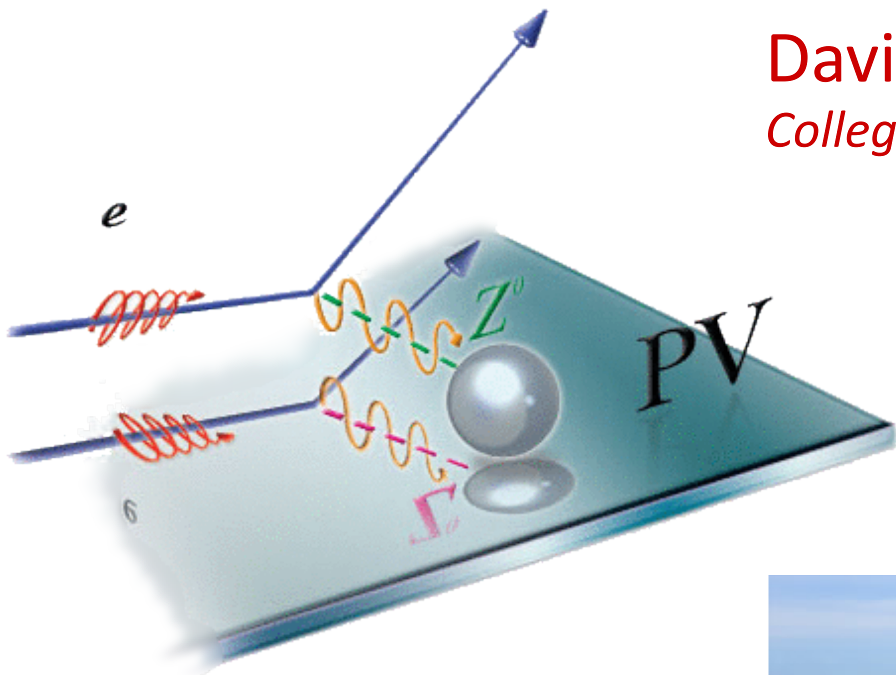
First Result from Q_{weak}



David S. Armstrong
College of William & Mary

MENU 2013
Rome, Italy
Oct 2 2013

The College of WILLIAM & MARY
Jefferson Lab

Search for physics *Beyond the Standard Model*

- Received Wisdom: Standard Model is incomplete, and is low-energy effective theory of more fundamental physics
- Low energy ($Q^2 << M^2$) precision tests: complementary to high energy measurements

- ***Neutrino mass and their role in the early universe*** — $0\nu\beta\beta$ *decay*, θ_{13}, β *decay,…*
- ***Matter-antimatter asymmetry in the present universe*** — *EDM, DM, LFV,* $0\nu\beta\beta$, θ_{13}
- ***Unseen Forces of the Early Universe*** — *Weak decays,* ***PVES****,* g_μ*-2,…*

LHC new physics signals likely will need additional indirect evidence to pin down their nature

- ***Neutrons:*** *Lifetime, P- & T-Violating Asymmetries (LANSCE, NIST, SNS...)*
- ***Muons:*** *Lifetime, Michel parameters, g-2, Mu2e (PSI, TRIUMF, FNAL, J-PARC...)*
- ***PVES:*** *Low-energy weak neutral current couplings, precision weak mixing angle (SLAC, Jefferson Lab, Mainz)*
- ***Atoms:*** *atomic parity violation*

Ideal*: select observables that are zero, or significantly suppressed, in Standard Model*

Qweak: Proton's weak charge

Q_W^p - Neutral current analog of electric charge

The Standard Model makes a firm prediction of Q_W^p

	EM Charge	Weak Charge
u	2/3	$1 - \frac{8}{3} sin^2(\theta_w) \approx 0.38$
d	-1/3	$-1 + \frac{4}{3} sin^2(\theta_w) \approx -0.69$
P (uud)	+1	$1 - 4\, sin^2(\theta_w) \approx 0.07$
N (udd)	0	-1

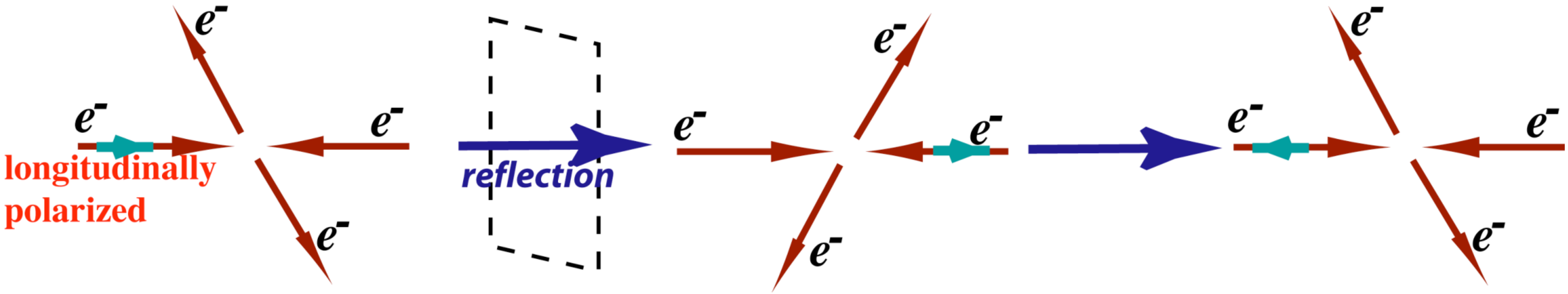
"Accidental suppression"
→sensitivity to new physics

Note: $Q_W^n = -1$

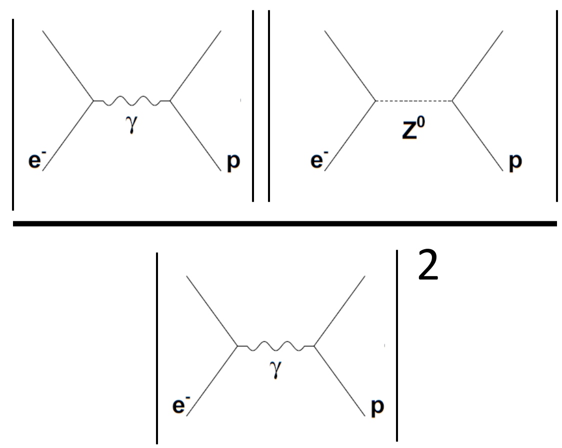
Q-weak is particularly sensitive to the quark *vector* couplings (C_{1u} and C_{1d}) .

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

Parity-violating electron scattering



$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \propto$$



$$\propto \frac{|M_Z|}{|M_\gamma|}$$

Electroweak interference

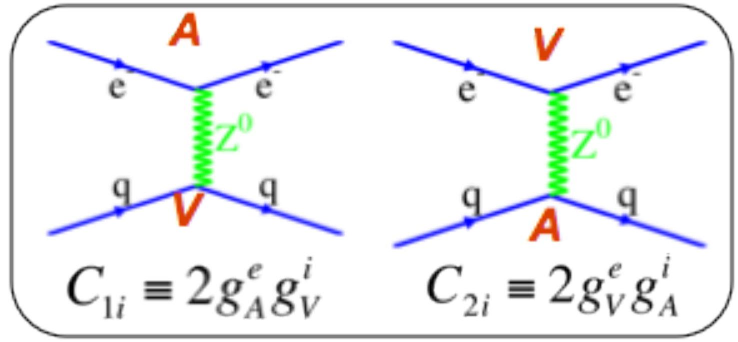
$$A_{PV} \propto \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \left(g_A^e g_V^T + \beta g_V^e g_A^T \right) \sim 10^{-4} Q^2 \left[\mathrm{GeV}^2 \right]$$

Qweak: Proton's weak charge

For electron-quark scattering:

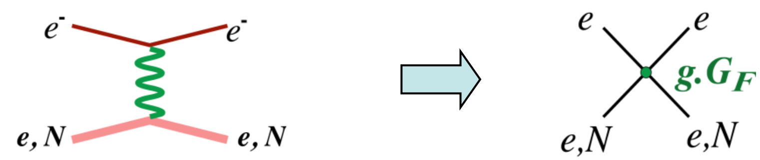
$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha}(g_A^e g_V^i + \beta g_V^e g_A^i)$$

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



Small θ Large θ

Use four-fermion contact interaction to parameterize the effective PV electron-quark couplings (mass scale and coupling)



$$\frac{1}{Q^2 - M^2} \xrightarrow{Q^2 \ll M^2} \frac{1}{M^2}$$

New physics:

$$\sigma \propto |M_\gamma + M_Z + M_{\text{new}}|^2$$
$$\sim |M_\gamma|^2 + 2M_\gamma M_Z^* + 2M_\gamma M_{\text{new}}^*$$

new Z', leptoquarks, SUSY ...

