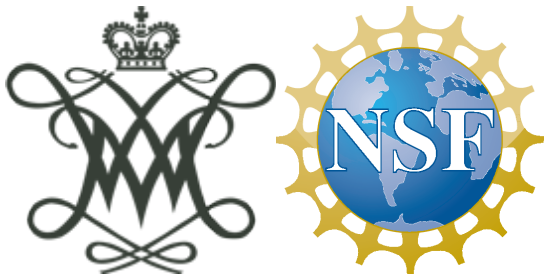
The Q_{Weak} Experiment

A Precision Search for New Physics at the TeV Scale

Wouter Deconinck



Users Group Meeting 2012

Outline

- Electroweak Interaction and Parity Violation
  - Electroweak Interaction
  - Parity-Violating Electron Scattering
  - Radiative Corrections
- The Q_{Weak} Apparatus
  - Target
  - Main Detector
- The Q_{Weak} Data
  - Uncertainties
  - Polarimetry
  - Tracking
  - Data Quality
  - Backgrounds
- First Results
  - Transverse Asymmetry
- Summary

Electroweak Interaction

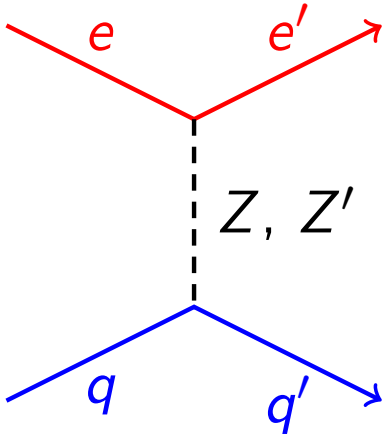
Glashow–Weinberg–Salam theory of weak interaction

- Gauge symmetry: $SU(2)_L \times U(1)_Y$
- Gauge couplings: g for $SU(2)_L$, g' for $U(1)_Y$
- Left-handed leptons in doublets, right-handed in singlets
- Fundamental symmetry of left and right helicity broken

Parity-violation neutral current

$$\mathcal{L}_{PV}^{EW} = -\frac{G_F}{\sqrt{2}} \left[g_A^e \left(\bar{e}\gamma_\mu\gamma_5 e\right) \cdot \sum_q g_V^q \left(\bar{q}\gamma^\mu q\right) + g_V^e \left(\bar{e}\gamma_\mu e\right) \cdot \sum_q g_A^q \left(\bar{q}\gamma^\mu\gamma_5 q\right) \right]$$

$$= -\frac{G_F}{2\sqrt{2}} \left[\sum_q C_{1q} \left(\bar{e}\gamma_\mu\gamma_5 e\right) \cdot \left(\bar{q}\gamma^\mu q\right) + \sum_q C_{2q} \left(\bar{e}\gamma_\mu e\right) \cdot \left(\bar{q}\gamma^\mu\gamma_5 q\right) \right]$$



Electroweak Interaction

Parity-violating electron scattering couplings

- Weak vector coupling: $C_{1q} = 2g_A^e g_V^q$
- Weak axial coupling: $C_{2q} = 2g_V^e g_A^q$

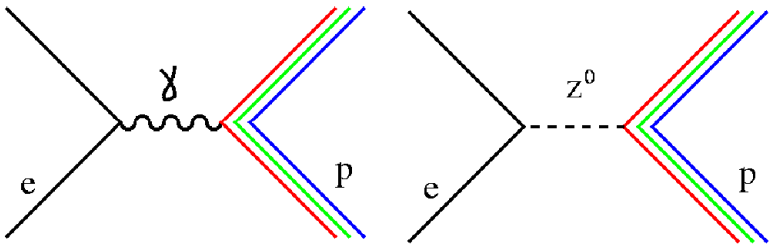
Particle	Electric charge	Weak vector charge ($\sin^2\theta_W \approx \frac{1}{4}$)
u	$+\frac{2}{3}$	$-2C_{1u} = +1 - \frac{8}{3}\sin^2\theta_W \approx +\frac{1}{3}$
d	$-\frac{1}{3}$	$-2C_{1d} = -1 + \frac{4}{3}\sin^2\theta_W \approx -\frac{2}{3}$
p(uud)	$+1$	$Q_W^p = 1 - 4\sin^2\theta_W \approx 0.07$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

Electron and proton weak charge Q_W^e and Q_W^p

Suppression of the proton and electron weak charge in Standard Model make them sensitive to new physics!

Parity-Violating Electron Scattering

Interference of photon and weak boson exchange



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

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

Very small asymmetry between left and right helicity

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

Parity-Violating Electron Scattering

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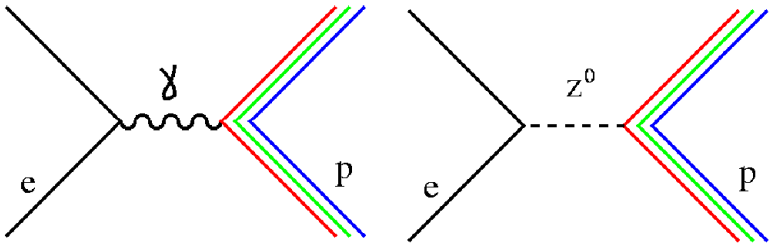

Asymmetry between left and right helicity in nucleons

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

In the forward elastic limit $Q^2 \to 0$, $\theta \to 0$ (plane wave)

$$A_{PV}(p) \xrightarrow{Q^2 \to 0} \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} \left[Q_W^p + Q^2 \cdot B(Q^2) \right] \approx 230\,\text{ppb}$$

Parity-Violating Electron Scattering: Quark Couplings

Weak vector charge *uud*

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

Early experiments

- SLAC and APV

Electron scattering

- HAPPEx, G0
- PVA4/Mainz
- SAMPLE/Bates

Q_{Weak} experiment

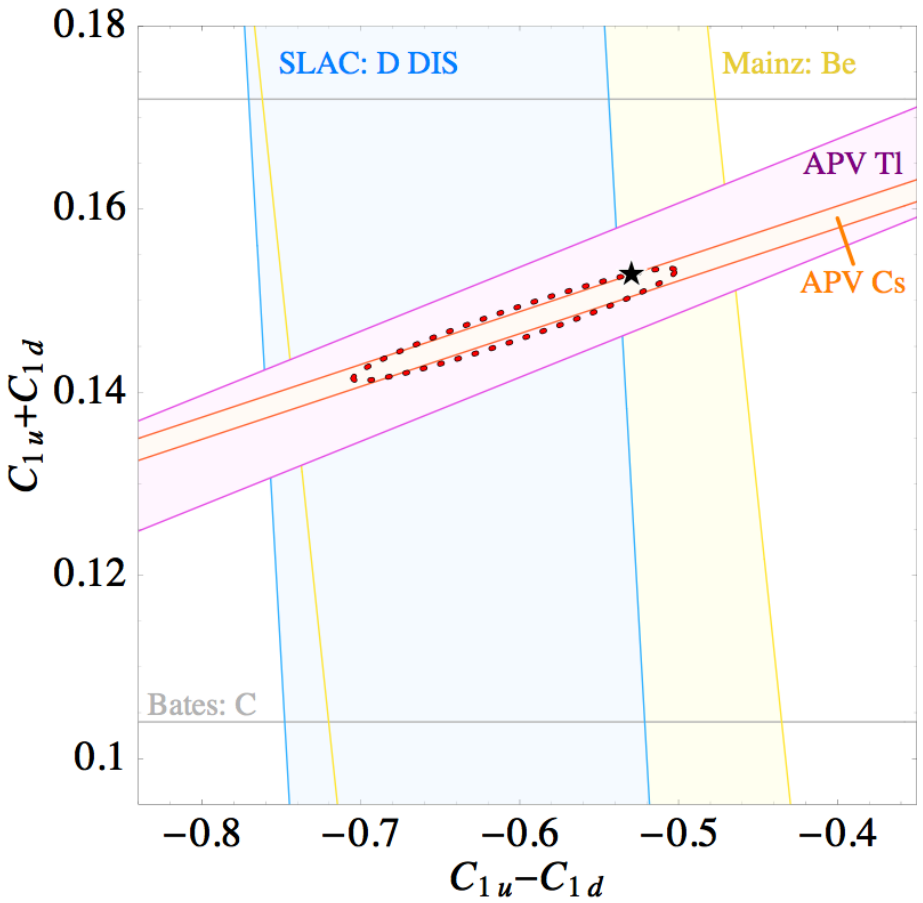

Figure: Young, Carlini, Thomas, Roche

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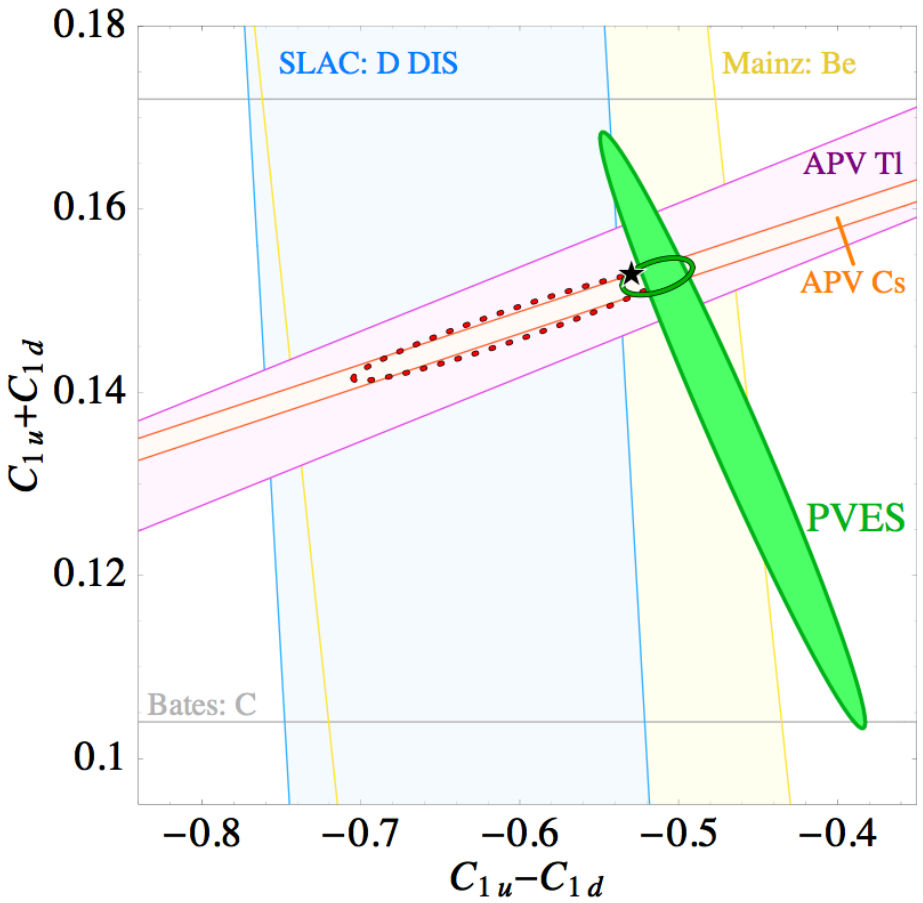

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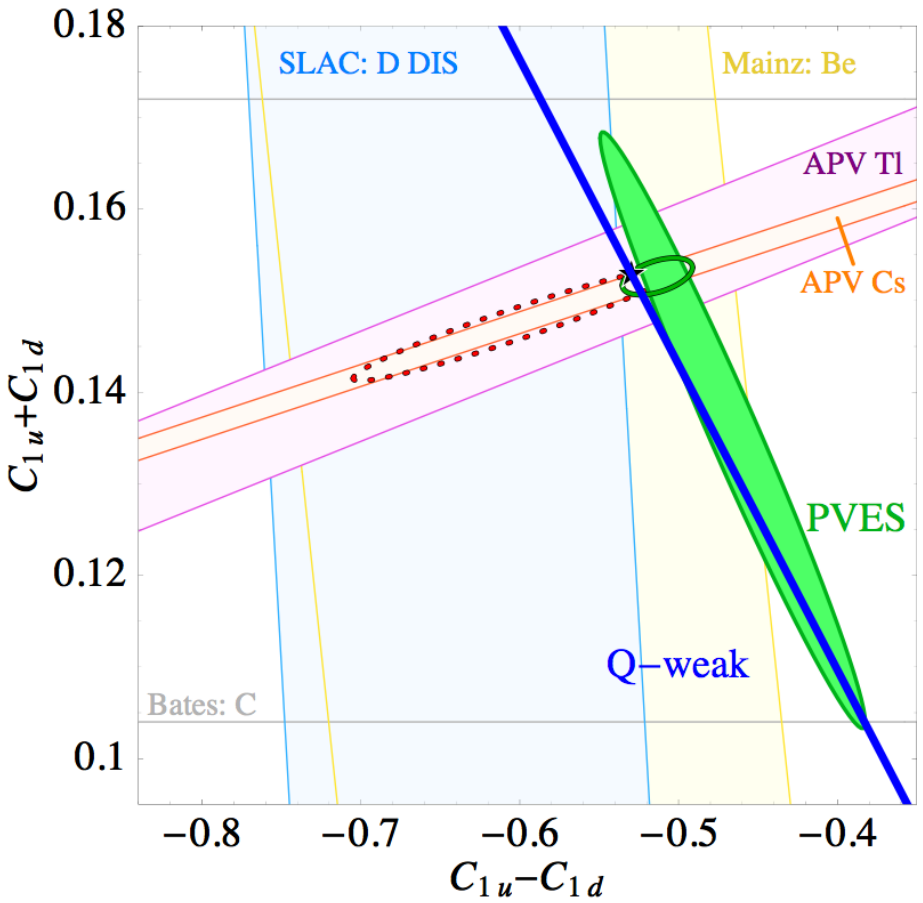


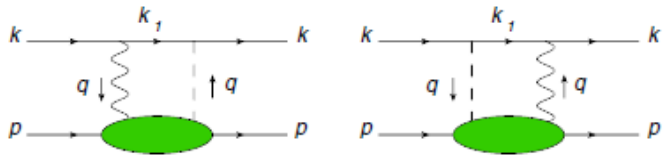
Figure: Young, Carlini, Thomas, Roche

Radiative Corrections

Several radiative corrections

- $Q_W^p = (\rho_{NC} + \Delta_e)(1 - 4\sin^2\theta_W(0) + \Delta_e') + B_{WW} + B_{ZZ} + B_{\gamma Z}$
- $\Delta\sin^2\theta_W(M_Z)$, WW, ZZ box diagrams: uncertainty small
- γZ box: 8% correction with $\approx$ 1% uncertainty

Corrections to $Q_W^p \approx 0.07$



Source	Q^p_{Weak} Uncertainty
$\Delta \sin\theta_W(M_Z)$	±0.0006
$Z\gamma$ box	±0.0005
$\Delta \sin\theta_W(Q)_{hadronic}$	±0.0003
WW, ZZ box - pQCD	±0.0001
Charge symmetry	0
Total	±0.0008

Erler et al.,
PRD 68(2003)016006.

- Verification in "DIS" region, calculation by Melnitchouk

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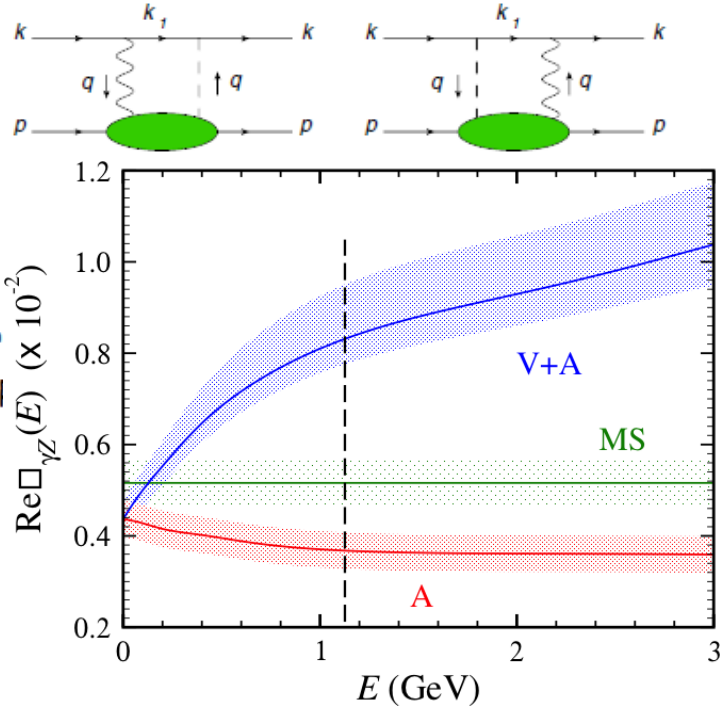

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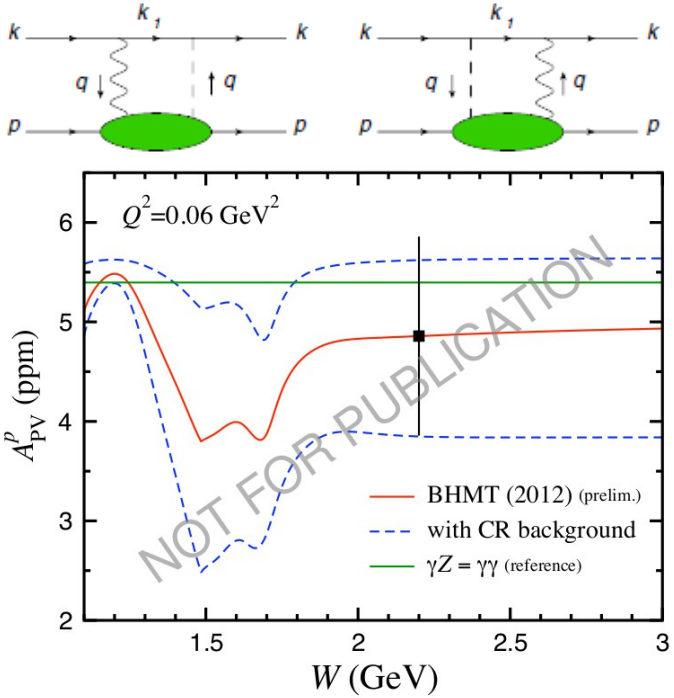

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The Q_{Weak} Experiment

- Precision measurement of a quantity suppressed by fundamental symmetries ($Q_W^p \approx 0$, asymmetry of 230 ppb)
- Elastic scattering of electron beam on proton target to measure the proton weak charge Q_W^p to a precision of 4%

Pushing the envelope of intensity (more events)

- Higher beam current (150 μA versus usually $< 100\,\mu$A)
- Longer cryo-target (35 cm versus 20 cm)
- Higher event rates up to 800 MHz (integration)

