The Qweak Experiment: First Determination of the Weak Charge of the Proton

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for the Qweak Collaboration

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Office of Nuclear Physics
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Overview

- Qweak measures the parity violating elastic asymmetry in e-p scattering at $Q^2 = 0.025$ GeV^2 in order to extract $Q_W(p)$ and $sin^2\theta_W$
  - Deviation from SM expectations would be a sign of new physics with a TeV mass-scale
- Qweak had three running periods in Hall C at Jefferson Lab
  - Run 0: (Jan-Feb 2011); about 1/25 of the total data set.

    Published Oct 2013; Phys.Rev.Lett. 111, 141803.
  - Run 1 (Feb-May 2011)
  - Run 2 (Nov 2011-May 2012)

  Ongoing analysis; results likely within a year or so
- Several ancillary measurements were taken to determine or constrain background processes or corrections

Parity violating electron scattering

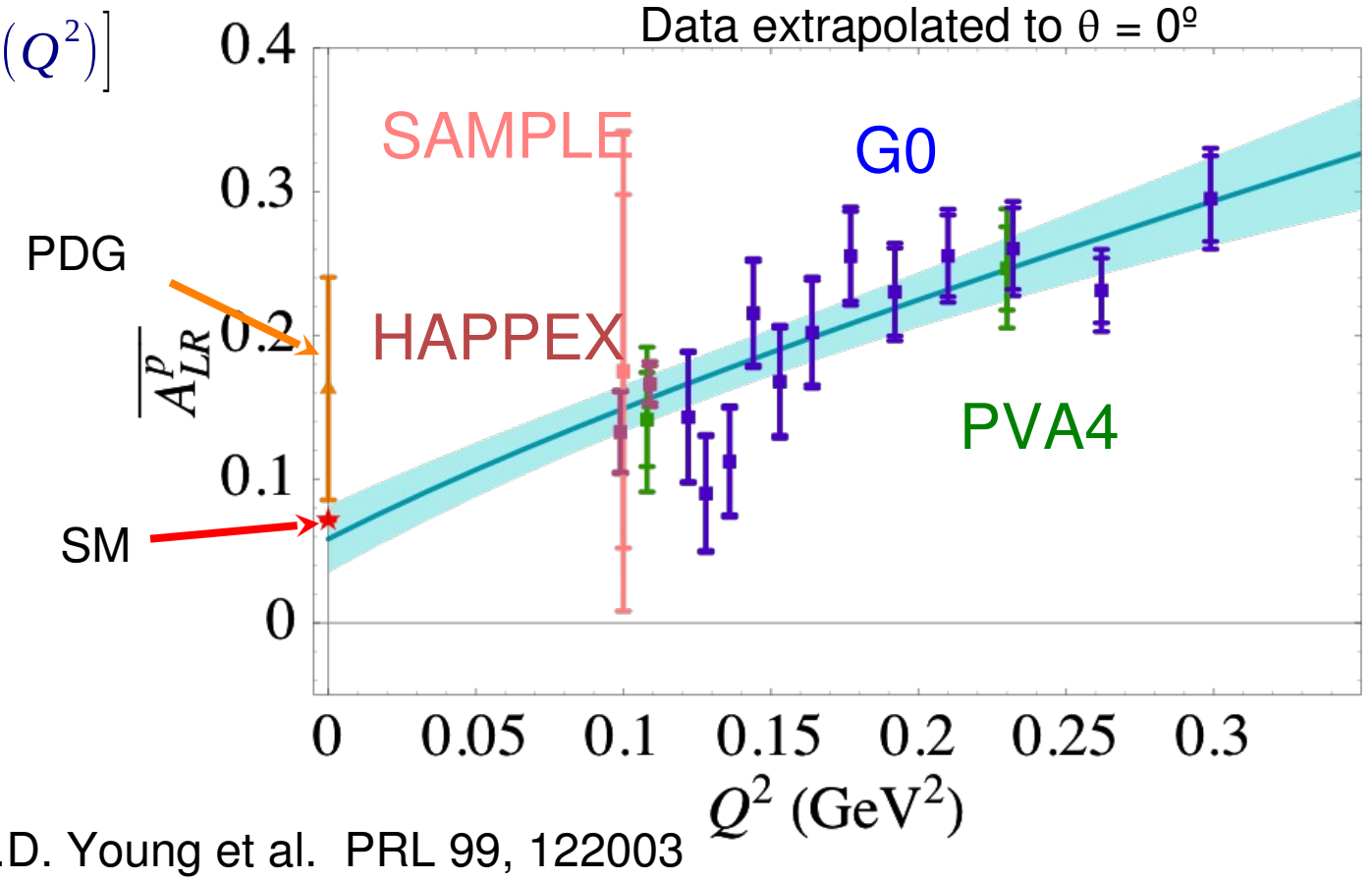
$$A_{LR}=\frac{-G_\mu\ Q^2}{4\pi\alpha\sqrt{2}}\left[\frac{\varepsilon G_E^\gamma G_E^Z+\tau G_M^\gamma G_M^Z-(1-4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^e}{\varepsilon(G_E^\gamma)^2+\tau(G_M^\gamma)^2}\right]$$

