Commissioning Run:	November 2010 - January 2011	~ 44 C
Production Run 1:	February 2011 - May 2011	~ 360 C
Production Run 2:	November 2011 - May 2012	~ 680 C
		(raw data recorded)

Commissioning Run:

Separate blinding factor (allows early unblinding)

~ 4% of our total data set

Some equipment for highest precision was still being commissioned

- ie. Compton polarimeter, beam modulation, and injector spin manipulation will only be used for the full dataset

Data taking period: Jan. 31, 2011 - Feb. 8, 2011

All results that follow are "Commissioning Run" Data that were first released at 2012 APS Division of Nuclear Physics meeting in Newport Beach, CA

Errors and Corrections for Commissioning Dataset

For "25% Commissioning Data set"

$$A_{PV} = \frac{\frac{A_{meas}}{P} - \sum f_i A_i}{1 - \sum f_i}$$

Source of Error (A)	Contribution (ppm)
A_meas Statistics	**0.0358**
A_meas Systematic*	0.0151
Polarization	0.0049
Al Window Asym	0.0087
Al Window Dilution	0.0046
QTOR Transport Asym	0.0021
QTOR Transport Dilution	0.0017
Beamline Asym	0.0232
Beamline Dilution	0.0035
$N \rightarrow \Delta$ Asym	0.0002
$N \rightarrow \Delta$ Dilution	0.0006
Det. Bias correction**	0.0019
EM Rad. Corrections	0.0014
Total Systematic	**0.0302**
Total	**0.0469 (16%)**

$$A_{meas} = -204.6 \pm 30.5\text{ppb}$$

$$A_{PV} = -281.2 \pm 35.1(\text{stat}) \pm 29.6(\text{sys})\ \text{ppb}$$

16.3% relative error

Correction	Correction (ppm)
Polarization	-0.0265
Aluminum Windows	-0.0592
QTOR transport channel (neutrals)	0.0000
Beamline Backgrounds (neutrals)	+0.0102
$N \rightarrow \Delta$ electrons	+0.0006
EM radiative effects + Detector bias	-0.0088
Total	**-0.0829**

*Includes cut dependence, regression systematics, detector non-linearities, and transverse asymmetry
**Simulation-based correction for variation in light produced across the detectors & non-uniform Q^2 distributions.

Correction for Helicity-Correlated Beam Parameters

$$A_{meas} = A_{phys} + \sum_{i=1}^{N} \left(\frac{\partial A}{\partial P_i}\right) \Delta P_i \quad \text{for } P_i = x, y, \theta_x, \theta_y, E$$

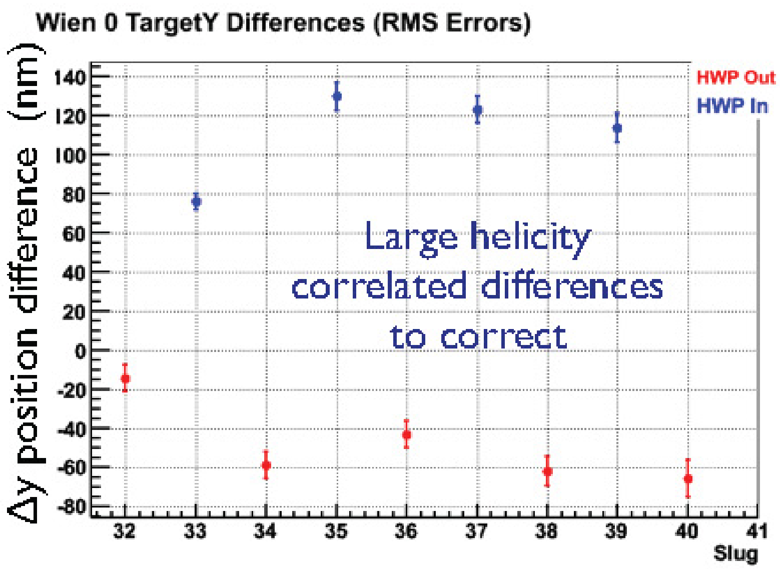
$$C_{\text{beam}} = -42.2 \pm 12.8 \text{ ppb}$$

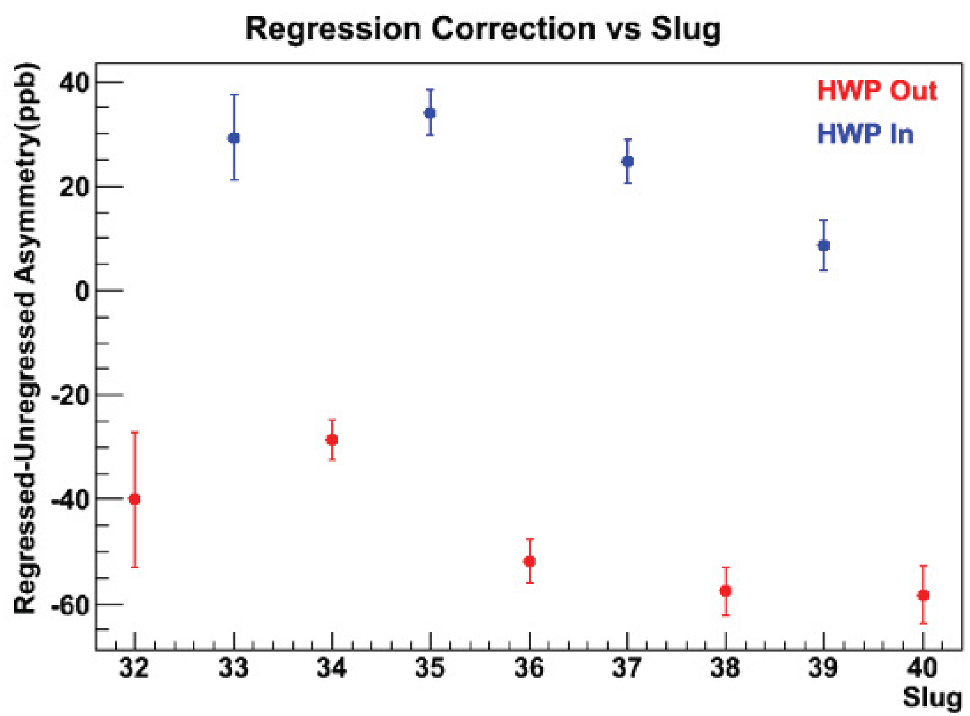
Sensitivities determined through linear regression on natural beam motion.

Large beam differences required large corrections.