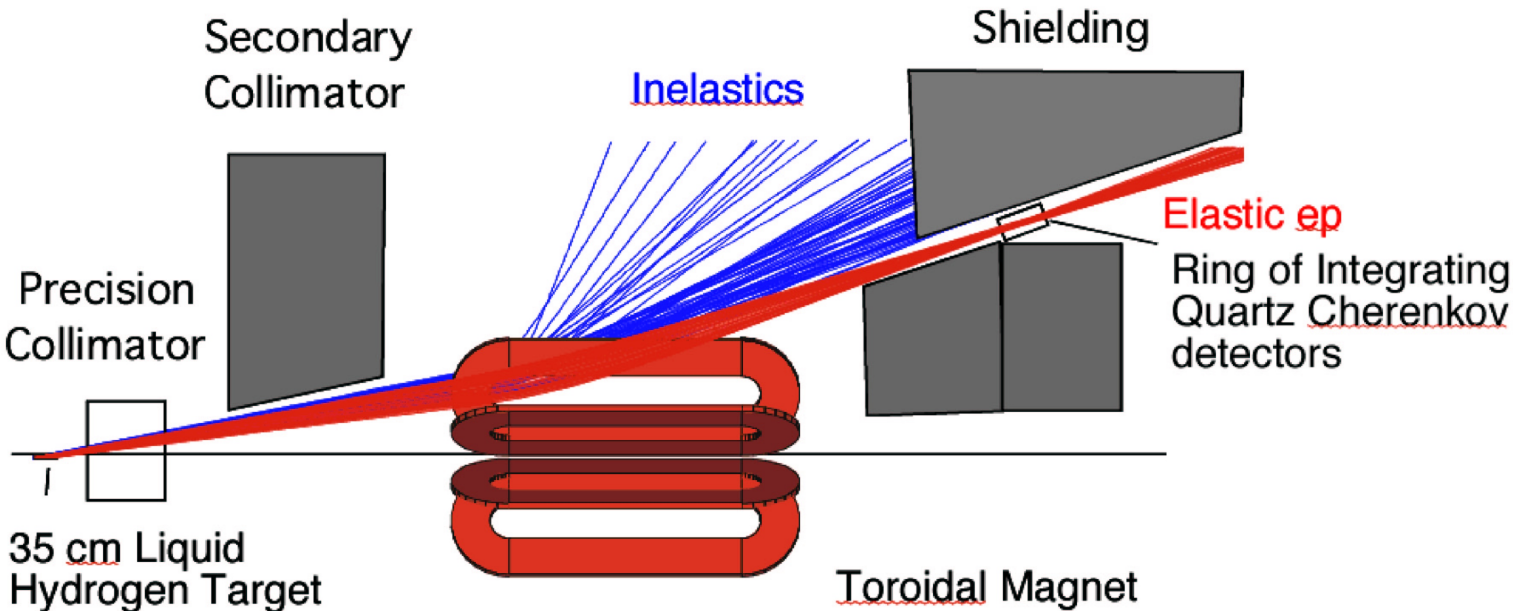
Pushing the envelope of precision

- Electron beam polarization precision of 1% at 1 GeV
- Helicity-correlated asymmetries at ppb level

The Q_{Weak} Experiment

Conceptual overview

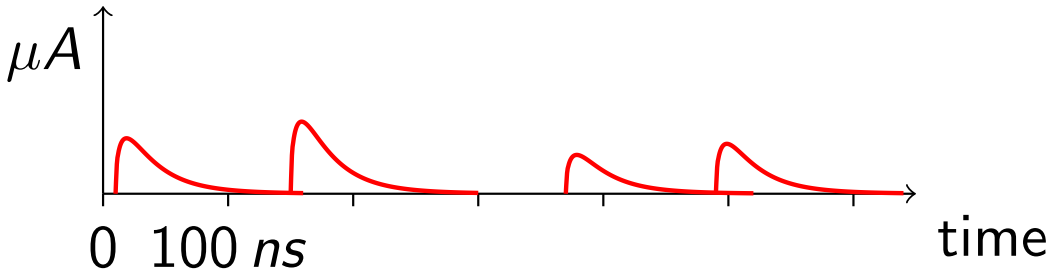
- Elastic $\vec{e}$-p scattering on liquid hydrogen target
- Toroidal magnet to provide energy dispersion
- Collimator and magnet system to select elastic events only
- Lower energy inelastic events bent outside of acceptance



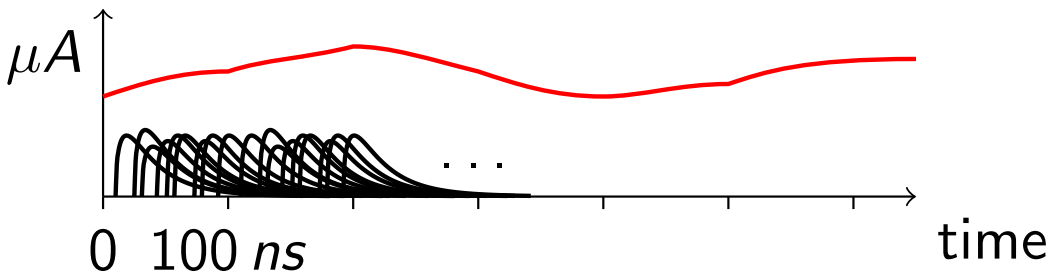
The Q_{Weak} Experiment

Event versus current mode

- Event mode
  - each event individually registered
  - event selection or rejection possible



- Current or integrating mode
  - high event rates possible (event every nanosecond!)
  - no suppression of background events possible



The Q_{Weak} Experiment

Asymmetry measurement in current mode

- Asymmetry generated by Q_W^p is $\approx 230\,\text{ppb}$
- Statistical width on individual measurements is 200 ppm (from sampling resolution/frequency of integrating ADC)
- Need to be dominated by counting statistics to avoid systematic corrections to resulting asymmetry
- Noise in excess of 200 ppm (target, detectors) increases needed running time

Head-aches of the parity-violation experimenter

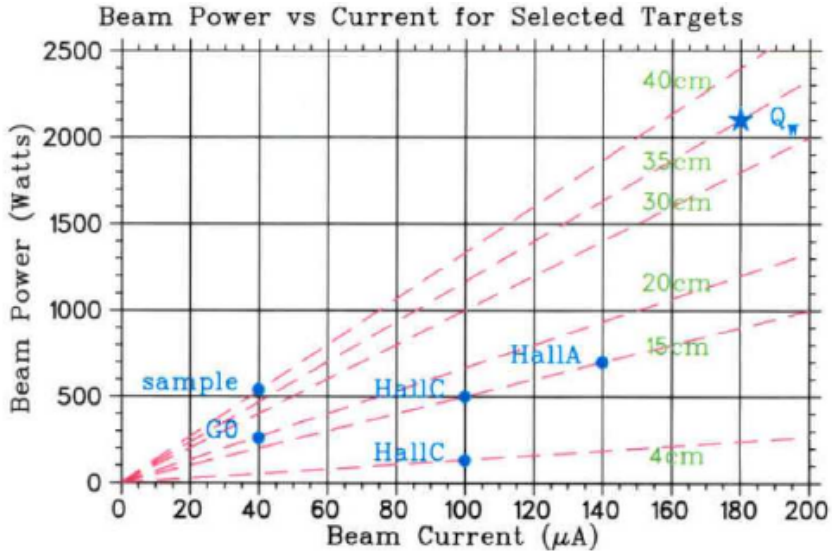
- Keep the noise down!
- Avoid false asymmetries
- Correct for systematic effects

The Q_{Weak} Experiment: High Power Cryotarget

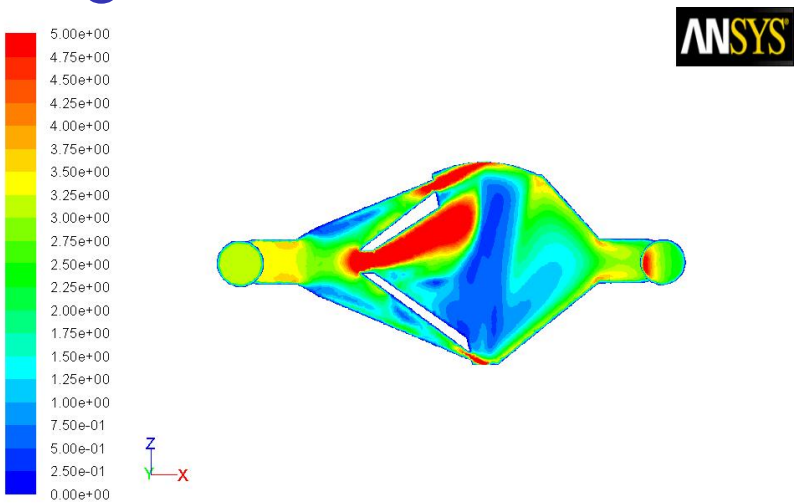
Operational Parameters

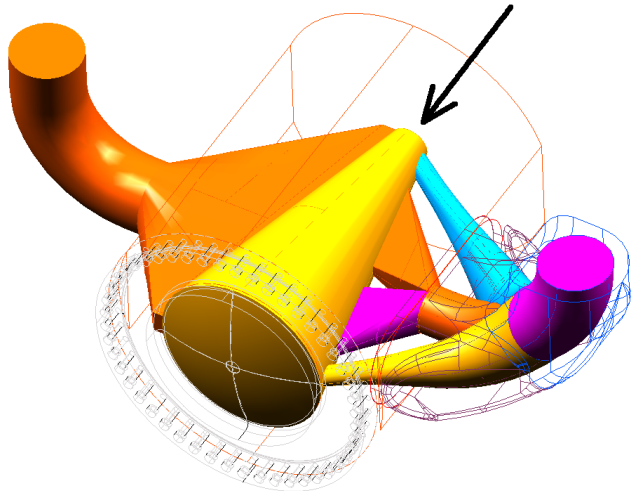
- Transverse flow: 2.8 m/s
- Target length: 35 cm
- Beam current: 150 μA
- Heating power: 2.5 kW

Power for other cryotargets



Design with CFD





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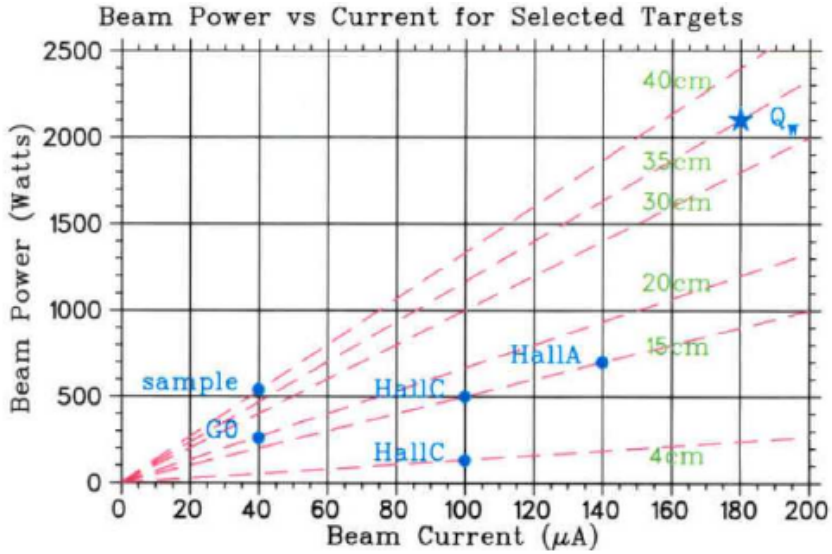
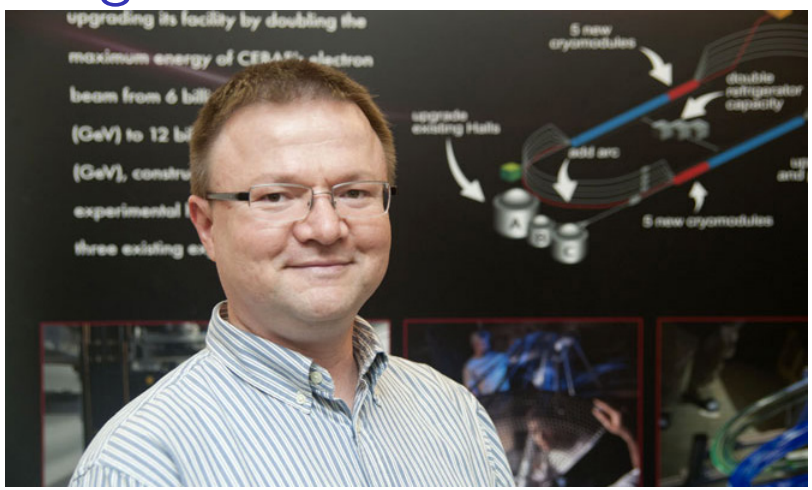
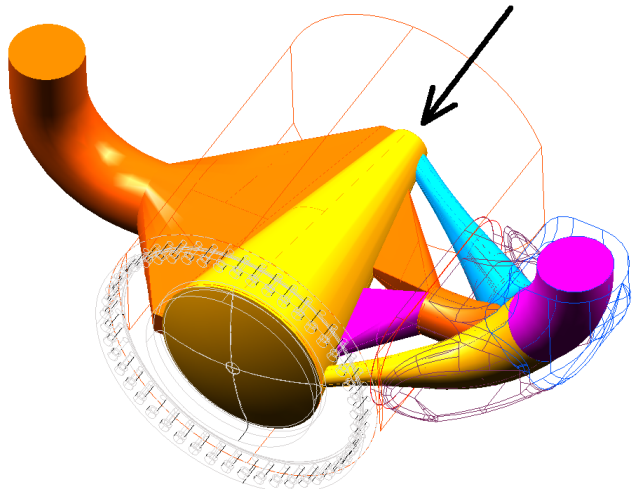


Design with CFD: CAREER!

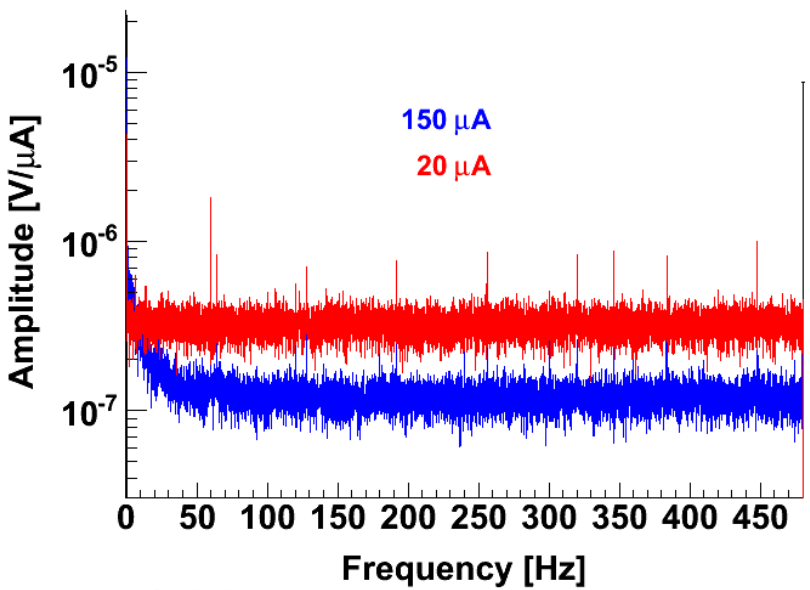




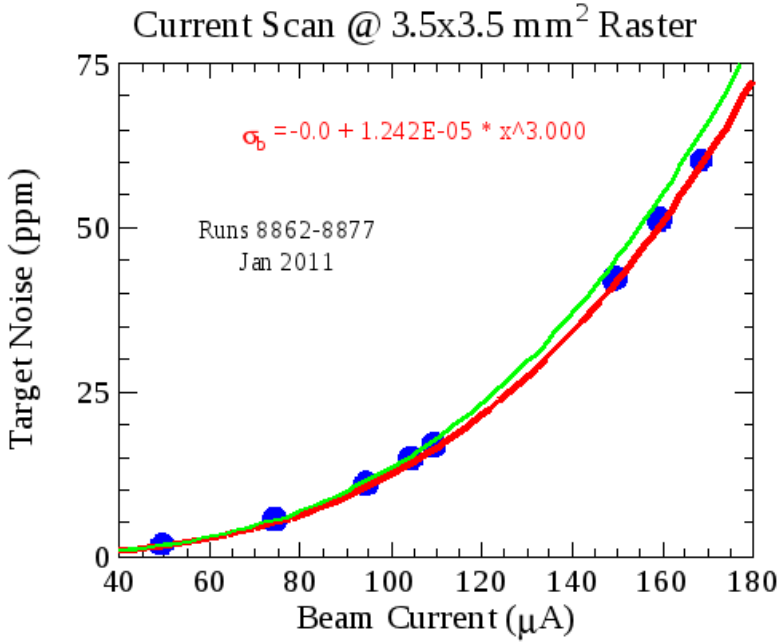
The Q_{Weak} Experiment: High Power Cryotarget

Low-frequency 'boiling' noise

- Helicity flip rate 960 Hz $\rightarrow$ 240 Hz (quartet cycles)
- Target density fluctuations at low frequencies occur
- Power spectrum of signal



Current dependence



- Additional noise smaller than statistical width
- Consistent for different current and beam rasters
- Current to 180 μA

The Q_{Weak} Experiment: Main Detector

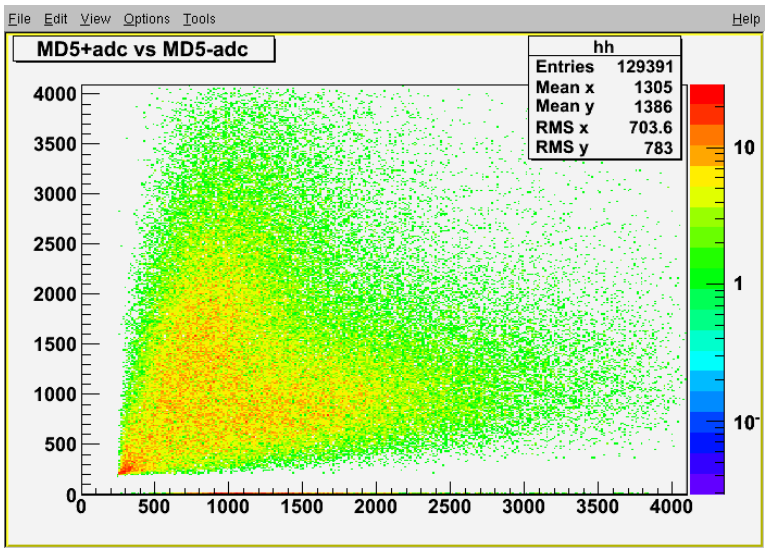
Preradiated Čerenkov detector bars

- 8 fused silica radiators, 2 m long $\times$ 18 cm $\times$ 1.25 cm
- Pb preradiator tiles to reduce low-energy tracks (neutrals)
- Light collection: total internal reflection
- 5 inch PMTs with gain of 2000, low dark current
- 800 MHz electron rate per bar, defines counting noise

