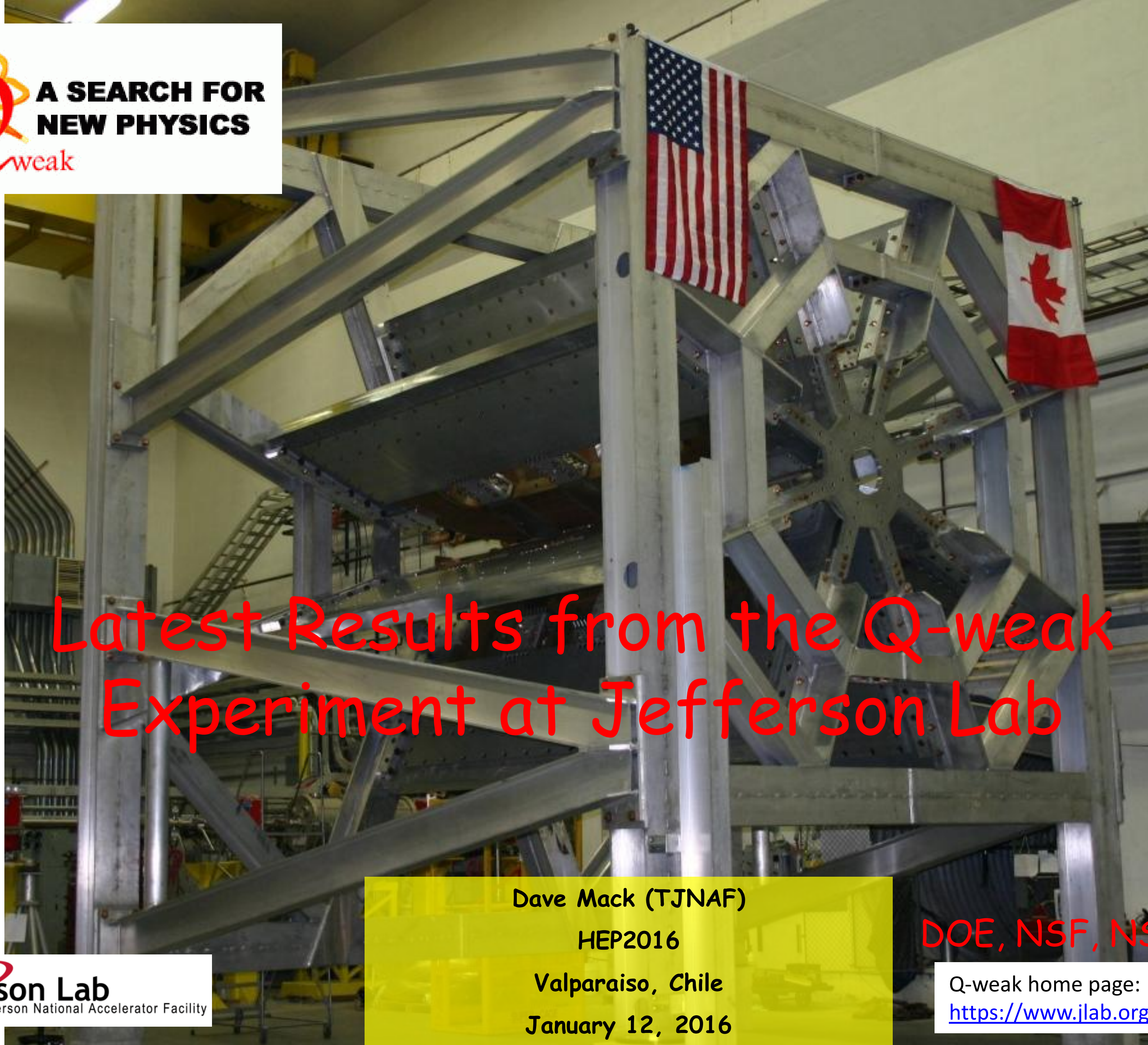
A SEARCH FOR NEW PHYSICS
Qweak



Latest Results from the Q-weak Experiment at Jefferson Lab

Dave Mack (TJNAF)

HEP2016

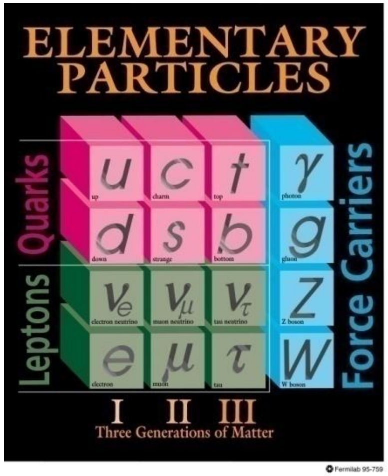
Valparaiso, Chile

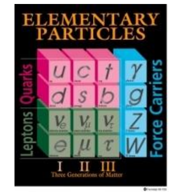
January 12, 2016

DOE, NSF, NSERC

Q-weak home page:
https://www.jlab.org/qweak/

Jefferson Lab
Thomas Jefferson National Accelerator Facility



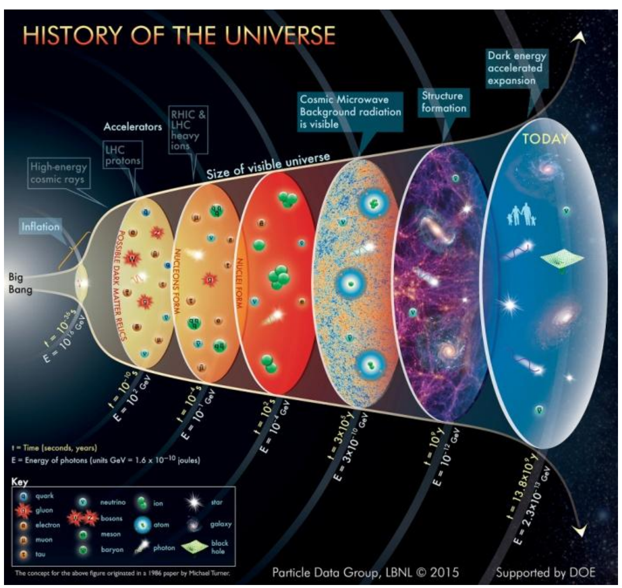


+gravity

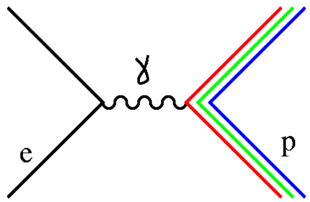
+dark matter

+dark energy

Physics Motivation



The Quark Weak Vector Charges



EM Charge

q^{up}	$+2/3$
q^{down}	-1/3
$Q^p = 2q^{up} + 1q^{down}$	$+1$
$Q^n = 1q^{up} + 2q^{down}$	0

Q_w^p is the neutral-weak analog of the proton's electric charge

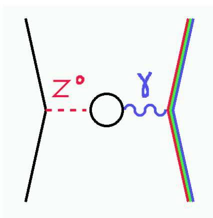
The roles of the proton and neutron are almost reversed:

ie, neutron weak charge is dominant, proton weak charge is almost zero.

This suppression of the proton weak charge in the SM makes any deviations <u>relatively</u> large. With an experimental accuracy of 4%, it is possible to make the best measurement of $\sin^2\theta_W$ at low energies

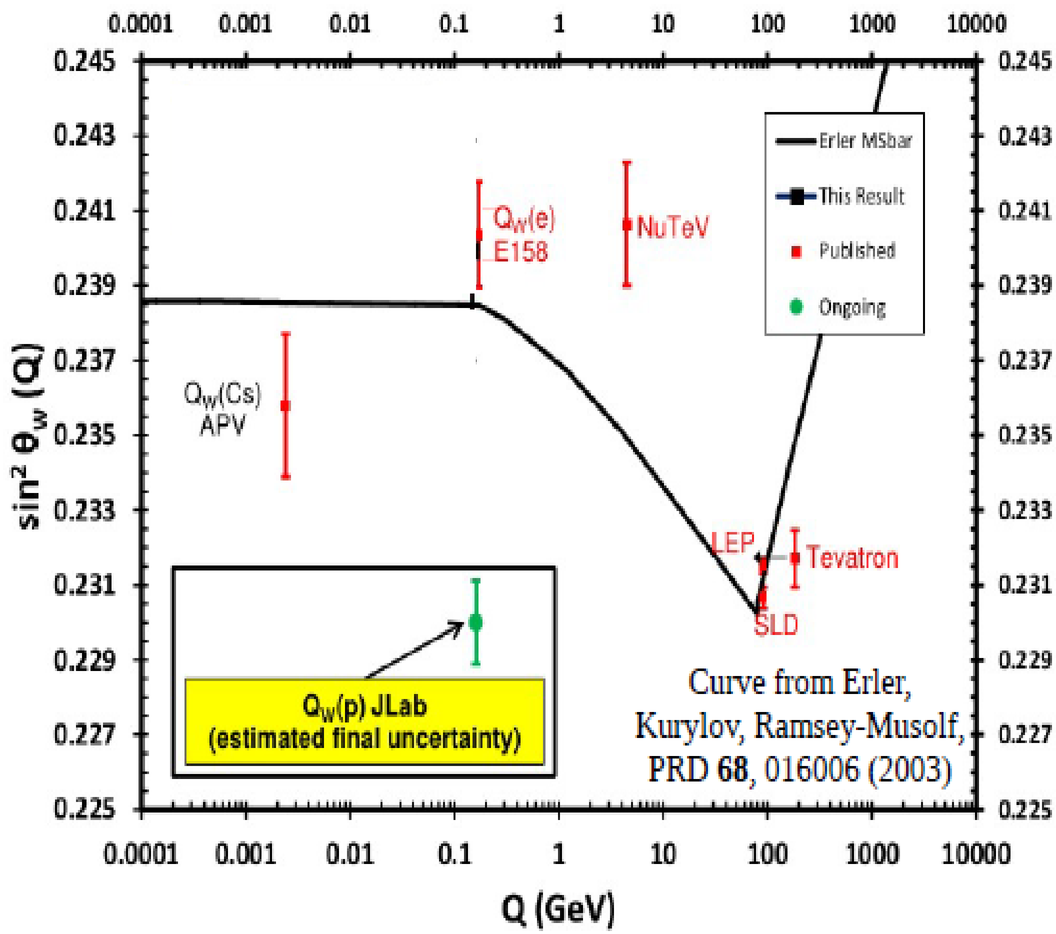
The Running of $\sin^2\theta_W$

In the context of the SM, the running due to γ-Z mixing is calculable at lower energy scales to high precision.



But $\sin^2\theta_W$ is determined better at the Z pole than we can match. So what's the point of Q-weak?

Comparing $\sin^2\theta_W(0)$ with $\sin^2\theta_W(M_Z)$ constrains the presence of non-SM shifts in the EW radiative corrections.

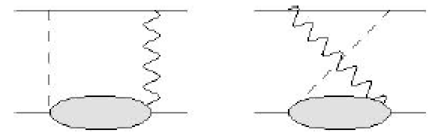


Since Q_w^p is a suppressed, weak scale observable, an experimental accuracy of 4% has multi-TeV scale sensitivity to new PV interactions between electrons and light quarks.

Interpretability and Electroweak Corrections

Although $Q_w^p \sim 1\text{-}4\sin^2\theta_W$, there are substantial box diagram corrections.

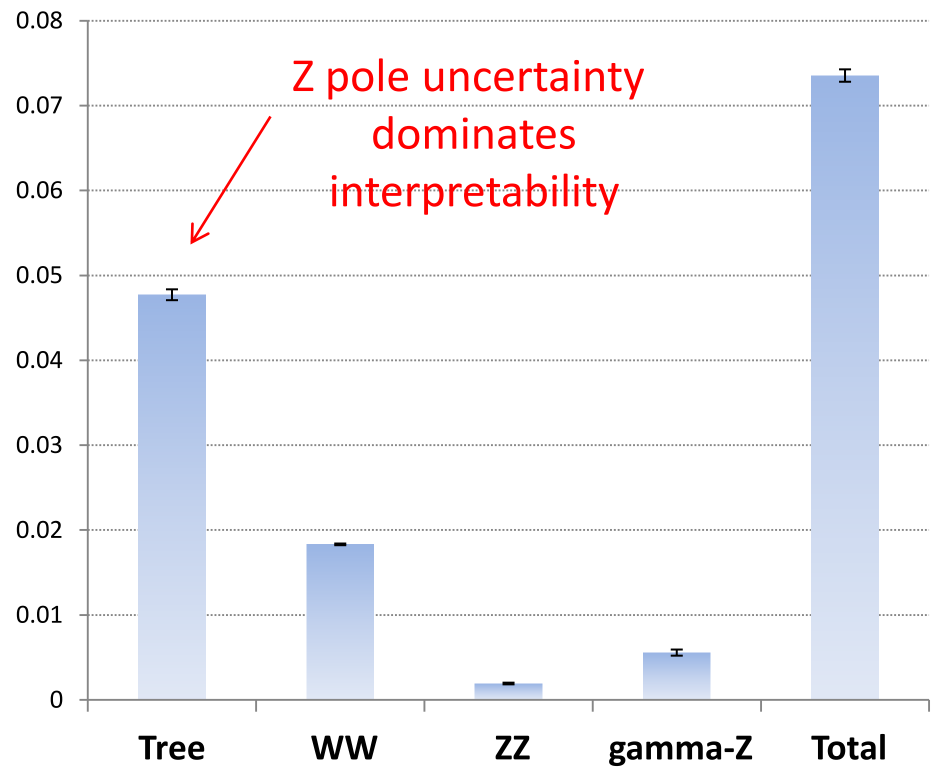
$$Q_W^p = [\rho_{NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_W(0) + \Delta_e'] + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$



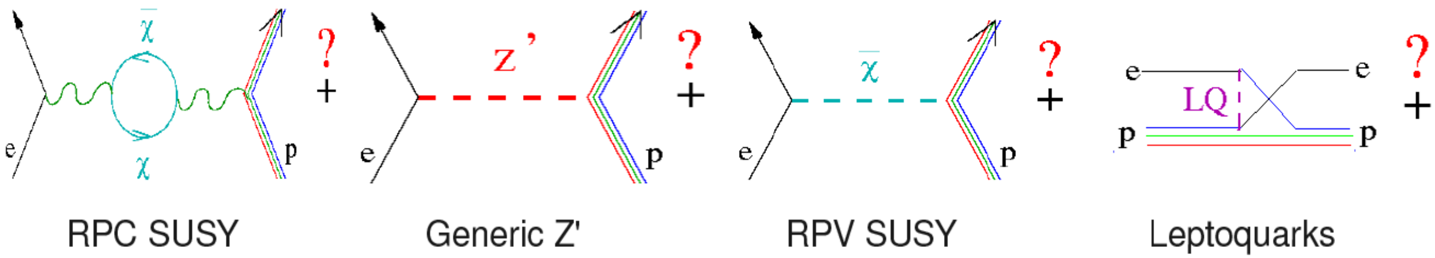
- WW box is relatively large, but precisely calculable.
- γZ box contains long distance contributions, but the uncertainty makes a smaller contribution than Z pole data.

Qweak(proton) can be calculated to ~1%, well below our experimental sensitivity.

Contributions to SM Qweak(proton)



Q-weak's Keyhole on New Physics

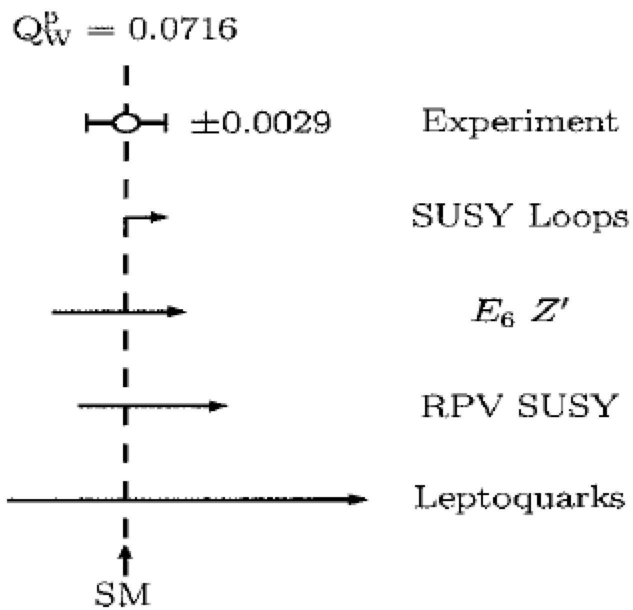


Our experiment is sensitive to new physics with PV couplings of electrons to light quarks.