A 4% measurement of the proton's weak charge would probe TeV scale new physics

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

Erler, Kurylov, and Ramsey-Musolf, PRD 68, 016006 2003

Extracting the weak charge

$$A_{PV} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[Q_w^p + B(\theta, Q^2)Q^2\right]$$

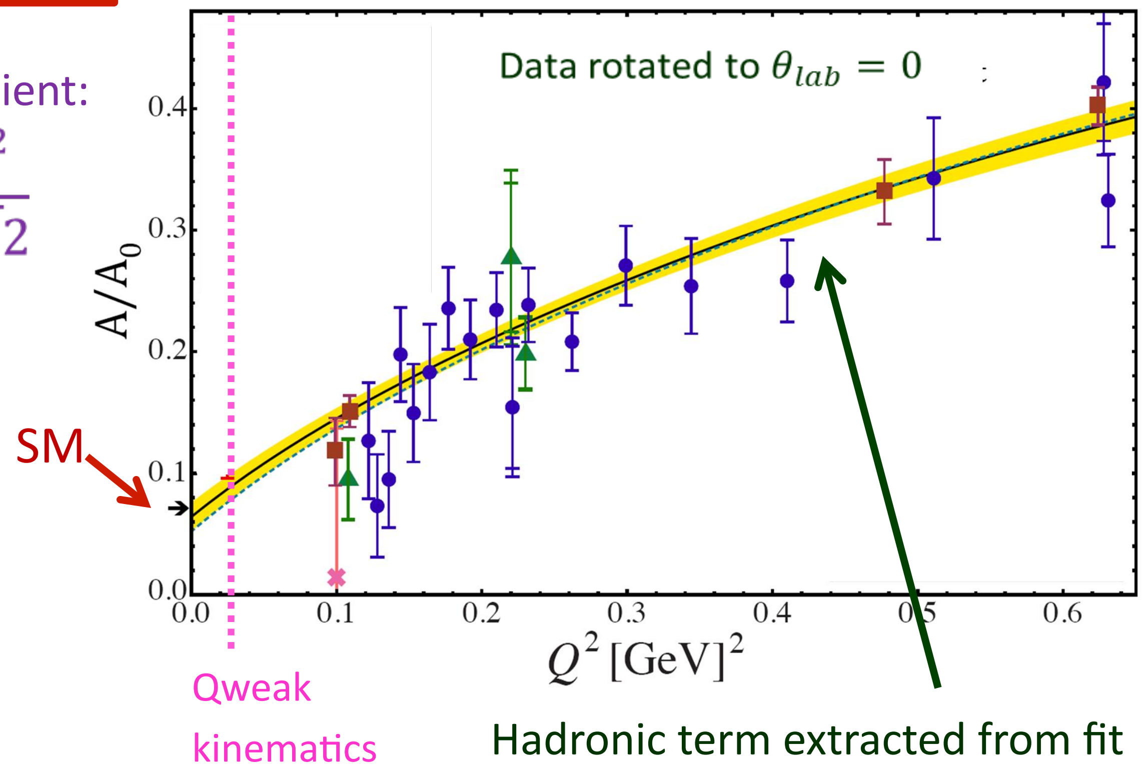
Hadron structure enters here: electromagnetic and electroweak form factors…

Reduced asymmetry more convenient:

$$A_{red} = \frac{A_{PV}}{A_0} \qquad A_0 = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}$$

One must extrapolate to $Q^2 = 0$.

We measure A^{PV}_{phys} at $Q^2 = 0.025\ GeV^2$.



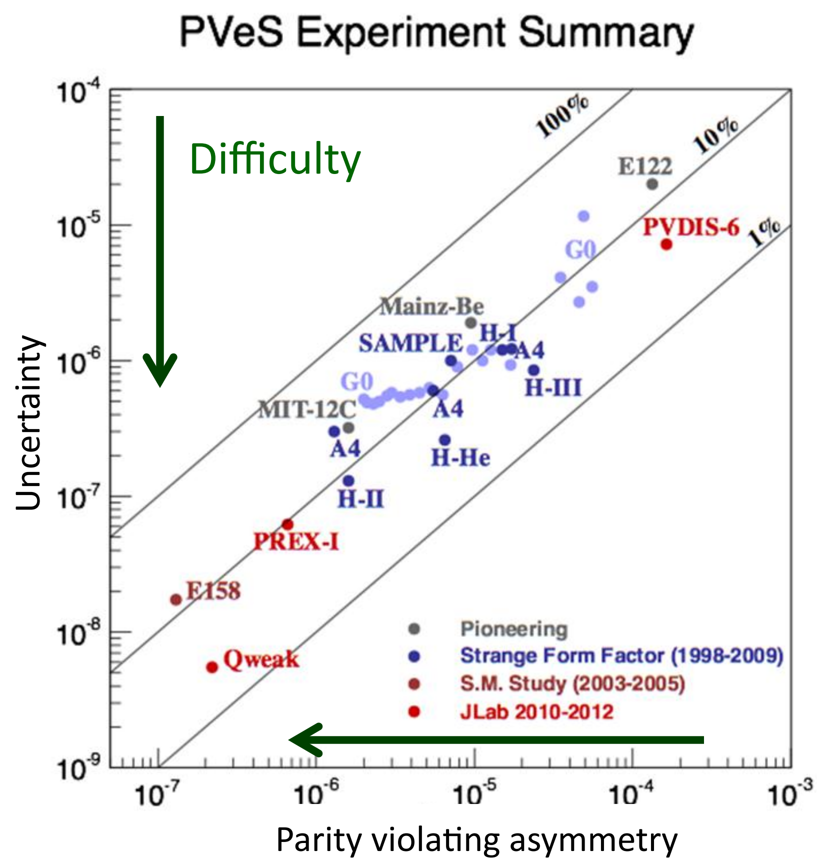
Previous experiments (strange form factor program: SAMPLE, HAPPEX, G0, PVA4 experiments at MIT/Bates, JLab and MAMI) explored hadron structure more directly; allow us to subtract our hadronic contribution

PVES Challenges

Qweak's goal: most precise (relative and absolute) PVES result to date.

PVES challenges:

- Statistics
  - High rates required
    - High polarization, current
    - High powered targets with large acceptance
- Low noise
  - Electronics, target density fluctuations
  - Detector resolution
- Systematics
  - Helicity-correlated beam parameters
  - Backgrounds (target windows)
  - Polarimetry
  - Parity-conserving processes



Small absolute *and* relative uncertainty (5ppb on A_{PV})