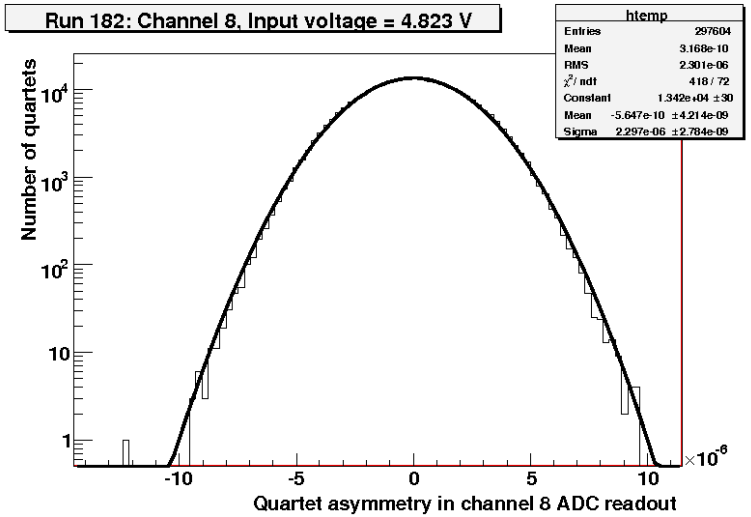
The Q_{Weak} Experiment: Main Detector

Event mode characterization

- Larger signal in + or - end depending on proximity
- Number of photo-electrons ≈ 85 per track



Integrating data chain noise



- Current source (battery)
  - Width ≈ 2.3 ppm
- Actual data with beam
  - Width ≈ 240 ppm
- Not limited by electronic noise

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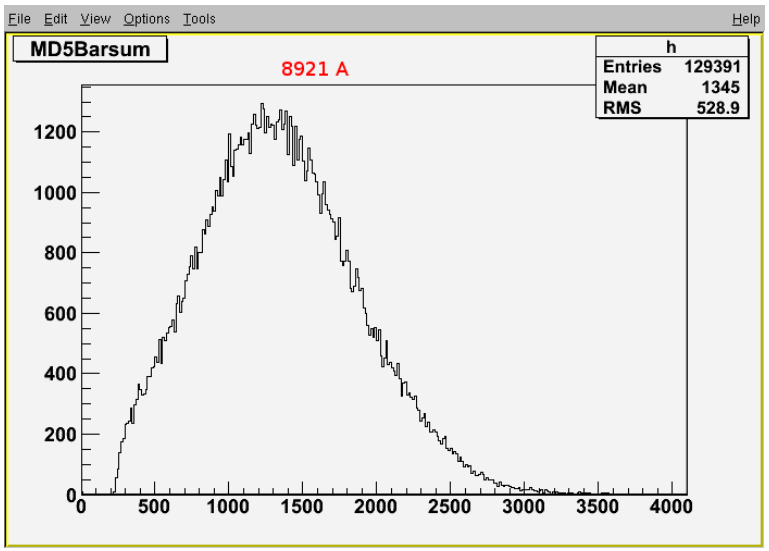

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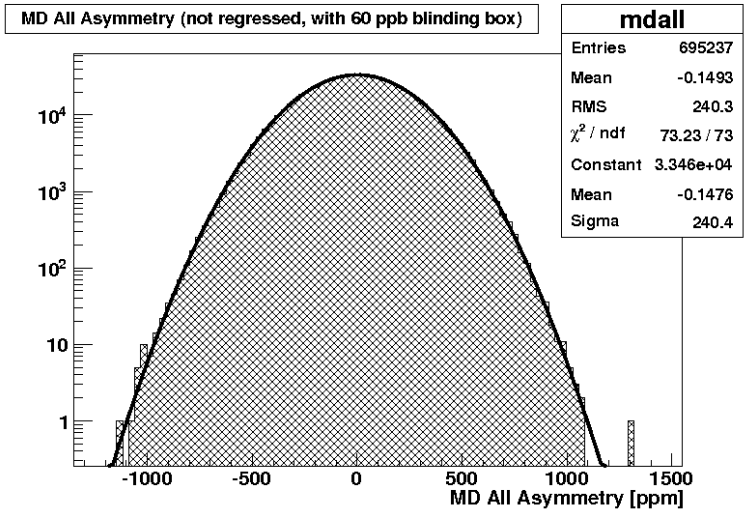

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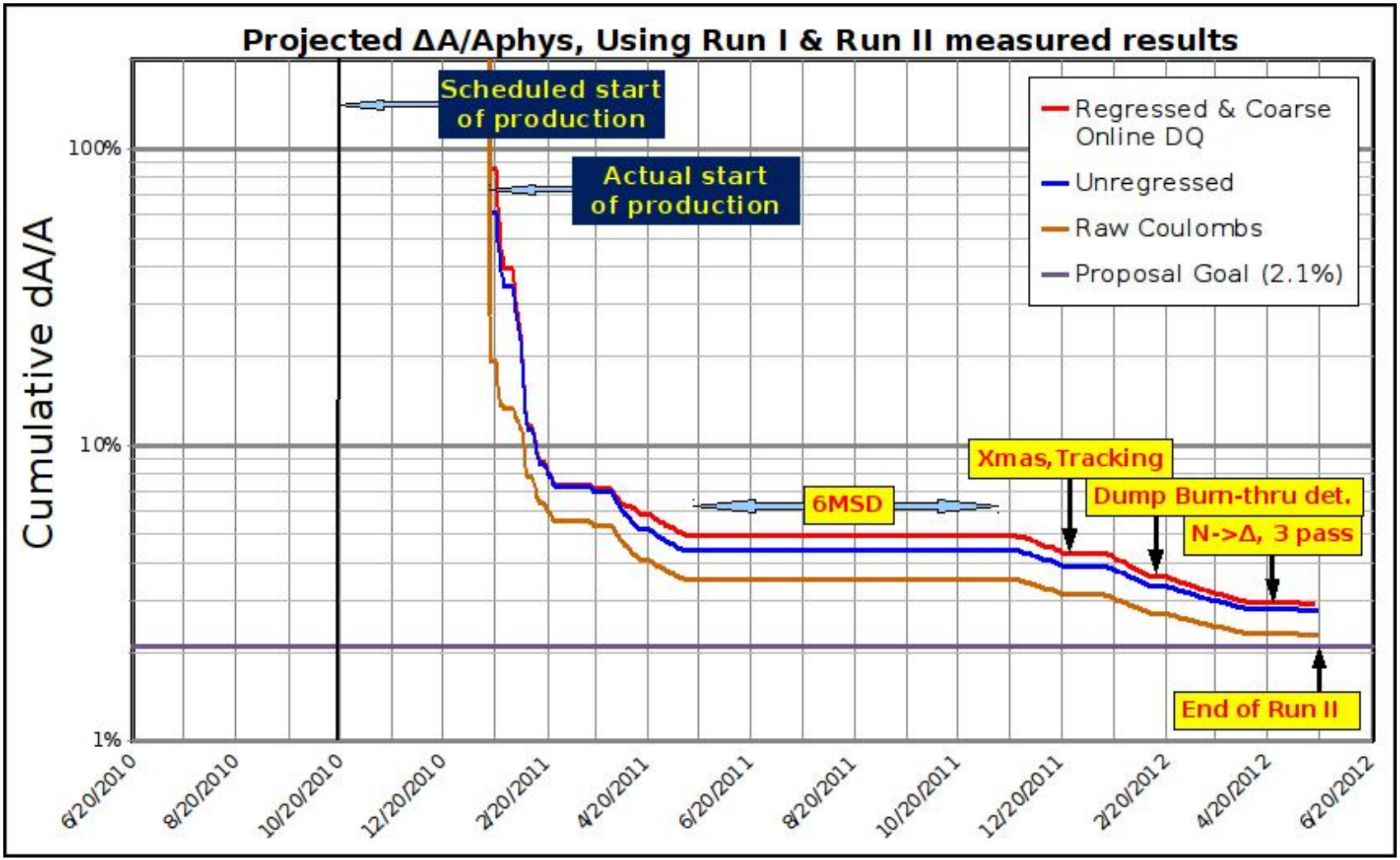
The Q_{Weak} Experiment: Statistical Uncertainties



The Q_{Weak} Experiment: Systematic Uncertainties

Projected uncertainties on A_{meas} and Q_W^p

Source of uncertainty	Contribution to $\Delta A_{meas}/A_{meas}$	Contribution to $\Delta Q_W^p/Q_W^p$
Statistics	2.1%	3.2%
Hadronic structure	–	1.5%
Beam polarimetry	1.0%	1.5%
Measurement Q^2	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated beam properties	0.5%	0.7%
Total	2.5%	4.1%

The Q_{Weak} Experiment: Beam Polarimetry

Requirements on beam polarimetry

- Statistical precision of 1% after one hour
- Systematic uncertainty of 1% (on absolute measurements)

Upgrade existing Møller polarimeter ($\vec{e} + \vec{e} \rightarrow e + e$)

- Scattering off atomic electrons in magnetized iron foil
- Operation limited to dedicated low current runs ($I \approx 1\,\mu$A)

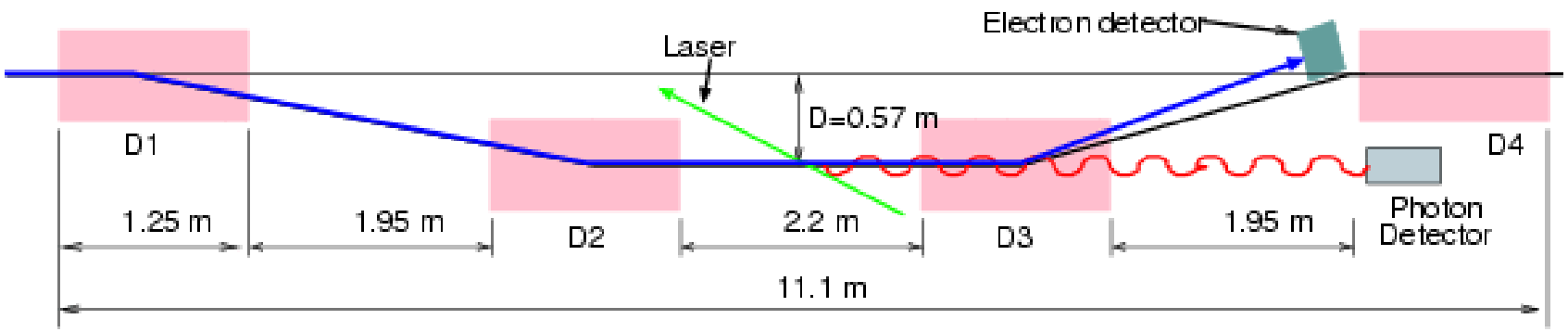
Construction new Compton polarimeter ($\vec{e} + \vec{\gamma} \rightarrow e + \gamma$)

- Compton scattering of electrons on polarized laser beam
- Continuous, non-destructive, high precision measurements
- Systematic uncertainty of 1% (for absolute measurements)

The Q_{Weak} Experiment: Beam Polarimetry

Compton polarimeter

- Beam: 150 μA at 1.165 GeV
- Chicane: interaction region 57 cm below straight beam line
- Laser system: 532 nm green laser
  - 10 W CW laser with low-gain cavity
- Photons: $PbWO_4$ scintillator in integrating mode
- Electrons: Diamond strips with 200 μm pitch



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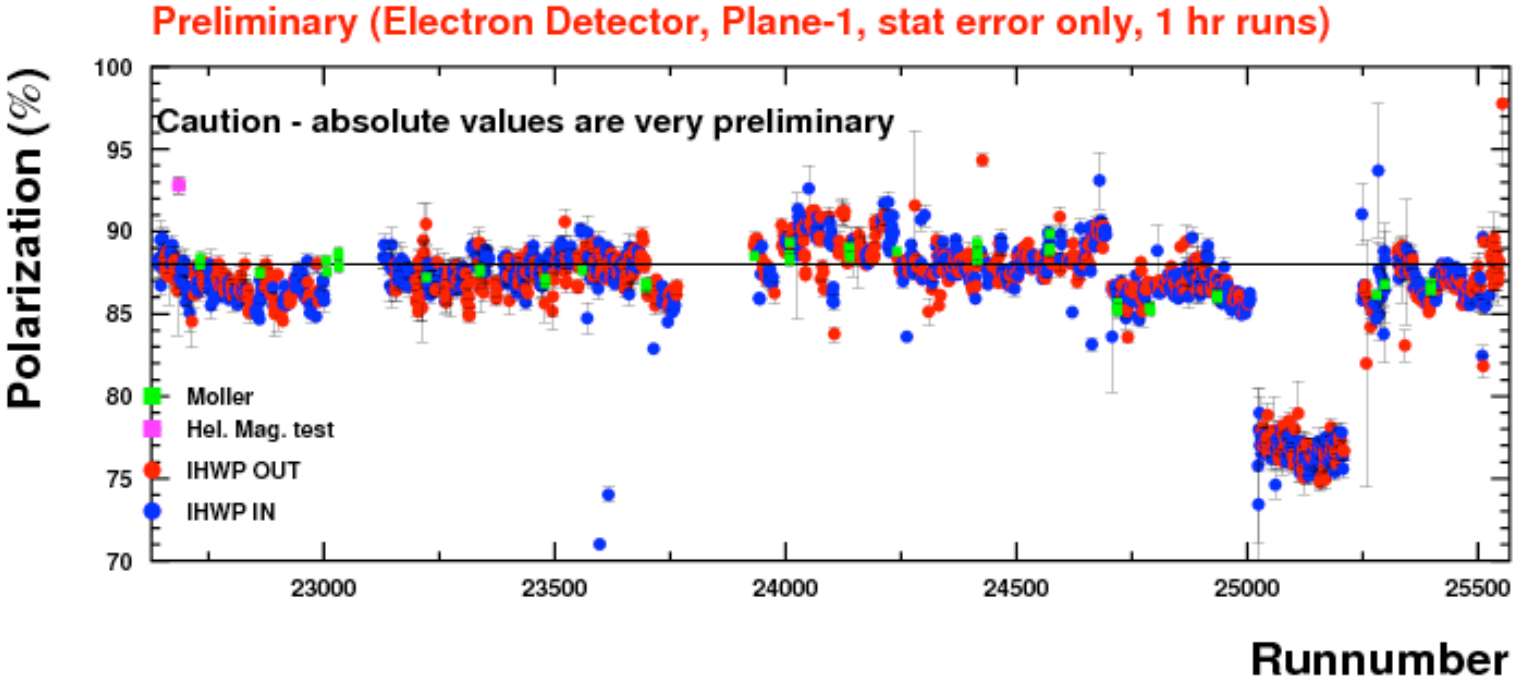


Møller polarimetry

- New beamline, refurbished
- Invasive measurements
- Polarization larger than anticipated: 86% to 88%

Compton polarimetry

- Excellent performance
- Continuous measurements
- Operates at full 180 μA
- Great statistical precision

The Q_{Weak} Experiment: Tracking Mode

Reasons for a tracking system?

- Determine Q^2, note: $A_{meas} \propto Q^2 \cdot (Q_W^p + Q^2 \cdot B(Q^2))$
- Main detector light output and Q^2 depend on position
- Contributions from inelastic background events

Instrumentation of only two octants

- Horizontal drift chambers (HDC) for front region
- Vertical drift chambers (VDC) for back region
- Rotation allows measurements in all eight octants

Track reconstruction

- Straight tracks reconstructed in front and back regions
- Front and back partial tracks bridged through QTOR field

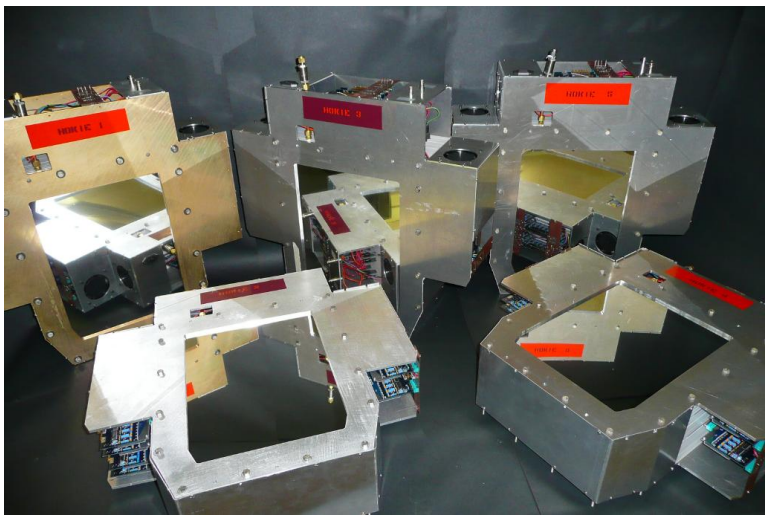
The Q_{Weak} Experiment: Tracking Mode

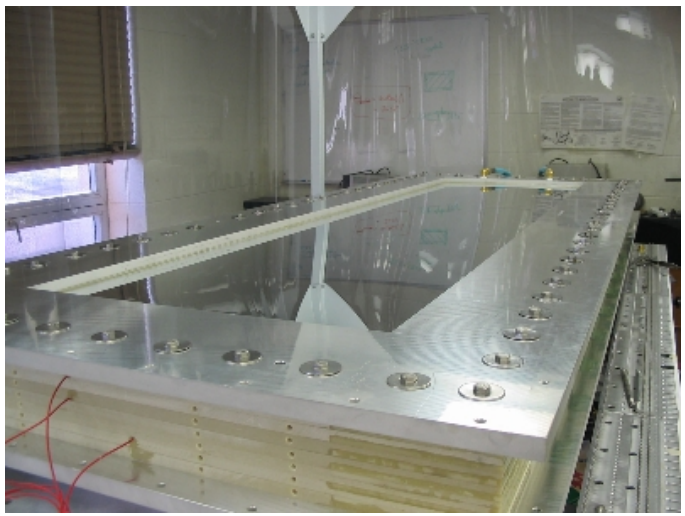
Horizontal drift chambers

- 32 wires in 0.5 m wide planes
- 12 planes per octant
- 2 instrumented octants
- Constructed at Va Tech