In this 2003 study, our biggest sensitivity was to lepto-quarks.

The RPV SUSY limits got much tighter in 2013.

Erler and Su,
Prog. Part. Nucl. Phys. 71 (2013) 119-149.



Erler et al., Phys. Rev. D 68, 016006 (2003).

LHC W' and Q-weak

In LHC Run 1 data, there was a possible signal rising out of the statistical mud in W' → WZ near a mass of 2 TeV. There aren't enough statistics yet in Run II to check it.

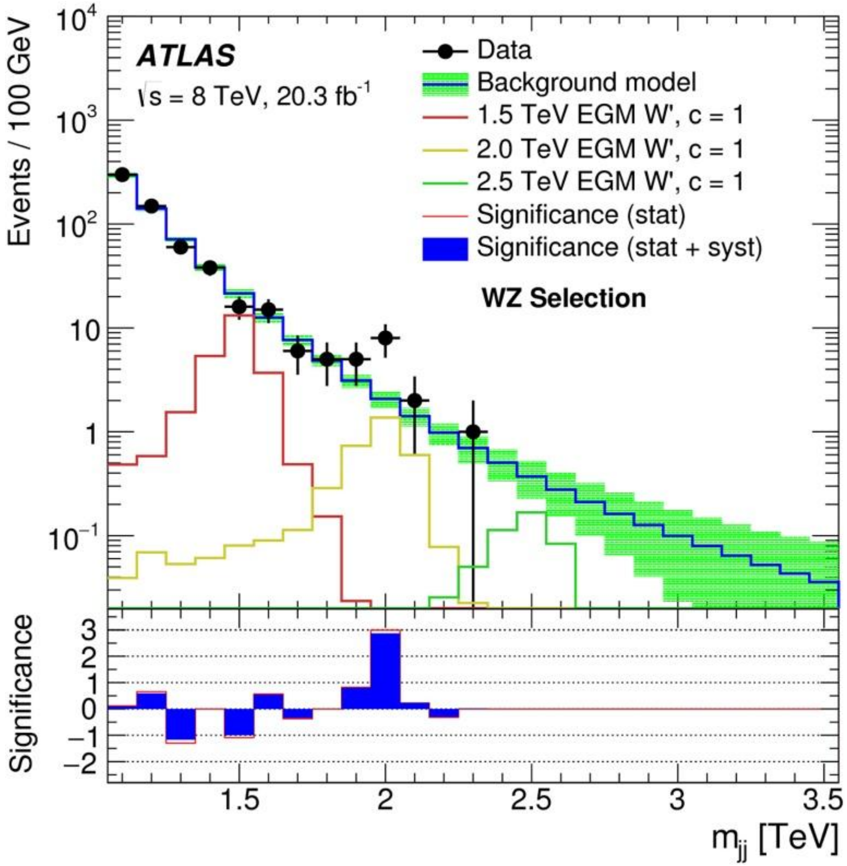
Q-weak is blind to a W' since it would shift G_f and not cause $\sin^2\theta_W$ to run.

But W' models always come with a Z'. A recent publication predicts a corresponding Z' near 4 TeV.

Dobrescu and Liu,
PRL 115, 211802 (2015).

This is a very high mass. Unless the specific couplings happen to be several times larger than SM values, the Q-weak pull would be significantly less than 1σ.

I'll be happy to be surprised though!



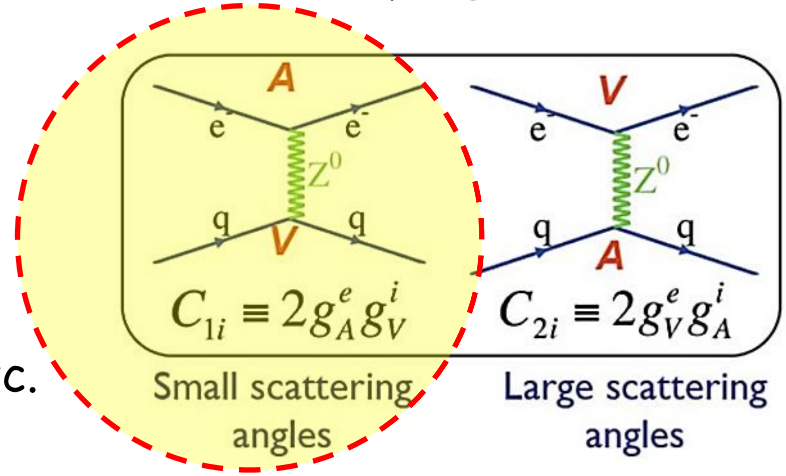
See Wed talk by H. Wahlberg this conference and references
https://indico.cern.ch/event/385771/timetable/#20160106.detailed

Determination of Q_W^p via PV Electron Scattering

Accessing Q_w^p from PV Electron Scattering

Parity violation in electron scattering arises from V x A couplings of the Z.

We isolate the small EM x Weak interference term, normalized to $|EM|^2$, thru the PV asymmetry.



By varying the angle and momentum Xfer, one can extract Qw^p and axial couplings, etc.

We wanted A(e) x V(q) to dominate.

In the limit of low momentum transfer and forward kinematics, the leading order term for elastic scattering contains the weak charge:

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

Roughly

-200 ppb

At our chosen kinematics, Q_w^p dominates the asymmetry (~2/3).

Energy Scale of a Q_w^p Measurement

The sensitivity to new physics Mass/Coupling ratio can be estimated by adding a new PV contact term to the electron-quark Lagrangian (Erler et al. PRD 68, 016006 (2003)):

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

where Λ is the mass and g is the coupling.

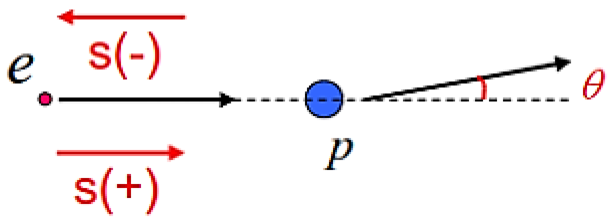
A new physics "pull" on the proton weak charge, ΔQ_w^p, can then be related to the mass to coupling ratio:

$$\frac{\Lambda}{g} = \frac{1}{\sqrt{\sqrt{2}G_F}} \cdot \frac{1}{\sqrt{\Delta Q_W(p)}}$$

- Assuming $\Delta Q_w^p = 4\% \times Q_w^p$, and $g \sim 1$, then Λ is TeV scale.
- Sensitivity is "broad band": one can be as sensitive to a 200 MeV new particle with small couplings as to a 20 TeV particle with large couplings.
- Tough game: statistically, 2 TeV is $2^4 = 16$ times harder than 1 TeV.

Methodology

We flip the longitudinal beam polarization up to 1000 times per second, with a brief pause for the beam polarization and intensity to stabilize. (That's as fast as we can manage without excessive dead-time.)



With an electron scattered into each detector every nsec, the signal must be integrated.

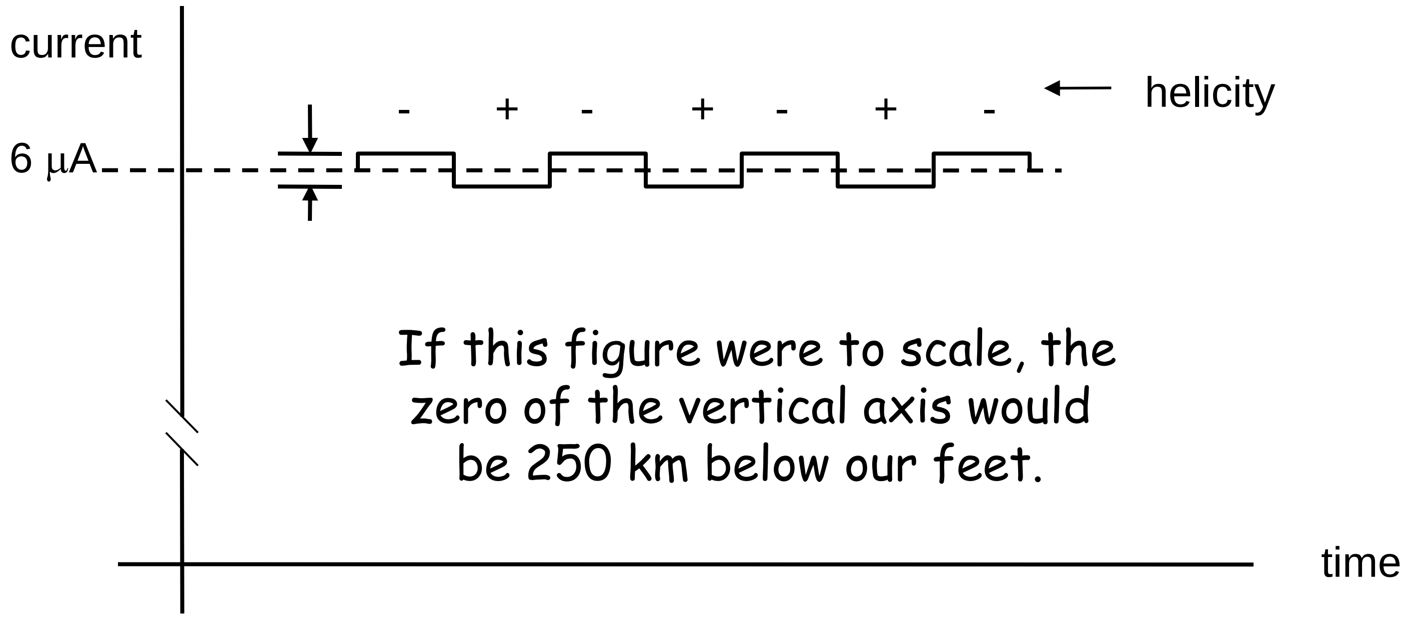
$$A_{PV} = \frac{1}{P}\frac{Y^{+} - Y^{-}}{Y^{+} + Y^{-}} = \frac{1}{P}\frac{\frac{N^{+}}{Q^{+}} - \frac{N^{-}}{Q^{-}}}{\frac{N^{+}}{Q^{+}} + \frac{N^{-}}{Q^{-}}}$$

(-200 ppb)

The experiment also requires:

- Noise from target density fluctuations and electronics must be << $1/\sqrt{N}$.
- Minimal beam parameter changes on spin flip (ie, << wavelength of visible light)
- Corrections for remaining small false asymmetries that *do* occur on spin flip
- Precise measurements of Q^2, beam polarization, and backgrounds.

How Small is the 200 ppb Q-weak PV Signal?



If this figure were to scale, the zero of the vertical axis would be 250 km below our feet.

It is like the thickness of a coat of paint on top of the 325m Eiffel Tower.

And we have to measure it to a several percent accuracy!

Statistical Facts of Life of Measuring Very Small Asymmetries

How long would it take to measure a 200 ppb asymmetry to 1% if one were tracking particles at Rate = 10 MHz (eg, 10 detectors each with 1 MHz rate)?

$\Delta A = 1/\sqrt{N}$

$N = 1/\Delta A^2 = 1/(0.01*200\times10^{-9})^2 = 2.5\times10^{17}$ events

That's 0.25 billion billion events.

Time = N/Rate = 2.5×10^{10} sec

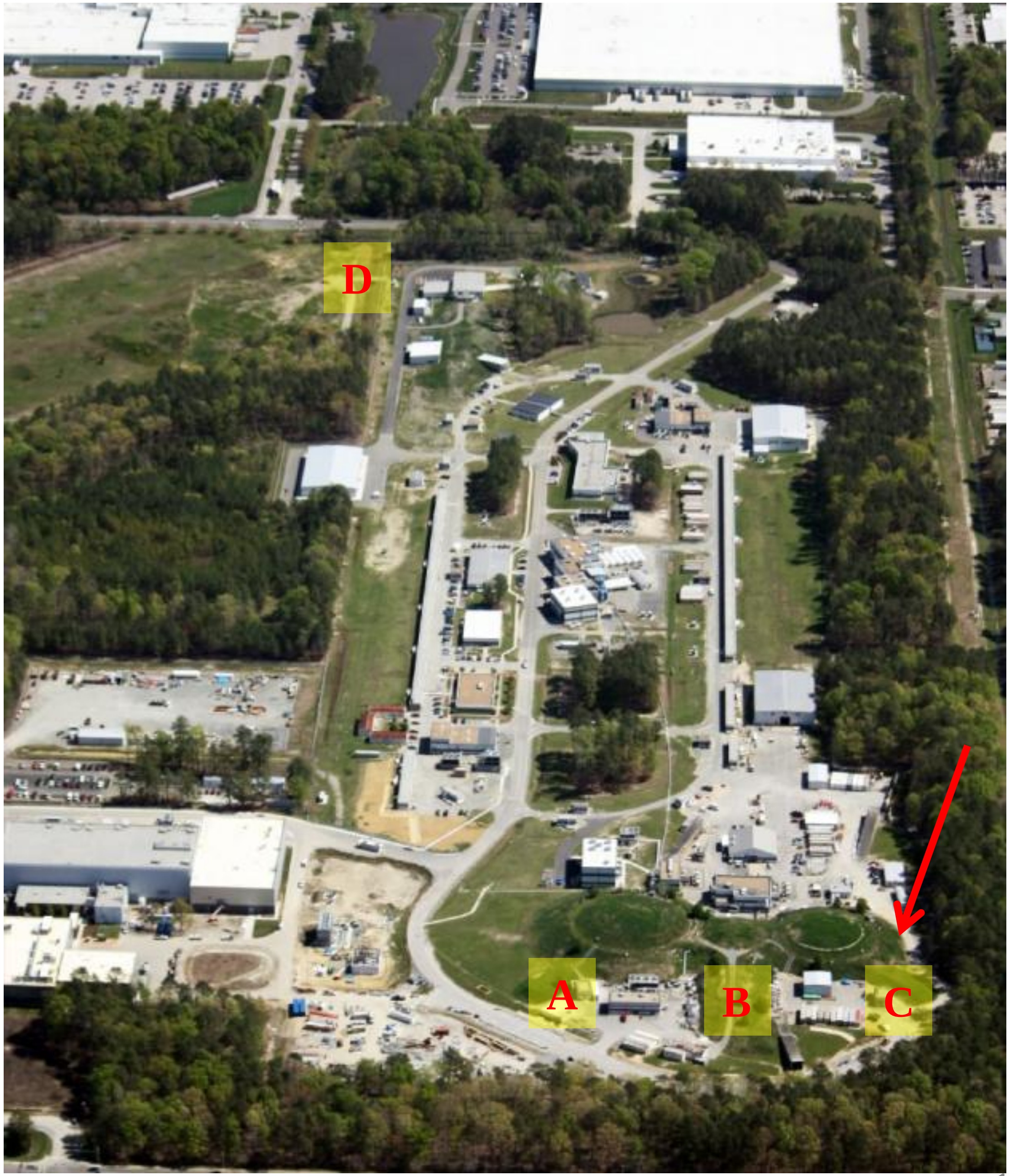
1 year = 3.2×10^{7} sec → 793 years

For $\Delta A < 10$ ppb like Q-weak, experiments are not feasible in event- or tracking-mode. The only choice is to design a low-background experiment and integrate.

For $\Delta A > 100$ ppb, event mode can be used. Tracking helps suppress backgrounds, but the downside is that dead-time and randoms must be controlled.

The Apparatus

Bird’s-eye View of Accelerator Site



JLab Proposal

The Qweak Experiment:
“A Search for New Physics at the TeV Scale via a Measurement of the Proton's Weak Charge“, December 10, 2007

http://qweak.jlab.org/doc-public/ShowDocument?docid=703

Q-weak Spectrometer

Must isolate elastic e+p events at small angles, with the largest acceptance possible, without tracking.

(A new particle traverses each detector approximately every nsec.)

Electromagnet since no ferromagnetic materials could be used.