$\delta A_{PV} \approx \pm 2.1\%$

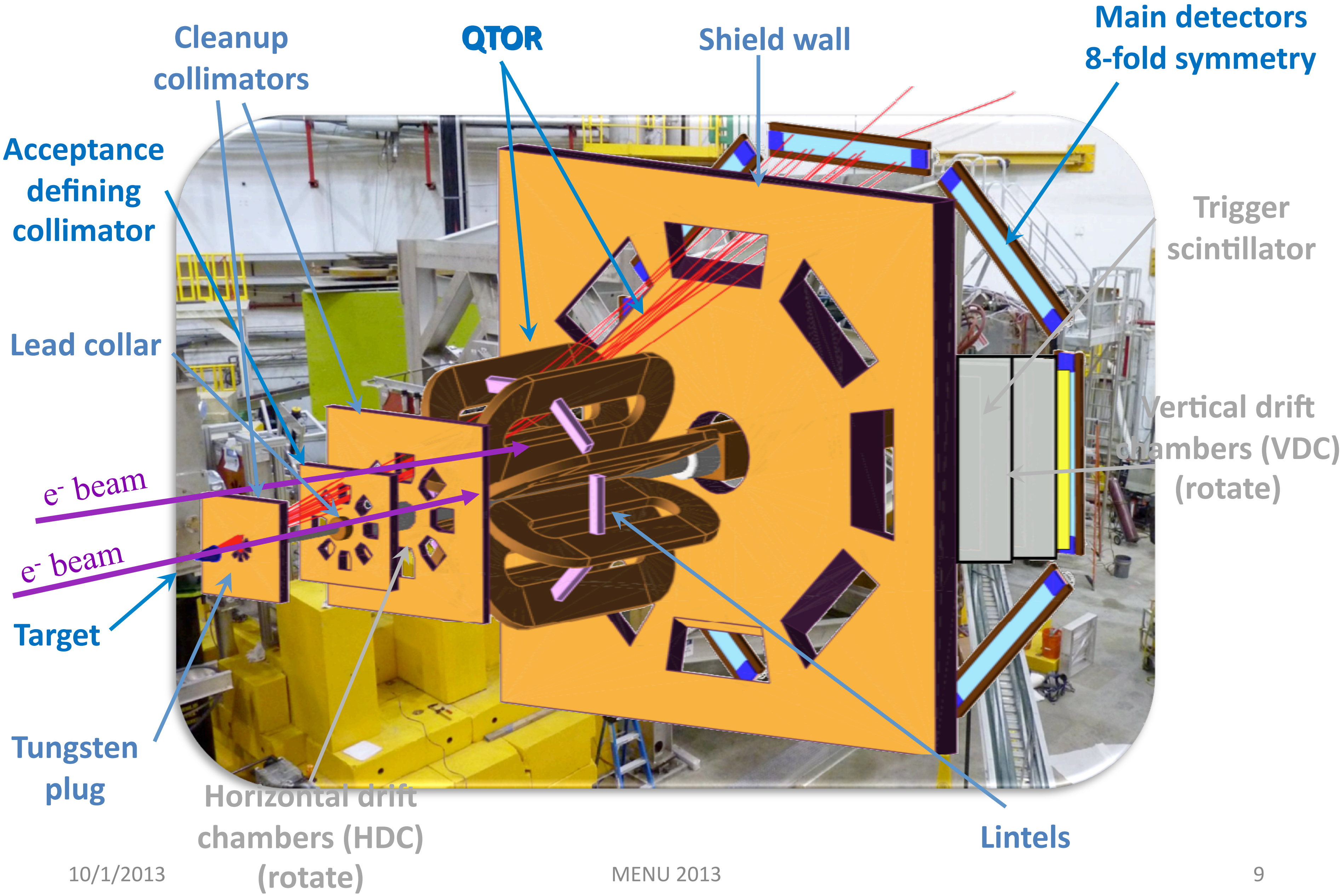
$\delta Q_W^p \approx \pm 4\%$

$\delta(\sin^2\theta_W) \approx \pm 0.3\%$

Meeting PVES Challenges

- Rapid helicity reversal (960 Hz)
- 180 μA beam current (JLab record)
- Small scattering angle: toroidal magnet, large acceptance
- GHz detected rates: data taking in integrating mode
- High power cryogenic target
- Exquisite control of helicity-correlated beam parameters
- Two independent high-precision polarimeters
- Radiation hard detectors
- Low noise 18-bit ADCs
- High resolution Beam Current monitors

The Qweak Apparatus



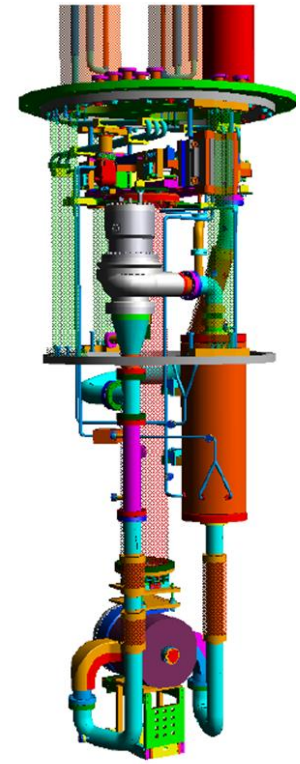
Qweak Target

35 cm, 2.5 kW liquid hydrogen target

World's highest powered cryotarget

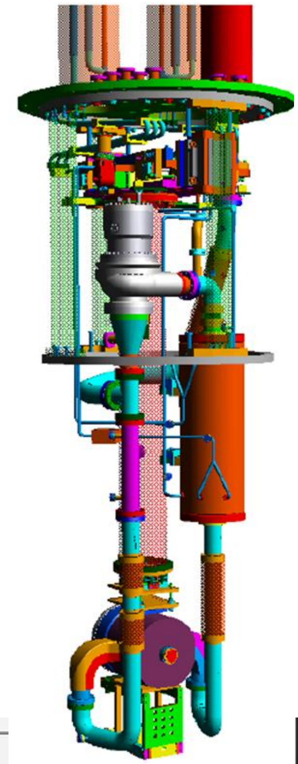
- Temperature ~20 K
- Pressure: 30-35 psia
- Beam at 150 – 180uA

Target boiling might have been problematic!



MD LH2 Asymmetry

Qweak Target



35 cm, 2.5 kW liquid hydrogen target

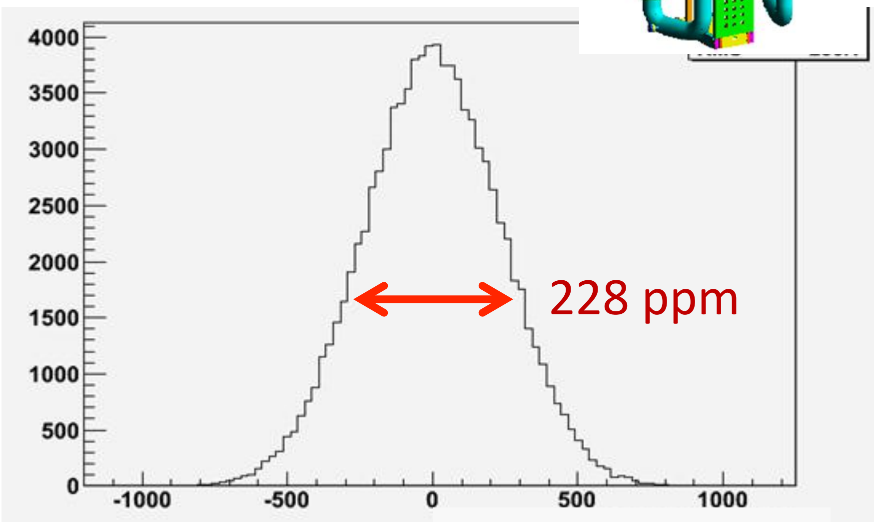
World's highest powered cryotarget

- Temperature ~20 K
- Pressure: 30-35 psia
- Beam at 150 – 180uA

Target boiling might have been problematic!

LH2 statistical width (per quartet):

• Counting statistics:	200 ppm
• Main detector width:	92 ppm
• BCM width:	50 ppm
• Target noise/boiling:	37 ppm



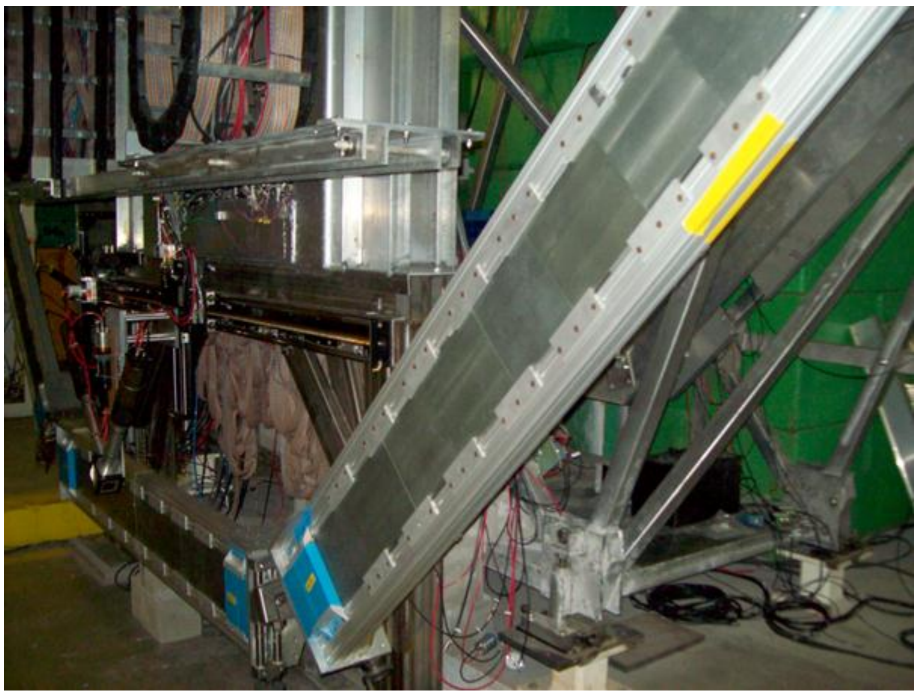
MD LH2 Asymmetry

Main Detectors

- Main detectors

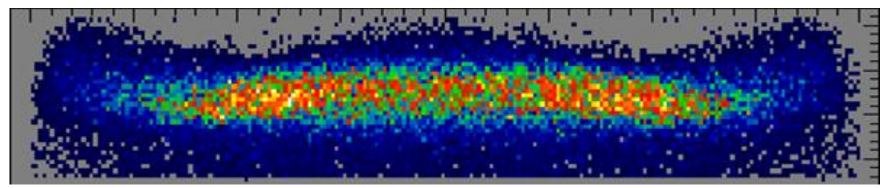
  Toroidal magnet focuses elastically scattered electrons onto each bar