Vertical drift chambers

- 181 wires in 2 m long planes
- 4 planes per octant (65° tilt)
- 2 instrumented octants
- Constructed at W&M





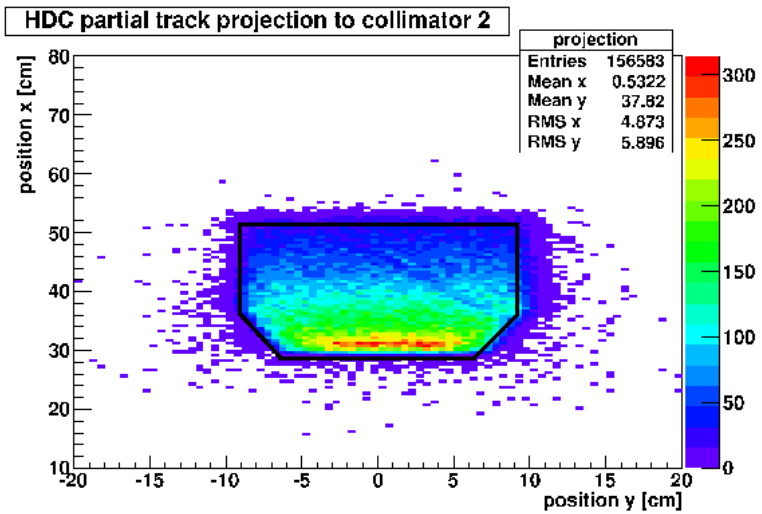
The Q_{Weak} Experiment: Tracking Mode

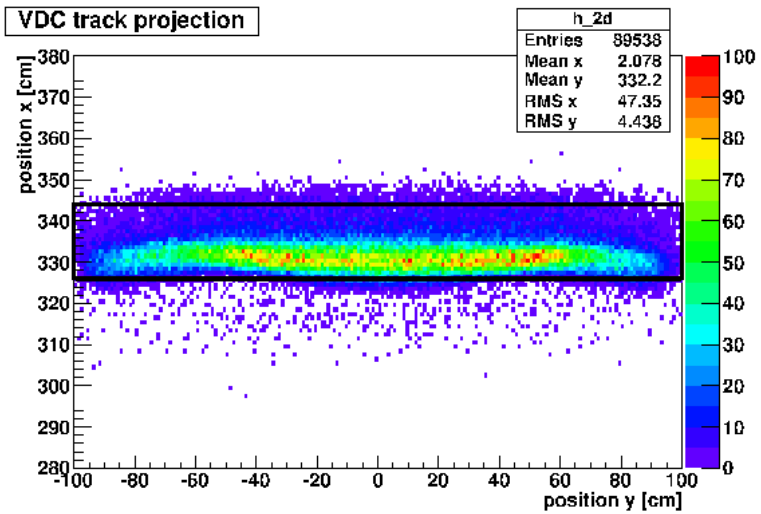
Horizontal drift chambers

- 32 wires in 0.5 m wide planes
- 12 planes per octant
- 2 instrumented octants
- Constructed at Va Tech

Vertical drift chambers

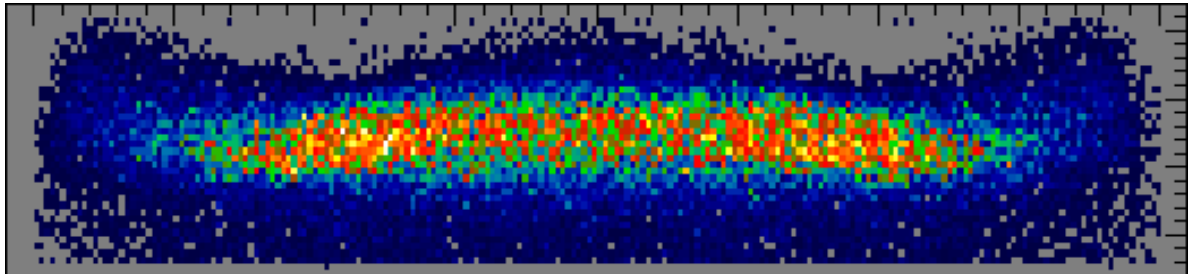
- 181 wires in 2 m long planes
- 4 planes per octant (65° tilt)
- 2 instrumented octants
- Constructed at W&M



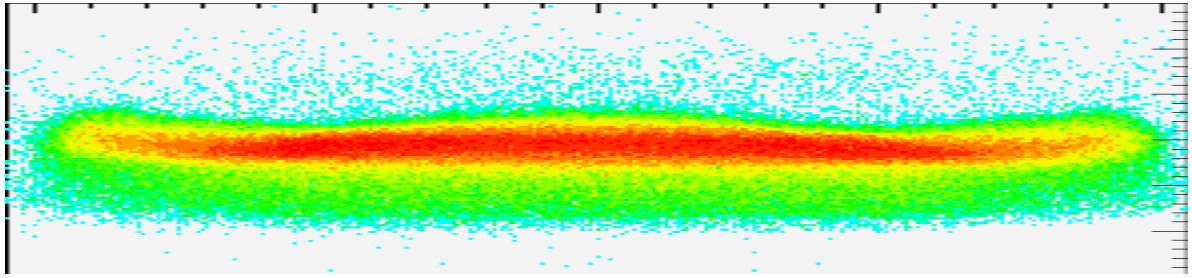


The Q_{Weak} Experiment: Tracking Mode

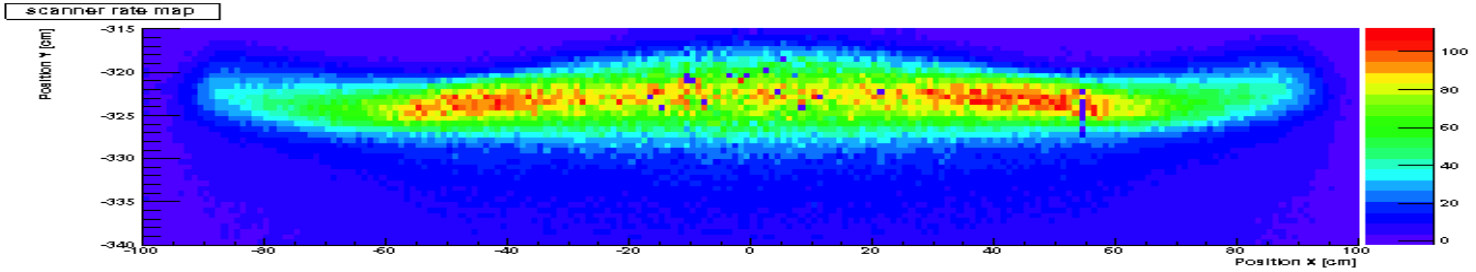
Simulation of electrons hitting main detector bar



Projection of reconstructed tracks to detector bar

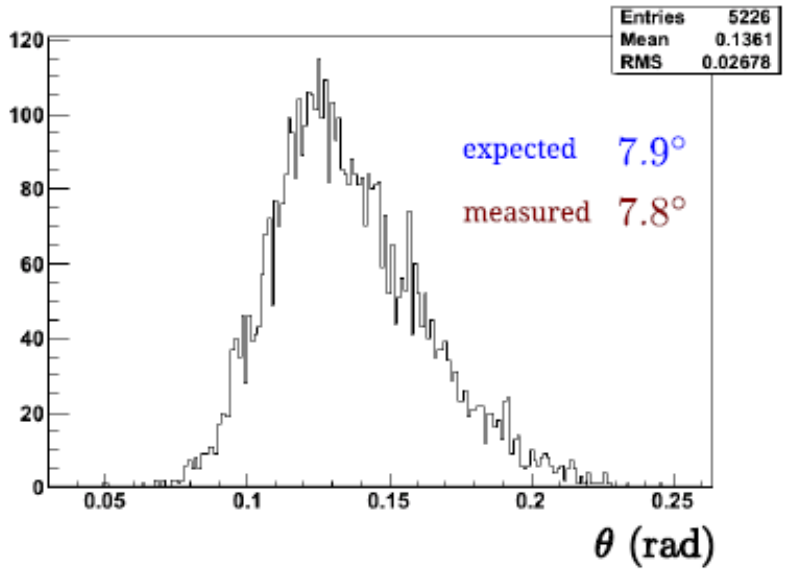


Focal plane scanner detector (1 cm square quartz)

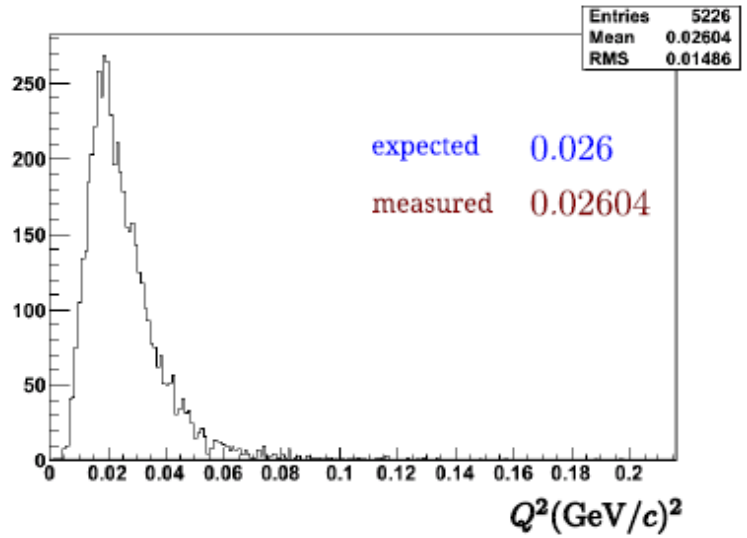


The Q_{Weak} Experiment: Tracking Mode

Reconstruction of angle θ (preliminary)



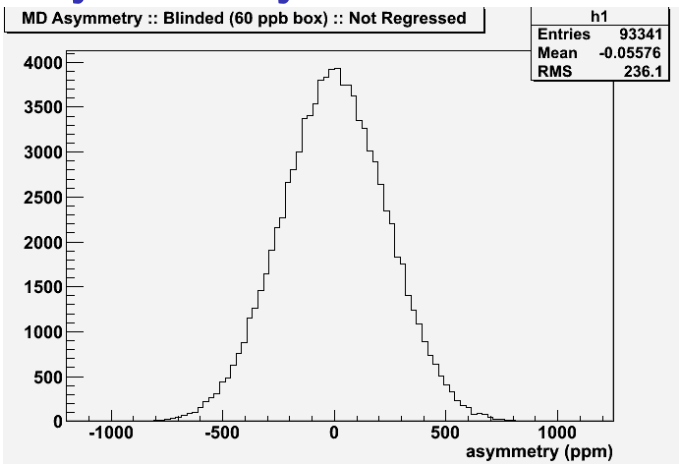
Reconstruction of momentum transfer Q^2 (preliminary)



- Periodic tracking runs at 50 pA (HDC/VDC) to few nA (VDC)
- VDC track resolution of 250 μm meets design goal
- HDC track resolution of 350 μm (work ongoing)
- Required precision of 0.5% on value of Q^2 is feasible

Data Quality: Understanding the Width

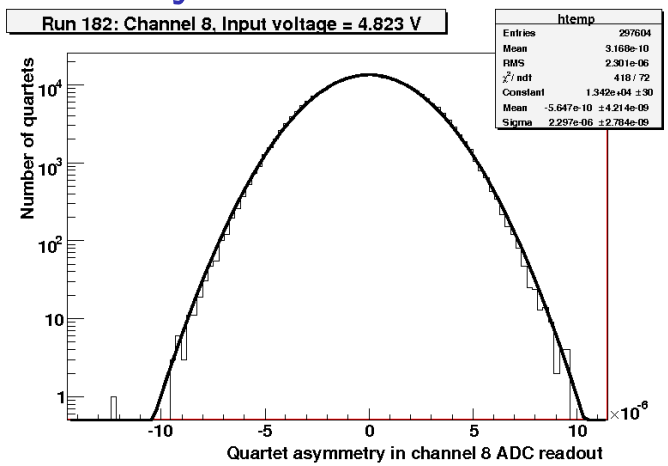
Asymmetry width



Measurement

- 240 Hz helicity quartets ($+--+$ or $-++-$)
- Uncertainty $= RMS/\sqrt{N}$
- 200 ppm in 4 milliseconds
- $<$ 1 ppm in 5 minutes

Battery width



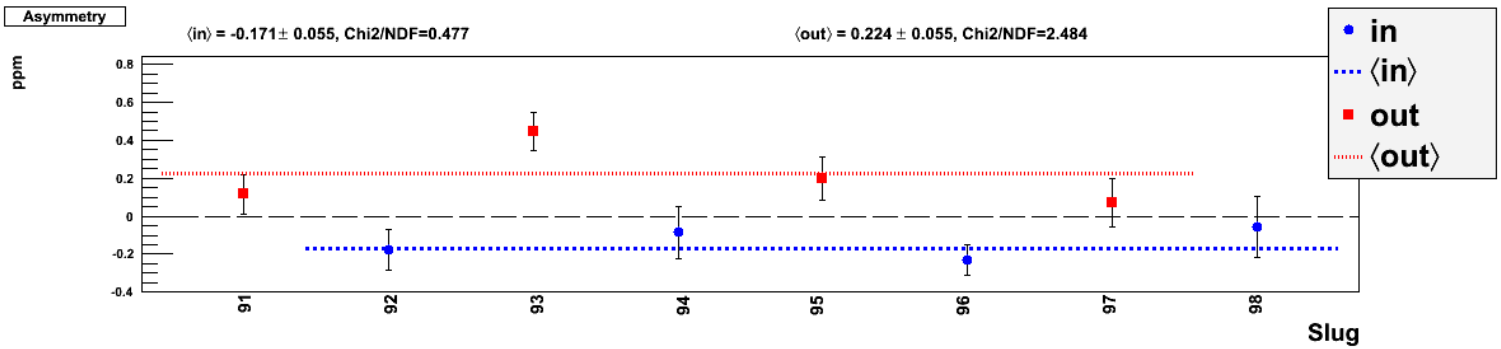
Asymmetry width

- Pure counting statistics $\approx$ 200 ppm
- $+$ detector resolution $\approx$ 90 ppm
- $+$ current monitor $\approx$ 50 ppm
- $+$ target boiling $\approx$ 57 ppm
- $=$ observed width $\approx$ 233 ppm

Data Quality: Slow Helicity Reversal

$\lambda/2$-plate and Wien filter changes

- Insertable $\lambda/2$-plate (IHWP) in injector allows 'analog' flipping helicity frequently
- Wien filter: another way of flipping helicity (several weeks)
- Each 'slug' of 8 hours consists of same helicity conditions



- Preliminary asymmetries: 60 ppb blinded, not corrected, not regressed! And only 8 of hundreds of slugs...
- Average asymmetries are consistent with sign change

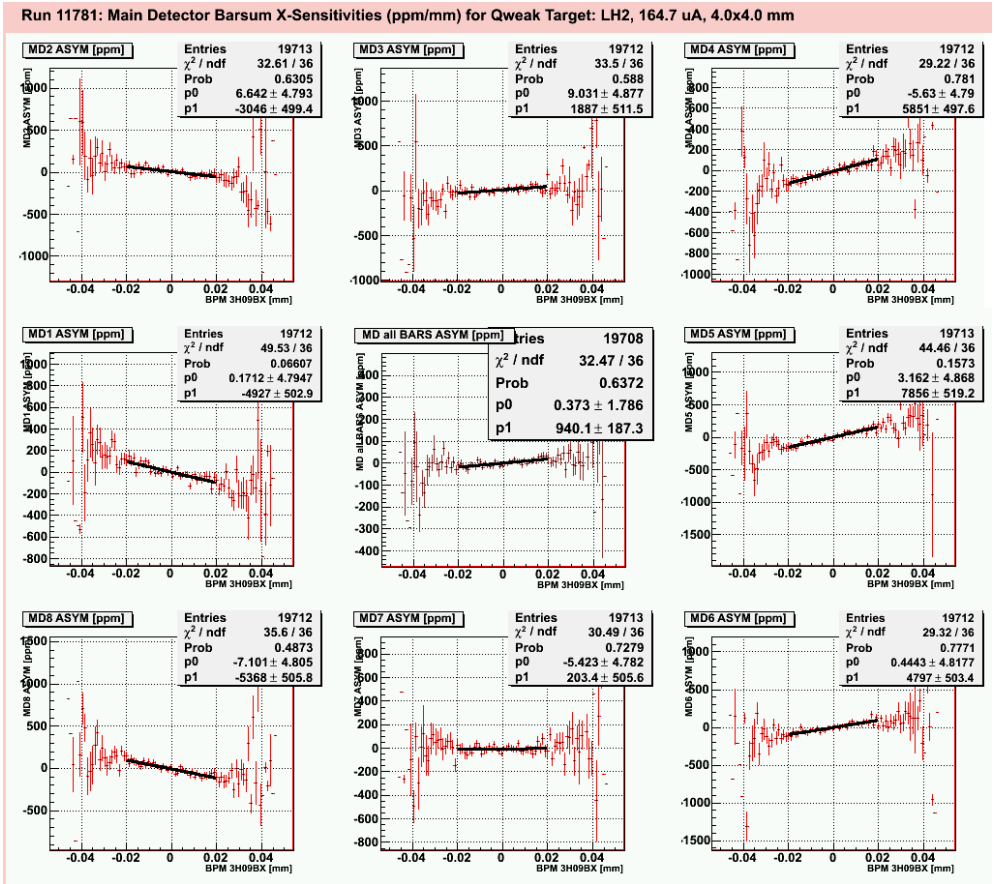
Data Quality: Helicity-Correlated Beam Properties