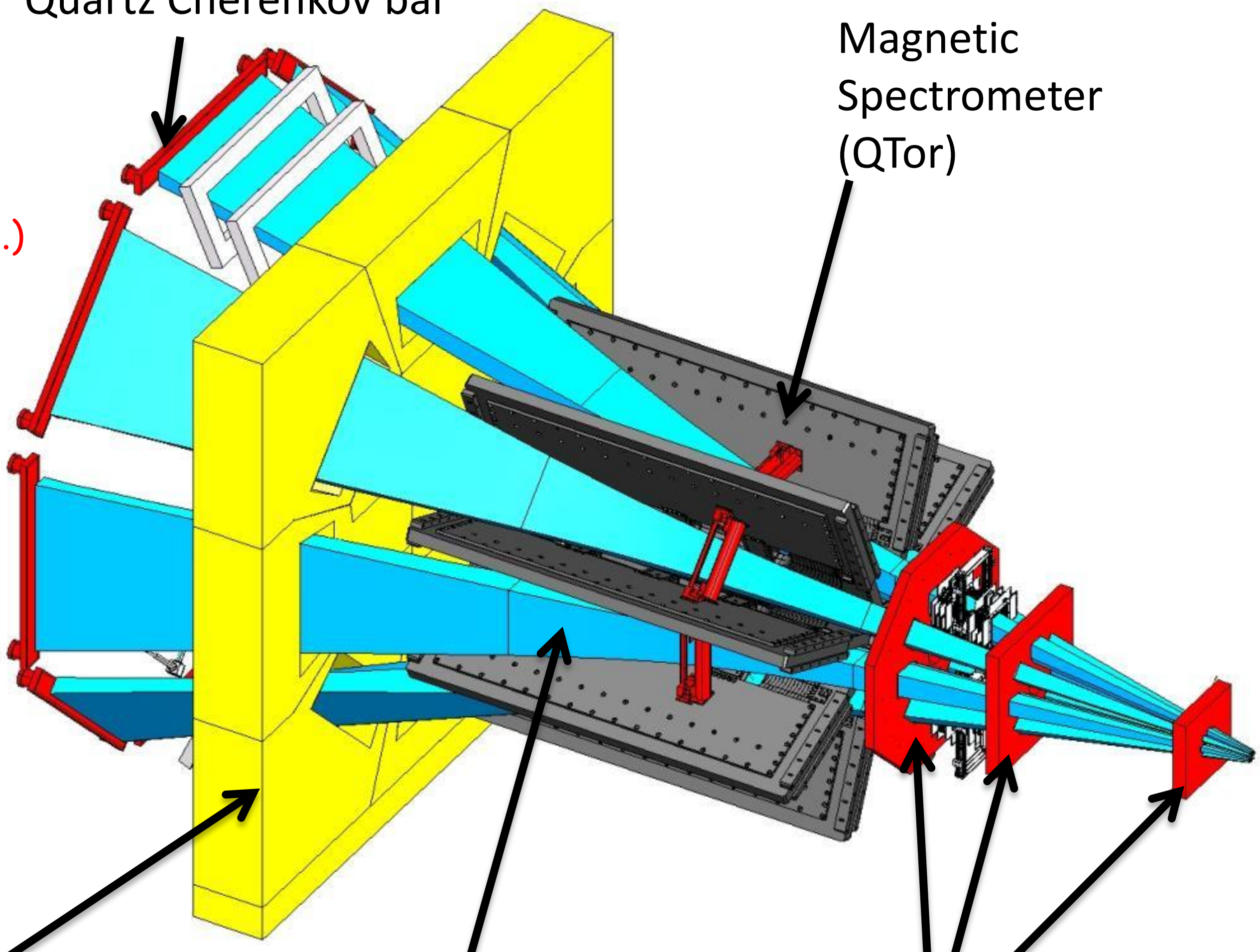
E_{beam} = 1.16 GeV

Lum. = 1.7×10^{39} $cm^{-2}s^{-1}$

$\theta = 6° - 12°$

$Q^2 = 0.025 \ (GeV/c)^2$

Total Rate = 6.4 GHz



Precision Polarimetry

Qweak requires ΔP/P ≤ 1%

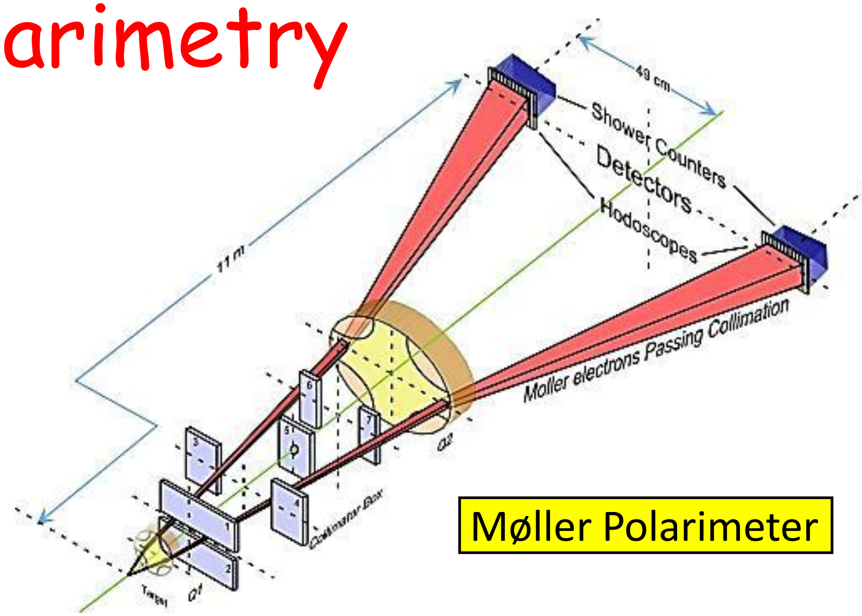
<ins>Two independent polarimeters</ins>

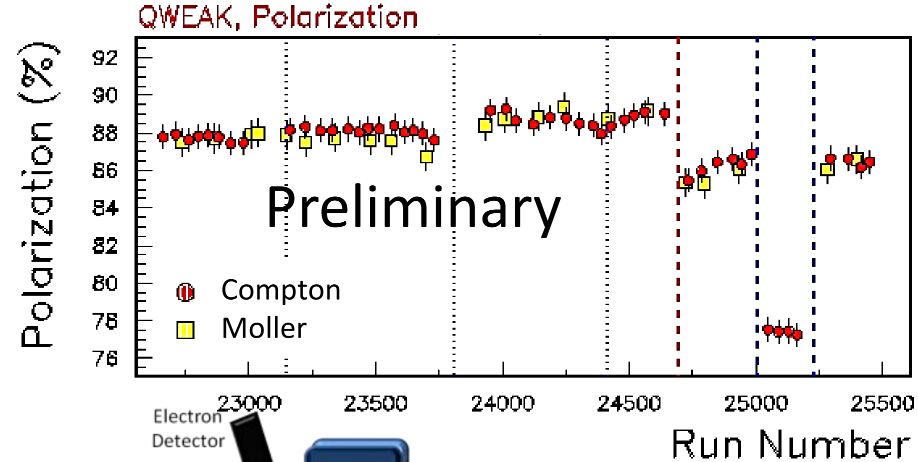
Existing <1% Hall C Møller polarimeter:

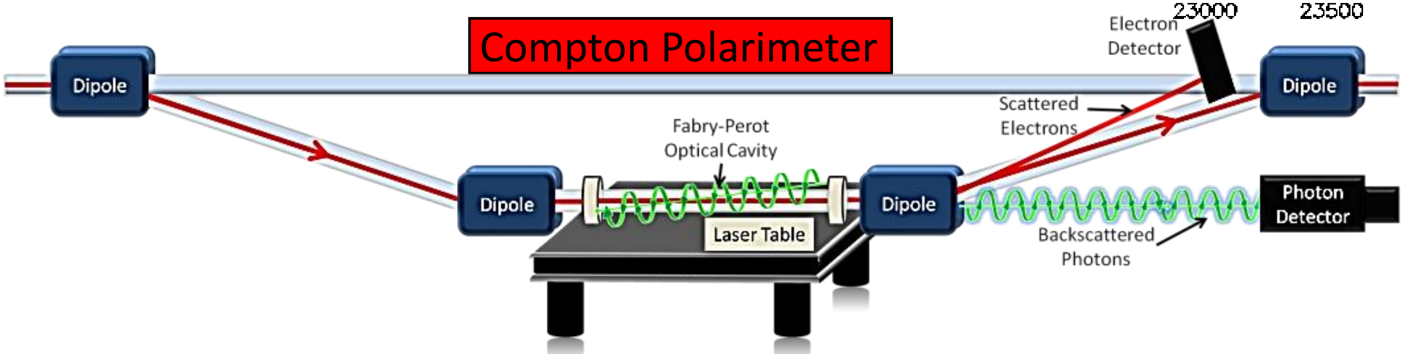
- Low beam currents, invasive
- Known analyzing power provided by polarized Fe foil in a 3.5 T field.

New Compton polarimeter (1%/h)

- High I_{beam}, non-invasive
- Known analyzing power provided by circularly-polarized laser

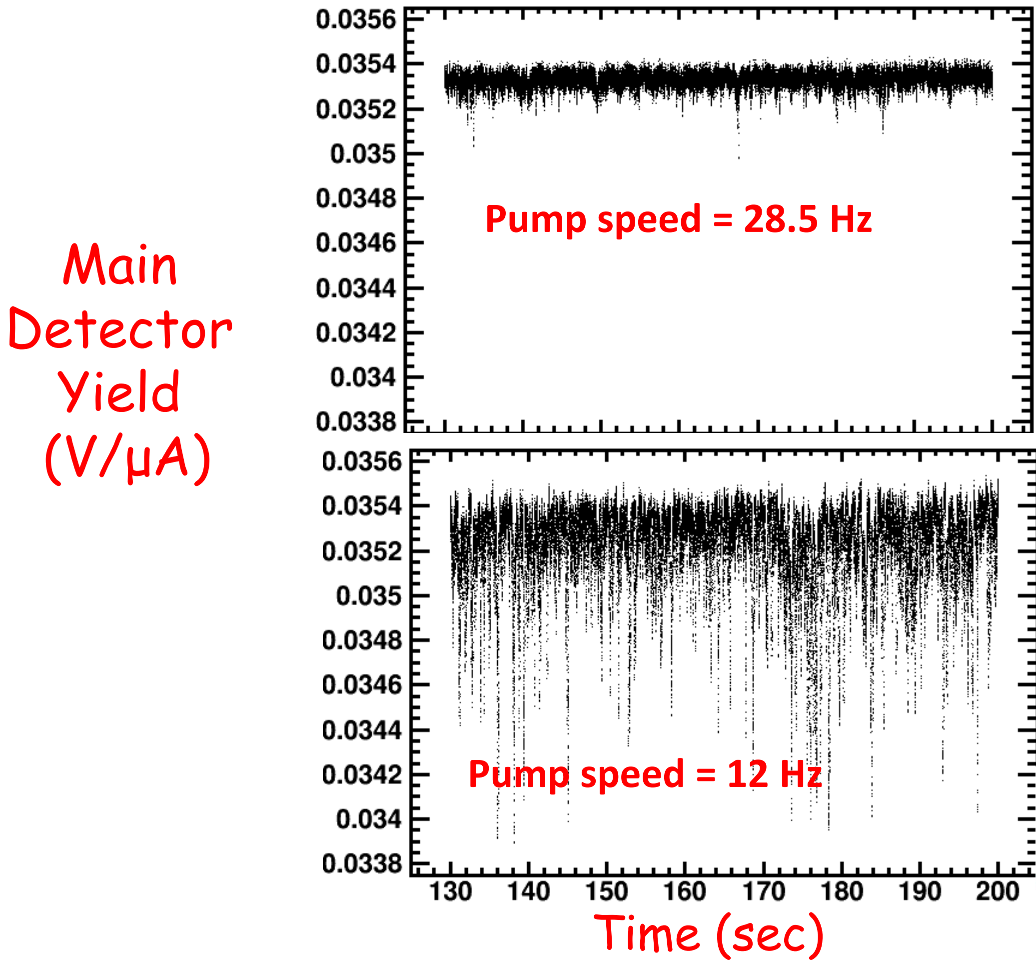






Target Bubble-ology

Changes in column density between + helicity and – helicity samples are a source of noise. The main source is bubble/vapor layer formation on the Al windows. Reversing helicity every 1 msec was critical to make the fluctuations appear negligible.



The target under nominal running conditions.

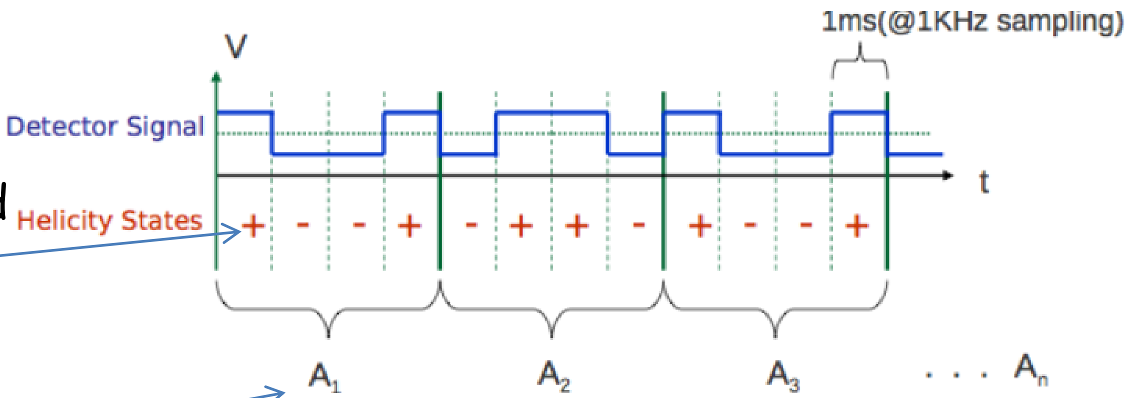
sin gas

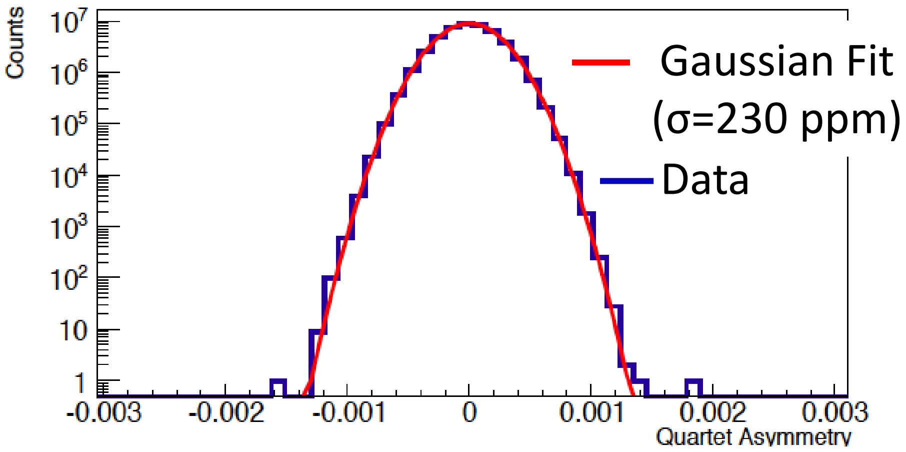
The target during a stress test.

con gas

Signal Manipulation

- Helicity flip every 1/960 sec
- PMT anode current integrated for each helicity state, normalized to beam charge
- Quartet asymmetries calculated (cancels linear drifts)
- Asymmetry width ~230 ppm at 180 μA is dominated by √N
- Half-wave plate inserted or removed every 8 hours. (No possibility of electronic pick-up.)
- Additive "blinding factor" applied.





(Quartet Asymmetries over several days)

Beamline Background

• A qualitatively new bkg in PV experiments at JLab. Regression with beam position monitor leaves a correlation. Perhaps a big asymmetry in a tiny (ppm level) halo or tail.

•Some of it cancelled by Half Wave Plate change every 8 hours, but not all.

•This "hidden variable" problem was strangled by removing residual correlations between the signal and background detectors after regressing for the usual position, angle, and energy changes.