Additional uncertainties from:

nonlinearity effects	4 ppb
X-sensitivity determination	8 ppb
monitor dependence	7 ppb





Aluminum Target Window Background Correction

Large asymmetry and high fraction make this a big effect.
Correction driven by measurement.

$$C_{\rm Al} = -64 \pm 10 \text{ ppb}$$

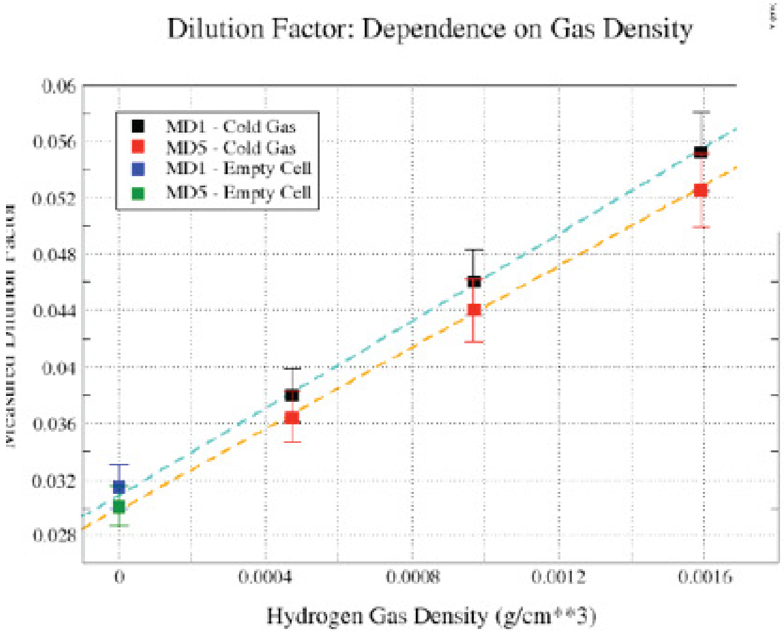
$$f_{\rm Al} = 3.23 \pm 0.24\ \%$$

- Rate from windows measured with empty target (actual windows)
- Corrected for effect of hydrogen using simulation and data driven models of elastic and QE scattering.

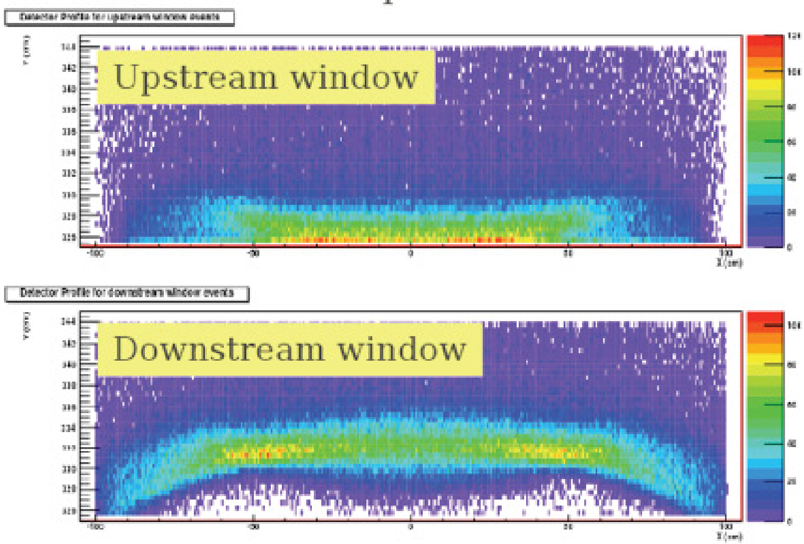
$$A_{\rm Al} = 1.76 \pm 0.26 \text{ ppm}$$

- Asymmetry measured from thick Al target
- Measured asymmetry agrees with expectations from scaling.

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



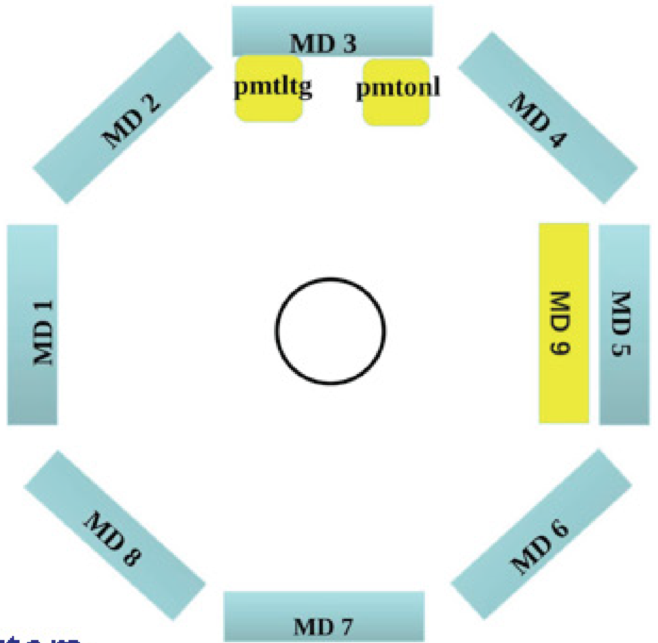
Simulated e- profile at detector:



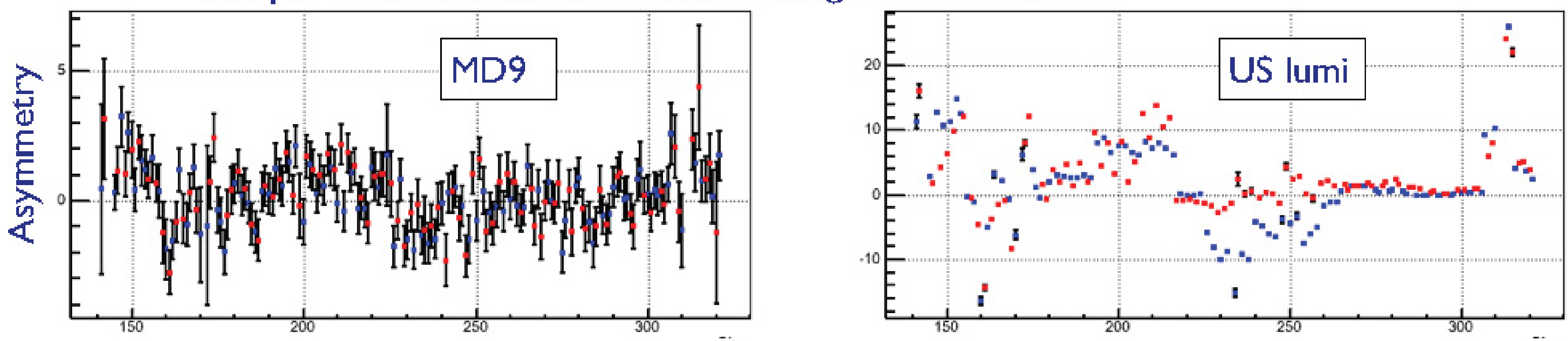
Beamline Background Asymmetry

- Various "background" detectors observed highly correlated non-zero asymmetries
- Asymmetries were primarily from beamline background (hypothesis: asymmetric "beam halo" events interacting in Tungsten beam collimator and beamline)
- Beamline background contributes only ~0.19% to the signal of the main detectors.
- Background detectors provided continuous monitoring of any asymmetry associated with this background
- Correction is determined from the upstream lumis.
- Relationship to main detector determined using a variety of methods (including direct blocking of primary events), appears to be well understood.