Natural beam motion

- Measured asymmetry correlated with beam position and angles
- False asymmetries
- Linear regression removes effect:

$$A_c = \sum_i \frac{\partial A}{\partial x_i} \Delta x_i$$

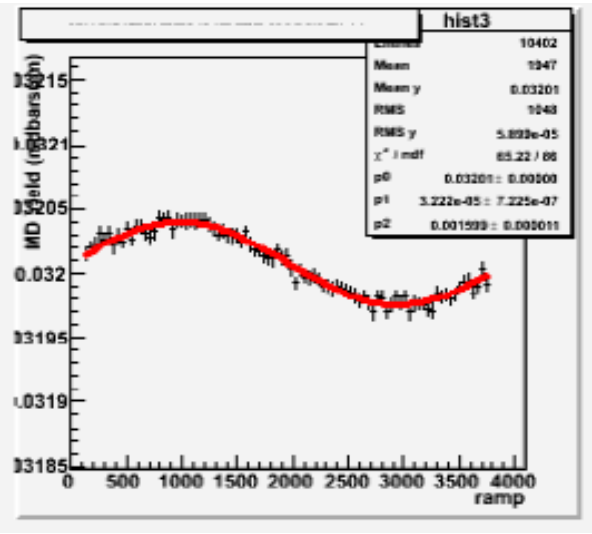
$$i = x, y, x', y', E$$

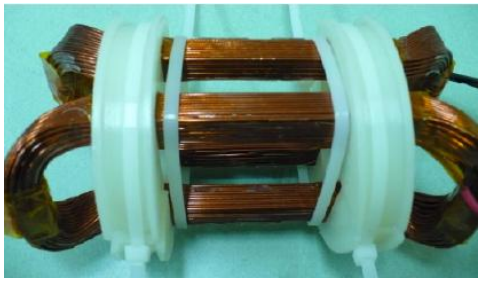


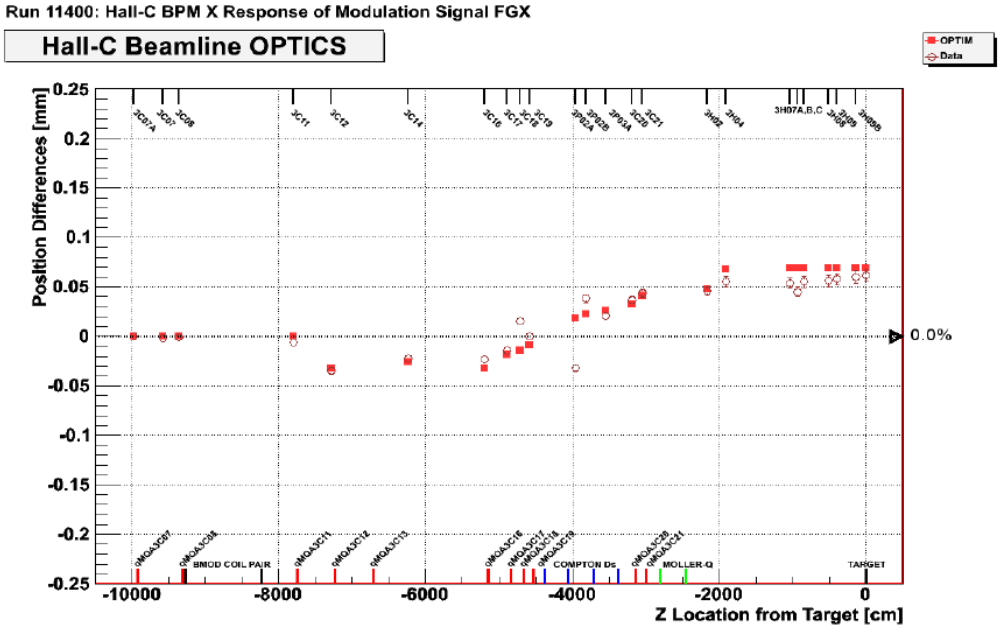
Data Quality: Helicity-Correlated Beam Properties

Beam modulation

- Deliberate motion
- $i = x, y, x', y', E$







- Sensitivity slopes $\frac{\partial A}{\partial x_i}$ determined from natural beam motion or from beam modulation $\rightarrow$ results consistent between methods
- Actual regression corrections smaller than specifications

Ancillary Measurements

Potential false asymmetries

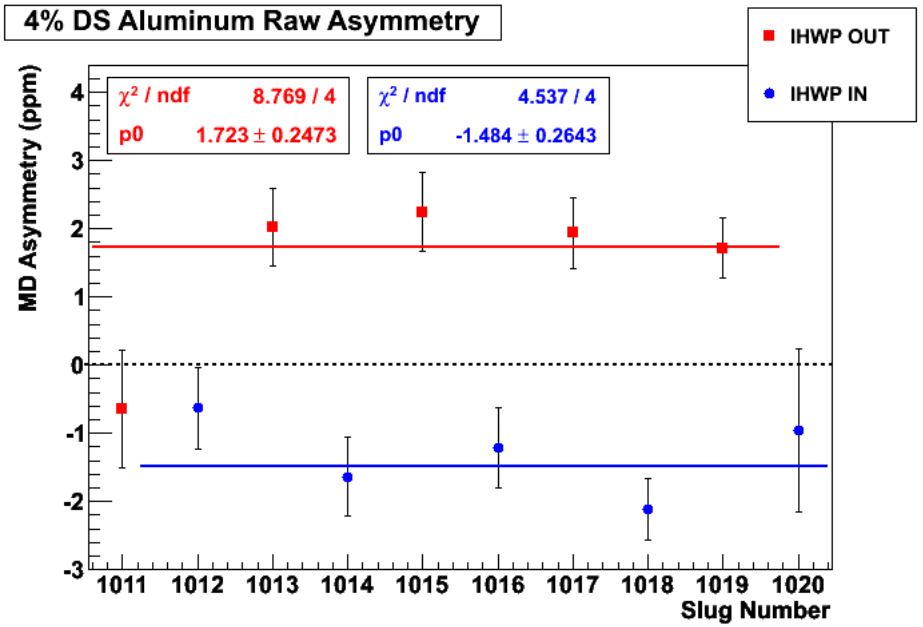
- Small contributions to number of events, of order 1%
- But from processes with large asymmetries, of order ppm!
- Result in significant corrections, of order 10 ppb

Processes:

- Aluminum target cell walls ($Q_W^n = 1$, large asymmetry)
- Inelastic processes ($N \rightarrow \Delta$)
- Transverse spin, azimuthal asymmetry (parity-conserving)

Ancillary Measurements: Background Processes

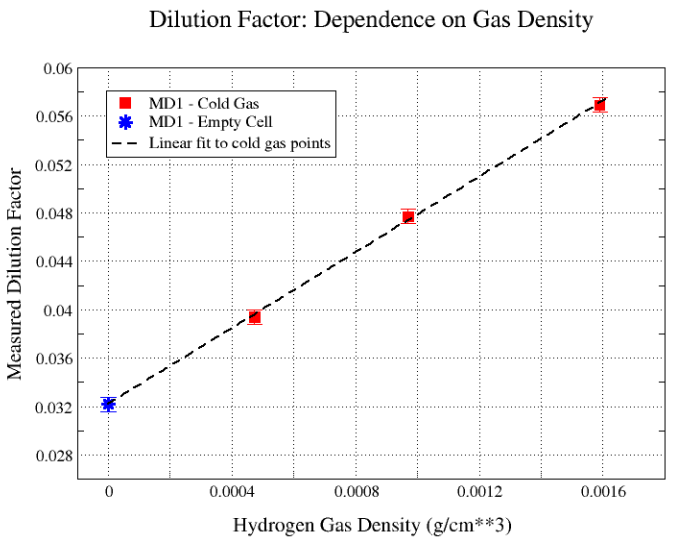
Aluminum asymmetry (preliminary)



- Asymmetry consistent with order of magnitude expected

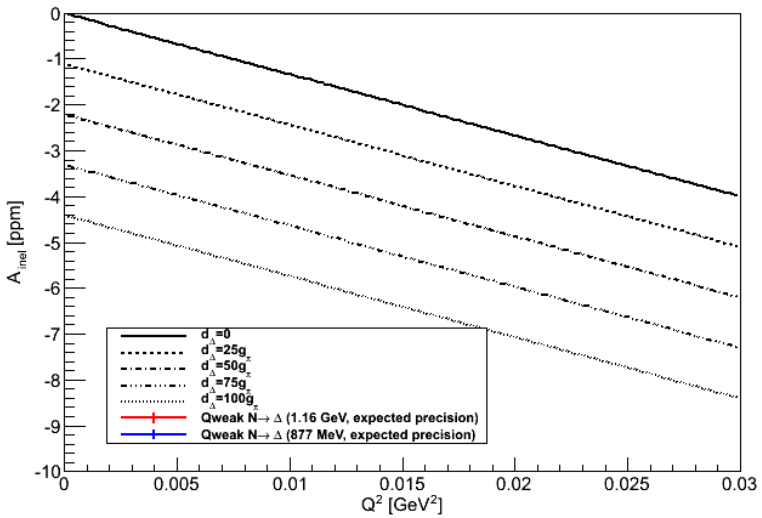
- Asymmetry: few ppm
- Dilution f of 3%
- Correction $\approx$ 20%

Dilution measurement (preliminary)



Ancillary Measurements: Background Processes

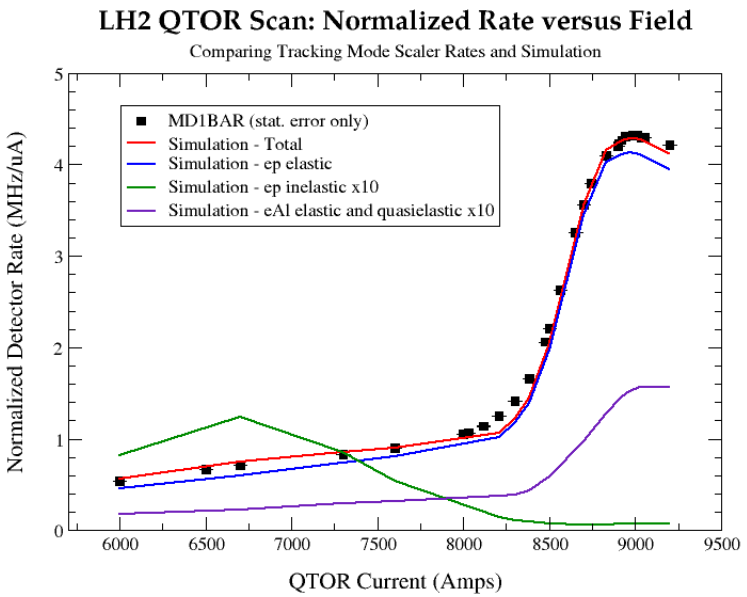
$N \rightarrow \Delta$ asymmetry (projected)



- In analysis, no result yet
- Expected precision 1 ppm
- $Q^2 = 0.025\,\mathrm{GeV}^2$

- Asymmetry: few ppm
- Dilution f of 0.1%
- Correction $\approx 1\%$

Simulation benchmark (preliminary)



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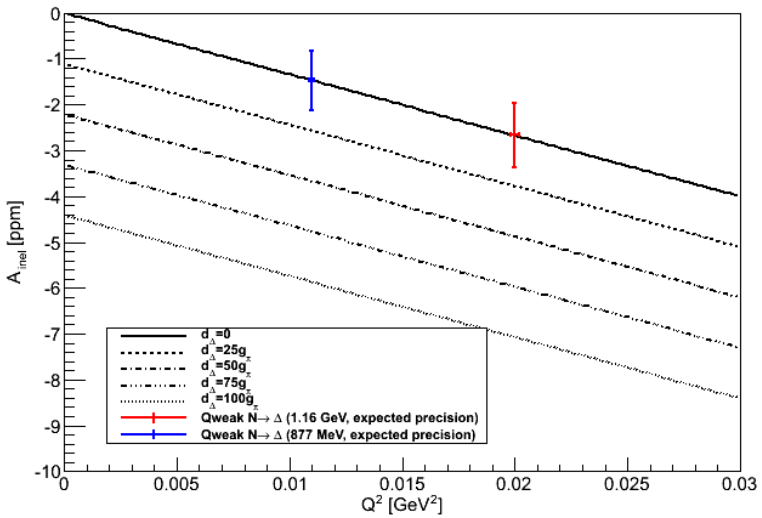

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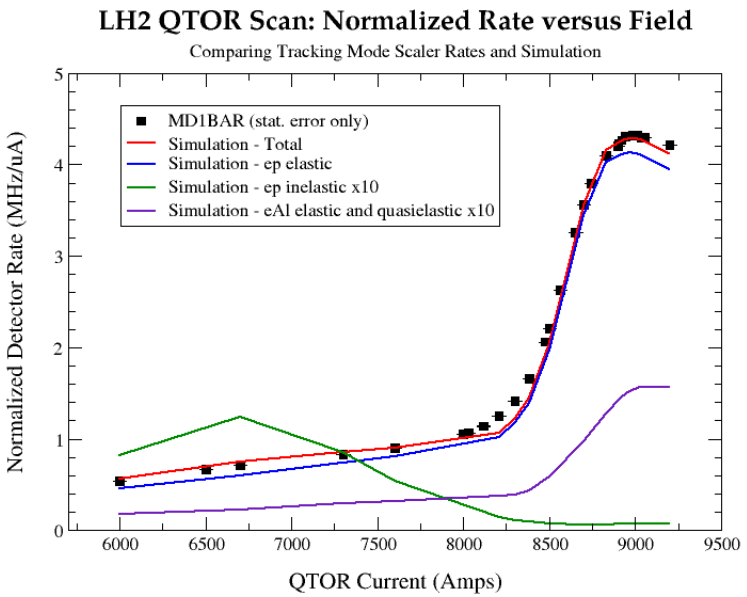


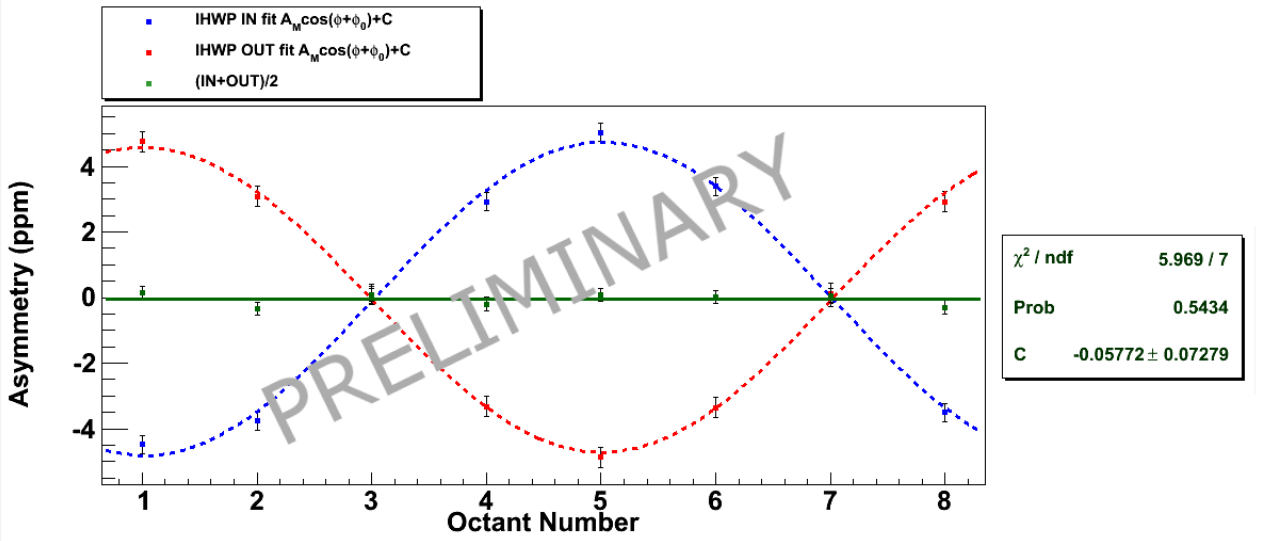
Ancillary Measurements: Transverse Asymmetry

- Transversely polarized beam on unpolarized target
- Parity-conserving (T-odd) transverse asymmetry of order ppm

$$B_n = \frac{2\Im(T_{1\gamma}^* \cdot T_{2\gamma})}{|T_{1\gamma}|^2}$$

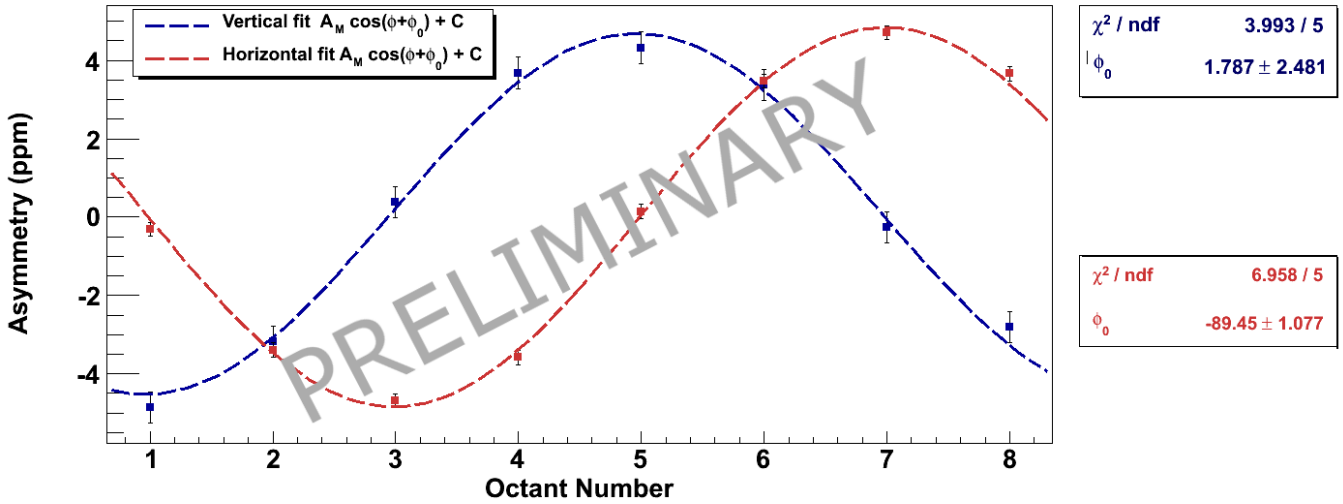
- Access to imaginary part of 2-photon exchange amplitude $T_{2\gamma}$
- False asymmetry for parity-violating asymmetry A_{PV} due to residual transverse polarization and broken azimuthal symmetry

Ancillary Measurements: Transverse Asymmetry



- Vertical polarization: cancellation with helicity reversal
- Horizontal polarization: 90° phase shift from vertical
- Shown asymmetries not corrected for backgrounds or polarization
- Preliminary transverse asymmetry: (by B. Waidyawansa)
  $\mathbf{B_n = -5.27 \pm 0.07}(\text{stat}) \pm \mathbf{0.14}(\text{syst})$
- Transverse asymmetry leakage in $A_{PV} < 2\,\text{ppb}$