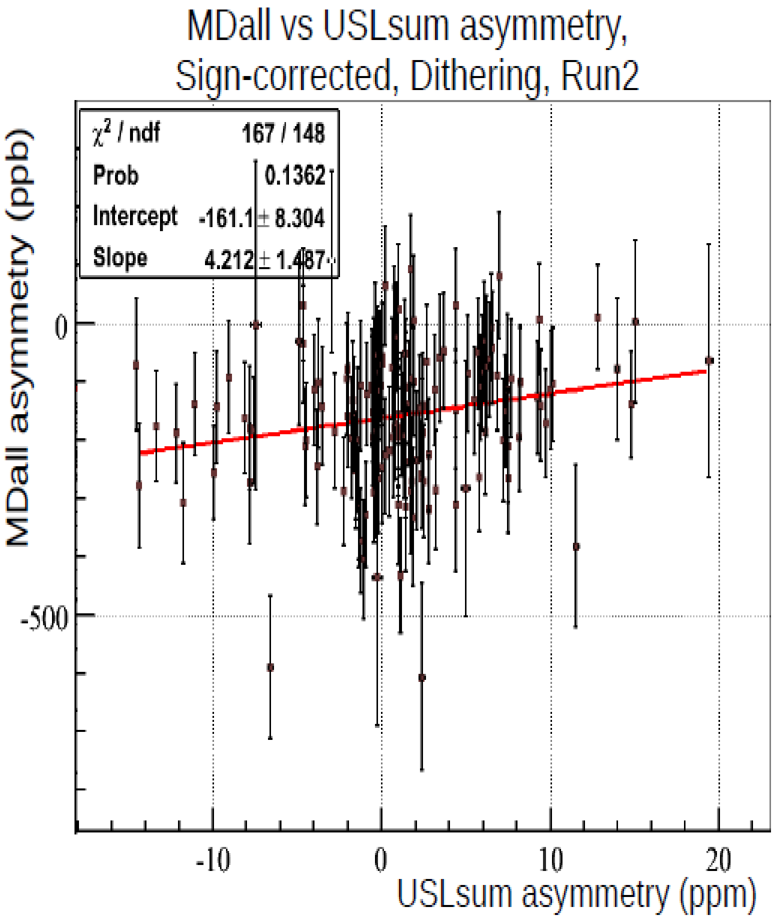
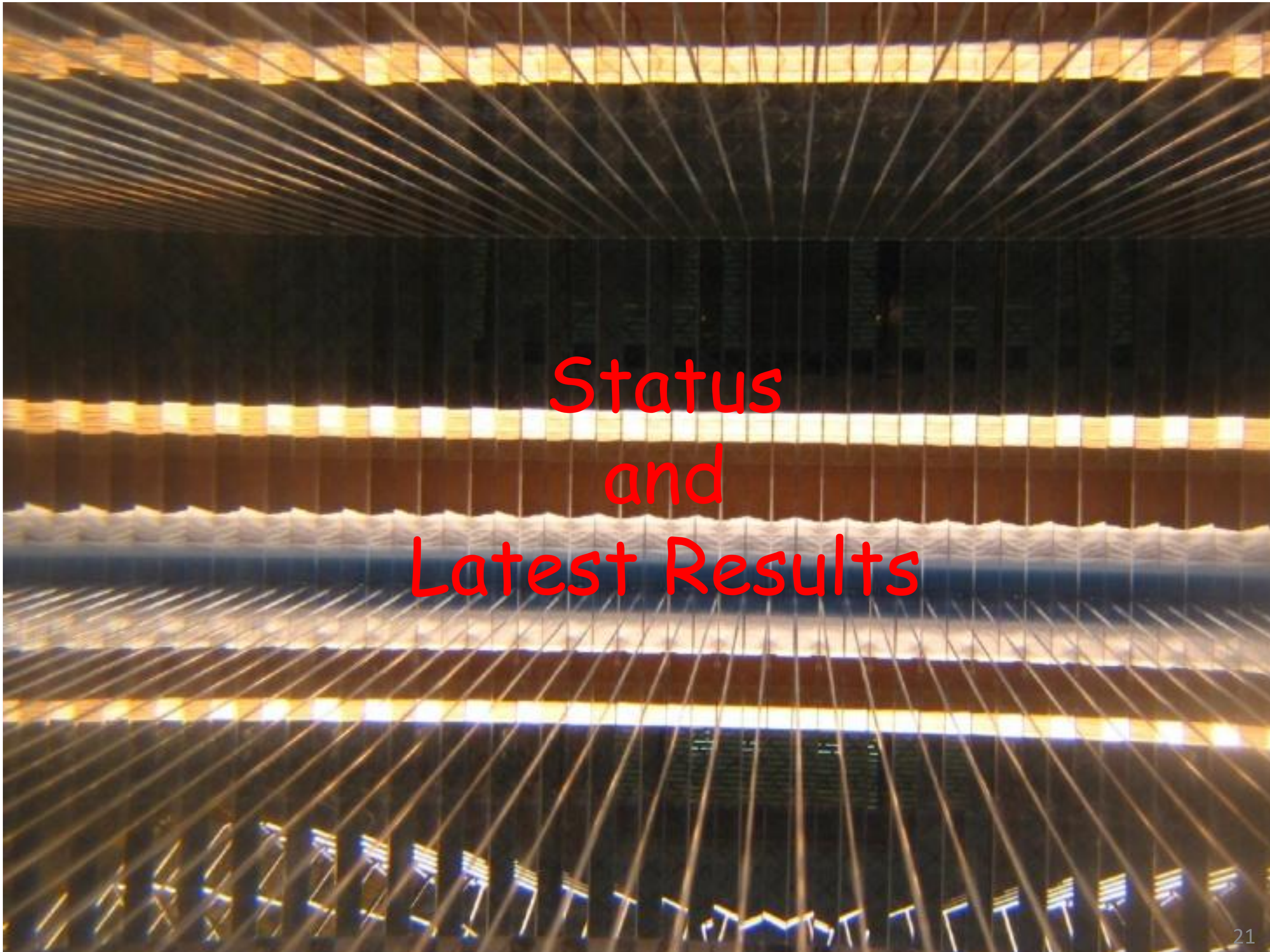


Figure 6.19: The correlation between MDall and USLsum asymmetries in the Sign-corrected formulation, averaged at the slug scale over the Run2 Modulation dataset. The extracted correlation slope is the correction factor $C^{BB}_{MD\text{-}USL}$ for the BB correction (6.6).

E. Kargiantoulakis, U. of Virginia, https://qweak.jlab.org/do-public/ShowDocument?docid=2276

Status and Latest Results



Status

- The Qweak Experiment finished successfully

  2 years in situ, ~1 year of beam

- Commissioning run analyzed

  ~ 4% of dataset

  Results presented here: 1st Determination of $Q_w(p)$, C_{1u}, C_{1d}, & $Q_w(n)$

- Remainder of experiment still being analyzed

  Expect final A_{pv} result to have ~5x better precision

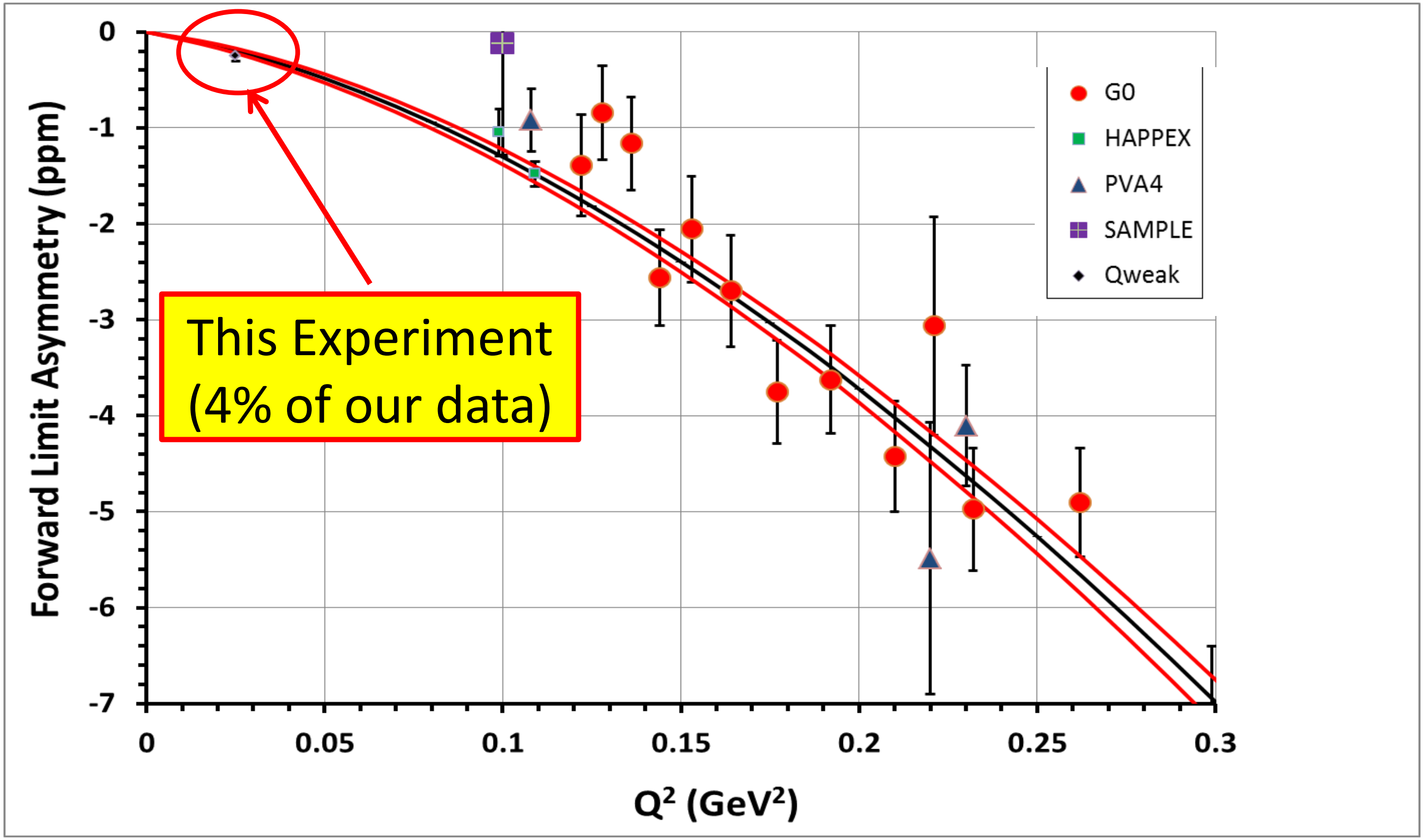
  Final $Q_w(p)$ uncertainty in the ballpark of "5%"

Fully Corrected Elastic e+p Asymmetry

(evolved to Θ = 0° at fixed Q^2)

A_{PV} = -279 ± 35 (statistics) ± 31 (systematics) ppb
<Q^2> = 0.0250 ± 0.0006 $(GeV/c)^2$
<E> = 1.155 ± 0.003 GeV

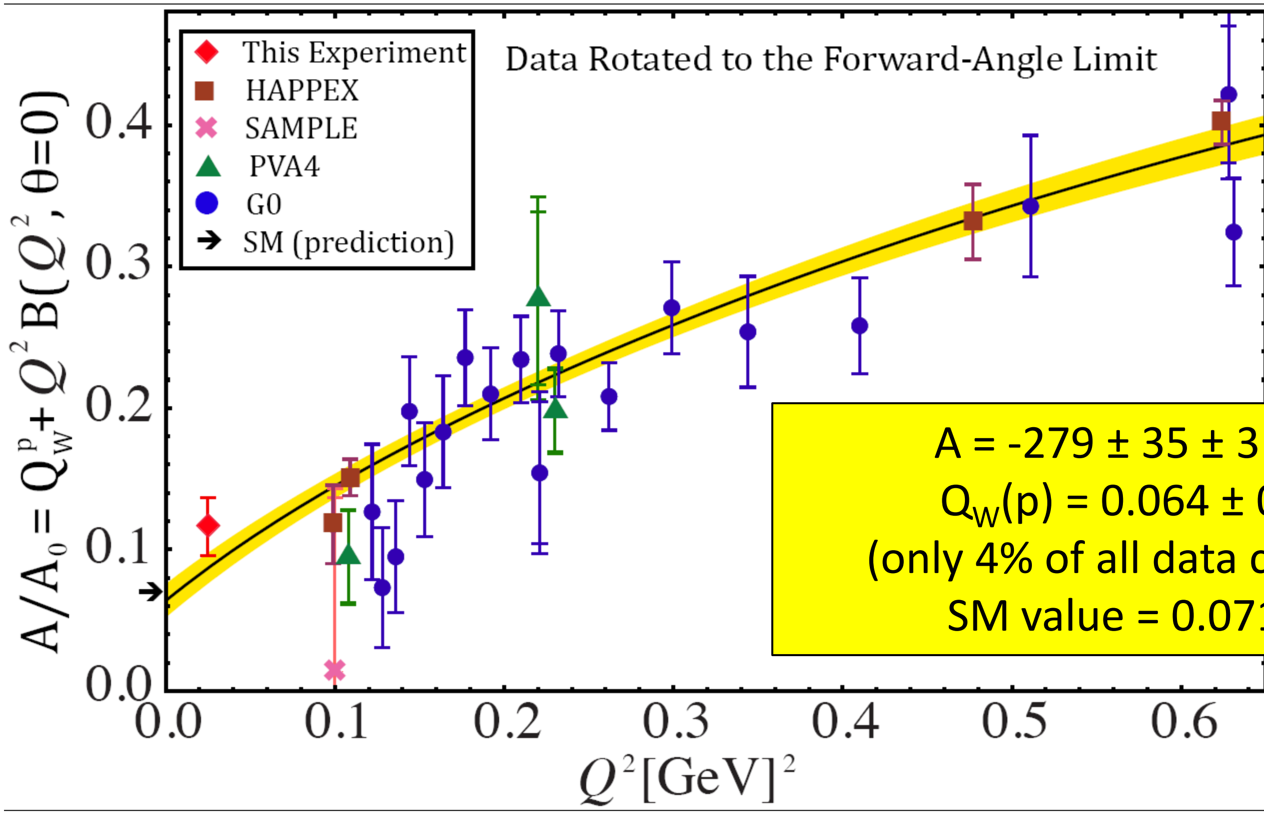
D. Androic et al., Phys. Rev. Lett. 111, 141803 (2013)
http://arxiv.org/abs/1307.5275v2



Global fit of PV Elastic Electron Scattering Data

Dividing out the leading Q^2 dependence makes it easier to see all the experiments on one plot and interpret.

- Recast $A_{ep} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[Q_w^p + Q^2 B(Q^2,\theta)\right]$
  - So in a plot of $A_{ep}/\left[\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\right]$ vs Q^2:
    - Q_w^p **is the *intercept*** (anchored by precise data near Q^2=0)
    - $B(Q^2,\theta)$ is the ***slope*** (determined from higher Q^2 PVES data)



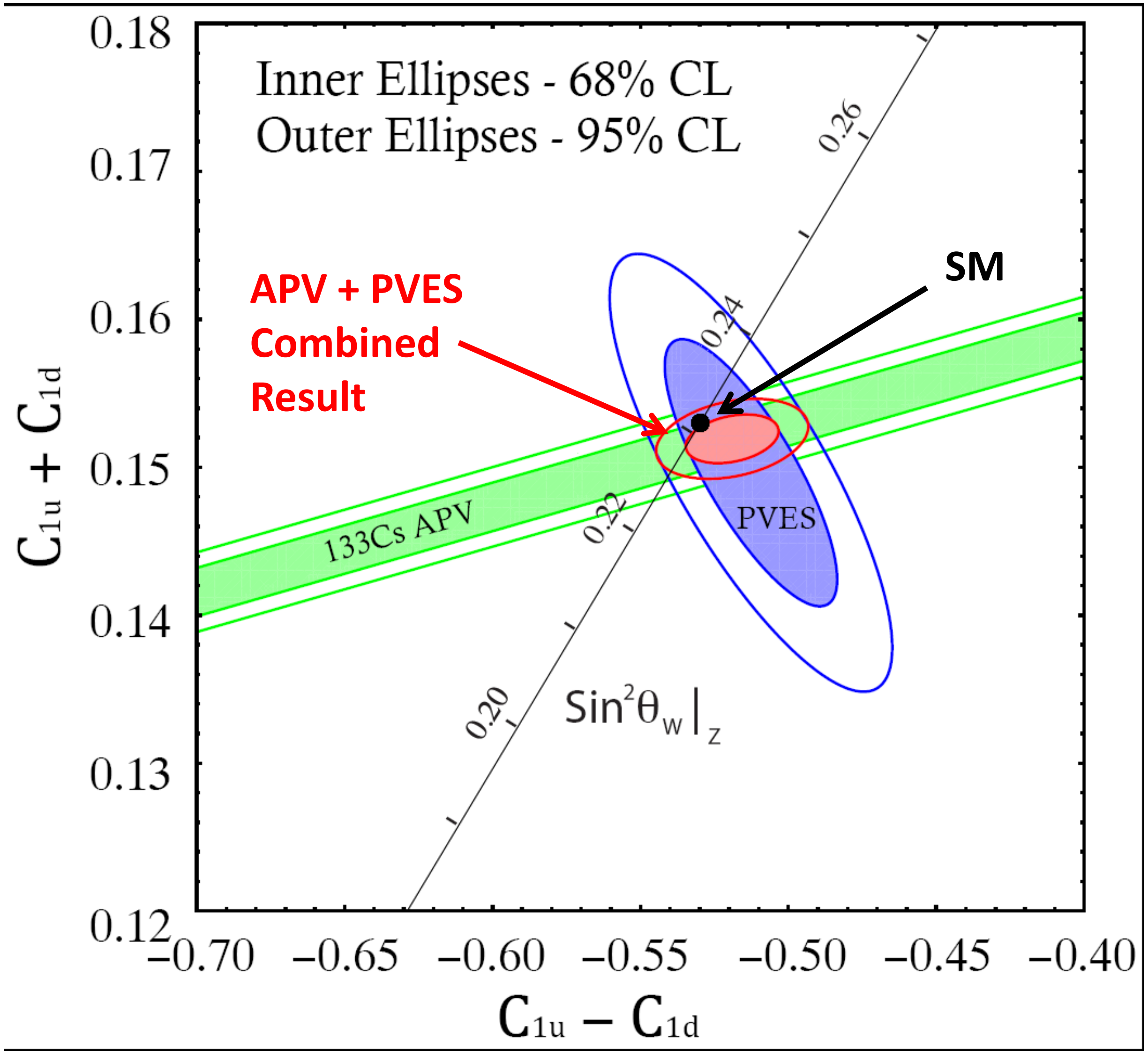
A = -279 ± 35 ± 31 ppb

$Q_W(p)$ = 0.064 ± 0.012

(only 4% of all data collected)