  – 8 Quartz Cerenkov bars
  – Azimuthal symmetry maximizes rates and reduces systematic uncertainties
  – 2 cm lead pre-radiators reduce background

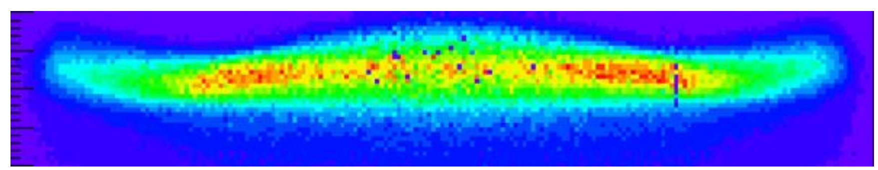


Close up of one detector *in situ*

Simulation of scattering rate MD face



Measured

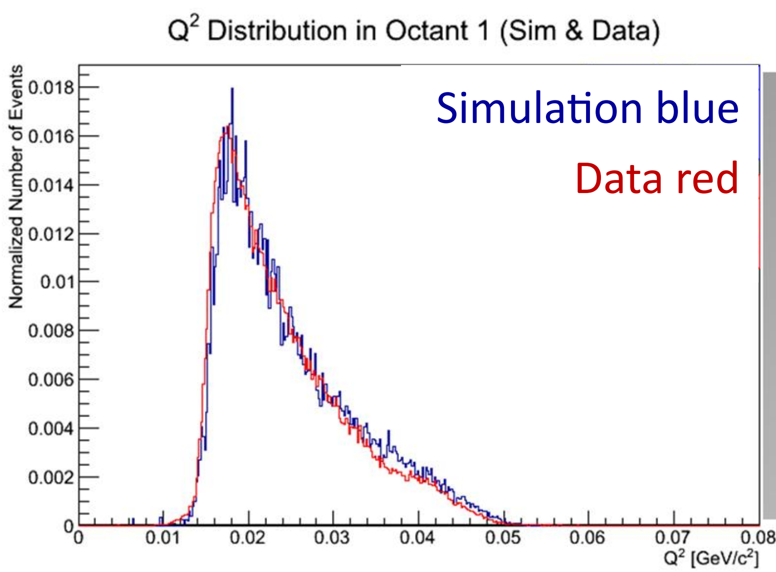


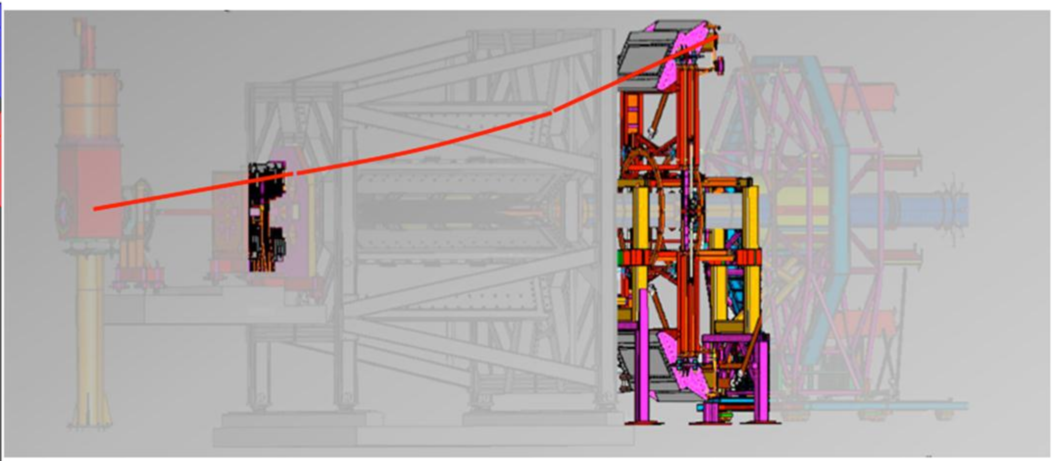
Kinematics (Q^2) determination

- To determine Q^2, we go to "tracking" mode:
  - Currents ~ 50 pA
  - Use Vertical + Horizontal Drift Chambers
  - Re-construct individual scattering events

$$A_{PV} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\{Q_w^p + B(\theta, Q^2)Q^2\}$$

Correct for radiative effects in target with Geant 4 simulations, benchmarked with gas-target & solid target studies





Beam Polarimetry

Polarization is our largest systematic uncertainty (goal: 1%)

This is a challenging goal; so we built a *second*, independent measurement device.

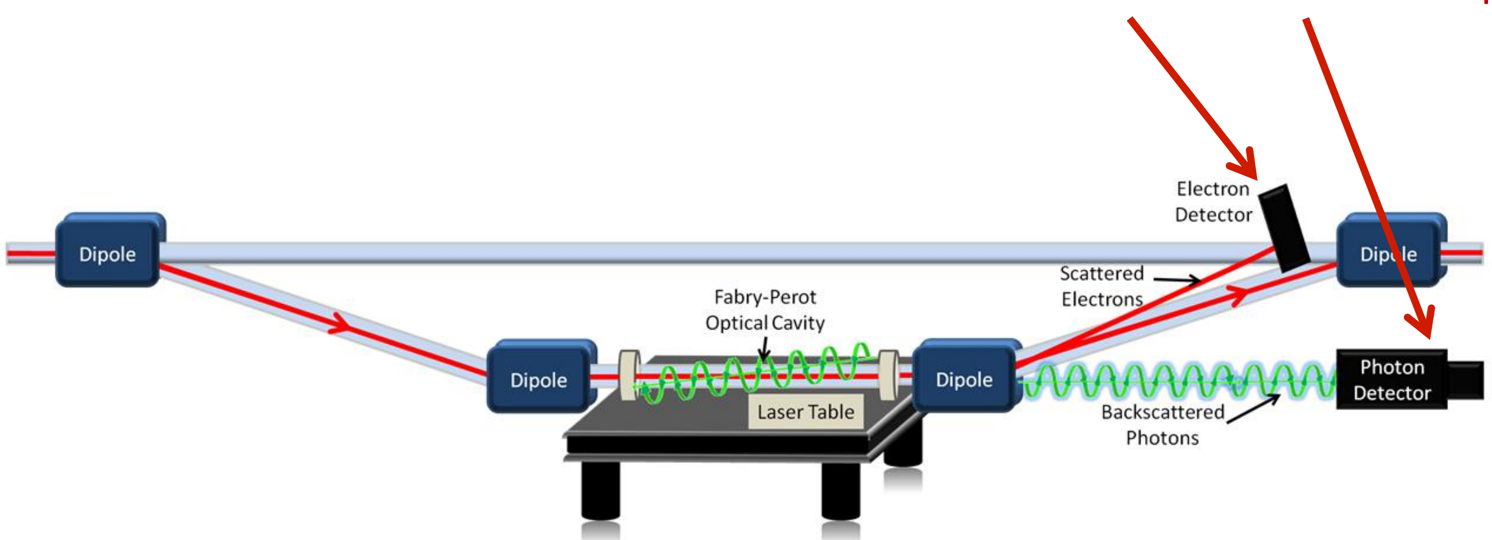
Møller polarimeter

- Precise, but invasive
- Thin, pure iron target
- Brute force polarization
- Limited to low current