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

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

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

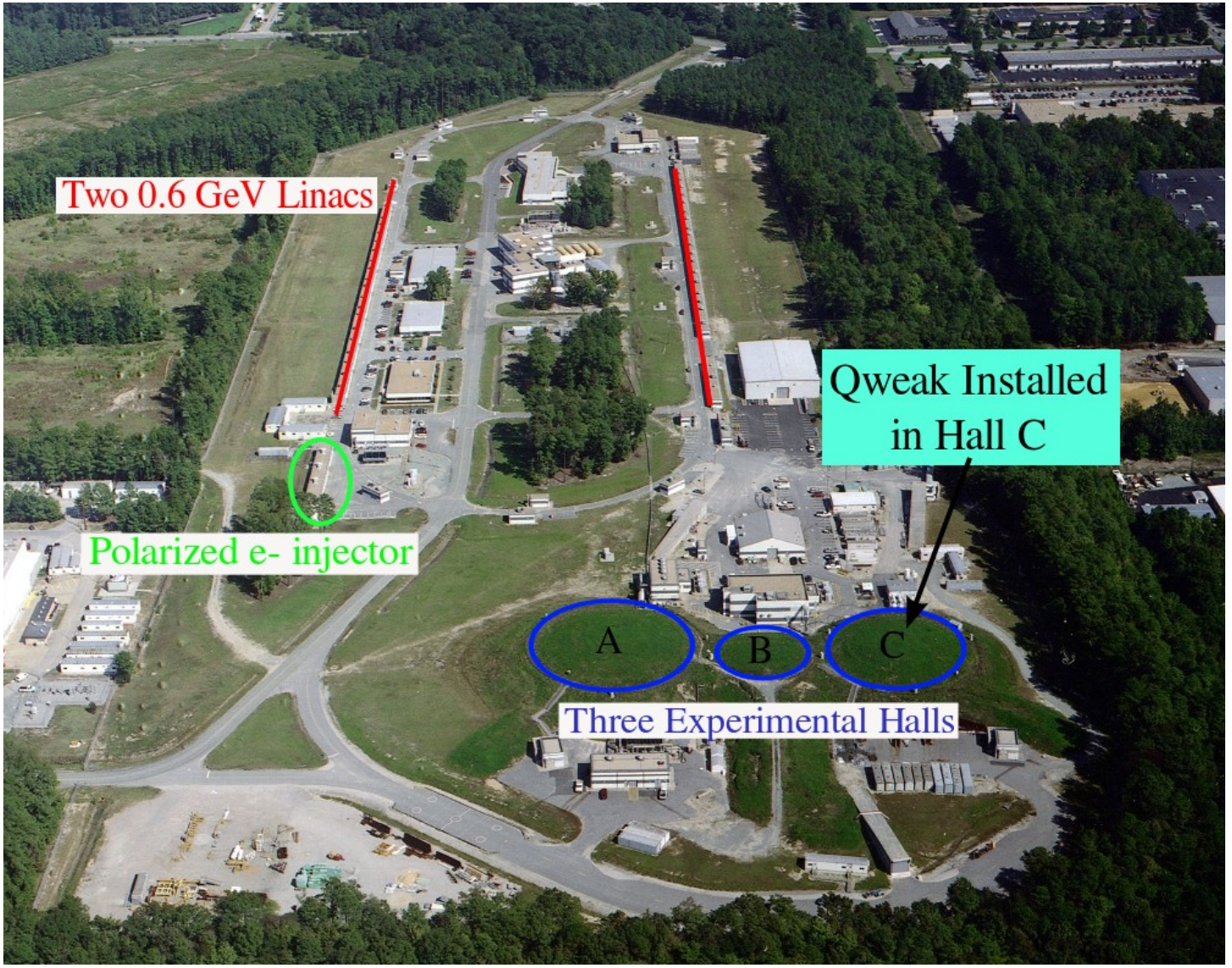
Role of QWEAK: A single precise value at low Q^2 to constrain the intercept



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

Qweak Overview

Jefferson Lab (6 GeV Era)