$$C_{\text{beamline}} = -10.2 \pm 23.5 \text{ ppb}$$

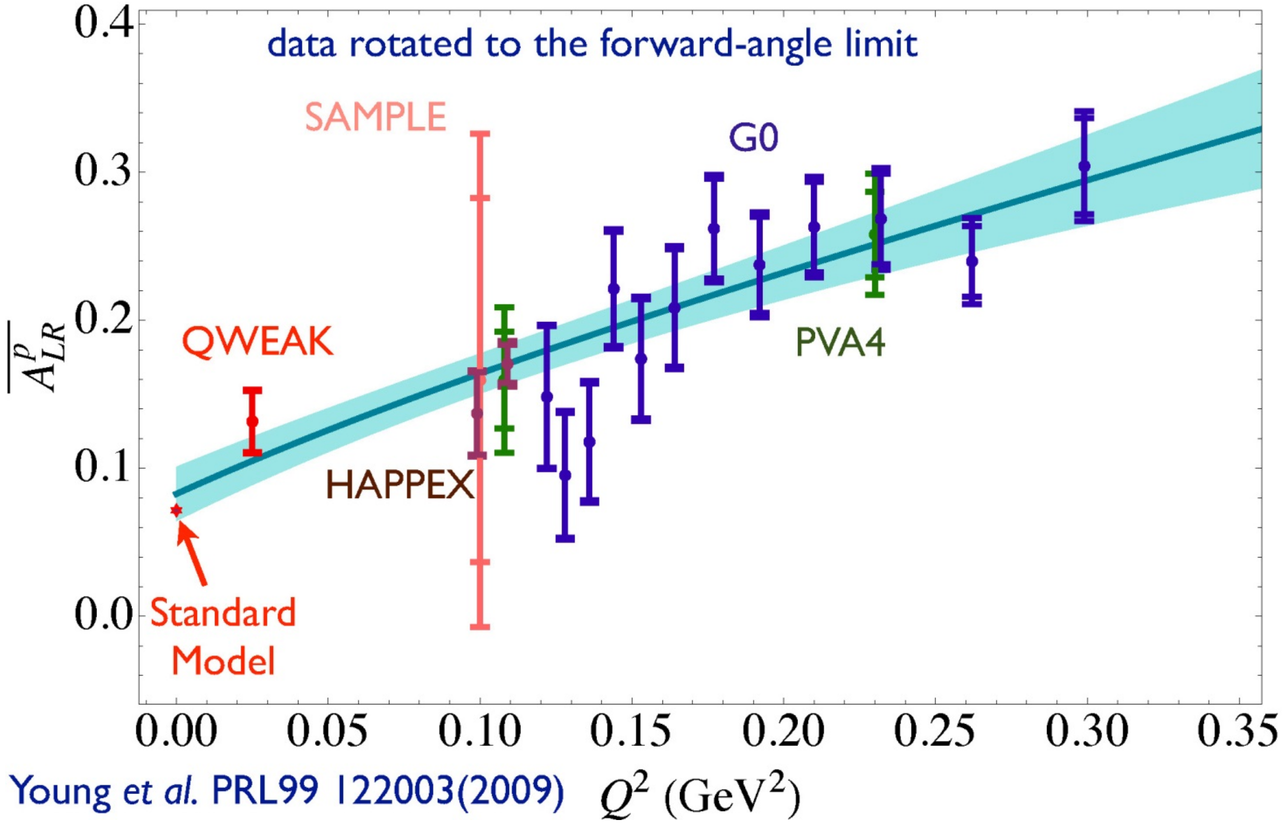


Example of the correlation between background detectors.



Including Q_{weak} Asymmetry with Other PVES Asymmetries

$$A_0 = -\frac{Q^2 G_F}{4\sqrt{2}\pi\alpha} \qquad \overline{A^p_{\rm LR}} = \frac{A_{LR}}{A_0} \xrightarrow{\theta\to 0} [Q^p_W + Q^2 B(Q^2)]$$



Hadronic part can be extracted through global fit of PVES data.

Qweak point:
4% of total data

The Qweak point is based on the asymmetry determined from the early commissioning data (4% of total data):