Ancillary Measurements: Transverse Asymmetry



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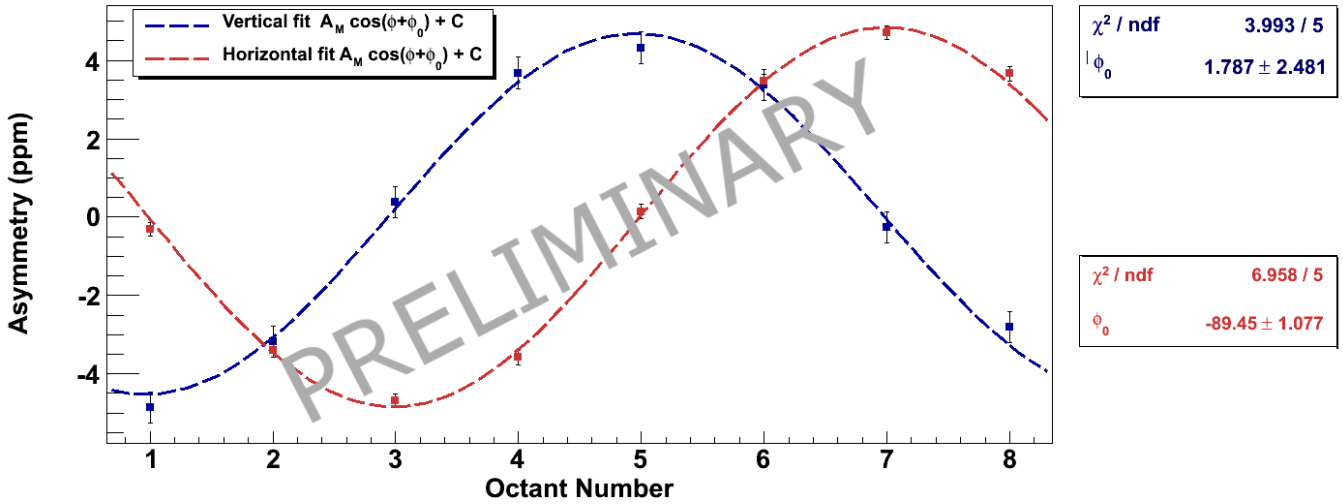

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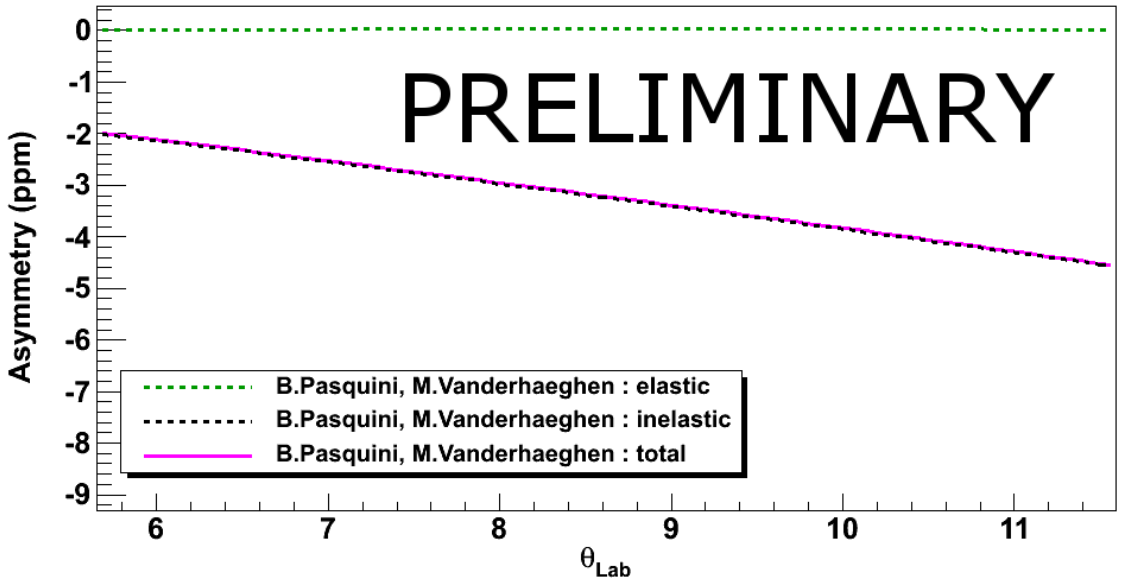

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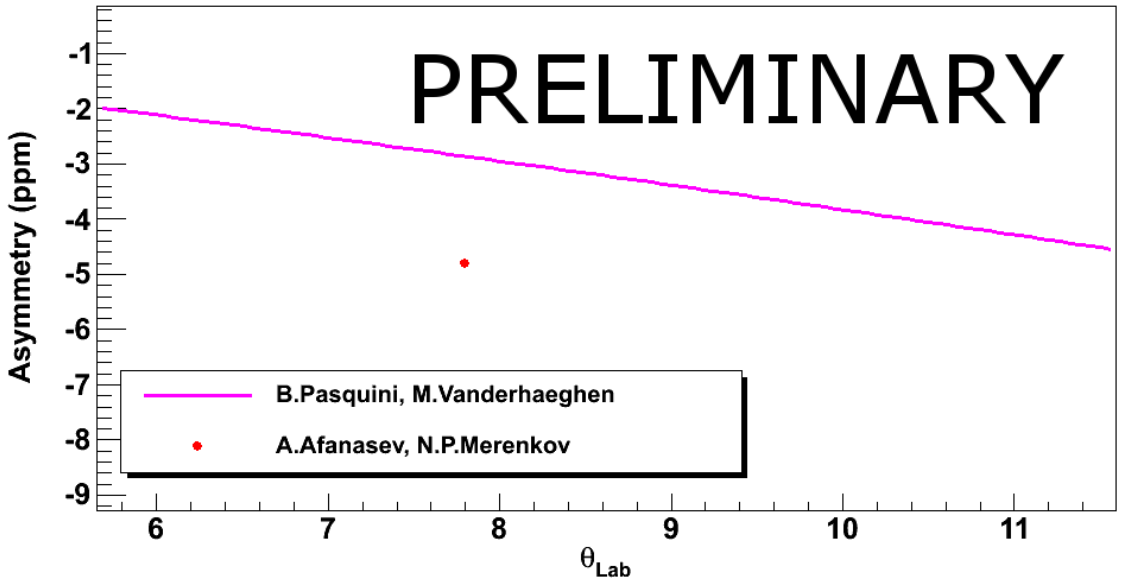
- Afanasev & Merenkov: forward Compton amplitudes from real photo-production
- $E = 1.160\,\text{GeV}$, $\theta = 7.8^\circ$, $Q^2 = 0.026\,\text{GeV}^2$
- Other measurements: 0.877 GeV and 3.36 GeV, on Al and C

Ancillary Measurements: Transverse Asymmetry



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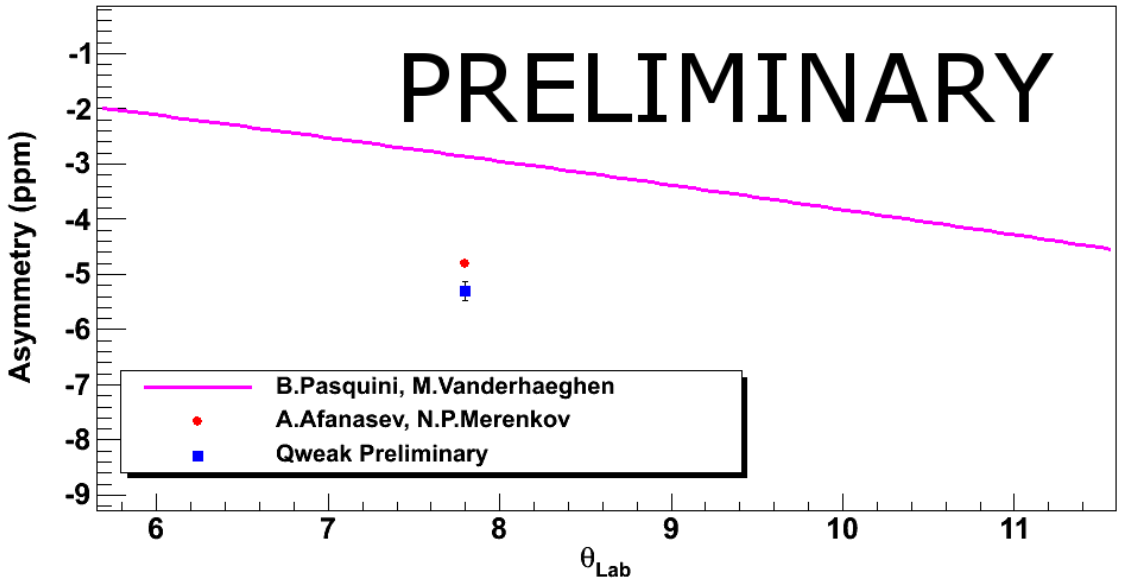

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Summary

The Q_{Weak} experiment

- Elastic $\vec{e}$-p scattering on liquid hydrogen target
- Precision measurement of a proton weak charge $Q_W^p \approx 0$, quantity suppressed by fundamental symmetries

Data-taking completed successfully

- Operated at very high luminosity of $2 \cdot 10^{39}\,\mathrm{cm}^2\mathrm{s}^{-1}$
- Figure of merit $\propto P^2 I$ exceeded expectations
- Key subsystems worked well over entire running period
- Main detector asymmetry width of 235 ppm close to counting statistics (200 ppm) and excess understood
- Many systematic measurements taken

Summary

First preliminary results

- Transverse asymmetry on hydrogen:
  $B_n = -5.27 \pm 0.07(\text{stat}) \pm 0.14(\text{syst})$ (preliminary)

Upcoming results

- Inelastic N$\rightarrow \Delta$ asymmetry
- Aluminum asymmetry
- Weak charge Q^p_{Weak}: 25% (later this year. . .), 8%, 4%

D. Androic, D. Armstrong, A. Asaturyan, T. Averett, J. Balewski, J. Beaufait, R. Beminiwattha, J. Benesch, F. Benmokhtar, J. Birchall, R.D. Carlini (PI), G. Cates, J.C. Cornejo, S. Covrig, M.M. Dalton, C.A. Davis, W. Deconinck, K. Dow, X. Deng, J. Diefenbach, K. Dow, J. Dowd, J. Dunne, D. Dutta, W. Duvall, M. Elaasar, R. Ent, J. Erler, W. Falk, J.M. Finn†, T.A. Forest, W. Franklin, M. Furic, D. Gaskell, M. Gericke, J. Grames, V. Gray, K. Grimm, F. Guo, M.H. Shabestari, 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, P. King, M. Kohl, E. Korkmaz, S. Kowalski, J. Leacock, J.P. Leckey, A. Lee, J.H. Lee, L. Lee, A. Lung, N. Luwani, S. MacEwan, D. Mack, J. Magee, R. Mahurin, J. Mammei, J. Martin, M. McHugh, N. McMahon, D. Meekins, J. Mei, R. Michaels, A. Micherdzinska, A. Mkrtchyan, H. Mkrtchyan, R. Munroe, K.E. Myers, A. Narayan, Nuruzzaman, A.K. Opper, S.A. Page, J. Pan, K. Paschke, S. Phillips, M. Pitt, B.(Matt) Poelker, J. Rajotte, W.D. Ramsay, M. Ramsey-Musolf, J. Roche, B. Sawatzky, T. Seva, R. Silwal, N. Simicevic, G. Smith, T. Smith, P. Souder, D. Spayde, A. Subedi, R. Subedi, R. Suleiman, V. Tadevosyan, E. Tsentalovich, W.T.H. van Oers, B. Waidyawansa, D. Wang, P. Wang, S. Wells, S.A. Wood, S. Yang, R. Young, S. Zhamkochyan, Z. Zhao, X. Zheng, D. Zou

Spokespersons (4), Project Manager (1), Graduate Students (22)

† deceased

College of William & Mary, University of Connecticut, Instituto de Fisica, Universidad Nacional Autonoma de Mexico, University of Wisconsin, Hendrix College, Louisiana Tech University, University of Manitoba, Massachusetts Institute of Technology, Thomas Jefferson National Accelerator Facility, Virginia Polytechnic Institute & State University, TRIUMF, University of New Hampshire, Yerevan Physics Institute, Mississippi State University, University of Northern British Columbia, Ohio University, Hampton University, University of Winnipeg, University of Virginia, George Washington University, Syracuse University, Idaho State University, University of Connecticut, Christopher Newport University, University of Zagreb

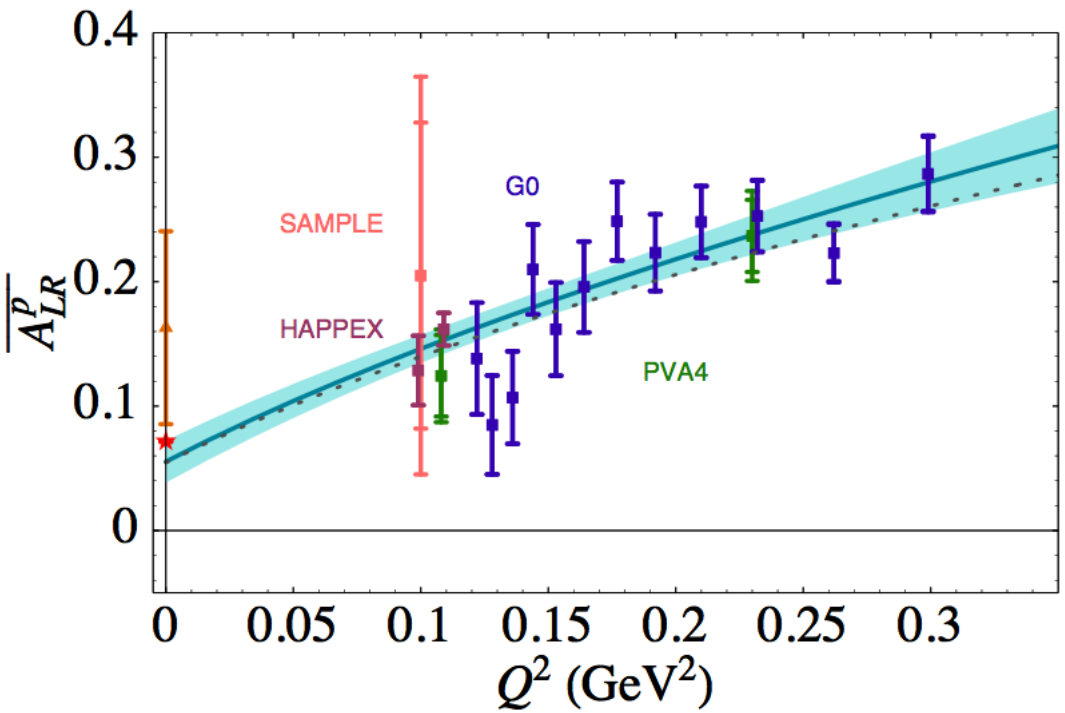
The Q_{Weak} Collaboration

Additional Material

Parity-Violating Electron Scattering

Reduced parity-violating asymmetry

$$\overline{A_{PV}}(p) = A_{PV}(p) \cdot \frac{4\pi\alpha\sqrt{2}}{-G_F Q^2} \xrightarrow{Q^2 \to 0} Q_W^p + Q^2 \cdot B(Q^2)$$



At $Q^2 = 0$

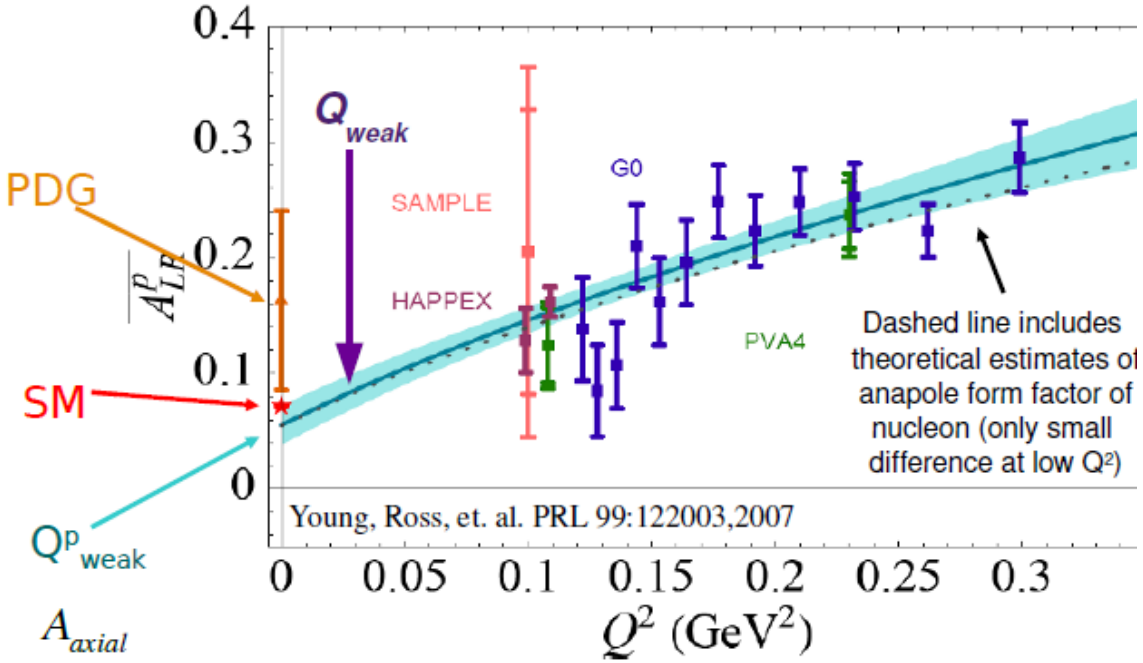
- PDG
- SM

Q_{Weak} Exp

- $Q^2 = 0.026\,\text{GeV}^2$

Divide out leading Q^2 dependence:

$$\overline{A^p_{LR}} \simeq Q^p_{weak} + B(Q^2)Q^2 + \ldots$$



$$A = A_{Q^p_w} + A_{hadronic} + A_{axial}$$

= - 0.17 ppm - 0.07 ppm - 0.01 ppm

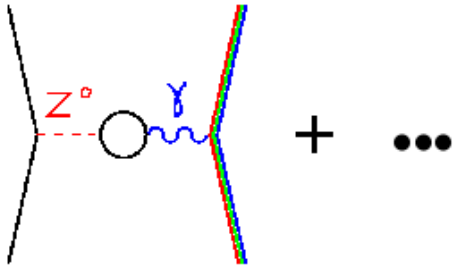
hadronic:
(31% of asymmetry)
contains $G^{\gamma}_{E,M}$ $G^{Z}_{E,M}$
Constrained by
HAPPEX, G⁰, MAMI PVA4