Compton polarimeter

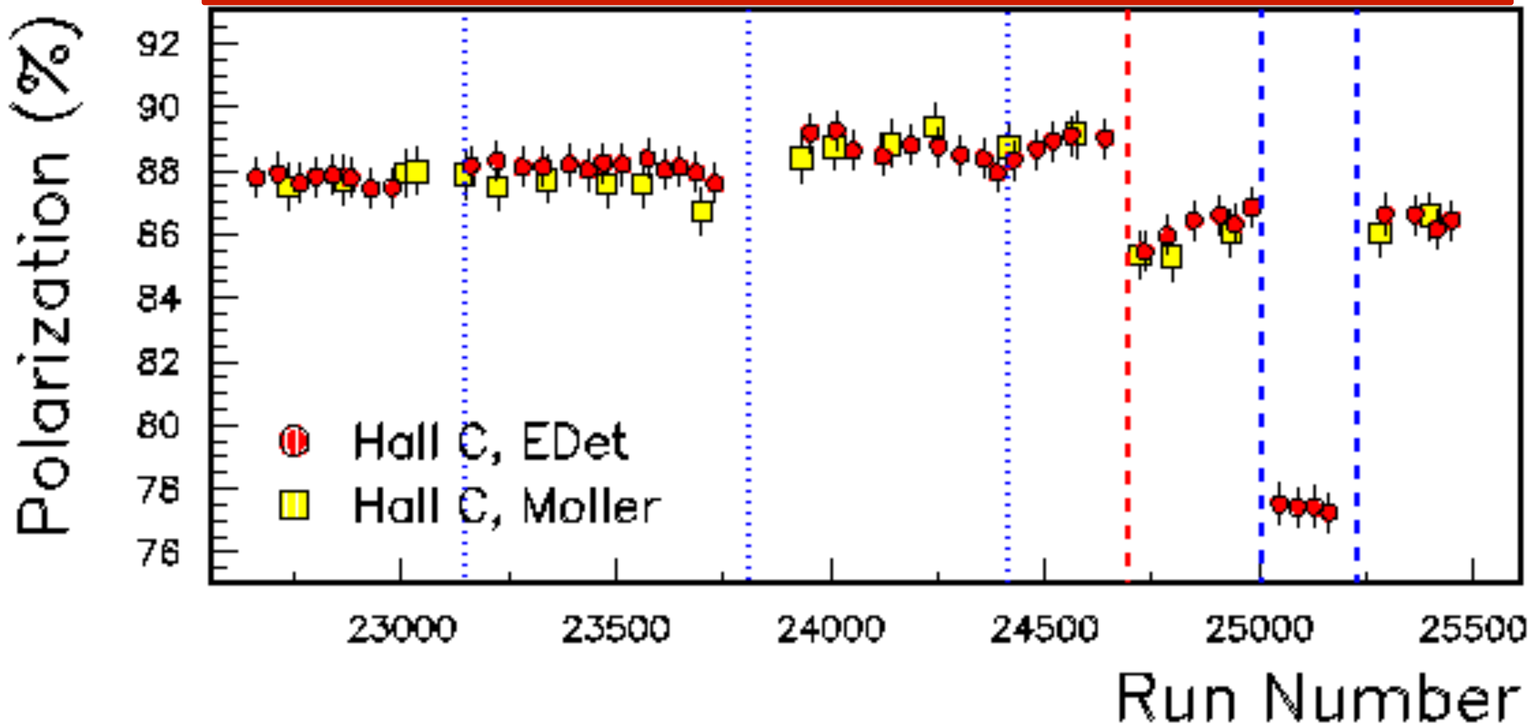
- Installed for Q-weak
- Runs continuously at high currents
- Statistical precision: 1% per hour

We detect *both* recoil electron and photon.



Beam Polarimetry

Preliminary Run 2 Polarization – For Illustrative Purposes Only



Note the good agreement between both polarimeters

A MENU of Auxiliary Measurements

Qweak has data (under analysis) on a variety of observables
of potential interest for Hadron physics:

- Beam normal single-spin asymmetry* for elastic scattering on proton
- Beam normal single-spin asymmetry for elastic scattering on ^{27}Al
- PV asymmetry in the $N \rightarrow \Delta$ region.
- Beam normal single-spin asymmetry in the $N \rightarrow \Delta$ region.
- Beam normal single-spin asymmetry near W= 2.5 GeV
- Beam normal single-spin asymmetry in pion photoproduction
- PV asymmetry in inelastic region near W=2.5 GeV (related to γZ box diagrams)
- PV asymmetry for elastic/quasielastic from ^{27}Al
- PV asymmetry in pion photoproduction

*: *aka* vector analyzing power *aka* transverse asymmetry;
generated by imaginary part of two-photon exchange amplitude
(*pace* Wim van Oers)

First result

Q-weak ran from Fall 2010 – May 2012 : four distinct running periods

- Hardware checkout (Fall 2010-January 2011)
- Run 0 (Jan-Feb 2011)
- Run 1 (Feb – May 2011)
- Run 2 (Nov 2011 – May 2012)

We have completed and unblinded the analysis of "Run 0" (about 1/25th of our total dataset).

$A^{p}_{PV} = -279 \pm 35 (stat) \pm 29\ (sys)$ ppb

$\langle Q^2 \rangle = 0.0250 \pm 0.0006\ GeV^2$

$\langle E_{beam} \rangle = 1155\ MeV$

$\theta_{eff} = 7.90\ ^\circ$

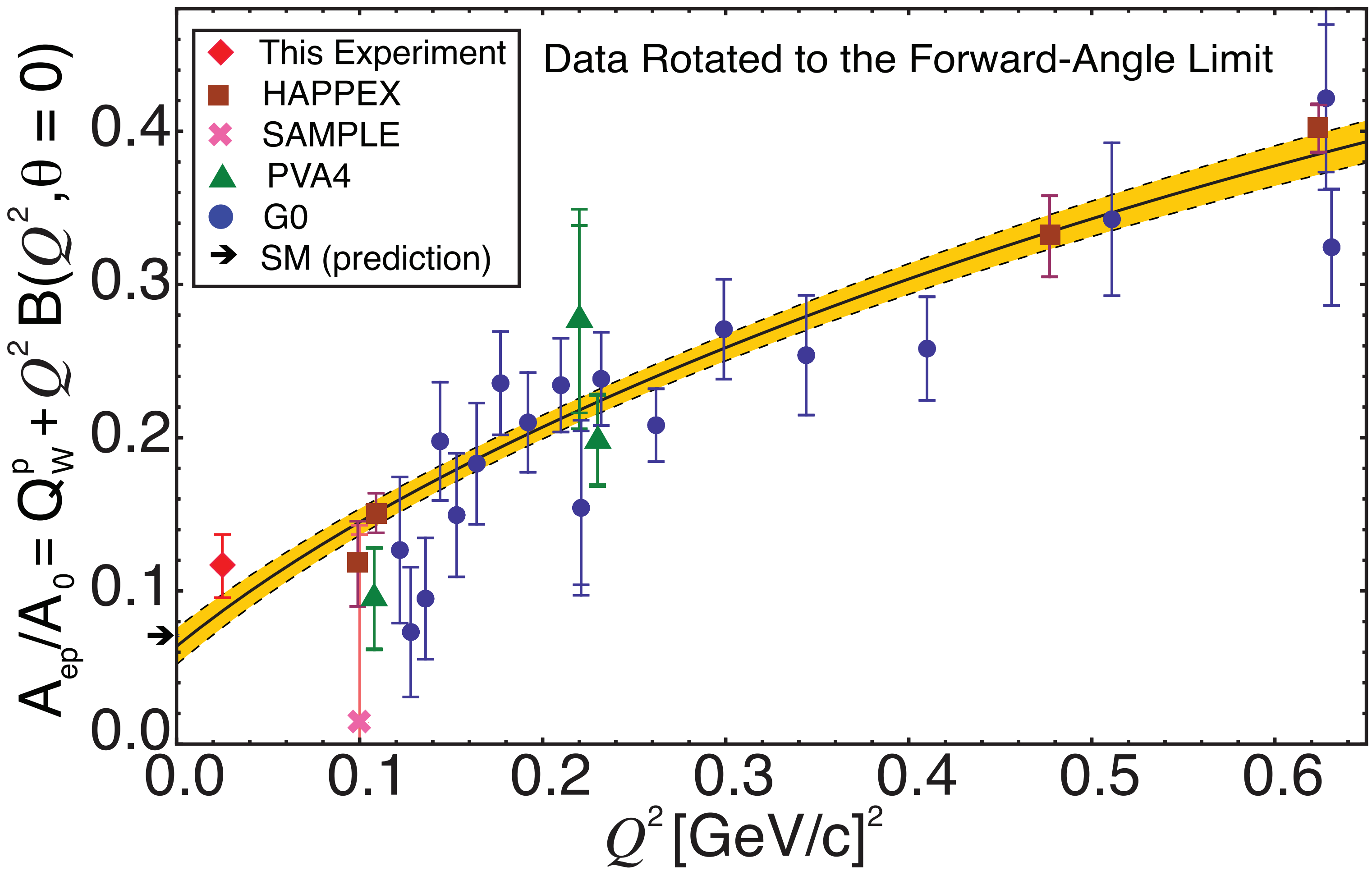
arXiv:1307:5275 accepted in PRL, to appear online Oct. 13

Reduced Asymmetry

in the forward-angle limit (θ=0)

4% of total data

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



Hadronic part extracted through global fit of PVES data.

$$\overline{A^p}^{data}(\theta = 0, Q^2) = \overline{A^p}^{data}(\theta^{data}, Q^2)$$