$$A_{phys} = -281.2 \pm 35.1(\text{stat}) \pm 29.6(\text{syst})\ \text{ppb}$$

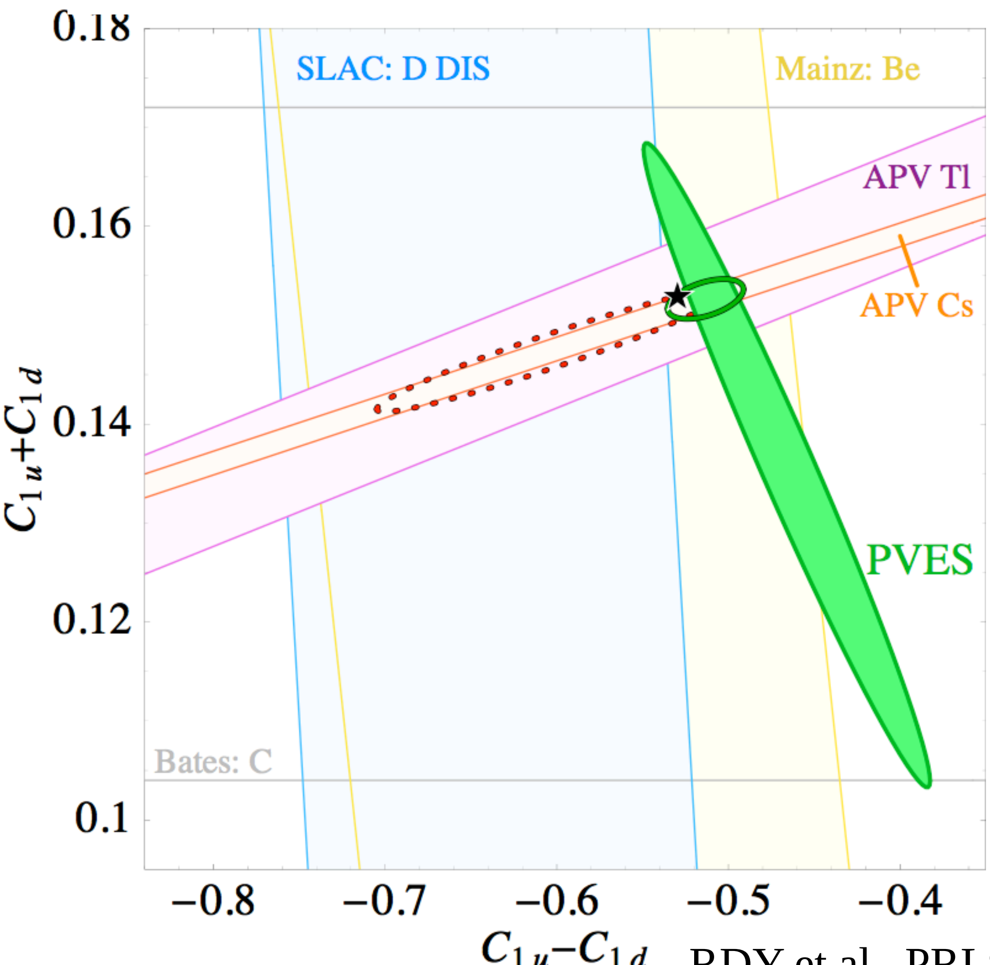
$$\text{at } Q^2 = 0.025\ (\text{GeV}/c)^2$$

Impact on Quark Vector Coupling Constants

After correcting for energy dependent electroweak radiative corrections →

$$Q_W^p = 0.0945 \pm 0.156\,(\text{stat}) \pm 0.0132\,(\text{syst}) \pm 0.001\,(\text{th})$$ (for 4% of data)

$$Q_W^p = -2(2C_{1u} + C_{1d})$$



★ Standard Model Value

Combined fit of Atomic Parity Violation (APV) data.

Combined fit of Parity Violating Electron Scattering (PVES) data.

PVES and APV combined

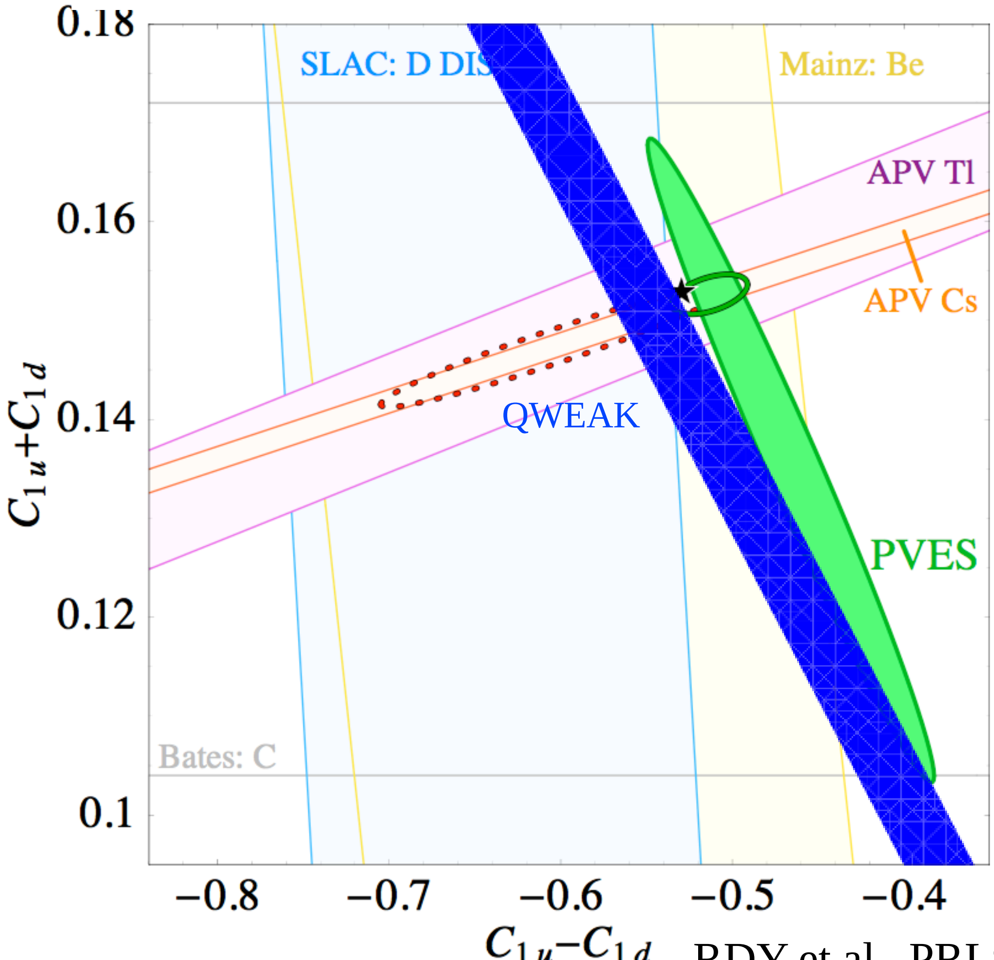
RDY et al., PRL99,122003(2007)

Impact on Quark Vector Coupling Constants

After correcting for energy dependent electroweak radiative corrections →

$$Q_W^p = 0.0945 \pm 0.0156\,(\text{stat}) \pm 0.0132\,(\text{syst}) \pm 0.001\,(\text{th})$$ (for 4% of data)

$$Q_W^p = -2(2C_{1u} + C_{1d})$$



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Combined fit of Parity Violating Electron Scattering (PVES) data.