SM value = 0.0710(7)

Combining PV Electron Scattering & Atomic PV



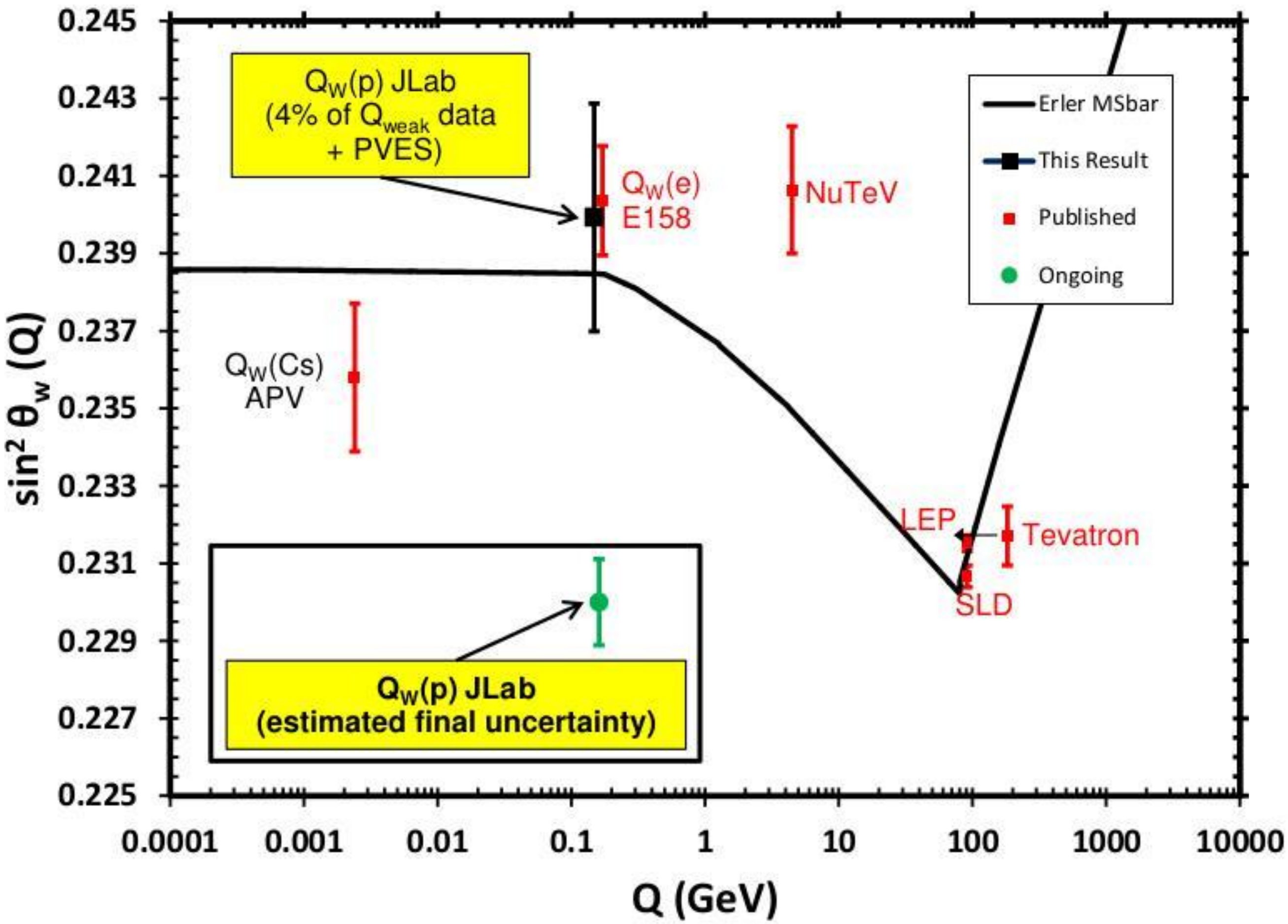
$Q_W(p) = -2(2C_{1u} + C_{1d})$
$= 0.064 \pm 0.012$
(only 4% of data)
SM value = 0.0710(7)

$C_{1u} = -0.184 \pm 0.005$
$C_{1d} = 0.336 \pm 0.005$
(only 4% of data)

$Q_W(n) = -2(C_{1u} + 2C_{1d})$
$= -0.975 \pm 0.010$
(only 4% of data)
SM value = -0.9890(7)

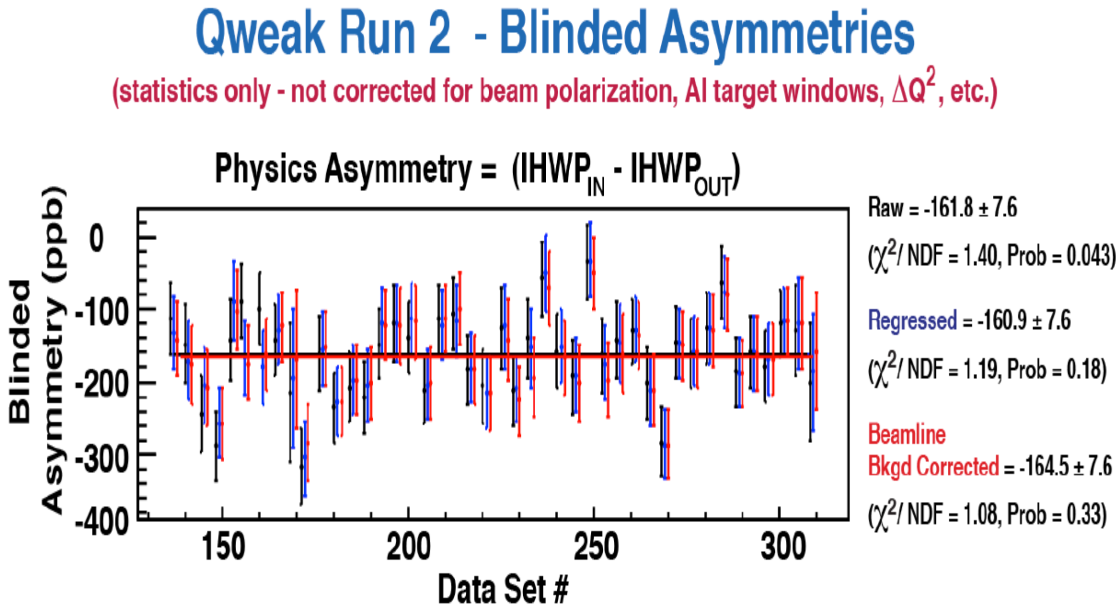
Weak Mixing Angle Result

$$\sin^2\theta_w = \frac{1}{4}\left\{1 + \Delta_e' - \frac{Q_w(p) - \Box_{WW} - \Box_{ZZ} - \Box_{\gamma Z}}{\rho_{NC} + \Delta_e}\right\}$$



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

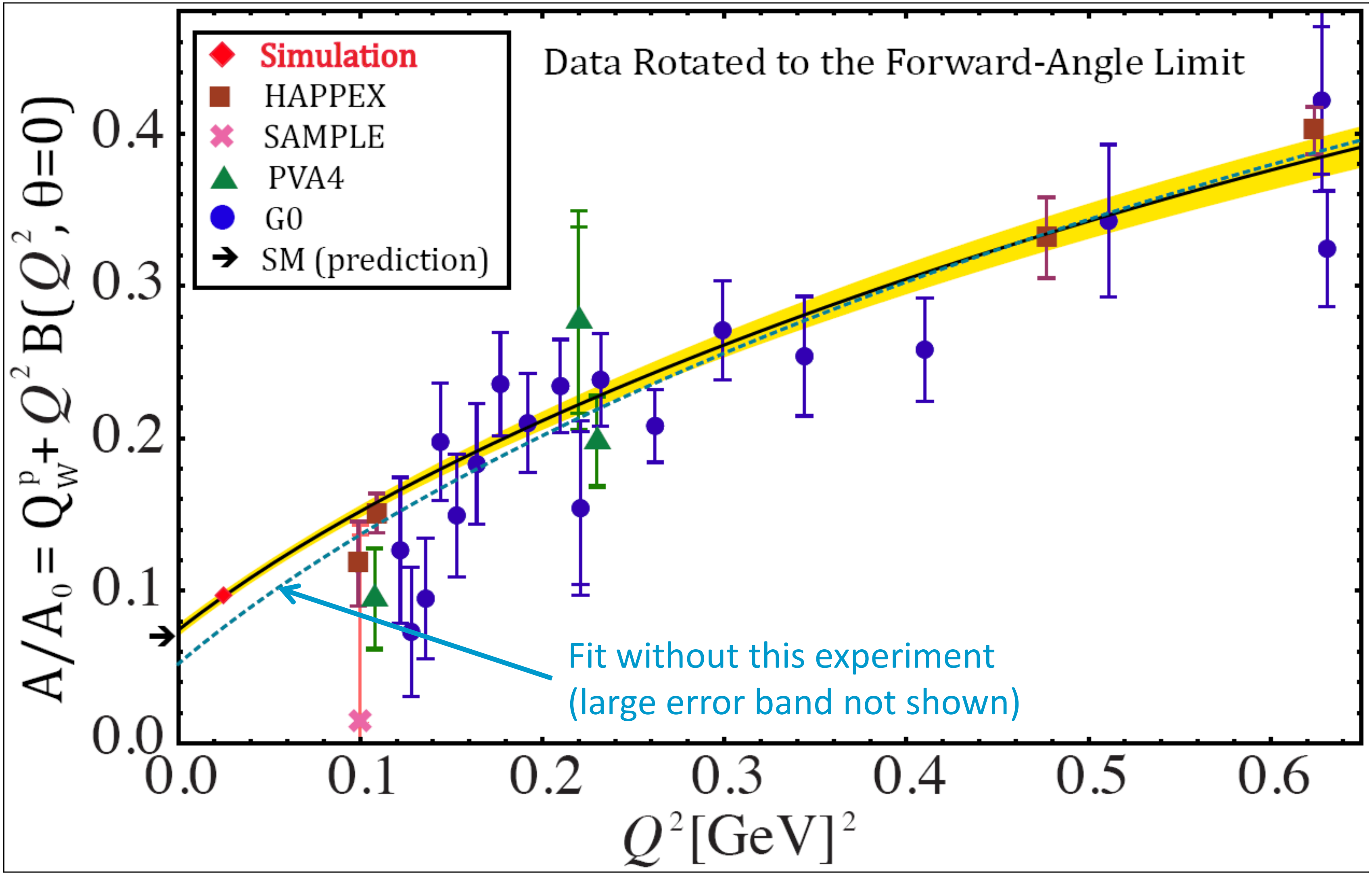
Quality of the Majority of Q-weak Data



Asymmetry - As expected, the probability of a fit to A_{pv} = constant improves with corrections to remove noise.

Null – This Null is consistent with zero, and the probability of a fit to Null = constant is okay.

Potential Impact with Final Result
(Assuming SM Value)

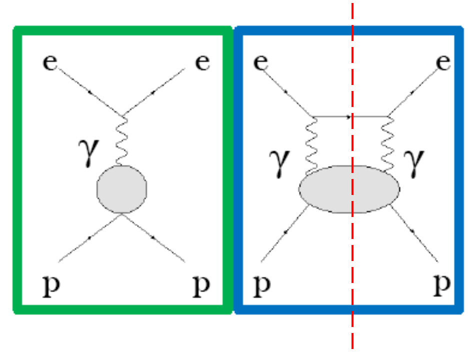


Transverse Asymmetry Measurement in e+p Elastic Scattering

B_n is a parity <u>conserving</u>, transverse asymmetry due to 2γ exchange.

B_n with 100% transverse polarization is O(100) times larger than Apv with 100% longitudinal polarization.

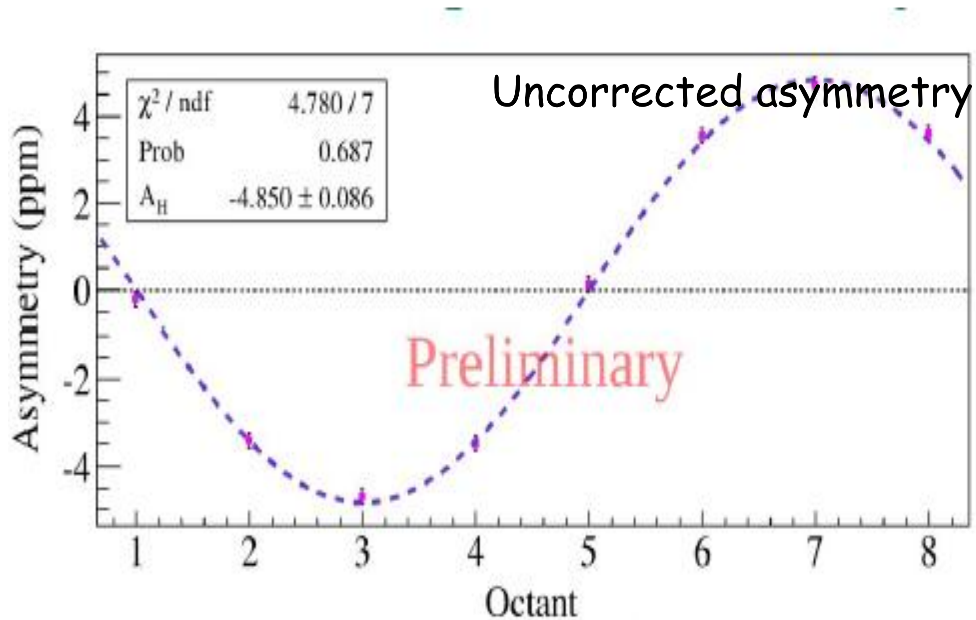
We carefully measured it because it leads to a ppb-level correction in our PV data due to a few % P_t and small broken azimuthal asymmetries in our detector.



B Waidyawansa talk at PAVI14, http://pavi14.syr.edu/Slides.html

$$B_N = \frac{2T_{1\gamma} \times \mathrm{Im}T_{2\gamma}}{|T_{1\gamma}|}$$

Since B_n depends on the imaginary part of the 2γ exchange amplitude, our 1.16 GeV beam energy data provides an integral measurement of all excitations of the proton up to E_{cm} = 1.7 GeV.