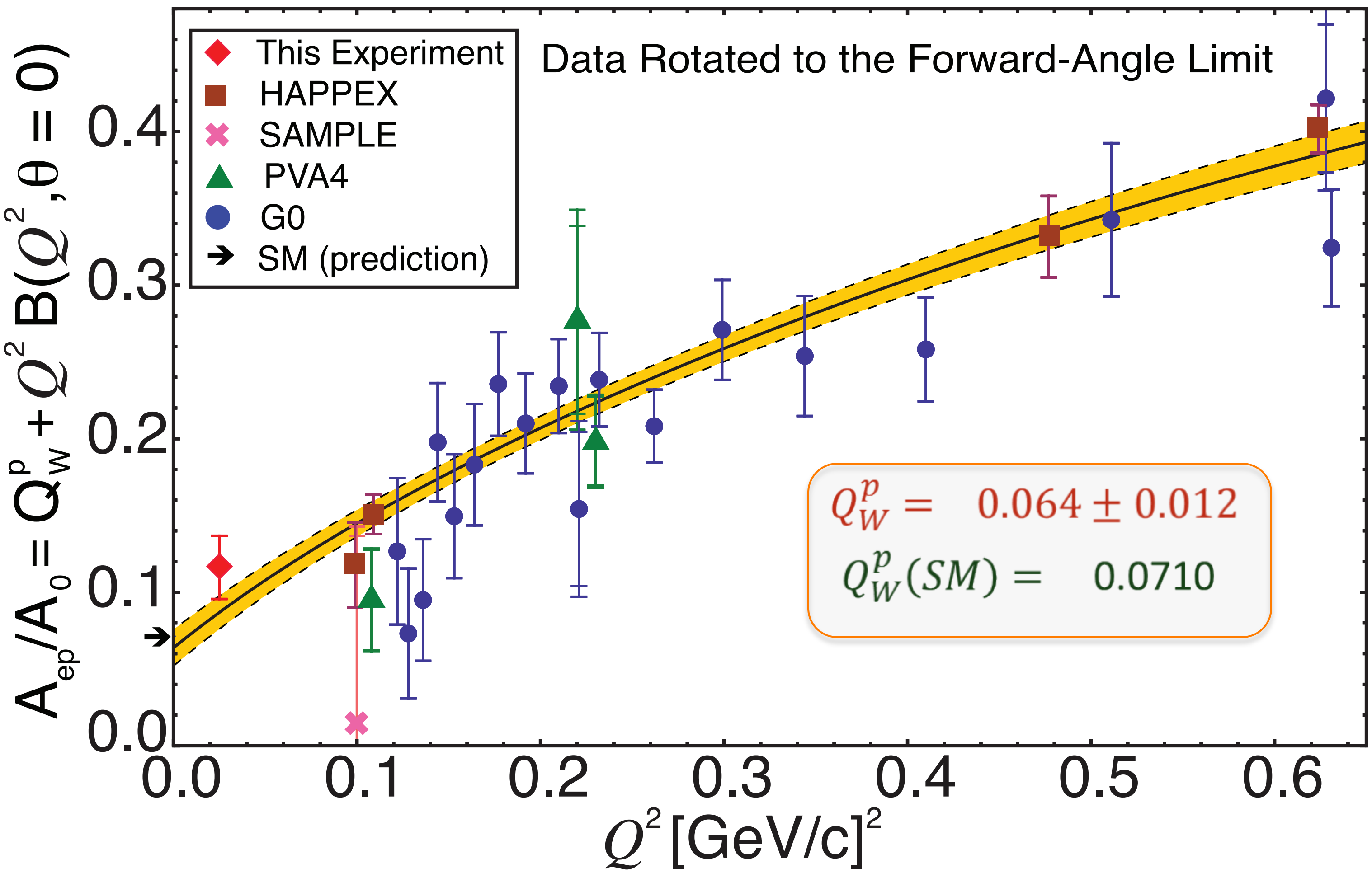
Reduced Asymmetry

4% of total data

in the forward-angle limit (θ=0)

$$A_0 = -\frac{Q^2 G_F}{4\sqrt{2}\pi\alpha}$$

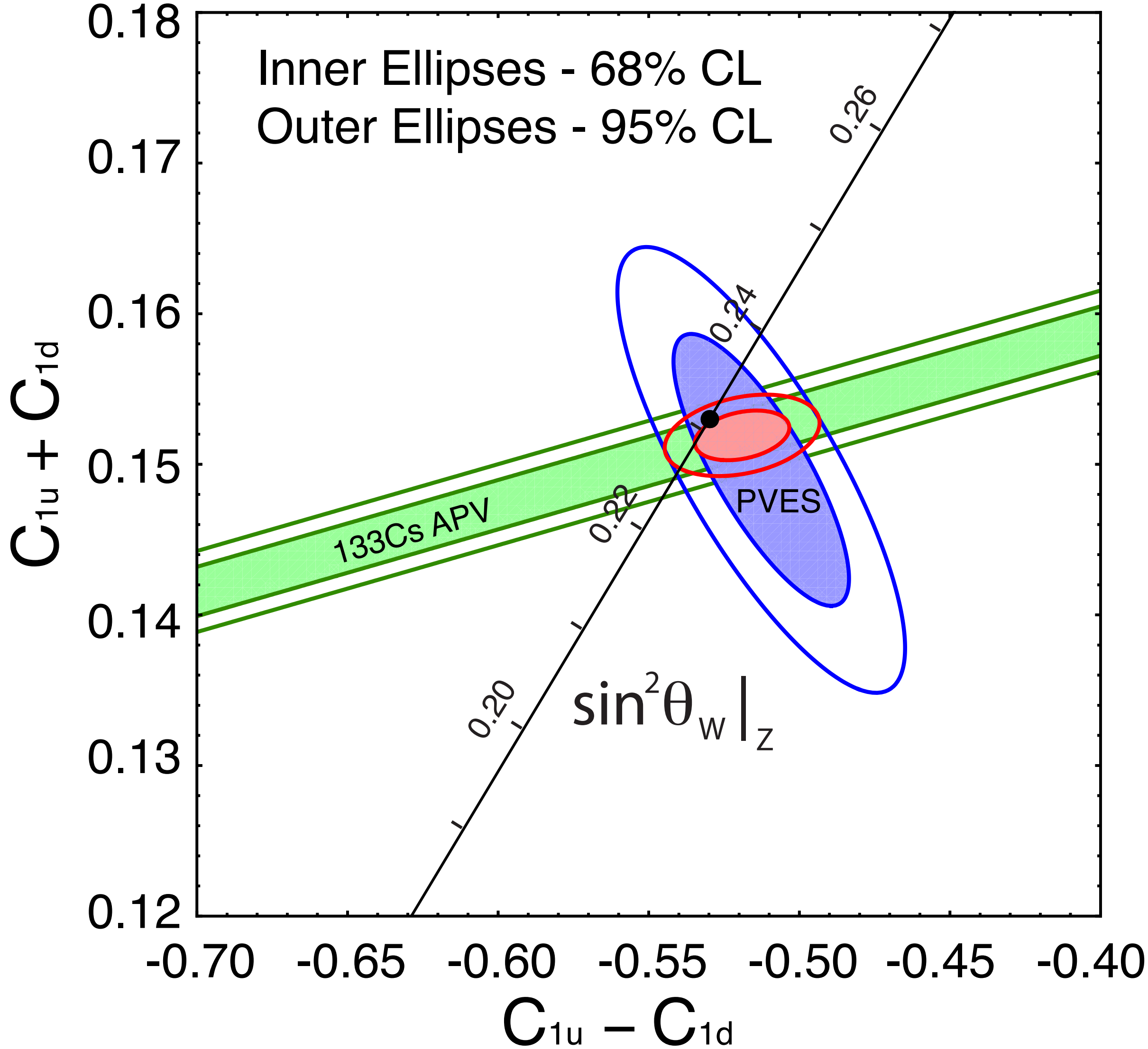
$$\overline{A^p_{LR}} = \frac{A_{LR}}{A_0} \xrightarrow{\theta\to 0} [Q^p_W + Q^2 B(Q^2)]$$