PVES and APV combined

Qweak Commissioning Run (4% of data)

RDY et al., PRL99,122003(2007)

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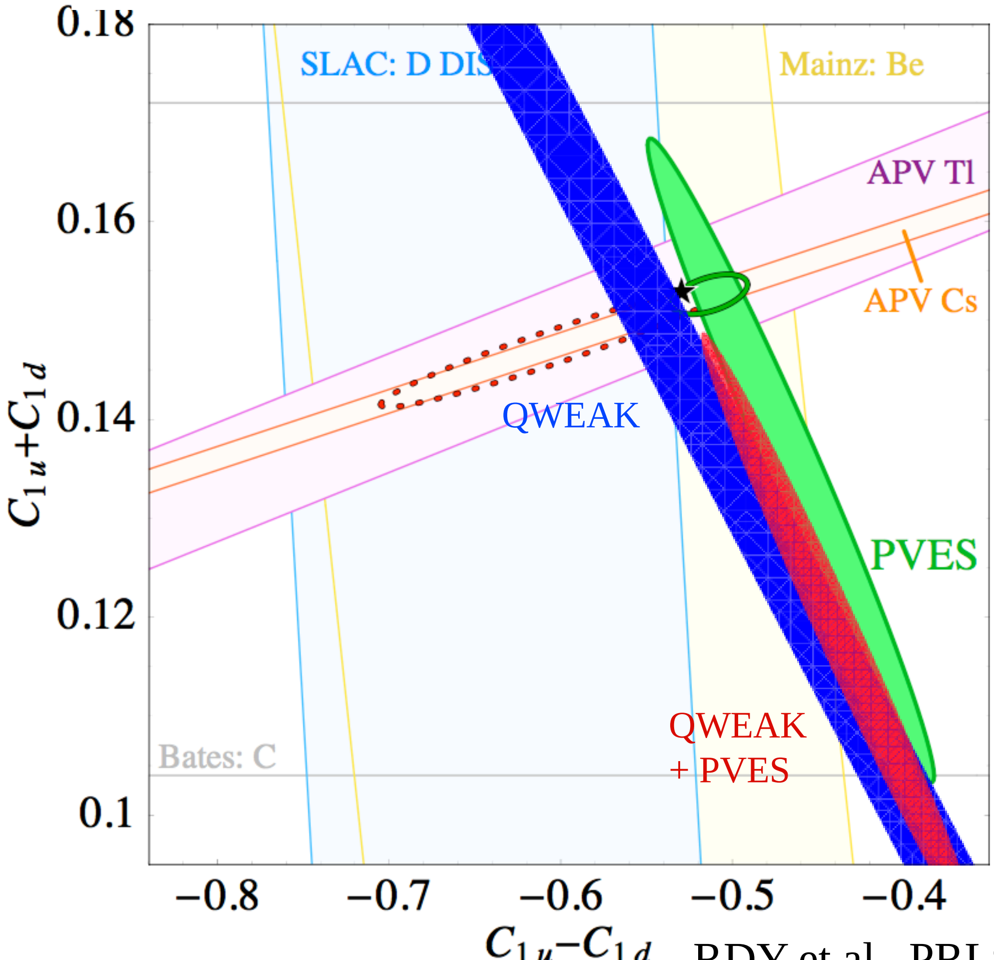

RDY et al., PRL99,122003(2007)

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Combined fit of Parity Violating Electron Scattering (PVES) data.

PVES and APV combined

Qweak Commissioning Run (4% of data)

Qweak and PVES combined without APV

Impact on Quark Vector Coupling Constants

After correcting for energy dependent electroweak radiative corrections →

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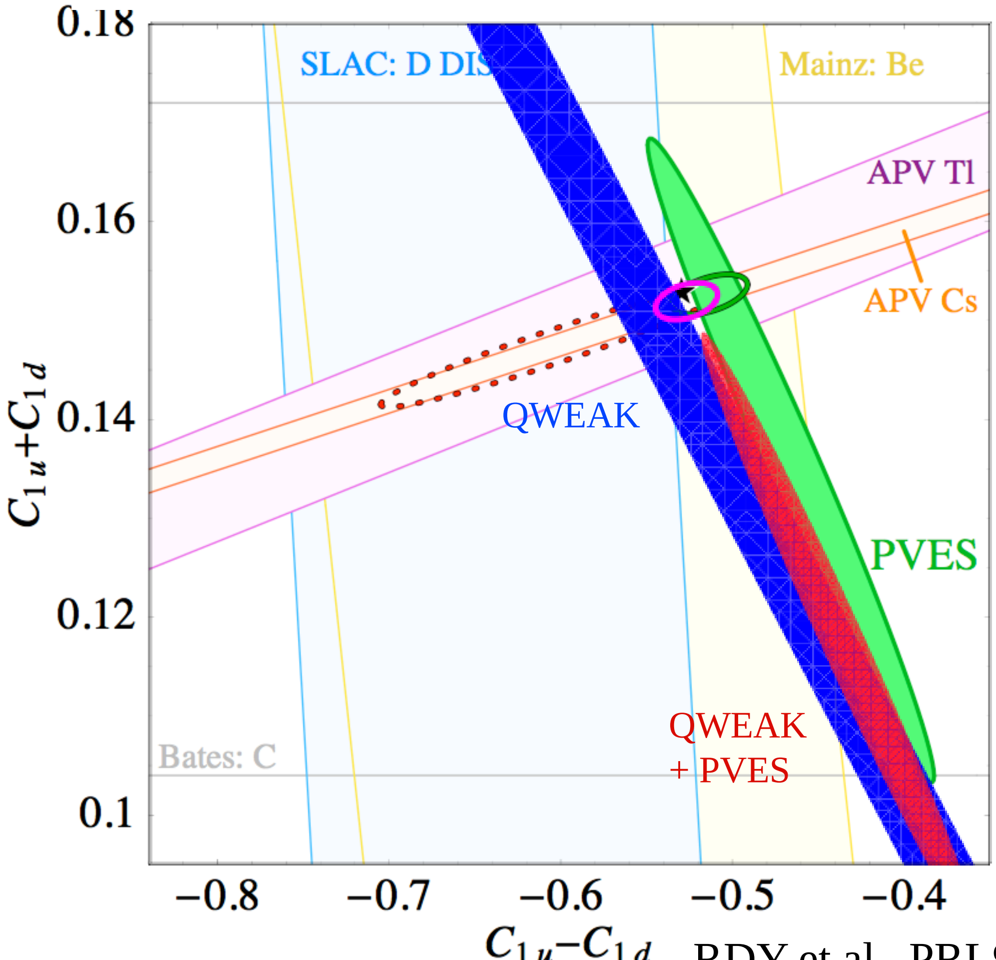

RDY et al., PRL99,122003(2007)

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Combined fit of Parity Violating Electron Scattering (PVES) data.