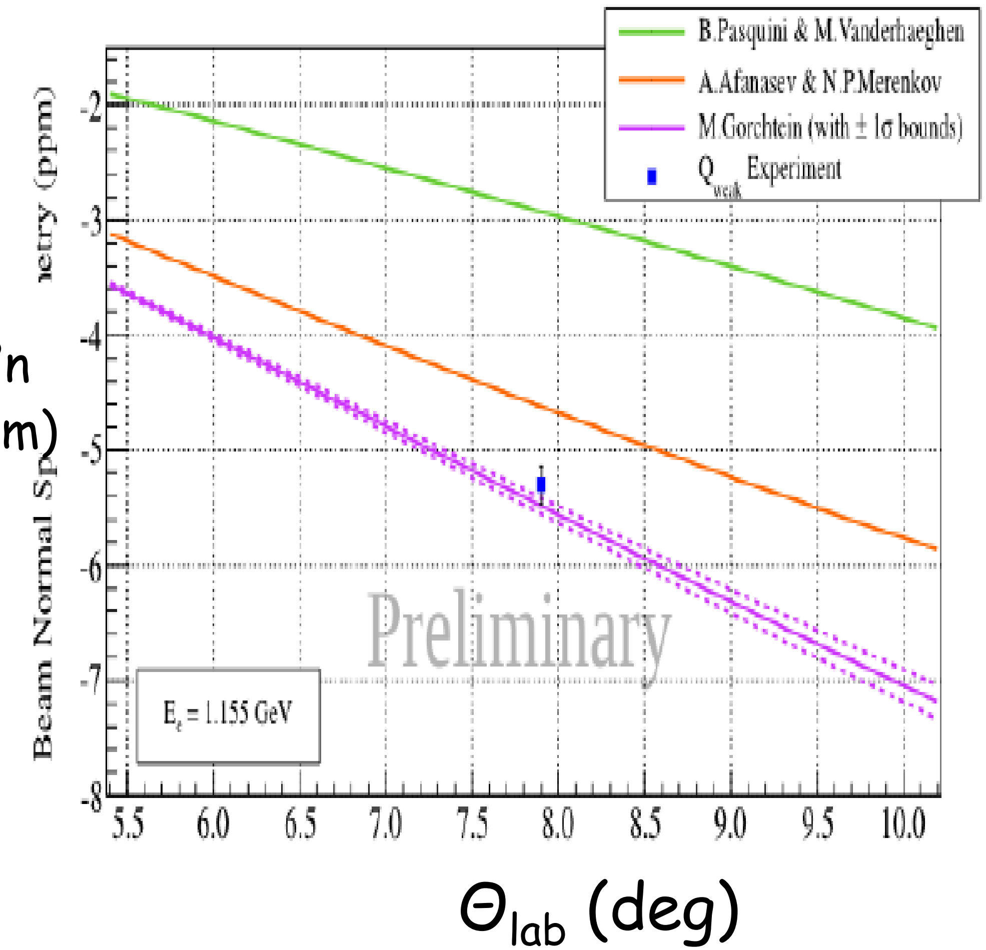


Elastic e+p Transverse Asymmetry Results

Our result is perhaps the most accurately measured e+p asymmetry at the GeV scale (it's a single spin asymmetry).

Green curve - A pioneering model which used only MAID single π amplitudes significantly under-predicted the data.

Red and **Purple** curves - Models which use photo-production data to constrain the forward Compton amplitude do reasonably well.

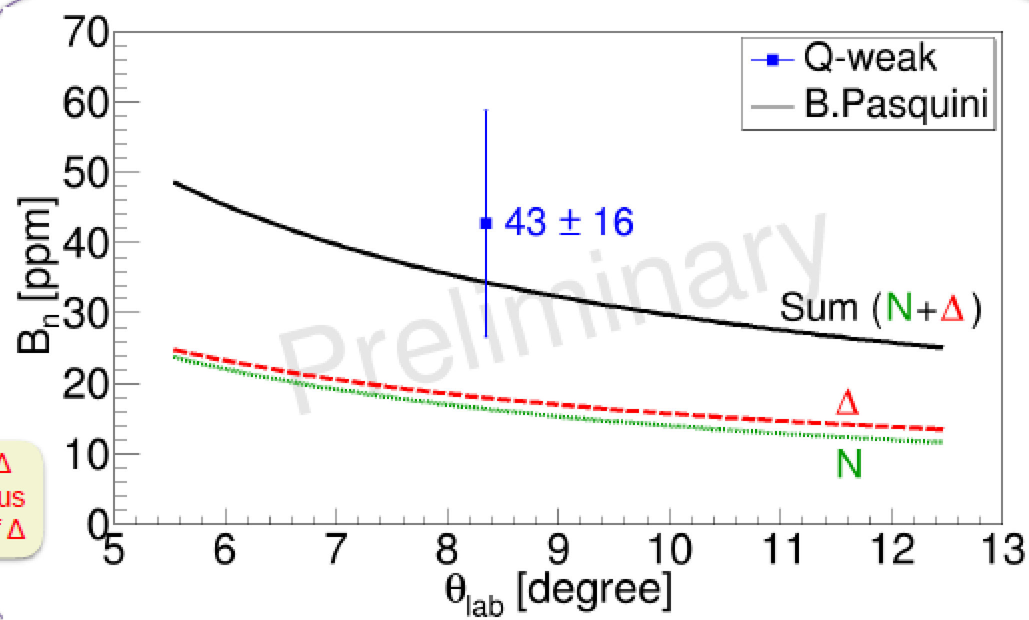


Intermediate states in the 2γ box diagram like N + multi-π are important.

Inelastic e+p Transverse Asymmetry Results

Parity conserving (2-boson exchange) azimuthal asymmetries

- Hydrogen elastic → constrains contribution to PV asymmetry, but also provides information on 2-photon exchange effects in form factor extraction
- **Hydrogen resonance (Delta)**
- Aluminum, carbon



Unique tool to study g*ΔΔ form factors, charge radius and magnetic moment of Δ

The prediction of a very large asymmetry at forward angles is confirmed.

Progress Since HEP2012

We're not done yet, but much progress since Jan 2012:

- Completed our data taking (our Run II) in May 2012
- Published low statistics Q_w^p result and global analysis in PRL Oct 2013
- Essentially finalized two transverse asymmetry results (B_n),

i. one in the elastic e+p channel (~20x larger than Apv),

ii. one in e+p→e' + Δ (~200x larger than Apv).

- Discovered a qualitatively new bkg/noise in PV experiments at JLab, the so-called Beamline Background. Strangled in the recent PhD thesis of E. Kargiantoulakis (UVa).

- Discovered a qualitatively new systematic (non-noise) bkg and working on that.

- 10 more PhD's awarded (15 to date)

Summary

- The weak vector charge of the proton, Q_w^p , is $1\text{-}4\sin^2\theta_W$ suppressed hence a good way to
  i. measure $\sin^2\theta_W$ at low energies,
  ii. search for new PV interactions between electrons and light quarks.

- Elastic PV electron scattering at low momentum transfer allows us to determine the weak vector charge of the proton. We have

  i. measured the smallest & most precise e+p PV asymmetry ever.
  ii. determined $Q_W(p)$ at low energies: 0.063 ± 0.012 (from only 4% of data)
  iii. Find a result consistent with the SM with nontrivial sensitivity

$$\Lambda/g = \tfrac{1}{2}(\sqrt{2}\, G_F\, \Delta Q_W)^{-1/2} = 1.1 \text{ TeV}$$

- Combining our result with Cs APV, we sharpen C1u, C1d, and hence Q_w^n.

- Expect to report results with ~5 times smaller uncertainties
  - Expected physics reach of ~ 2.3 TeV.

The Q-weak Collaboration

W&M meeting

A. Almasalha, D. Androic, D.S. Armstrong, A. Asaturyan, T. Averett, J. Balewski, R. Beminiwattha, J. Benesch, F. Benmokhtar, J. Birchall, **R.D. Carlini[1] (Principal Investigator)**, G. Cates, J.C. Cornejo, S. Covrig, M. Dalton, C. A. Davis, W. Deconinck, J. Diefenbach, K. Dow, J. Dowd, J. Dunne, D. Dutta, R. Ent, J. Erler, W. Falk, **J.M. Finn[1]***, T.A. Forest, M. Furic, D. Gaskell, M. Gericke, J. Grames, K. Grimm, D. Higinbotham, M. Holtrop, J.R. Hoskins, E. Ihloff, K. Johnston, D. Jones, M. Jones, R. Jones, K. Joo, E. Kargiantoulakis, J. Kelsey, C. Keppel, M. Kohl, P. King, E. Korkmaz, **S. Kowalski1**, J. Leacock, J.P. Leckey, A. Lee, J.H. Lee, L. Lee, N. Luwani, S. MacEwan, D. Mack, J. Magee, R. Mahurin, J. Mammei, J. Martin, M. McHugh, D. Meekins, J. Mei, R. Michaels, A. Micherdzinska, A. Mkrtchyan, H. Mkrtchyan, N. Morgan, K.E. Myers, A. Narayan, 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, M. Ramsey-Musolf, J. Roche, B. Sawatzky, T. Seva, R. Silwal, N. Simicevic, **G. Smith[2]**, T. Smith, P. Solvignon, P. Souder, D. Spayde, A. Subedi, R. Subedi, R. Suleiman, E. Tsentalovich, 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

Misc. Q_w^p References

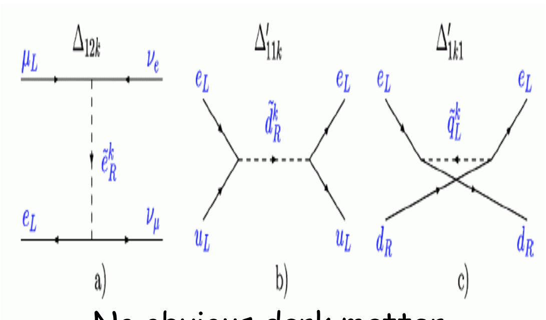
Description	Reference
Q-weak home page	https://www.jlab.org/qweak/
New Physics Sensitivities (most notably lepto-quarks)	"Weak Charge of the Proton and New Physics", Jens Erler et al. Phys. Rev. D 68, 016006 (2003). http://arxiv.org/abs/hep-ph/0302149
Proposal	The Qweak Experiment: "A Search for New Physics at the TeV Scale via a Measurement of the Proton's Weak Charge", December 10, 2007 http://qweak.jlab.org/doc-public/ShowDocument?docid=703
High accuracy calculation of the running of the weak mixing angle	"Weak Mixing Angle at Low Energies", J. Erler and M. J. Ramsey-Musolf, Phys. Rev. D 72 (2005) 073003 http://arxiv.org/abs/hep-ph/0409169
First Q-weak Result in PRL	"First Determination of the Weak Charge of the Proton", D. Androic et al., Phys. Rev. Lett. 111, 141803 (2013) http://arxiv.org/abs/1307.5275v2
Updated RPV SUSY Sensitivities	Fig 10 in "The Weak Neutral Current", Erler and Su, Prog. Part. Nucl. Phys. 71 (2013) 119-149, http://arxiv.org/abs/1303.5522
Dark Z'	"Muon Anomaly and Dark Parity Violation", H. Davoudiasl et al., PRL 109, 031802 (2012), http://arxiv.org/abs/1205.2709
W' Model near 2 TeV	"W' Boson near 2 TeV: Predictions for Run 2 Of the LHC", Dobrescu and Liu, PRL 115, 211802 (2015). http://arxiv.org/abs/1506.06736

Extras

SUSY Sensitivities

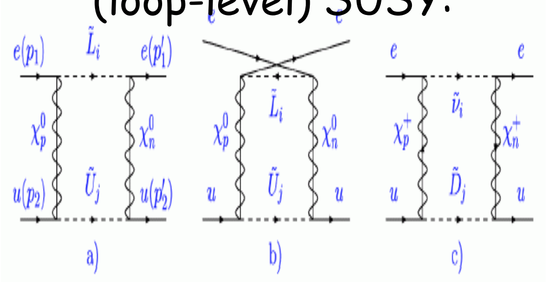
updated with plot from Erler and Su (2013)

R-parity Violating (tree-level) SUSY:



No obvious dark matter.
("New" particles would decay to normal matter.)

R-parity Conserving (loop-level) SUSY:



Dark matter may be the lightest SUSY particle.
(It got "stuck" carrying the R quantum number.)

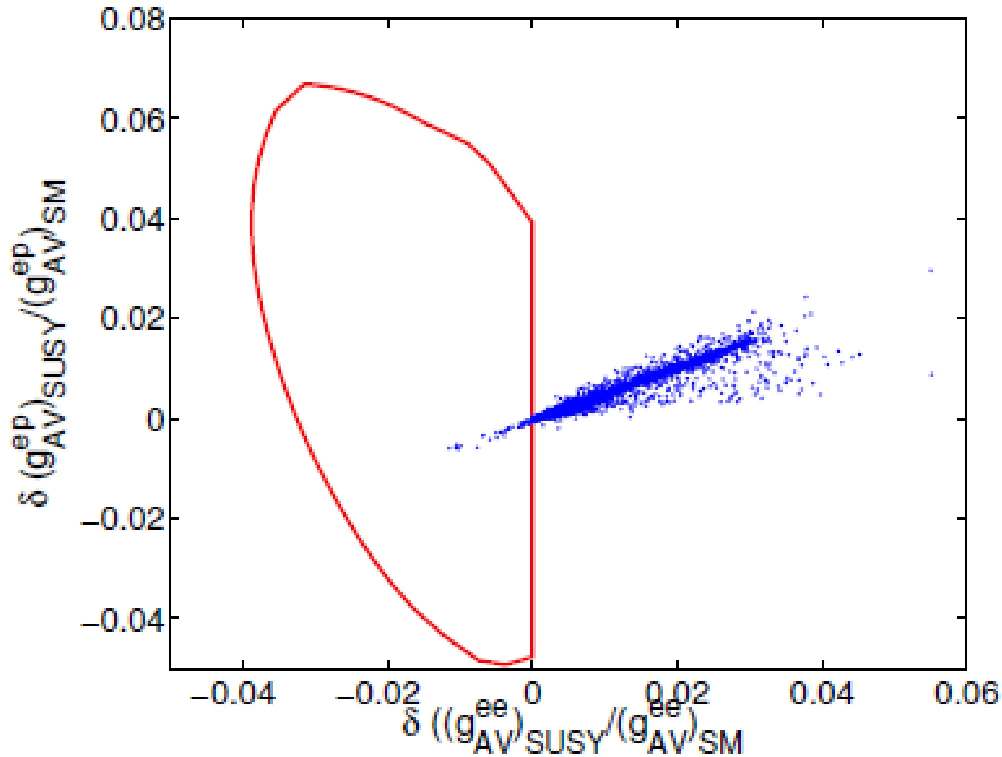


Figure 10: Relative shifts in g_{AV}^{ee} and g_{AV}^{ep} (normalized to the respective SM values) due to SUSY effects. The dots indicate the RPC corrections for $\sim$ 3000 randomly generated SUSY-breaking parameters. The interior of the truncated elliptical region gives the possible shifts due to the RPV SUSY interactions at the 95% CL. (Figure updated from Ref. [169].)

"The Weak Neutral Current", Erler and Su, Prog. Part. Nucl. Phys. 71 (2013) 119-149, http://arxiv.org/abs/1303.5522

Low Energy PV and the Tevatron Top A_{FB} Anomaly

M. Gresham et al., arXiv:1203.1320v1 [hep-ph] 6 Mar 2012

Tevatron CF and D0 collaborations saw an excess in the t-tbar forward-backward asymmetry, A_{FB}.
(Precision measurements can also be made at the energy frontier!)

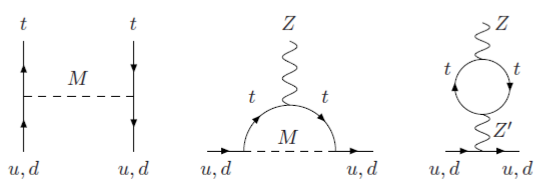


FIG. 1: A_{FB} from t-channel exchange of M (left). Anomalous coupling of Z to u, d at one-loop is generated by M (center) and by flavor-conserving Z' associated with certain vector M models.