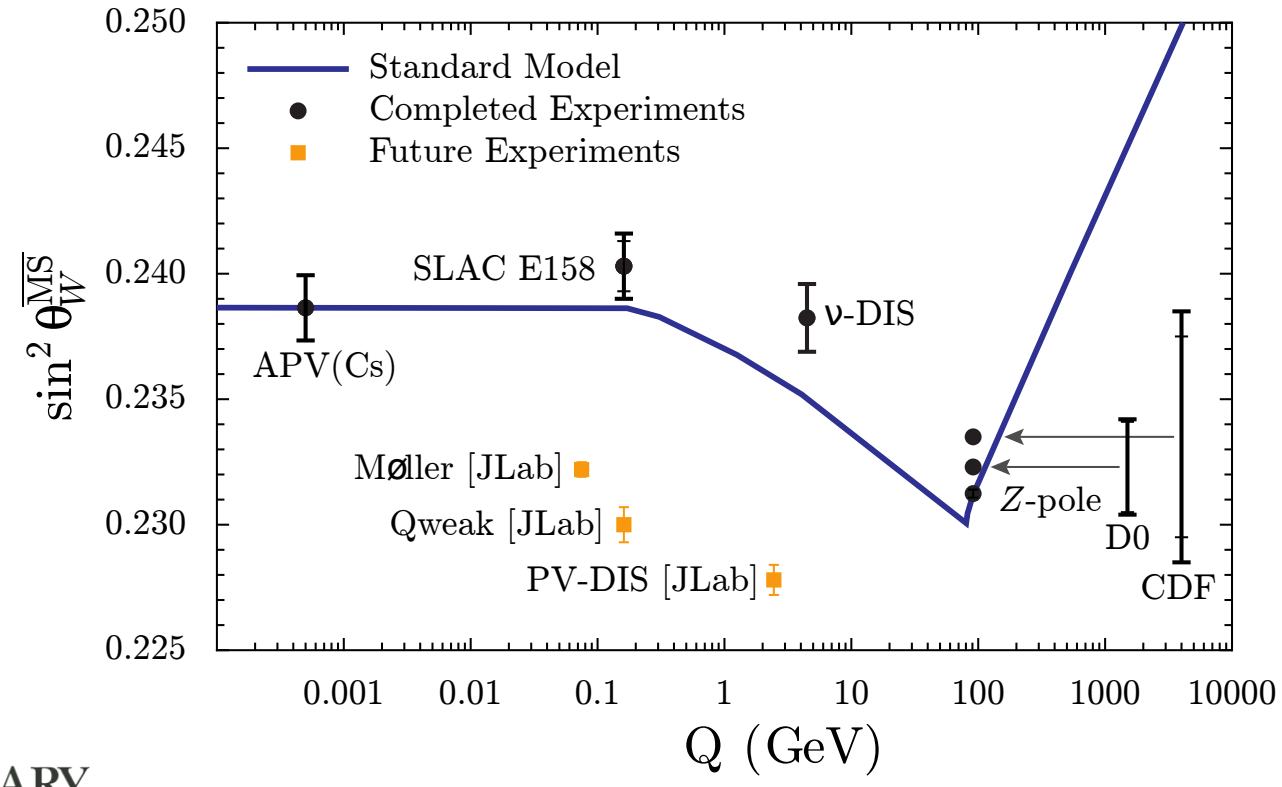
axial:
(4% of asymmetry)
contains G^{e}_{A}
large electroweak
radiative corrections
Constrained by G⁰
and SAMPLE

Parity-Violating Electron Scattering: $\sin^2\theta_W$

Running of $\sin^2\theta_W$ ($Q_W^p = 1 - 4\sin^2\theta_W$)

- Higher order loop diagrams
- $\sin^2\theta_W$ varies with Q^2





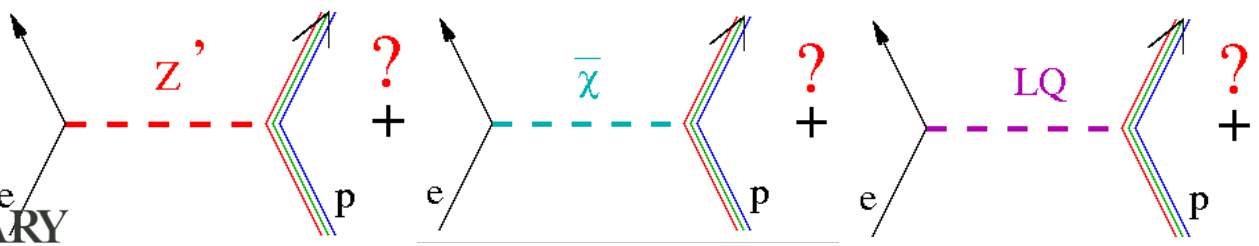
Sensitivity to New Physics

New physics

- Consider effective contact interaction
- Coupling constant g, mass scale Λ
- Effective charges $h_V^u = \cos\theta_h$ and $h_V^d = \sin\theta_h$

Effective Lagrangian

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



Sensitivity to New Physics

Lower bound on new physics (95% CL)

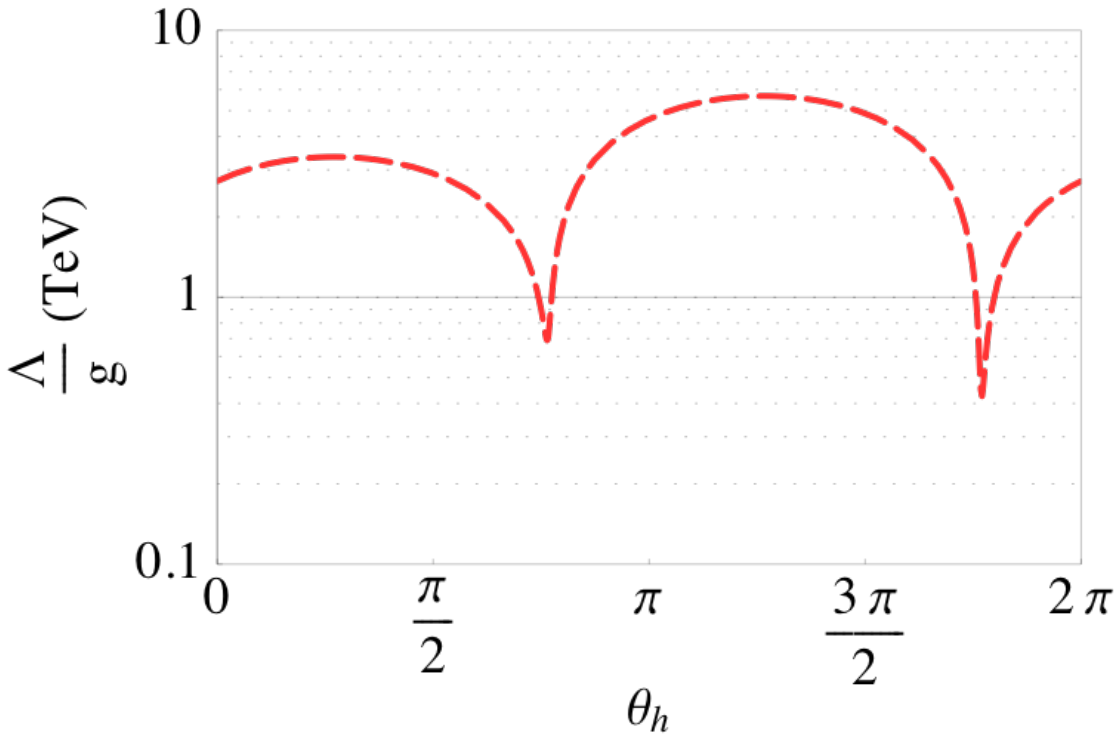


Figure: Young, Carlini, Thomas, Roche (2007)

Constraints from

- Atomic PV: $\frac{\Lambda}{g} > 0.4\ TeV$
- PV electron scattering: $\frac{\Lambda}{g} > 0.9\ TeV$

Projection Q_{Weak}

- $\frac{\Lambda}{g} > 2\ TeV$
- 4% precision

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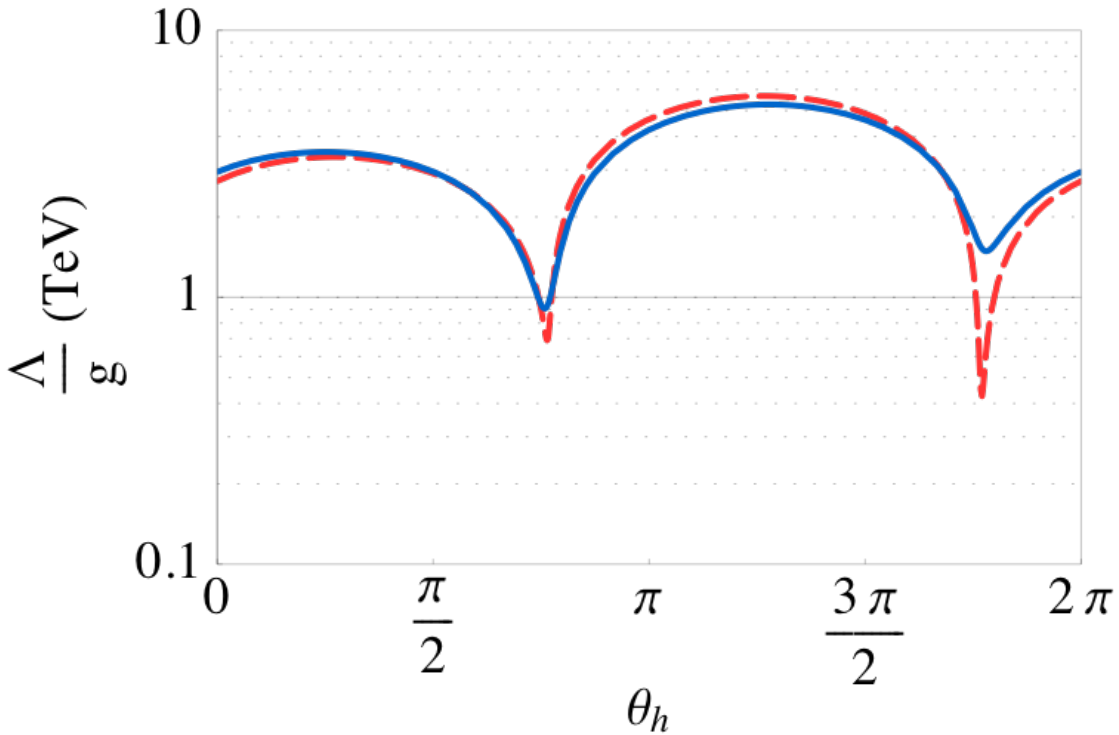

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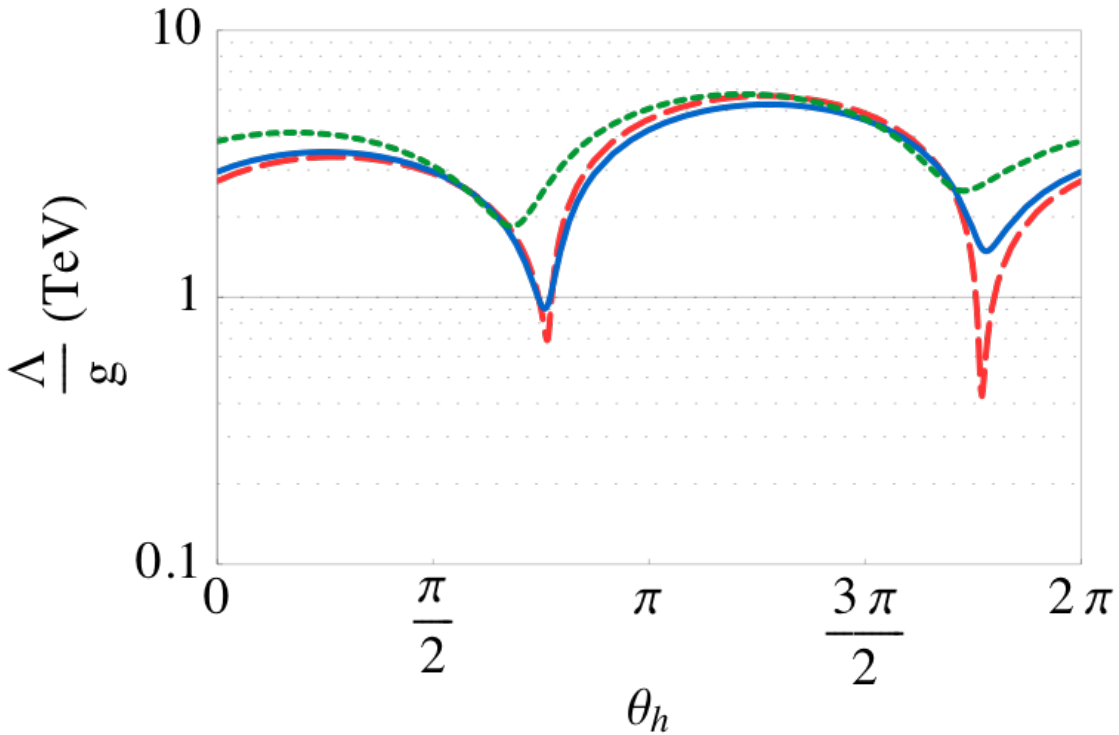

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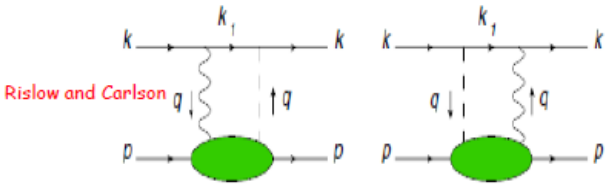
γZ Box Corrections near 1.16 GeV



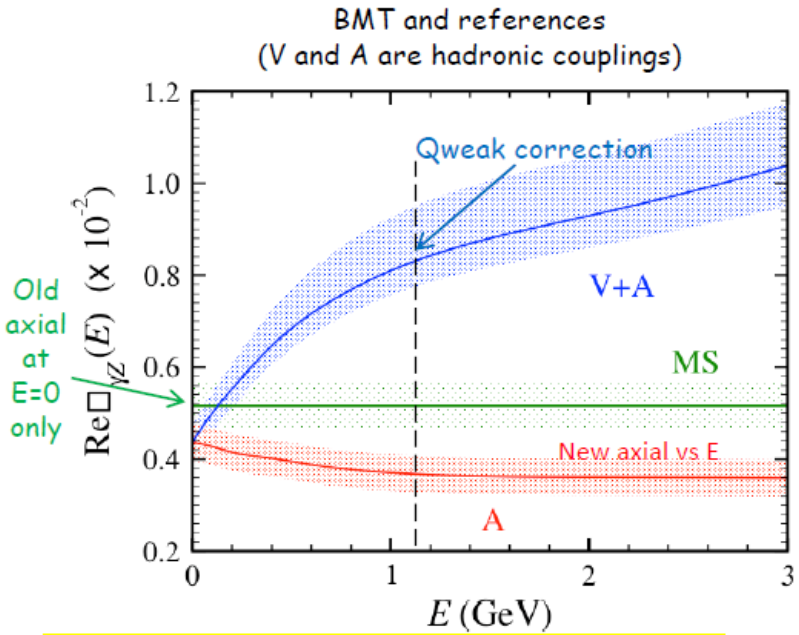
In 2009, Gorchtein and Horowitz showed the vector hadronic contribution to be significant and energy dependent.

This soon led to more refined calculations with corrections of ~8% and error bars ranging from ±1.1% to ±2.8%.

It will probably also spark a refit of the global PVES database used to constrain G_E^s, G_M^s, G_A.

PV Amplitude	Authors	Correction* @ E=1.165 (GeV)
$A^e x V^p$ (vanishes as E→0)	GH	0.0026+-0.0026**
	SBMT	$0.0047\ ^{+0.0011}_{-0.0004}$
	RC	0.0057±0.0009
	GHR-M	0.0054±0.0020
$V^e x A^p$ (finite as E→0)	MS (as updated by EKR-M)	0.0052±0.0005***
	BMT	0.0037±0.0004

*Does not include a small contribution from the elastic.
** 5.7%xQ_w^p(LO) = 0.0026. Q_w^p(LO) = 0.04532.
***Included in Q_w^p. For reference, Q_w^p =0.0713(8).



Forthcoming axial results for Q_w^n have the potential to impact the interpretation of Cs APV.