PVES and APV combined

Qweak Commissioning Run (4% of data)

Qweak and PVES combined without APV

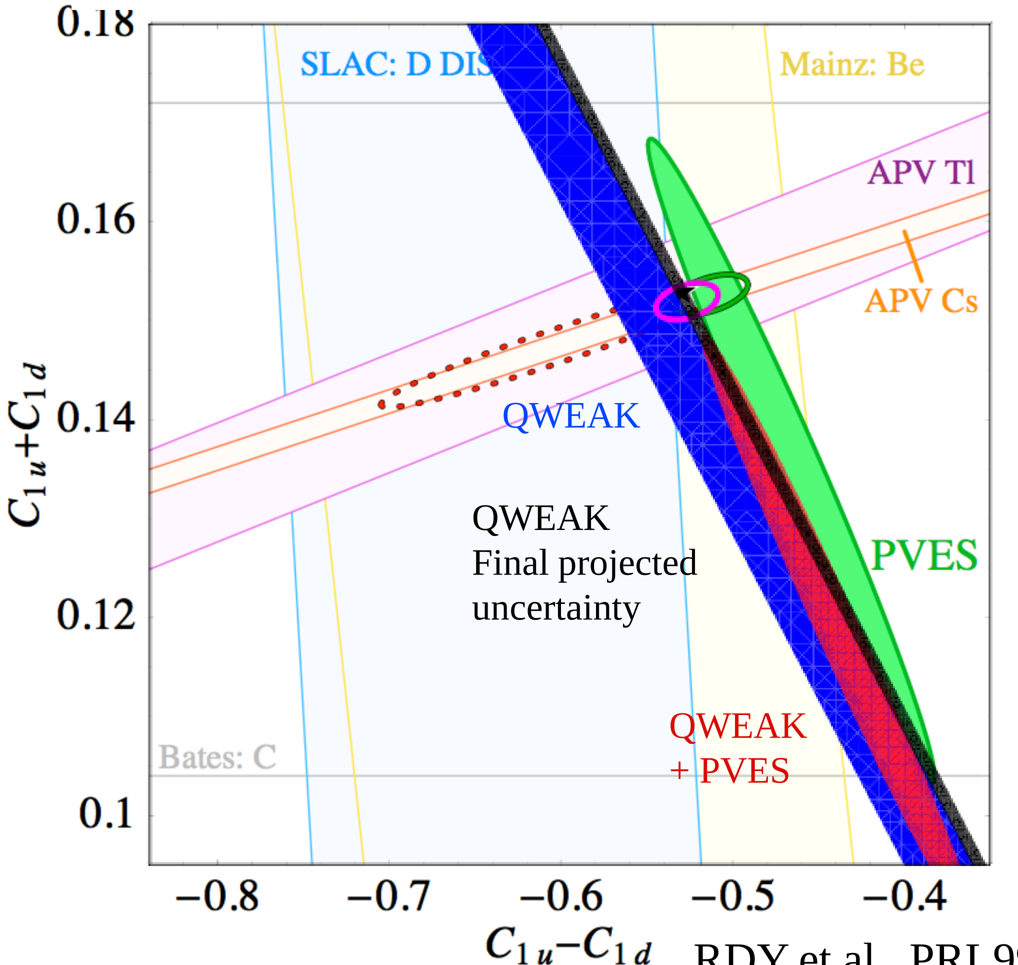
PVES, APV and Qweak

Impact on Quark Vector Coupling Constants

After correcting for energy dependent electroweak radiative corrections →

$$Q_W^p = 0.0945 \pm 0.0156\,(\mathrm{stat}) \pm 0.0132\,(\mathrm{syst}) \pm 0.001\,(\mathrm{th})$$ (for 4% of data)

$$Q_W^p = -2(2C_{1u} + C_{1d})$$



★ Standard Model Value

Combined fit of Atomic Parity Violation (APV) data.

Combined fit of Parity Violating Electron Scattering (PVES) data.

PVES and APV combined

Qweak Commissioning Run (4% of data)

Qweak and PVES combined without APV

PVES, APV and Qweak

Potential impact of uncertainty from total expected Qweak data set is shown at arbitrary location.

RDY et al., PRL99,122003(2007)

Weak Mixing Angle

First direct measurement of proton's weak charge (based on only 4% of the dataset):

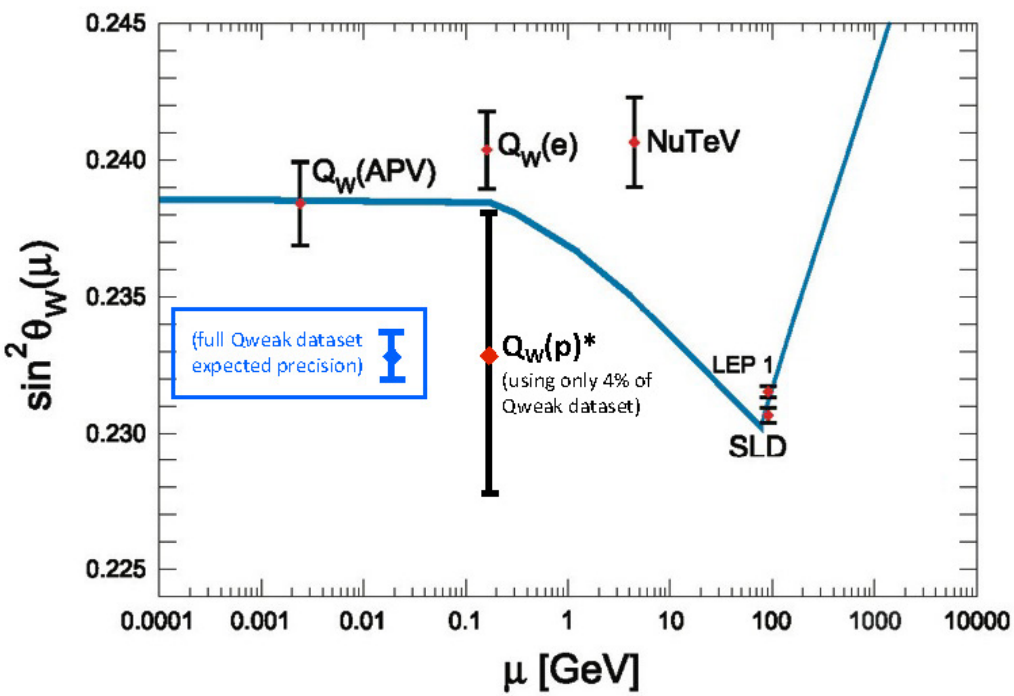
$$Q_W^p = 0.0945 \pm 0.0156\,(\text{stat}) \pm 0.0132\,(\text{syst}) \pm 0.001\,(\text{th})$$

agrees well with Standard Model prediction:

$$Q_W^p\,(\text{SM}) = 0.0712 \pm 0.0008$$

Using calculated electroweak radiative corrections can extract mixing angle for comparison with other observables:

$$Q_W(p) = [\rho_{NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_W(0) + \Delta_e'] + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