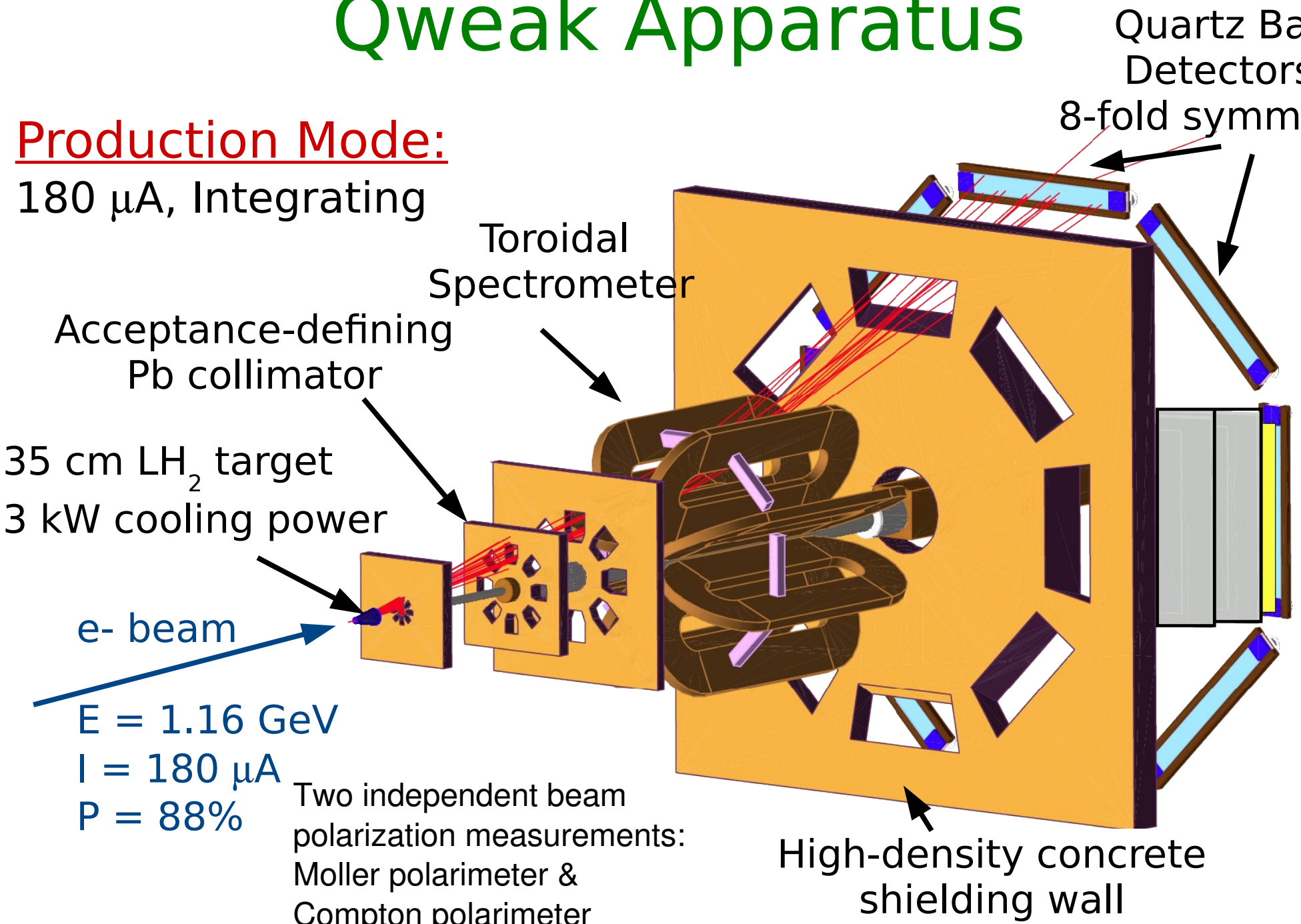
Qweak Installation:
May 2010-May 2012

~1 year of beam in 3 running periods:

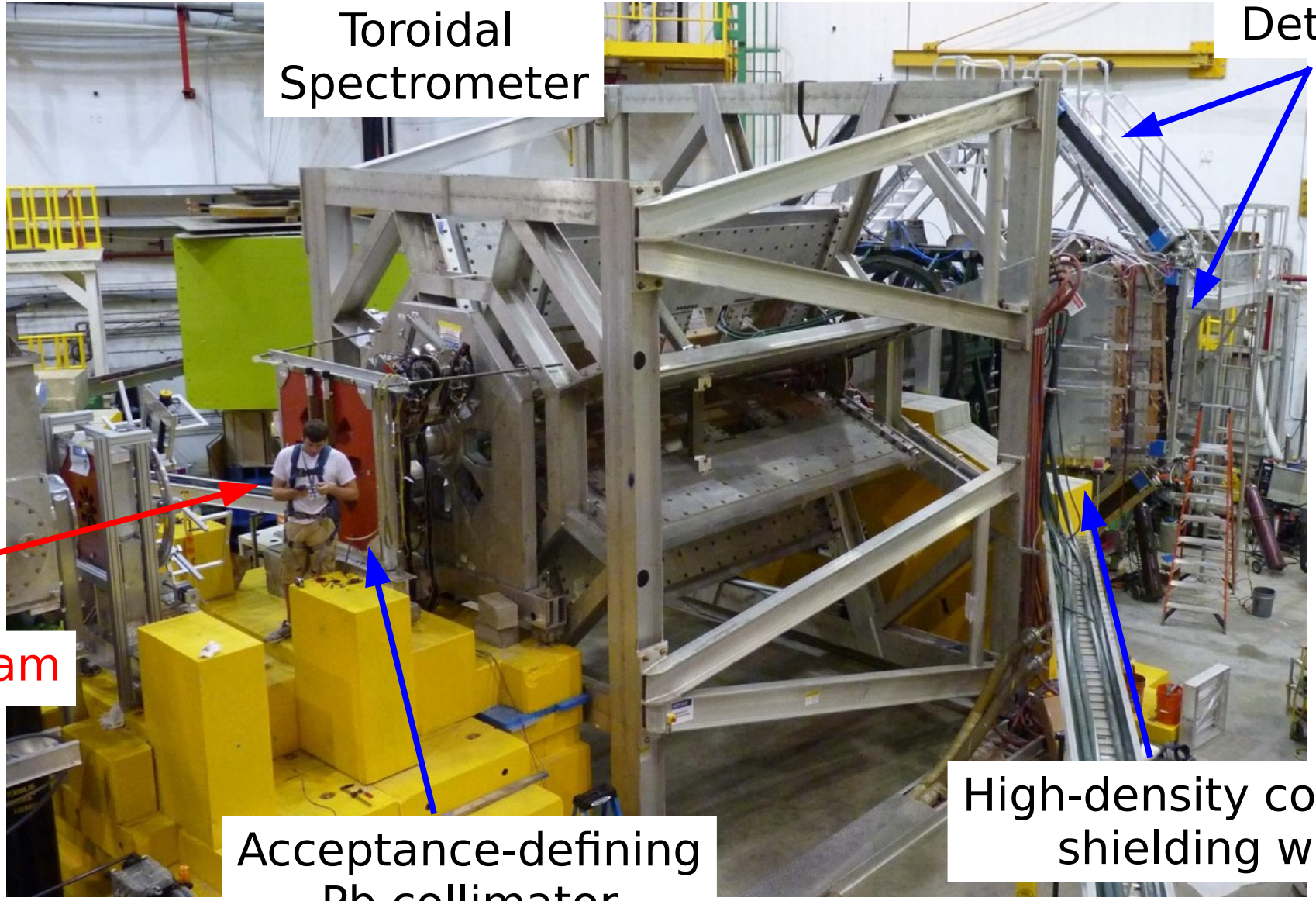
- Run 0
  Jan – Feb 2011
- Run 1
  Feb – May 2011
- Run 2
  Nov 2011 – May 2012

Asymmetry ~250 ppb
Error goal ~5 ppb

Qweak Apparatus



Qweak During Installation



Constructing the asymmetry

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

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

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

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

R_{tot} = includes radiative correction and correction for light-variation

Background corrections: Al windows, neutrals, scattering from beamline, inelastic scattering
f = background fraction
A = background asymmetry