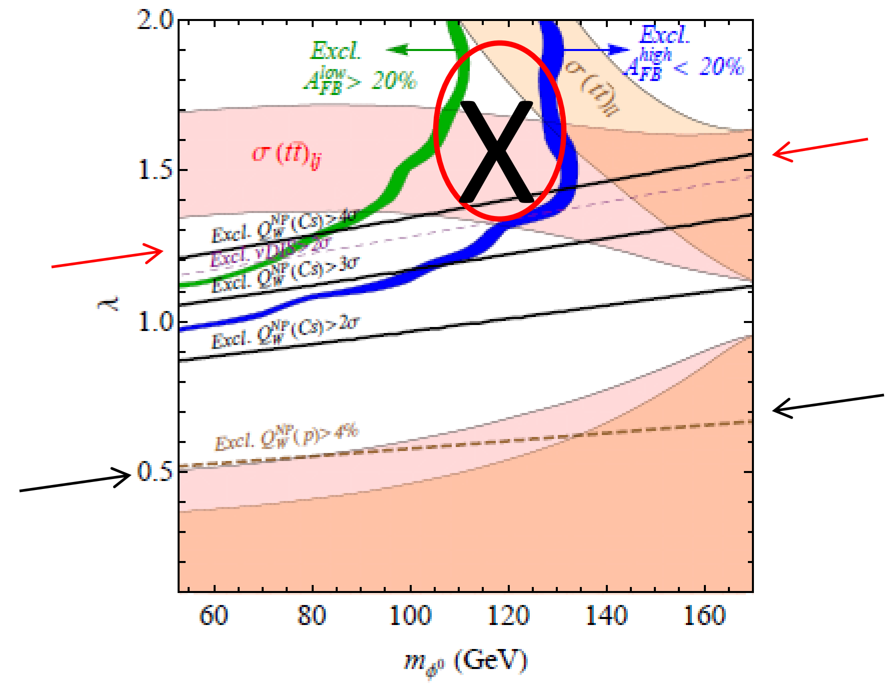


FIG. 2: Exclusion plot for weak doublet (ϕ) model. Pink and tan shaded regions are consistent with $\sigma(t\bar{t})_{\ell j}$ and $\sigma(t\bar{t})_{\ell\ell}$, respectively. Mass-dependent-A_{FB}-favored region is within the blue and green curves, marking $A_{FB}^{high} > 20\%$ and $A_{FB}^{low} < 20\%$, respectively. Constraints from Q_W(Cs), νDIS, and future Q_W(p) measurements shown by black solid, purple dashed, and brown dashed lines, respectively.

A possible explanation which avoided known constraints was a new, not-too-massive, scalar or vector particle.

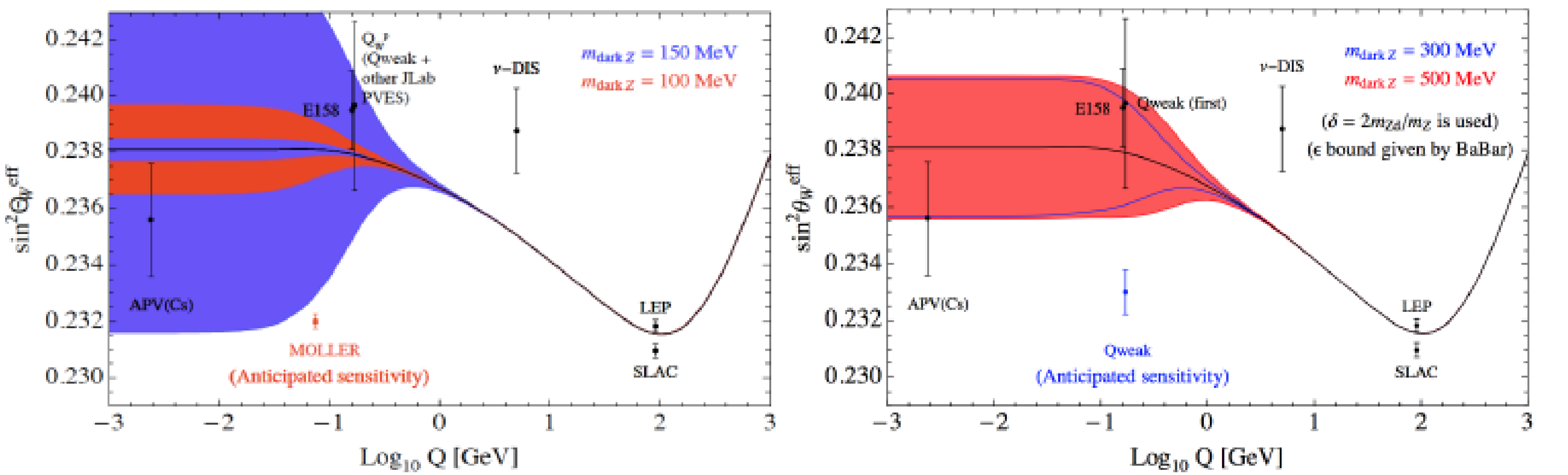
Sufficiently precise low energy PV experiments can constrain new physics models.

PRL 109, 031802 (2012)

New Physics Example - Dark Z

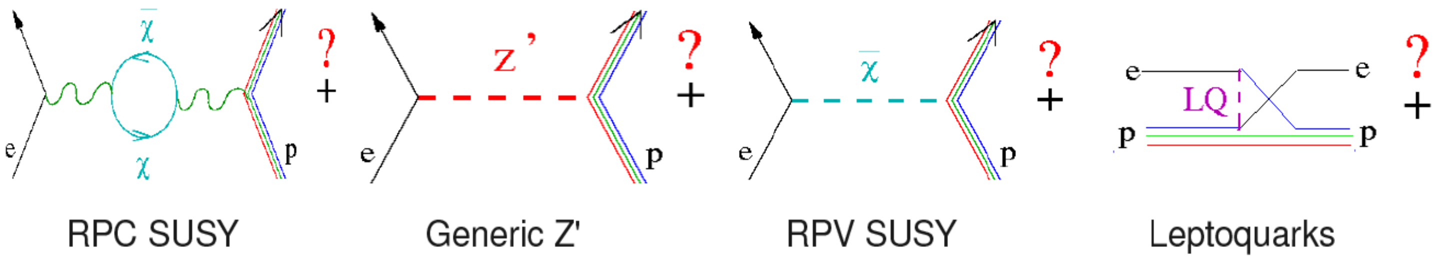
"Dark parity violation" (Davoudiasl, Lee, Marciano, arXiv 1402.3620)

- Introduces a new source of low energy parity violation through mass mixing between Z and Z_d with observable consequences.
- Complementary to direct searches for heavy dark photons.



Low-E experiments most sensitive to deviations from SM due to Dark Z

Q-weak's Keyhole on New Physics

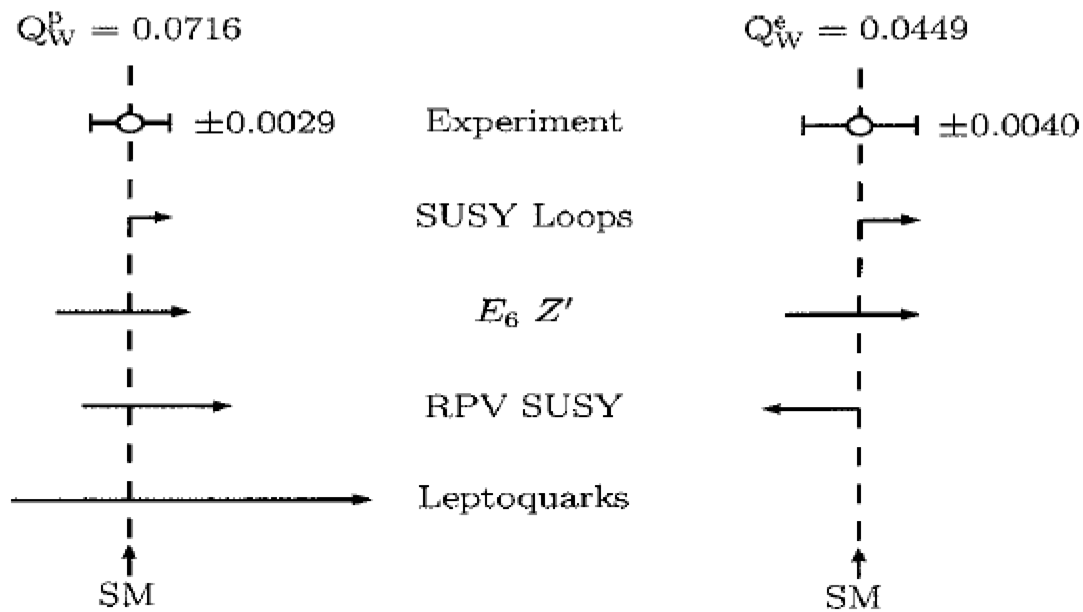


Our experiment is sensitive to new physics with PV couplings of electrons to light quarks.

In this 2003 study, our biggest sensitivity was to lepto-quarks.

The RPV SUSY limits got much tighter in 2013.

Erler and Su,
Prog. Part. Nucl. Phys. 71 (2013) 119-149.



Erler et al., Phys. Rev. D 68, 016006 (2003).

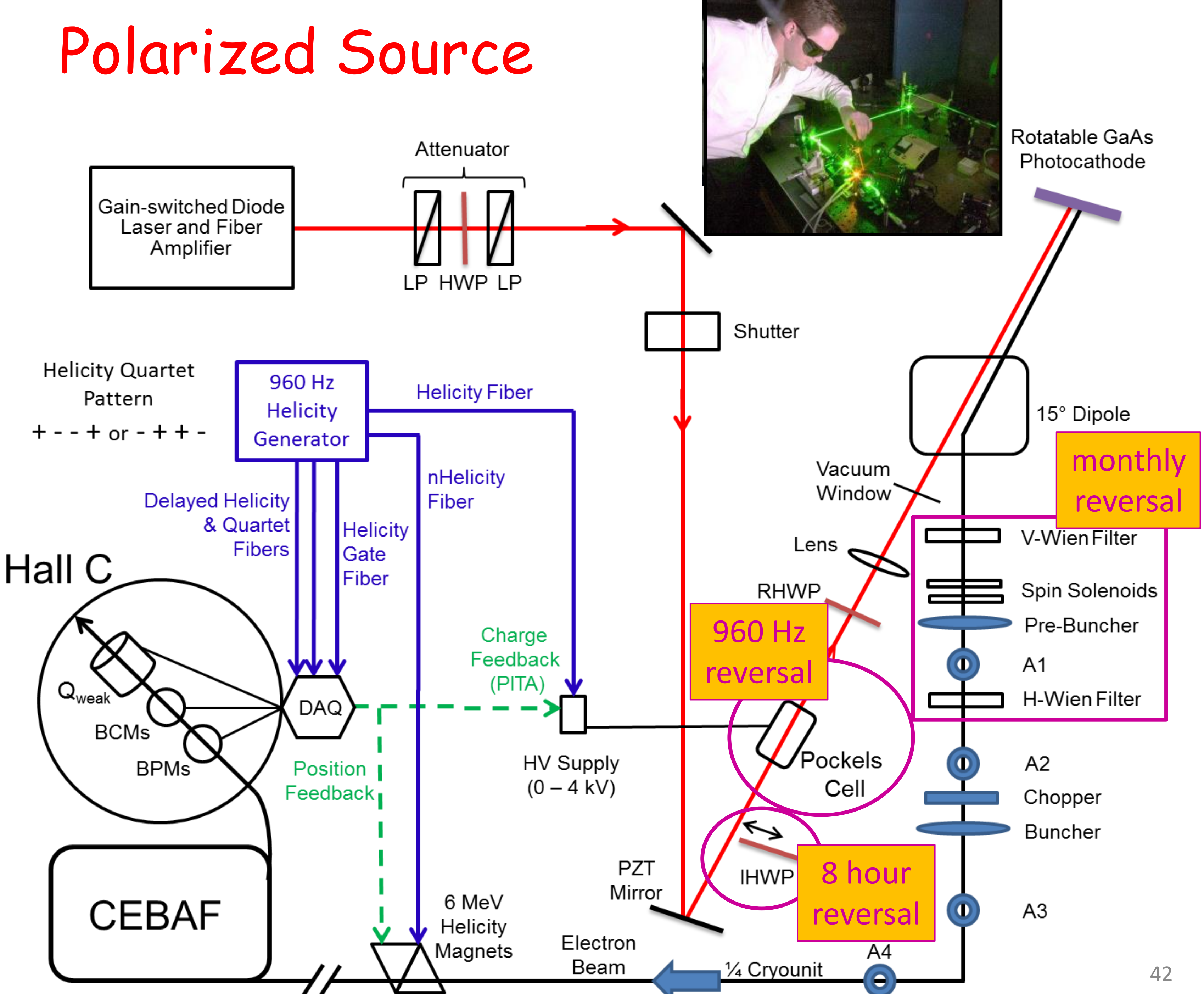
Uncertainty Goals

2% on A_z ≈ 4% on Q_w ≈ 0.3% on $sin^2\theta_W$

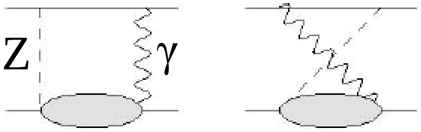
Source of error	Contribution to $\Delta A_{phys}/A_{phys}$	Contribution to $\Delta Q_w^p / Q_W^p$
Counting Statistics	2.1%	3.2%
Hadronic structure	—	1.5%
Beam polarimetry	1.0%	1.5%
Absolute Q^2	0.5%	1.0%
Backgrounds	0.7%	1.0%
Helicity-correlated beam properties	0.5%	0.8%
TOTAL:	2.5%	4.2%

Hadronic contributions to A_{PV} magnify the error in going from A_{PV} to Q_W^p

Polarized Source



Gamma-Z Box Correction

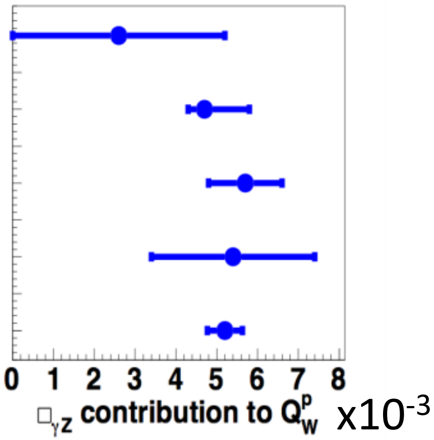


$$Q_W^p = [\rho_{\rm NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_{\rm W}(0) + \Delta_e'] + \square_{WW} + \square_{ZZ} + \square_{\gamma Z}$$

~7% correction

Table 1: $\square^V_{\gamma Z}$ contribution to Q^p_W (Qweak kinetmatics)

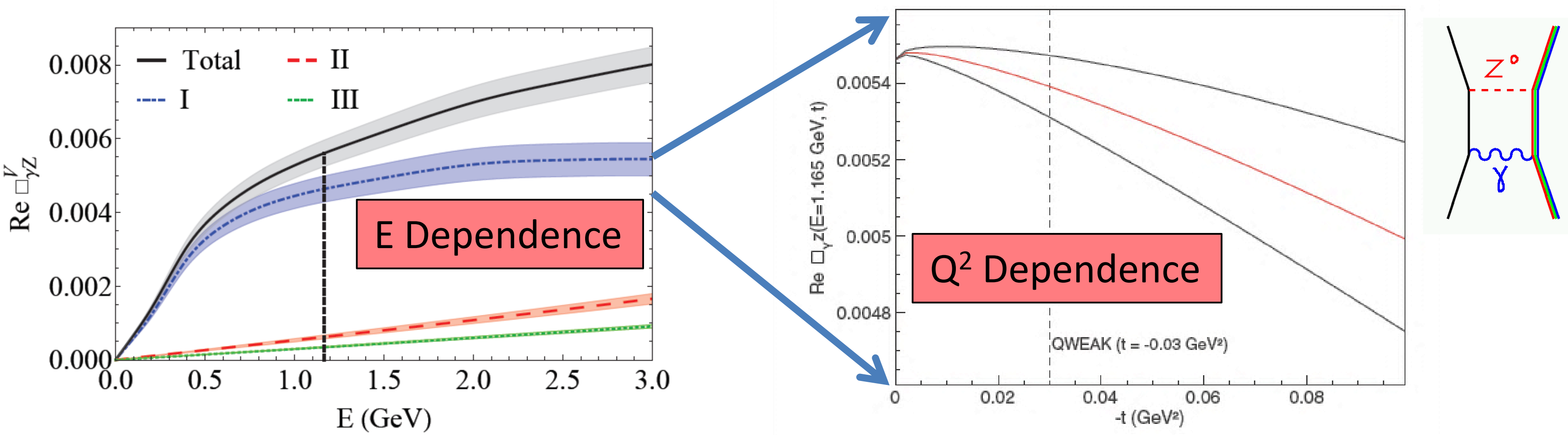
Gorchtein & Horowitz Phys. Rev. Lett. **102**, 091806 (2009)	0.0026 ± 0.0026
Sibirtsev, Blunden, Melnitchouk, & Thomas Phys. Rev. D **82**, 013011 (2010)	$0.0047^{+0.0011}_{-0.0004}$
Rislow & Carlson Phys. Rev. D **83**, 113007 (2007)	0.0057 ± 0.0009
Gorchtein, Horowitz, & Ramsey-Musolf Phys. Rev. C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