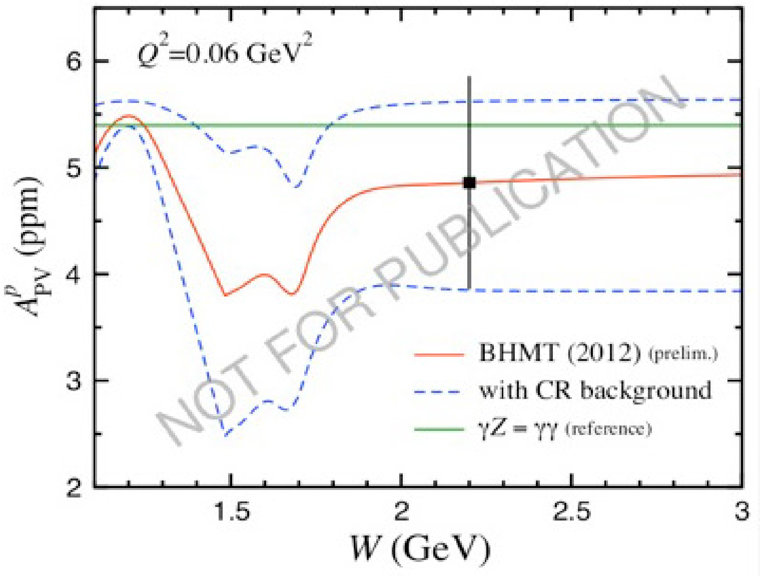


* Uses electroweak radiative corrections from Erler, Kurylov, Ramsey-Musolf, PRD **68**, 016006 (2003).

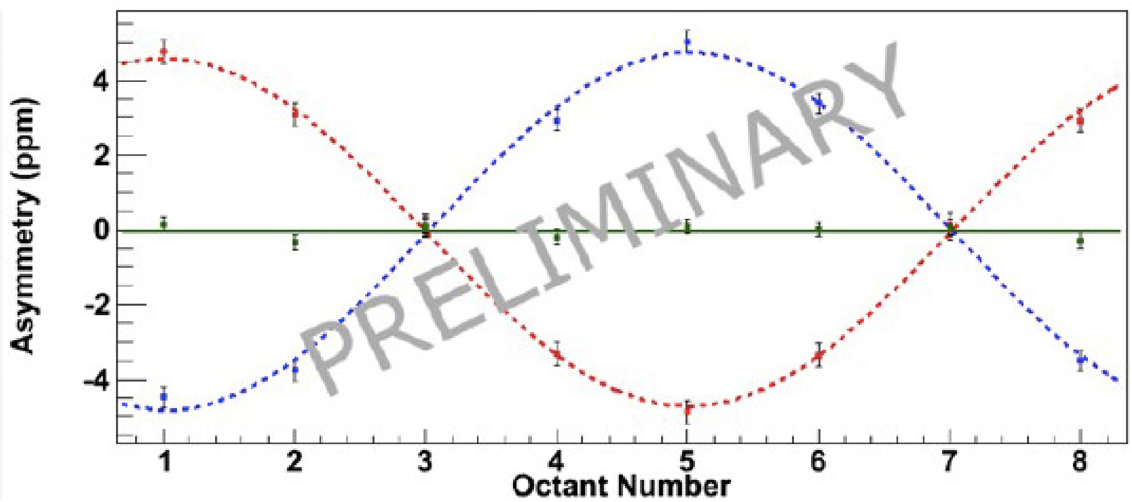
Other Physics Results Anticipated from Qweak

- Proton weak charge final ~4% measurement
- Proton-elastic transverse-asymmetry (2-photon exchange)
- Nuclear-elastic transverse-asymmetries (Coulomb distortion)
- N-Δ PV measurement at 2 beam energies
- Transverse asymmetry in Δ production at 2 beam energies.
- Non-resonant inelastic PV measurement (gamma-Z box diagram)
- Non-resonant inelastic transverse asymmetries
- PV asymmetries in pion photoproduction at 3.3 GeV
- Transverse asymmetries in pion photoproduction at 3.3 GeV

Non-resonant inelastic PV measurement



Proton-elastic transverse-asymmetry



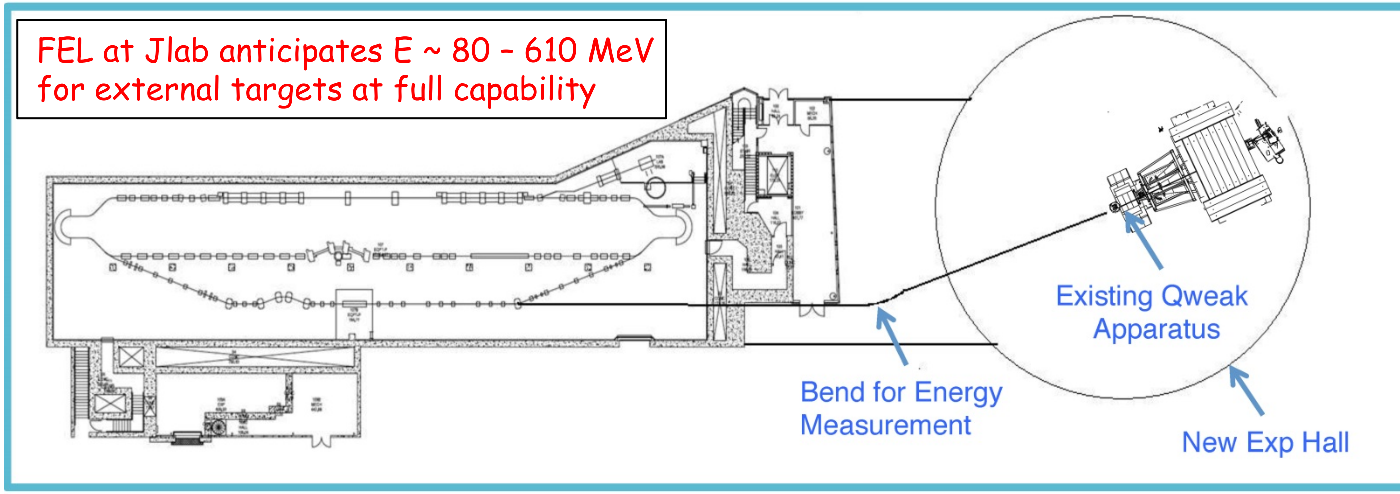
Outline

- Motivation and Interpretation
- Qweak apparatus and performance highlights with emphasis on aspects useful for lower energy PVES experiments
- Results from "25% Commissioning Dataset"
  – First Direct Measurement of the Proton's Weak Charge
- Thoughts about reusing Qweak apparatus at lower energies