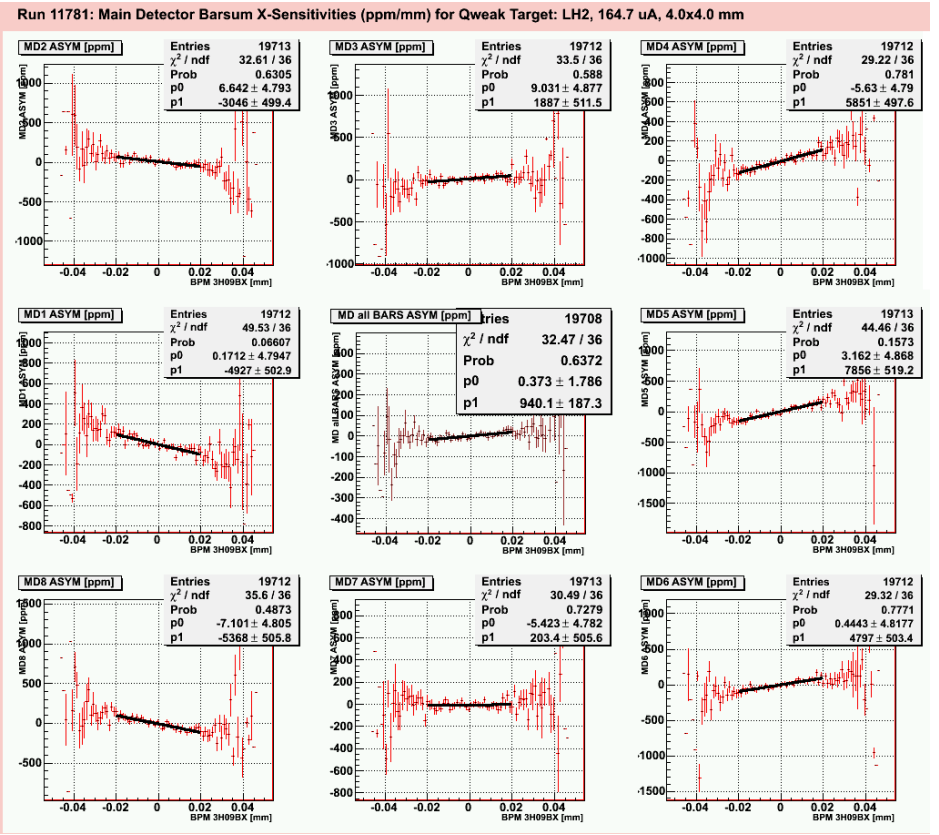
Beam Parameter Corrections

- 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

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

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

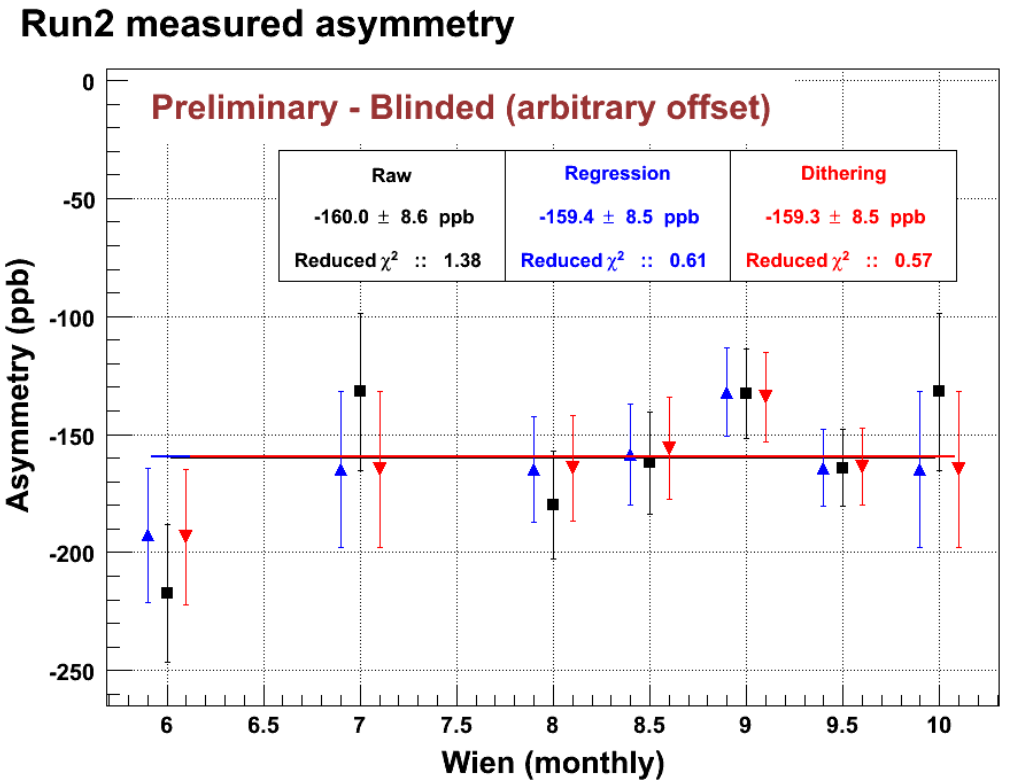
Example: Detector Sensitivity to X position variation



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

Some Backgrounds

- Target cell backgrounds
  - Recall that $Q^n_{weak} \sim 1$
    Scattering from the aluminum cell walls will contribute a large asymmetry
  - Need dilution and Al asymmetry
- Inelastic scattering from LH2
  - Measure the asymmetry with reduced magnetic field

- Two-boson exchange

  Longitudinal e- spin

  γ-Z box contributions lead to ~6% shift in Q^p_{weak} with error estimates of about 1%

  Transverse e- spin

  2-γ exchange with transverse electron spin leads to a azimuthal asymmetry variation

Ancillary Measurements

Many additional measurements under analysis:

- Parity violating asymmetry:
  - elastic ^{27}Al
  - $N \rightarrow \Delta$ (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
  - $N \rightarrow \Delta$
  - Møller
  - Near W = 2.5 GeV
  - Pion photoproduction (E = 3.3 GeV)