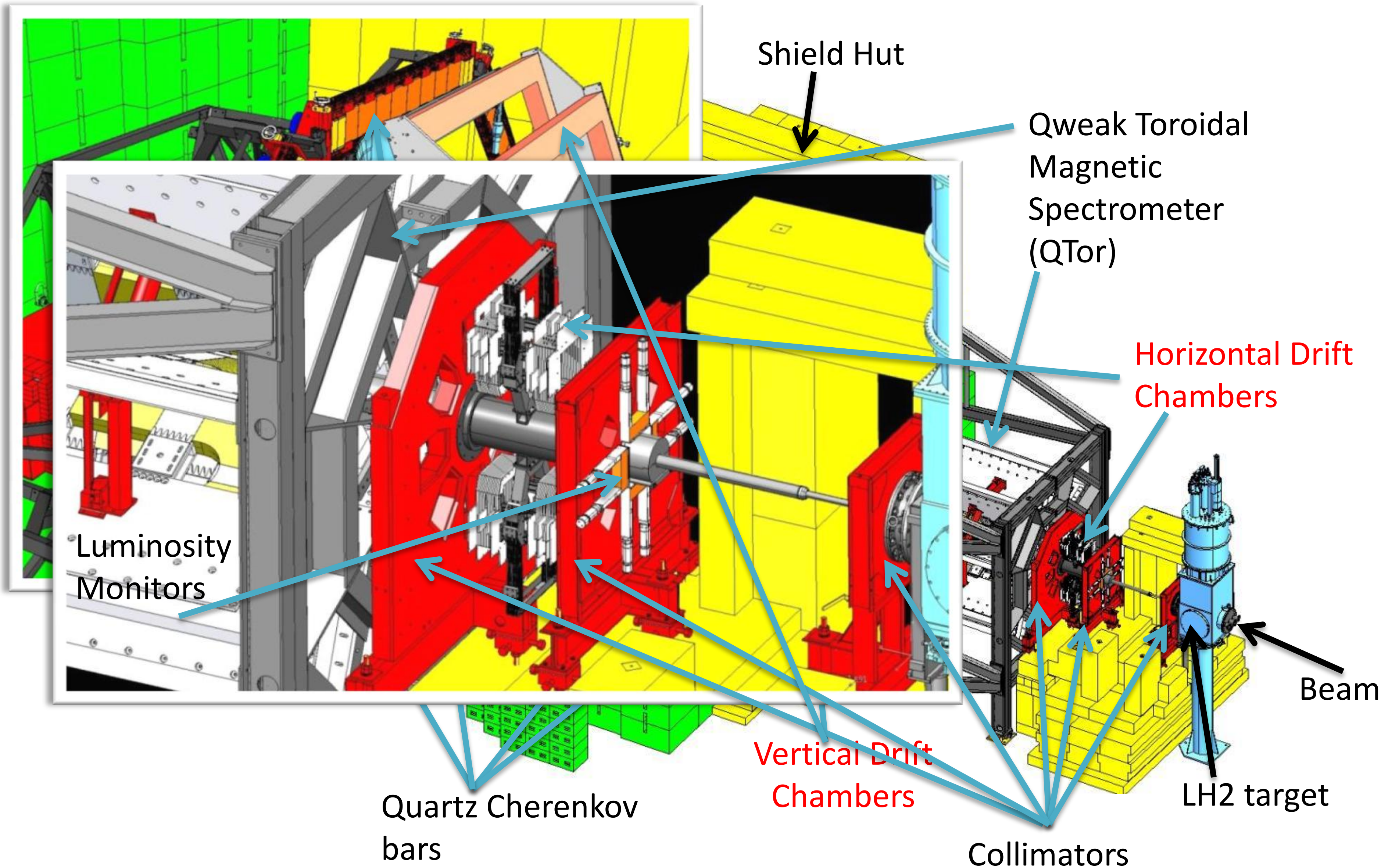
The $\square_{\gamma Z}$ is the only E & Q^2 dependent EW correction.

→ Correct the PVES data for this E & Q^2 dependence.

- Calculations are primarily dispersion theory type
  - error estimates can be firmed up with data!



Q-weak Spectrometer (detail)

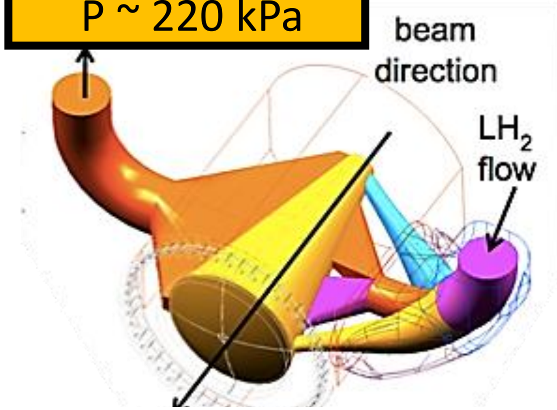


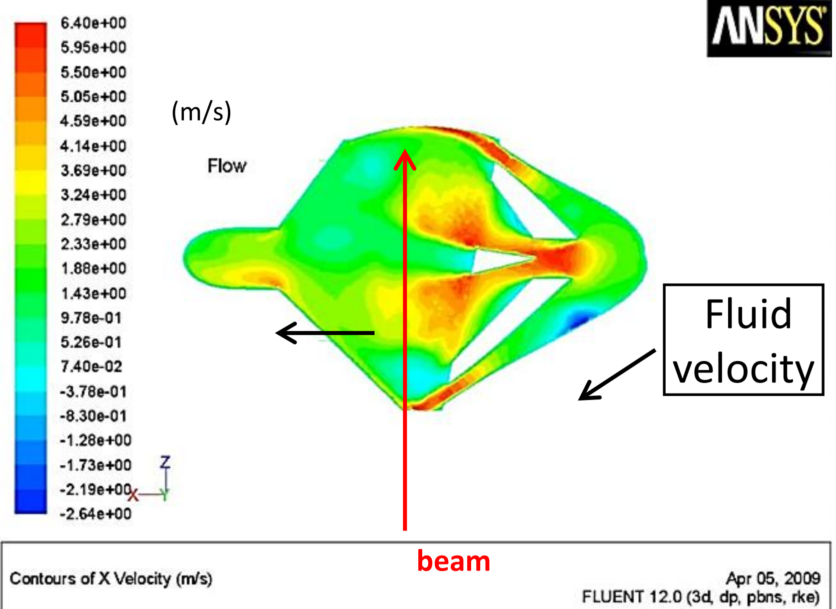
Used only during low current tracking mode operation

LH_2 Cryotarget Design

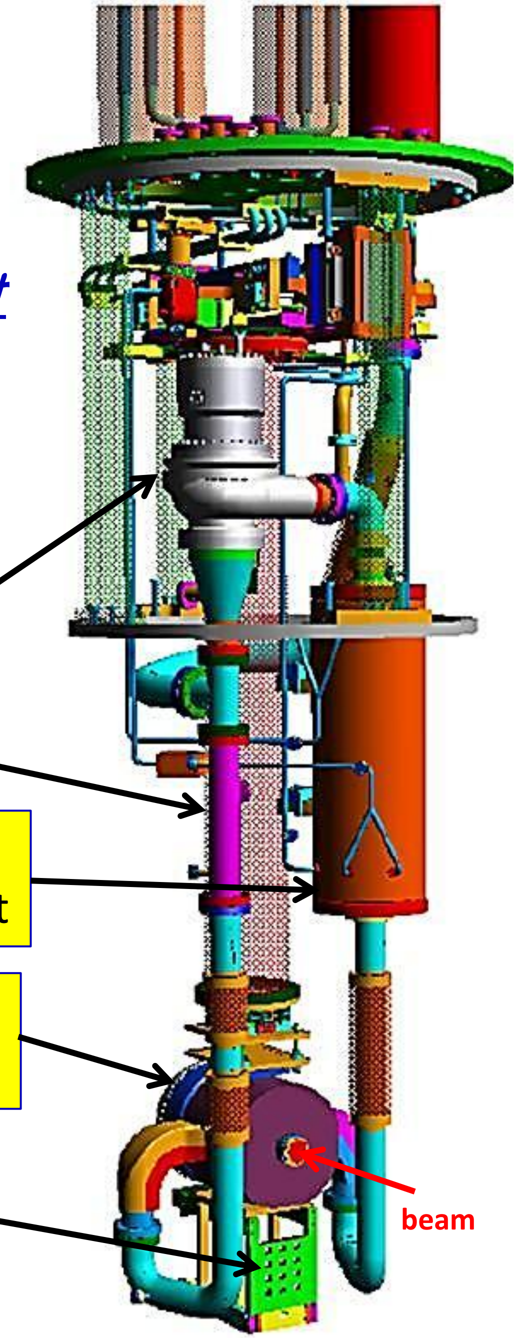
I_{Beam} = 180 uA
L = 35 cm (4% X_0)
P_{beam} = 2.2 kW
A_{spot} = 4x4 mm^2
V = 57 liters
T = 20.00 K
P ~ 220 kPa

World's highest power *and lowest noise* cryogenic target ~3 kW





ANSYS



Centrifugal pump (17 l/s, 7.6 kPa)

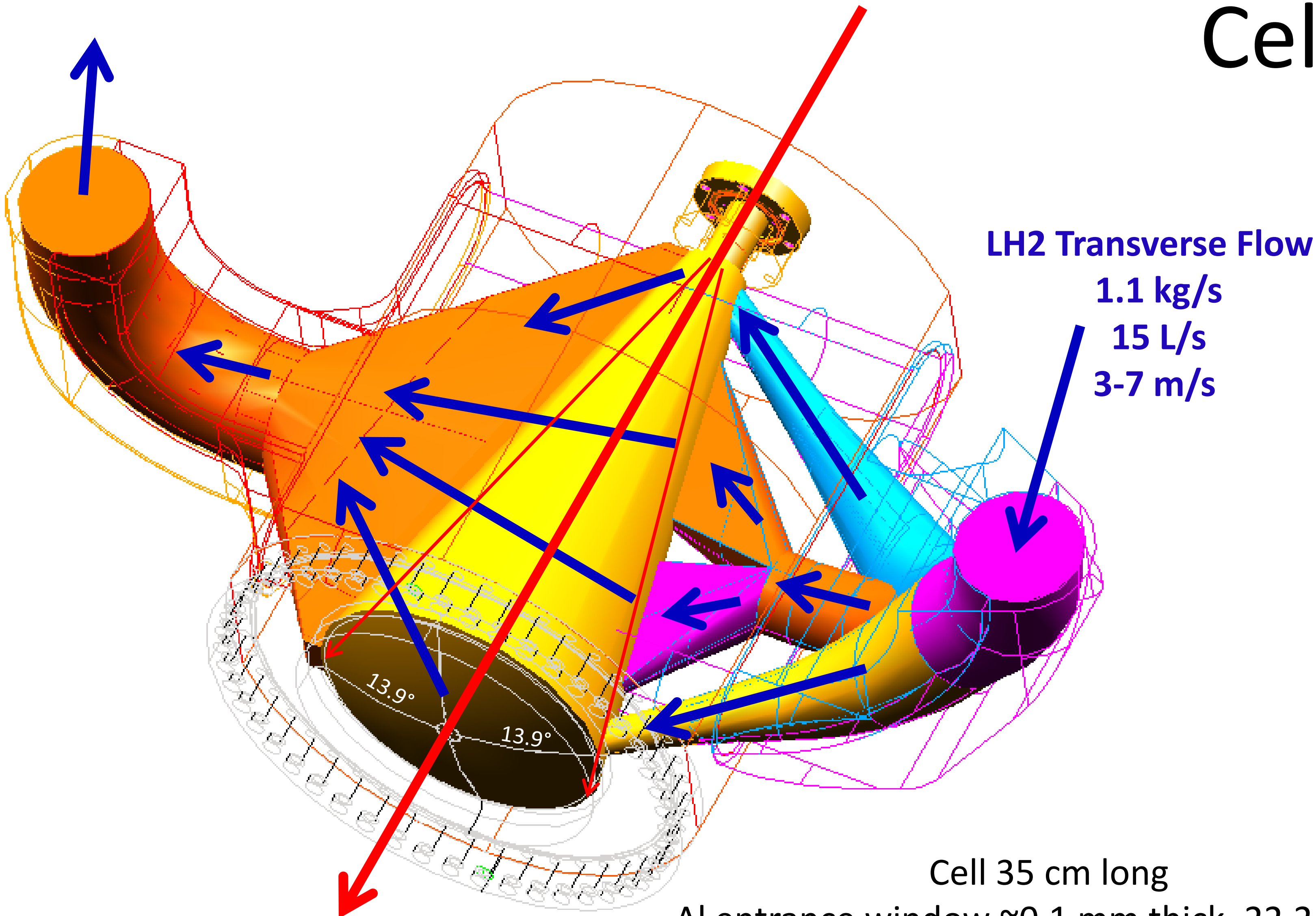
3 kW Heater

3 kW HX utilizing 4K & 14K He coolant

35 cm cell (beam interaction volume)

Solid Tgts

Cell

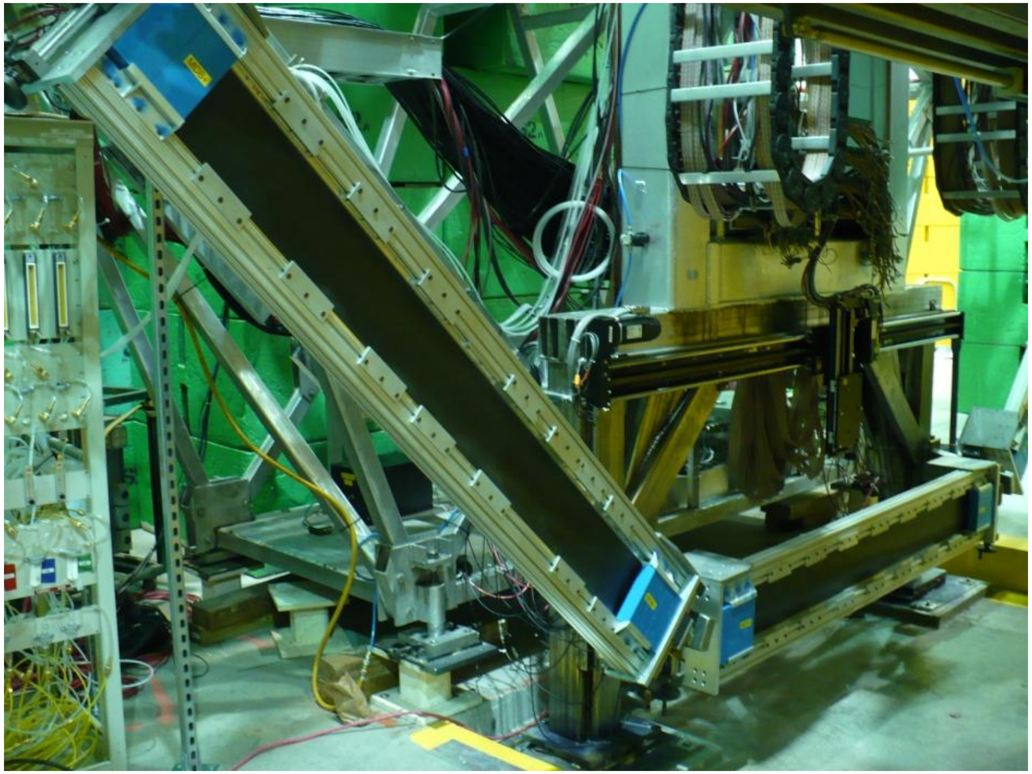


Cell 35 cm long
Al entrance window ~0.1 mm thick, 22.2 mm Φ
Al exit window ~0.125 mm thick over 15 mm Φ,
0.635 mm thick over 173.5 mm
Scattered electron acceptance ±13.9°

Jlab Exo-Skeletons

Manitoba radiator modules (physicist responsibility) were installed in a strong, stiff Jlab exo-skeleton suitable for carrying Pb shielding and pre-radiators (engineering and safety responsibility).

Each module carries 200 lbs (90 kg) of Pb bricks to provide limited shielding for PMTs. (Pre-radiators would double that.)



Collimation