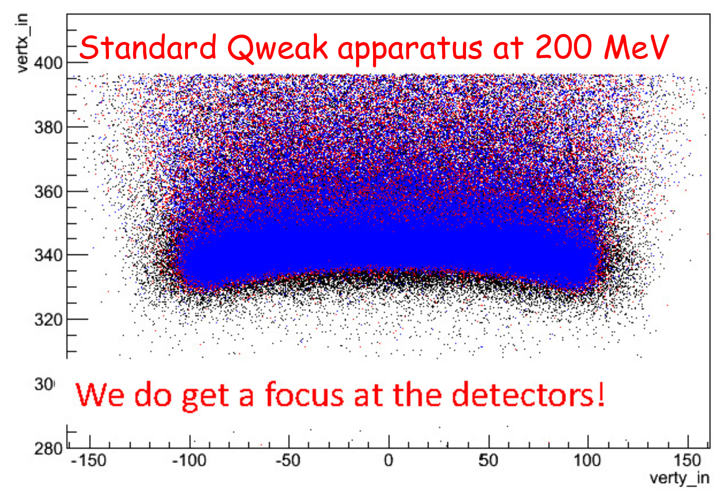
Qweak Apparatus Reused at Lower Energy?

As a thought experiment, what is achievable by re-using the Qweak apparatus at a lower beam energy for a much lower Q^2 measurement of the proton's weak charge?

How Qweak would look at FEL, as an example



Quick Monte Carlo study by Juliette Mammei (using standard apparatus with same relative target/collimator/spectrometer postions) indicates there is a focus down to 200 MeV



→ Make a quick check on what sort of precision could be achieved at 600 MeV for standard Qweak apparatus.

Projections for Using Qweak Apparatus at 600 MeV

Projected rates/asymmetries for standard Qweak apparatus at 600 Mev:

for Case A: standard 2.5 kW LH_2 target; Case B: 3.8 kW LH_2 target

Compare to MESA P2 as reference example

Parameter	MESA P2*	Q-weak 600, case A	Q-weak 600, case B
E_{beam}	200 MeV	600 MeV	600 MeV
Time	10000 hours	10000 hours	10000 hours
Current	150 μA	200 μA	300 μA
LH_2 Target Length	60 cm	35 cm	35 cm
Polarization	85%	85%	85%
Central θ	20^o	8^o	8^o
$\langle Q^2 \rangle$	.0029 GeV^2	.0065 GeV^2	.0065 GeV^2
Total rate	440 GHz	30 GHz	44 GHz
Asym. Width @240 Hz	23 ppm	89 ppm	74 ppm
A_{phys} (ppb)	-20.25 ppb	-46 ppb	-46 ppb
Hadronic "B" term	9%	10%	10%
ΔA (stat)	0.25 ppb (1.2%)	0.96 ppb (2.1%)	0.79 ppb (1.7%)
ΔA (syst)	0.19 ppb (0.9%)	0.41 ppb (0.9%)	0.41 ppb (0.9%)
ΔA (tot)	0.34 ppb (1.7%)	1.20 ppb (2.6%)	1.01 ppb (2.2%)
ΔQ^p_W	0.0014 (2.0%)	0.0021(3.0%)	0.0019 (2.6%)
$\Delta \sin^2\theta_W$	3.6×10^{-4} (0.15%)	5.4×10^{-4} (0.23%)	4.7×10^{-4} (0.20%)

* MESA P2 parameters come from F. Maas talk at "Dark Forces at Accelerators" Frascati, Oct. 2012

Projections for Using Qweak Apparatus at 600 MeV

Parameter	MESA P2	Q-weak 600, A	Q-weak 600, B
E_{beam}, Current, LH_2	200 MeV,150μA,60 cm	200 MeV,150μA,60 cm	200 MeV,150μA,60 cm
$<Q^2>$	.0029 GeV^2	.0065 GeV^2	.0065 GeV^2
Total rate	440 GHz	30 GHz	44 GHz
Asym. Width @240 Hz	23 ppm	89 ppm	74 ppm
A_{phys} (ppb)	-20.25 ppb	-46 ppb	-46 ppb
Hadronic "B" term	9%	10%	10%
ΔA (stat)	0.25 ppb (1.2%)	0.96 ppb (2.1%)	0.79 ppb (1.7%)
ΔA_{syst} (syst)	0.19 ppb (0.9%)	0.41 ppb (0.9%)	0.41 ppb (0.9%)
ΔA (tot)	0.34 ppb (1.7%)	1.20 ppb (2.6%)	1.01 ppb (2.2%)
ΔQ^p_W	0.0014 (2.0%)	0.0021(3.0%)	0.0019 (2.6%)

- Assumes standard target/collimator/spectrometer geometry as at 1165 MeV; no further optimizations done yet; more statistical power may be possible
- Figure of merit: Case A has ~ 1.7 worse statistical error in equivalent time
Case B has ~ 1.4 worse statistical error in equivalent time
- Compton polarimetry may be(?) possible at 600 MeV to needed accuracy
- Hydrogen target: Case A assumes parameters of existing LH2 target (~ 2.5 kW)
Case B assumes density fluctuations under control at 1.5x (~ 3.8 kW)
- Factor of 4 lower in Q^2 than Qweak – hadronic contribution ~ 10% (~ 30% for Qweak)
- Note: systematic error for Qweak cases just assumes same relative number as MESA P2

Conclusions

Qweak has produced the first direct measurement of the weak charge of the proton, with ~4% of the total data set.

The result is a 16% measurement of the PV asymmetry:

$$A_{phys} = -281.2 \pm 35.1(\text{stat}) \pm 29.6(\text{syst})\ \text{ppb}$$

at the effective kinematics $\langle Q^2 \rangle = 0.0250 \pm .0006\ (\text{GeV}/c)^2$

This is a 22% measurement of the weak charge of the proton:

$$Q_W^p = 0.0945 \pm 0.0156(\text{stat}) \pm 0.0132(\text{syst}) \pm 0.001(\text{th})$$

The result is ~1.1 sigma higher than the SM prediction:

$$Q_W^p(\text{SM}) = 0.0712 \pm 0.0008$$

Analysis of the full dataset is in progress $\rightarrow$
~25 times more statistics and additional calibration data are in hand for high precision with low systematic error

A preliminary, non-optimized estimate of the figure of merit for the standard Qweak apparatus re-used at 600 MeV beam energy indicates a ~ 2.6-3.0% precision determination of Q^p_W at Q^2 ~ .0065 $(\text{GeV}/c)^2$ appears possible.

Thanks to Qweak collaborators (especially Mark Dalton) for many slide materials used here.