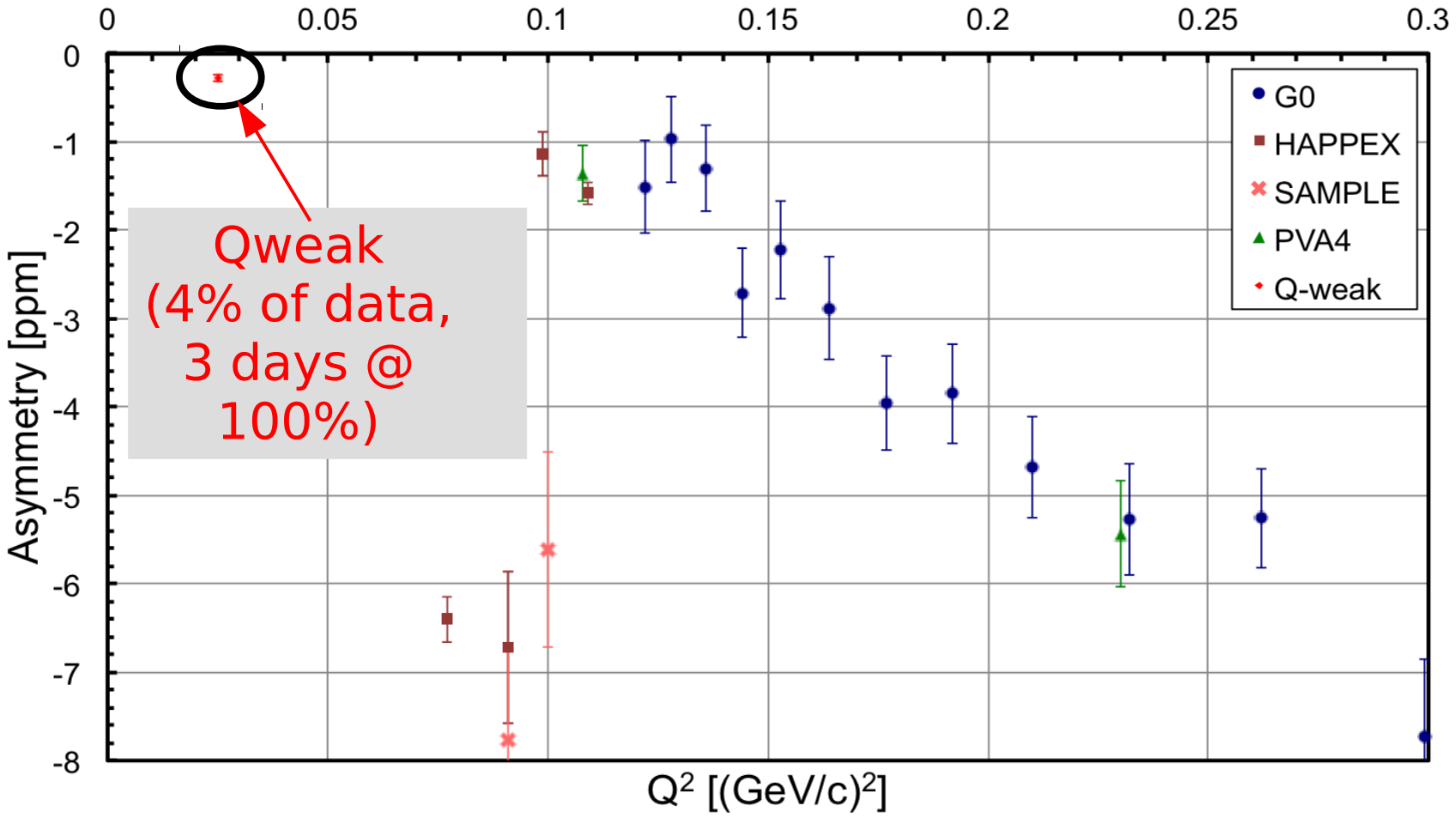
Published 10/2/2013: PRL **111,**141803 (2

First Results: Asymmetry

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

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

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



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 $(GeV/c)^2$
  - 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

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 precise 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

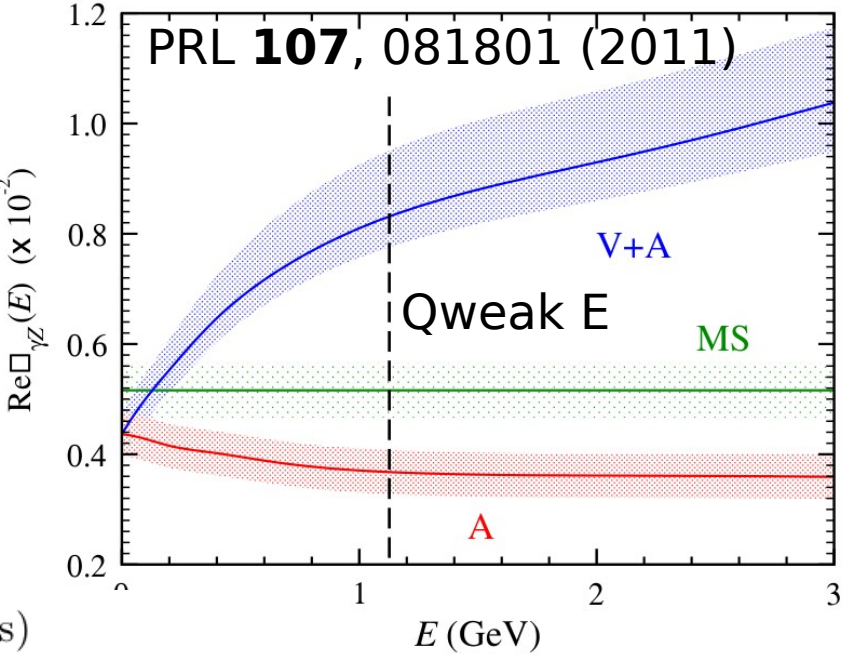
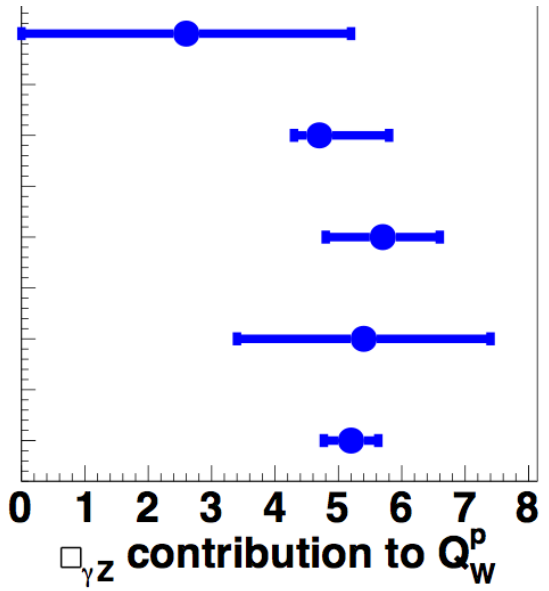