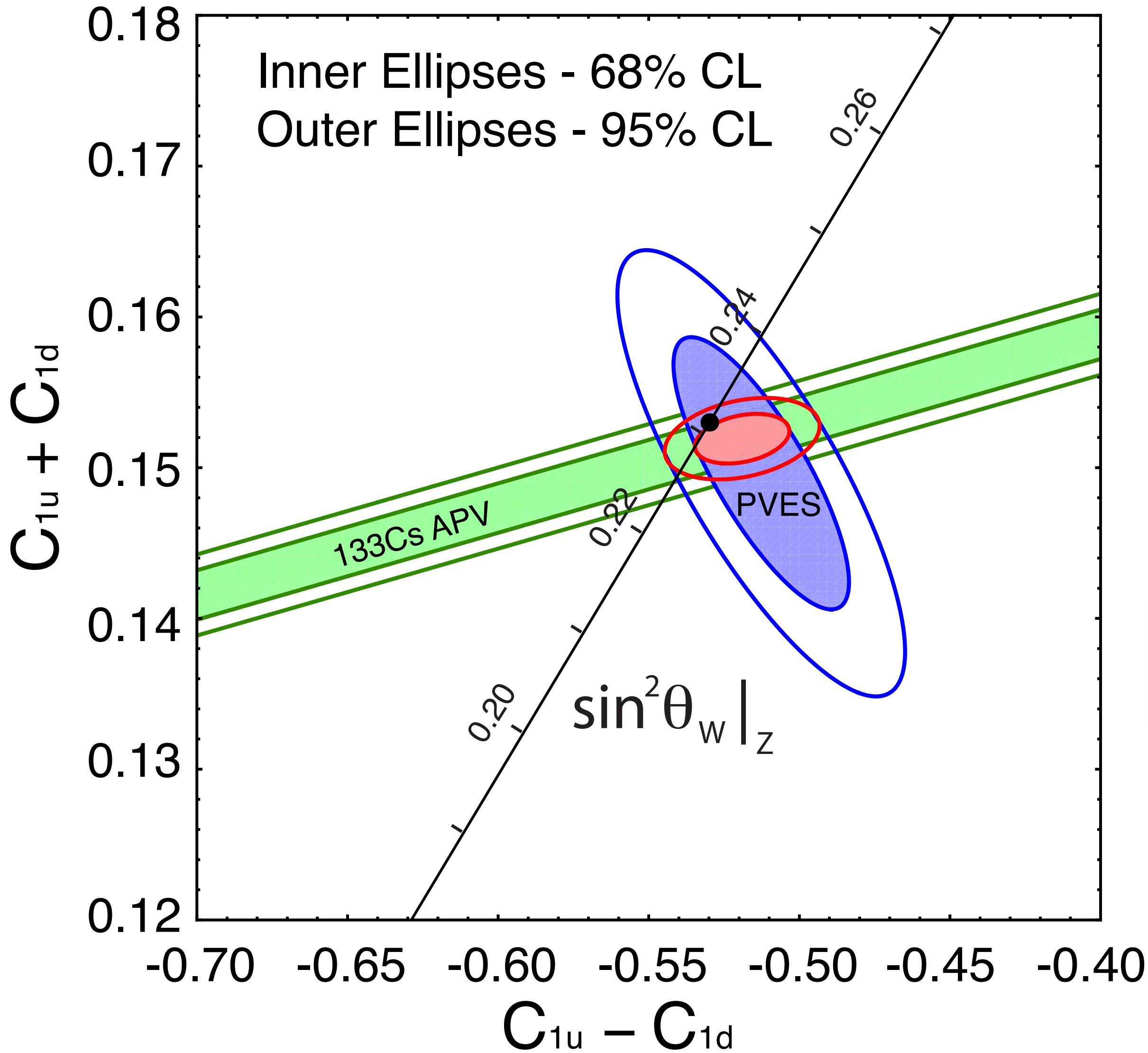
Hadronic part extracted through global fit of PVES data.

$$\overline{A^p}^{data}(\theta = 0, Q^2) = \overline{A^p}^{data}(\theta^{data}, Q^2)$$

The C_{1q} & the neutron's weak charge



The C_{1q} & the neutron's weak charge



Combining this result with the most precise atomic parity violation experiment we can also extract, for the first time, the neutron's weak charge:

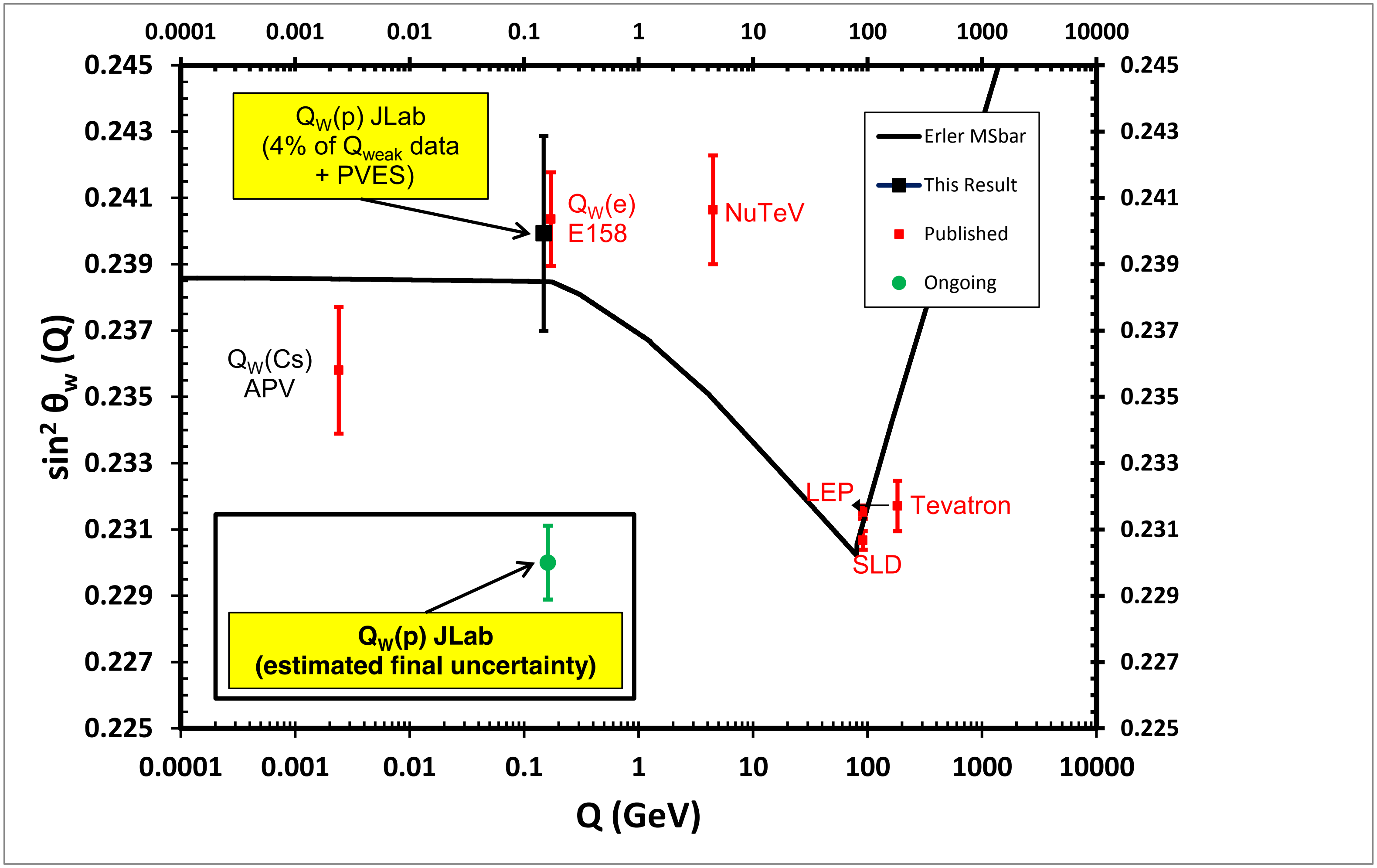
$$Q_W^n = -0.975 \pm 0.010$$

$$Q_W^n(SM) = -0.9890$$

Weak mixing angle result

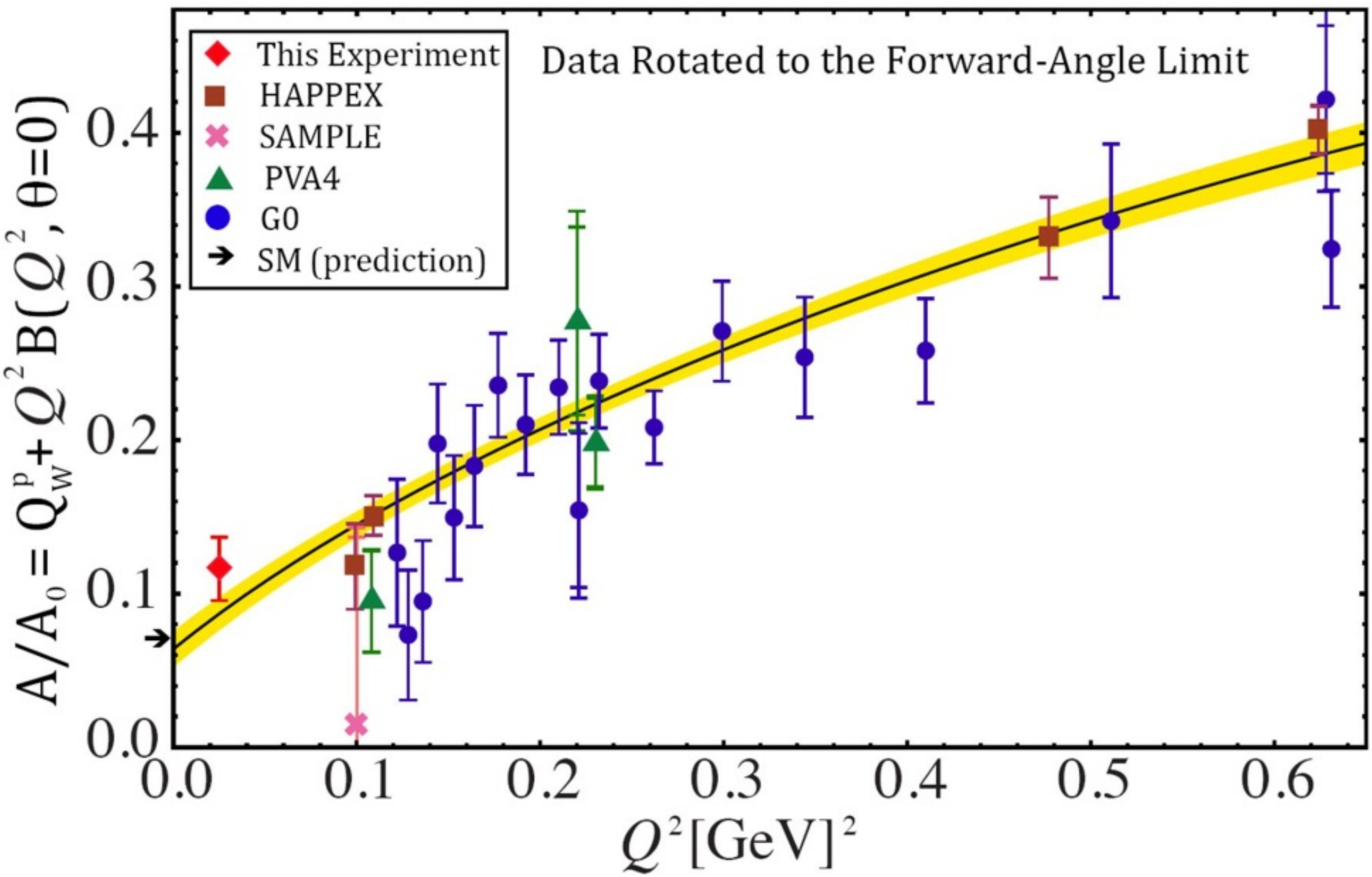
4% of total data

Recall: in Standard Model, at tree-level, $Q_W^p = (1 - 4\sin^2\theta_W)$



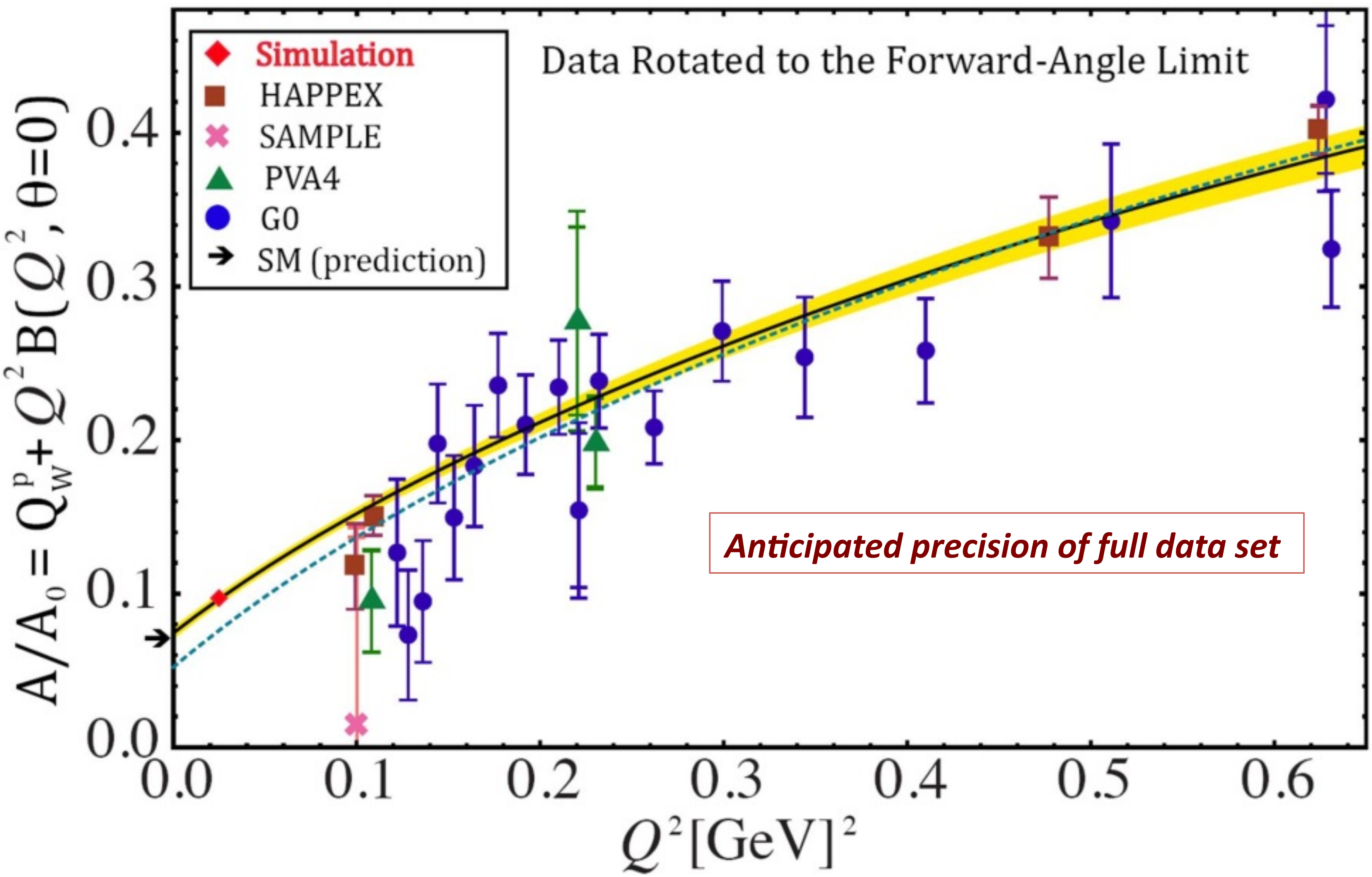
* Uses electroweak radiative corrections from Erler, Kurylov, Ramsey-Musolf, PRD 68, 016006 (2003)

“Teaser”



This Experiment
HAPPEX
SAMPLE
PVA4
G0
SM (prediction)
Data Rotated to the Forward-Angle Limit
$A/A_0 = Q_W^p + Q^2 B(Q^2, \theta=0)$
0.0
0.1
0.2
0.3
0.4
0.0
0.1
0.2
0.3
0.4
0.5
0.6
$Q^2 [\text{GeV}]^2$

“Teaser”



Simulation
HAPPEX
SAMPLE
PVA4
G0
SM (prediction)
Data Rotated to the Forward-Angle Limit
Anticipated precision of full data set
$A/A_0 = Q_W^p + Q^2 B(Q^2, \theta=0)$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
$Q^2 [\mathrm{GeV}]^2$

Summary

First result (4% of data set):

$A^p_{PV} = -279 \pm 35(stat) \pm 29\ (sys)$ ppb $\quad \langle Q^2 \rangle = 0.0250 \pm 0.0006\ GeV^2$

The weak charges

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

$Q^n_W = -0.975 \pm 0.010 \quad Q^n_W(SM) = -0.9890$

Lots of work to push down systematic errors, but no show-stoppers found….

Expect final result in 12-18 months time.

***Grazie* to MENU-2013 organizers for the chance to give this talk!**

Thanks to my Qweak collaborators, from whom many slides borrowed…

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Experiment probes strength of the weak interaction

Sep 16, 2013 6 comments

Q-weak at Jefferson Lab has measured the proton's weak charge

An international collaboration has made the first determination of the proton's "weak charge" – a quantity that is related to the strength of the weak interaction. The Q-weak experimental collaboration, working at Jefferson Lab in Newport News, Virginia, says that the small number of data analysed so far agree with predictions of the Standard Model of particle physics but that it believes a full analysis

Qweak Collaboration

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

[1]Spokespersons [2]Project Manager Grad Students