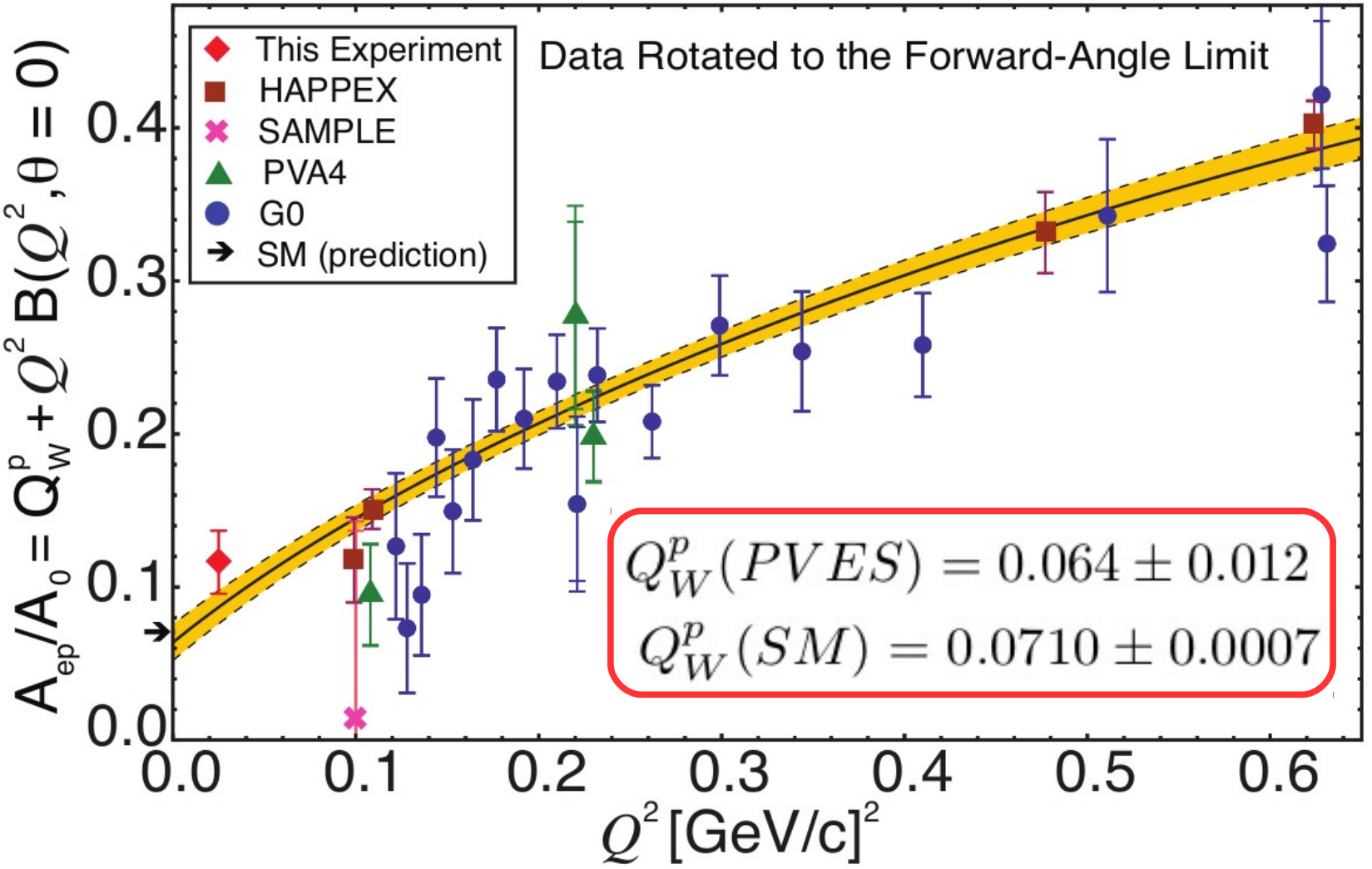
Table 1: $\Box_{\gamma Z}^V$ contribution to Q_W^p (Qweak kinetmatics)

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



First Results: Weak Charge

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



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

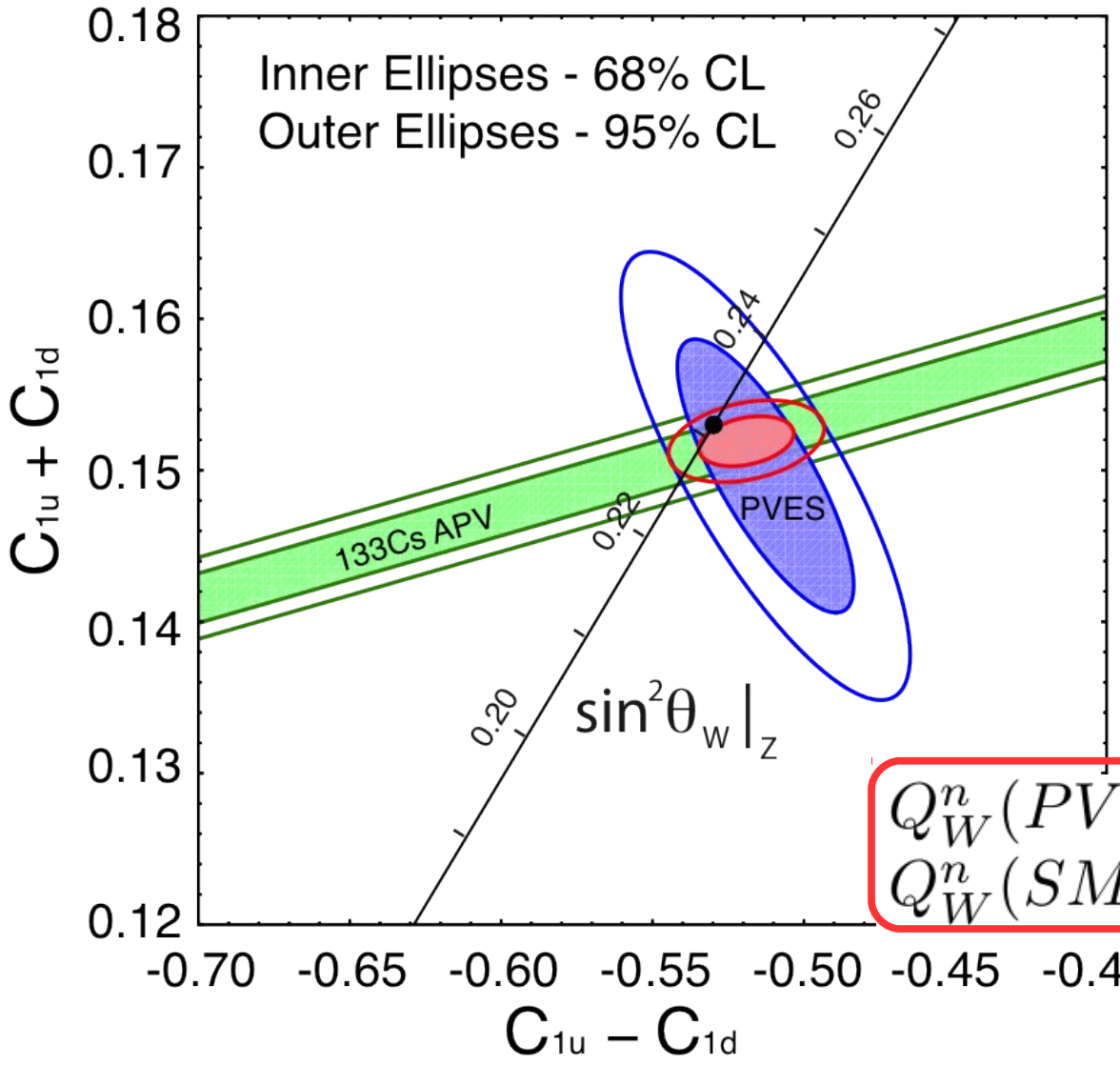
Data rotated to forward-angle for plotting

Remove energy- & Q^2-dependence of gZ-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

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

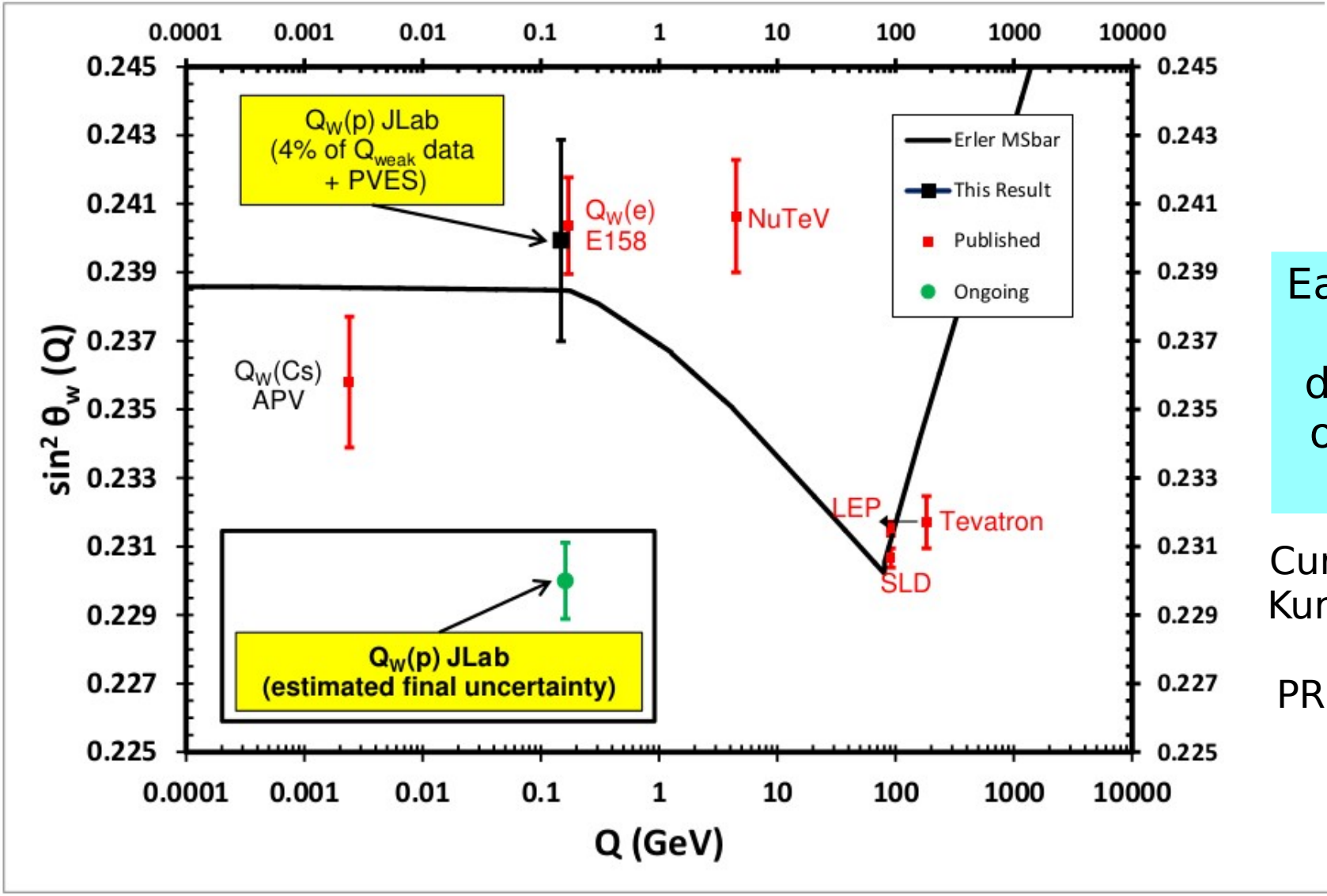
$$Q_W^n(PVES + APV) = -0.975 \pm 0.010$$
$$Q_W^n(SM) = -0.9890 \pm 0.0007$$

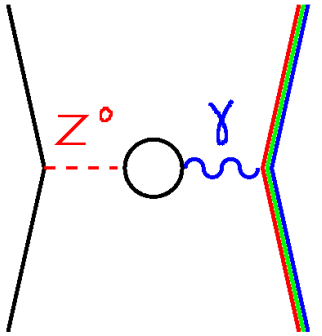
4% of Qweak Data

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

First Results: Weak Mixing Angle

At tree level: $Q^p_w = 1 - 4\sin^2\theta_w$



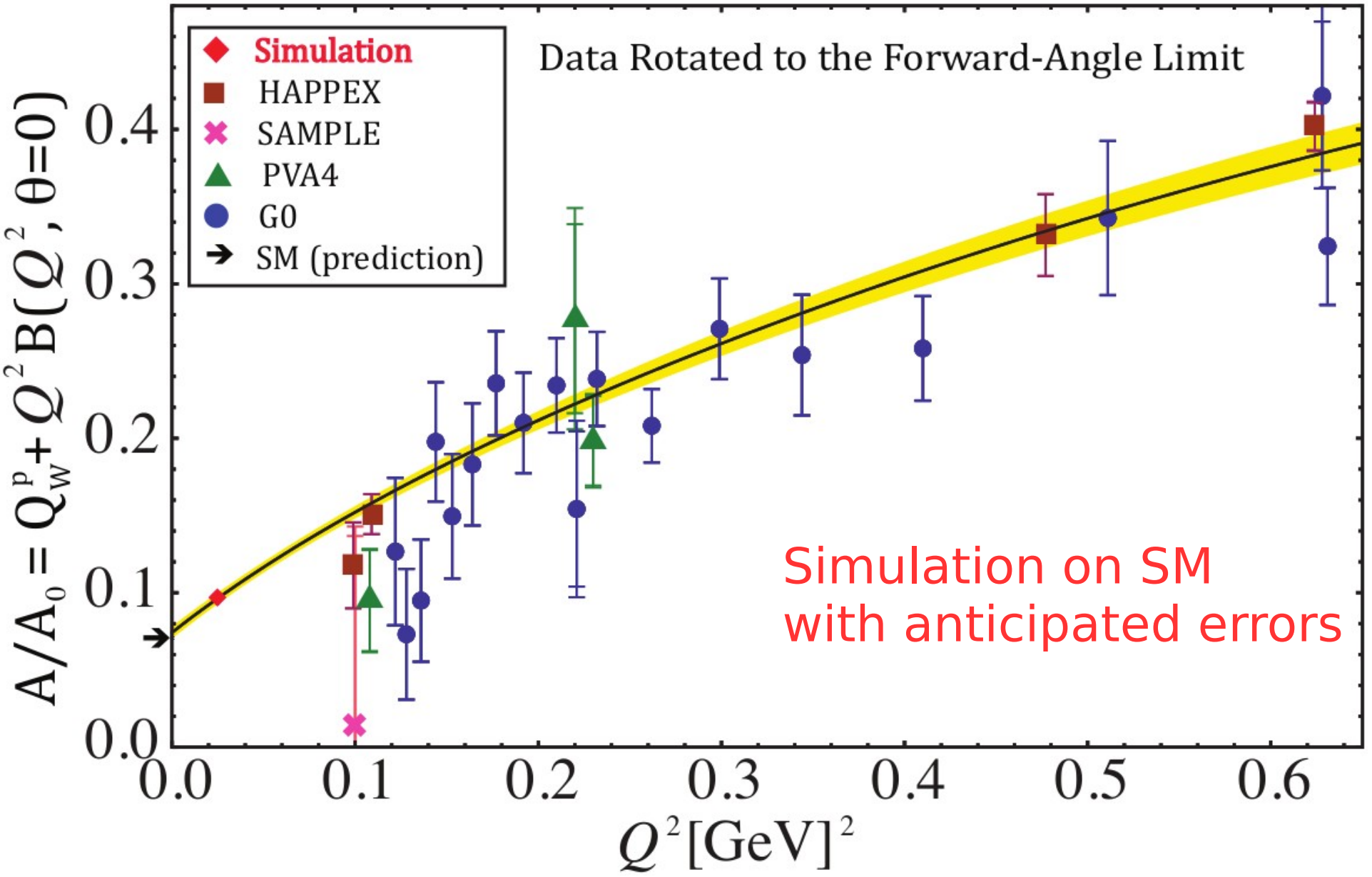


Each experiment sensitive to different types of new physics

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

4% of Qweak Data

“Teaser” with anticipated final errors



Summary

- First published result from the Qweak experiment

Phys.Rev.Lett. **111,**141803 (2013)

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

4% of Qweak Data

Determination of the proton and neutron weak charge

$$Q_W^p(PVES) = 0.064 \pm 0.012$$
$$Q_W^p(SM) = 0.0710 \pm 0.0007$$

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

In agreement with Standard Model predictions

- Final result expected ~year from now
  - Statistical error 5 times smaller, reduced systematics, no show stoppers found
  - Additionally, many ancillary results under analysis

The Qweak Collaboration

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