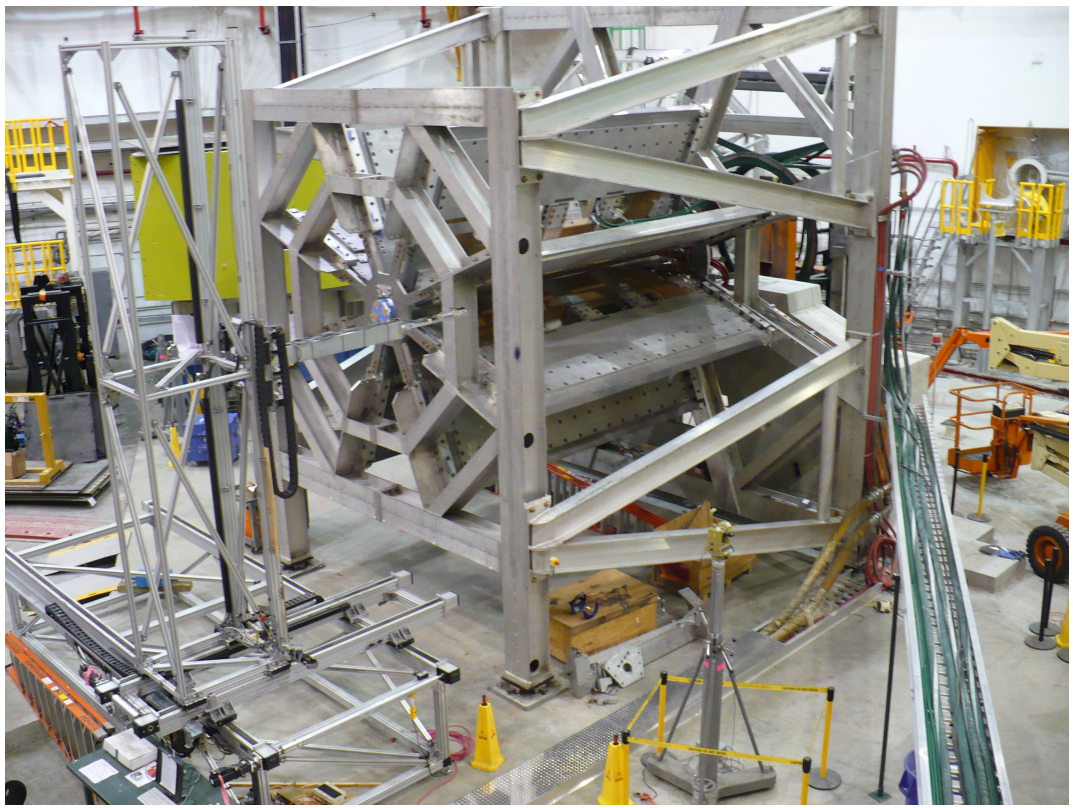
γZ Box Corrections near 1.16 GeV
A Partial Bibliography

PV Amplitude	Authors	Reference
$A^e x V^p$ (vanishes as E→0)	GH	Gorchtein & Horowitz, PRL **102**, 091806 (2009)
	SBMT	Sibirtsev, Blunden, Melnitchouk, andThomas, PRD **82**, 013011 (2010)
	RC	Rislow & Carlson, PRD **83**, 113007 (2011)
	GHR-M	Gorchtein, Horowitz, and Ramsey-Musolf, PRC **84**, 015502 (2011)
$V^e x A^p$ (finite as E→0)	MS	Marciano and Sirlin, PRD **27**, 552 (1983), PRD **29**, 75 (1984)
	EKR-M	Erler, Kurylov, and Ramsey-Musolf, PRD **68**, 016006 (2003)
	BMT	Blunden, Melnitchouk, and Thomas, PRL **107**, 081801 (2011)

The Q_{Weak} Experiment: Toroidal Magnet (QTOR)

QTOR installed in Hall C

- Full assembly and power supply tests
- Mapped at half field, within tolerances

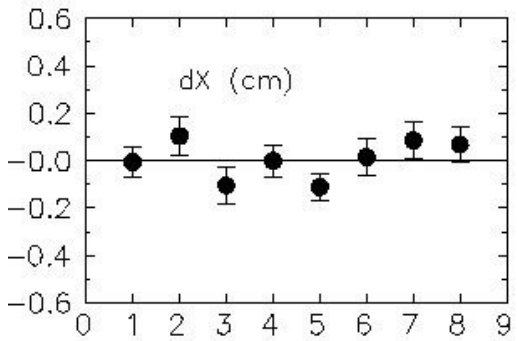


QTOR properties

- Warm coils
- 10000 A
- 6 m high

Large coils aligned to 1 mm

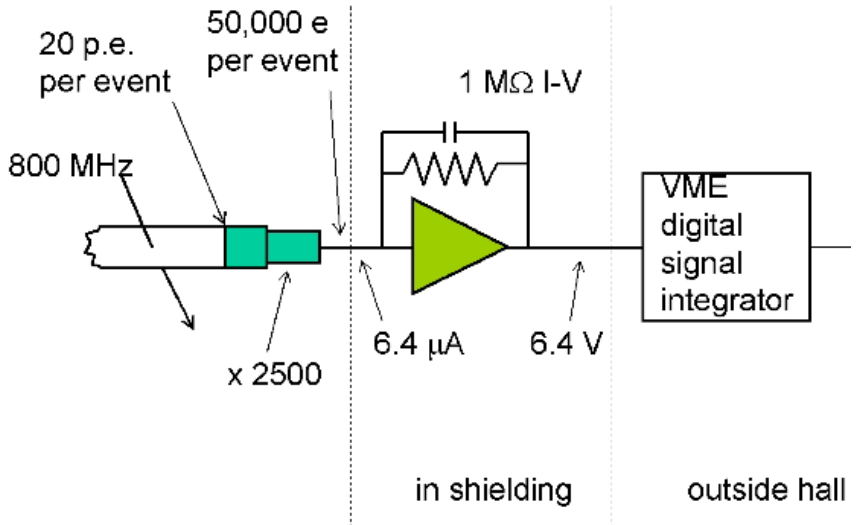
At MIT/Bates



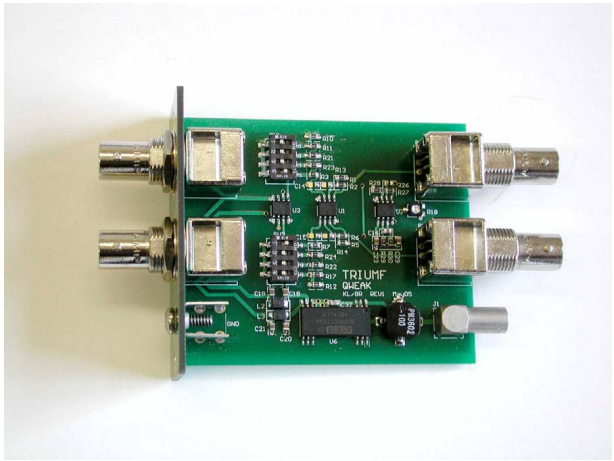
The Q_{Weak} Experiment: Main Detector

Low noise electronics

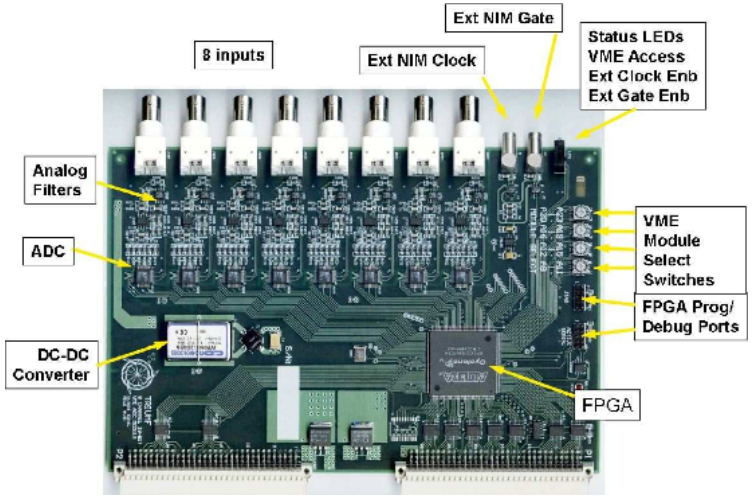
- Event rate: 800 MHz/PMT
- Asymmetry of only 0.2 ppm
- Low noise electronics (custom design, TRIUMF)



I-V Preamplifier



18-bit 500 kHz sampling ADC



Delivered, tested: noise is 3 times lower than counting statistics

The Q_{Weak} Experiment: Systematic Uncertainties

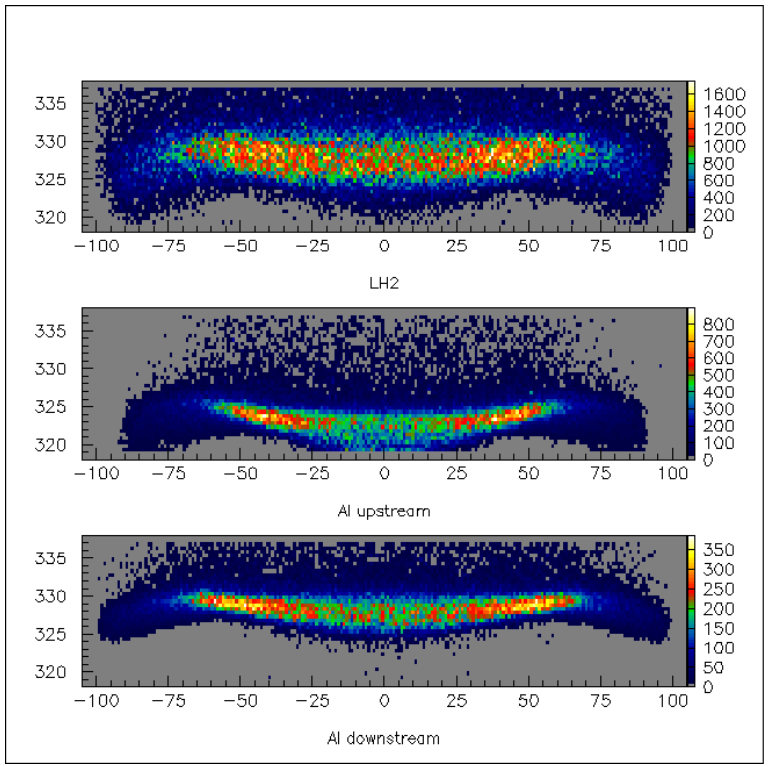
Reminder: weak vector charges

- Proton weak charge $Q_W^p \approx -0.072$
- Neutron weak charge $Q_W^n = -1$

Sources of neutron scattering

- Al target windows
- Secondary collimator events
- Small number of events, but huge false PV asymmetry

Al target windows



The Q_{Weak} Experiment: Systematic Uncertainties

Largest projected uncertainties on Q_W^p

- Total uncertainty on Q_W^p: 4.1%
- Statistical uncertainty: 3.2%
- Hadronic structure: 1.5%
- Beam polarimetry: 1.5%
- Measurement of Q^2: 1.0%
- Background events: 0.7%
- Helicity-correlated beam properties: 0.7%

Responsibilities of MIT group

- Track reconstruction/momentum determination software
- Construction of Compton polarimeter

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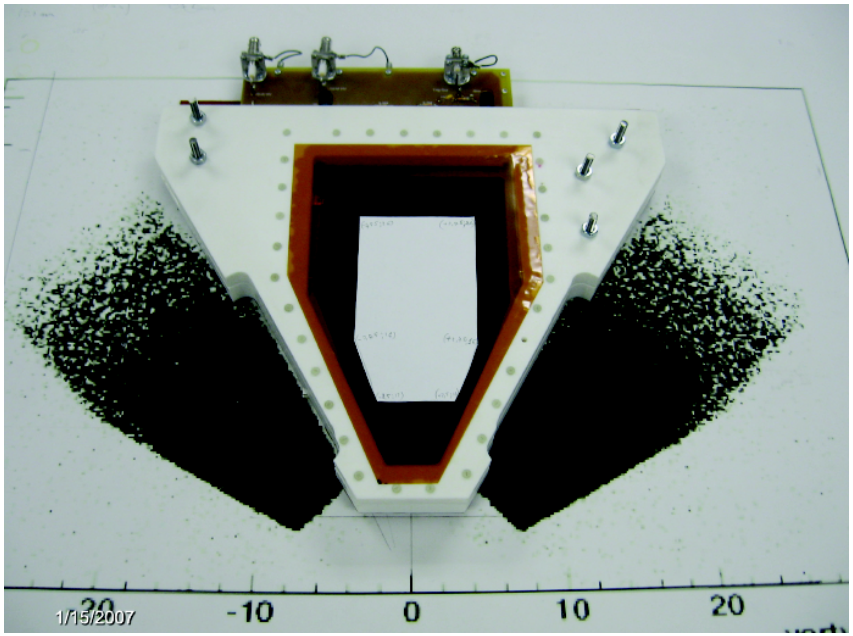
The Q_{Weak} Experiment: Tracking Mode

Gas-electron multiplier (GEM)

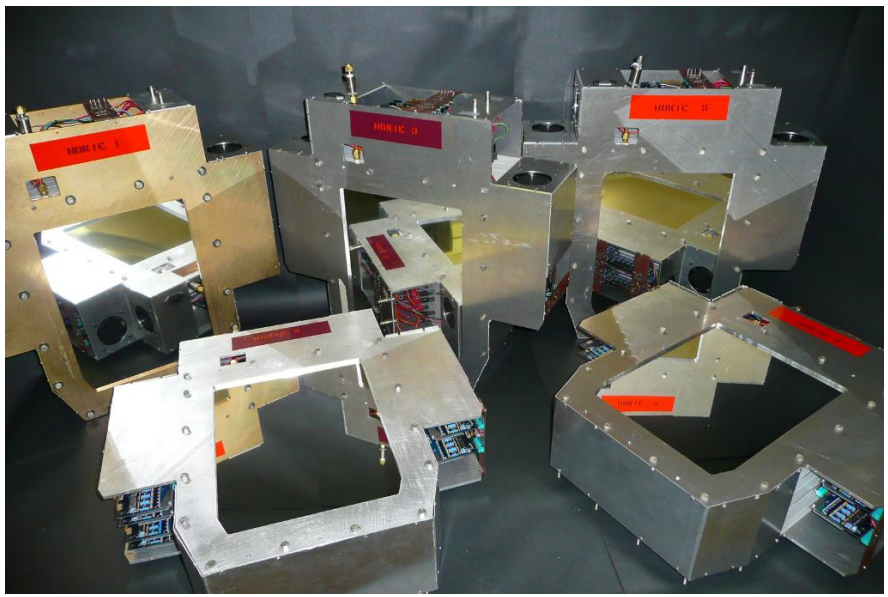
- Very close to target, very high dose
- GEMs have high radiation hardness
- Several days of radcon cool-down in GEM bunker
- Remotely controlled rotator mounted on collimator



The Q_{Weak} Experiment: Tracking Mode

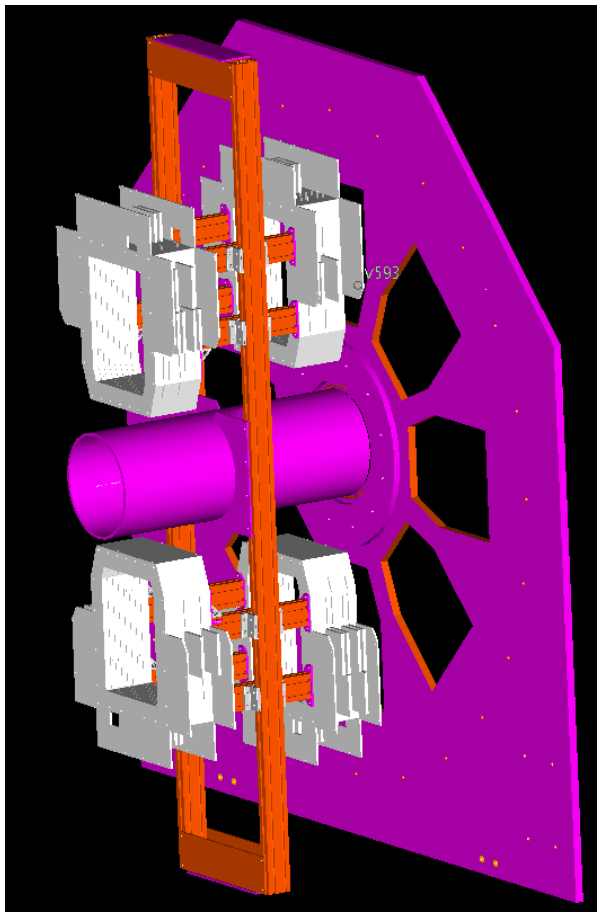
Horizontal drift chambers (HDC)

- 12 planes per octant
- u, v, x, u, v, x planes per assembly



- $4 + 1$ constructed, tested
- Residuals from cosmic events
- Ready for installation

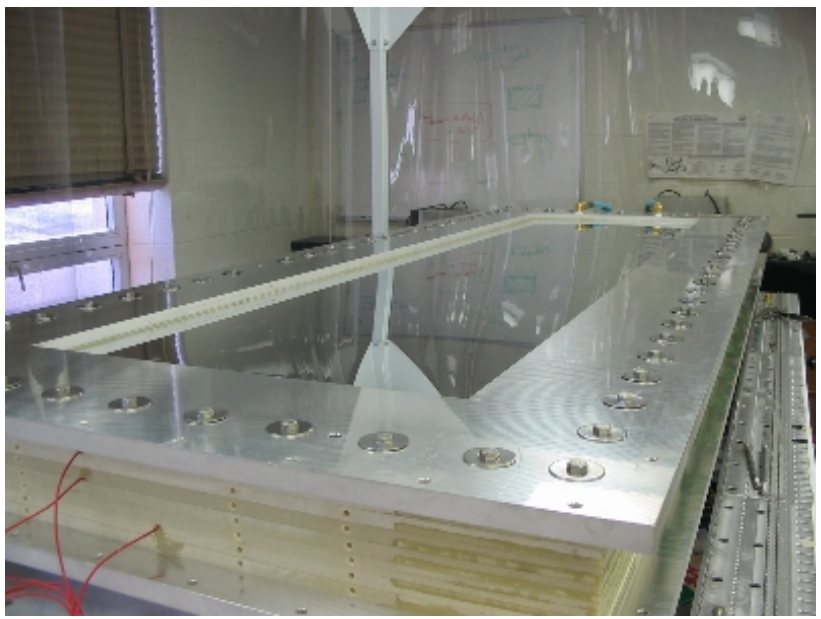
HDC rotator system



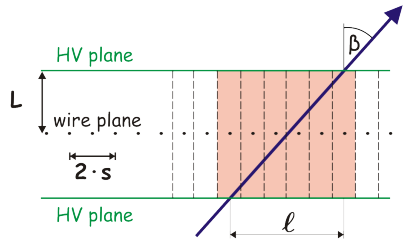
The Q_{Weak} Experiment: Tracking Mode

Vertical drift chambers (VDC)

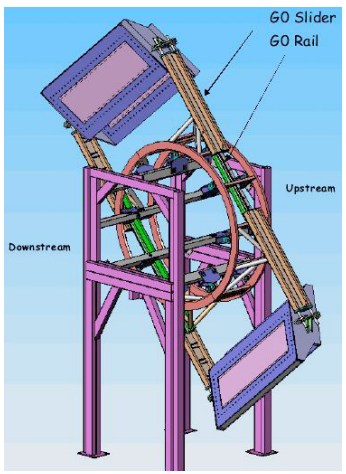
- 181 wires in 2 m wide planes
- u, v, u, v planes per assembly
- Multiplexed read-out on delay lines



Principle of operation



VDC rotator system



Electroweak Interaction: Running of $\sin^2\theta_W$

Atomic parity-violation on ^{133}Cs

- New calculation in many-body atomic theory
- Porsev, Beloy, Derevianko; arXiv:0902.0335 [hep-ph]
- Experiment: $Q_W(^{133}\mathrm{Cs}) = -73.25 \pm 0.29 \pm 0.20$
- Standard Model: $Q_W(^{133}\mathrm{Cs}) = -73.16 \pm 0.03$

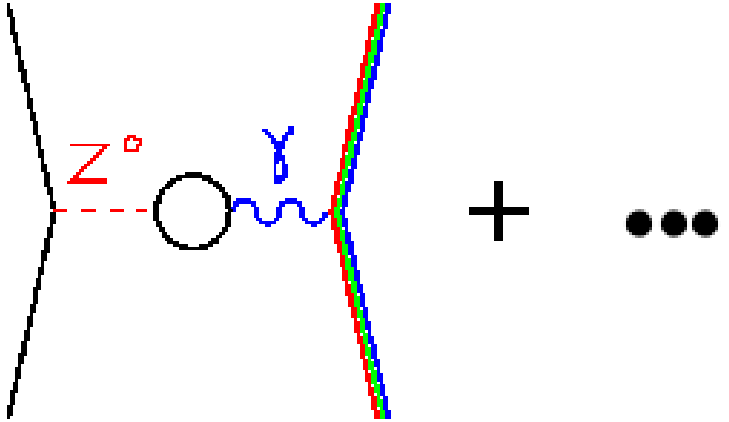
NuTeV anomaly explained

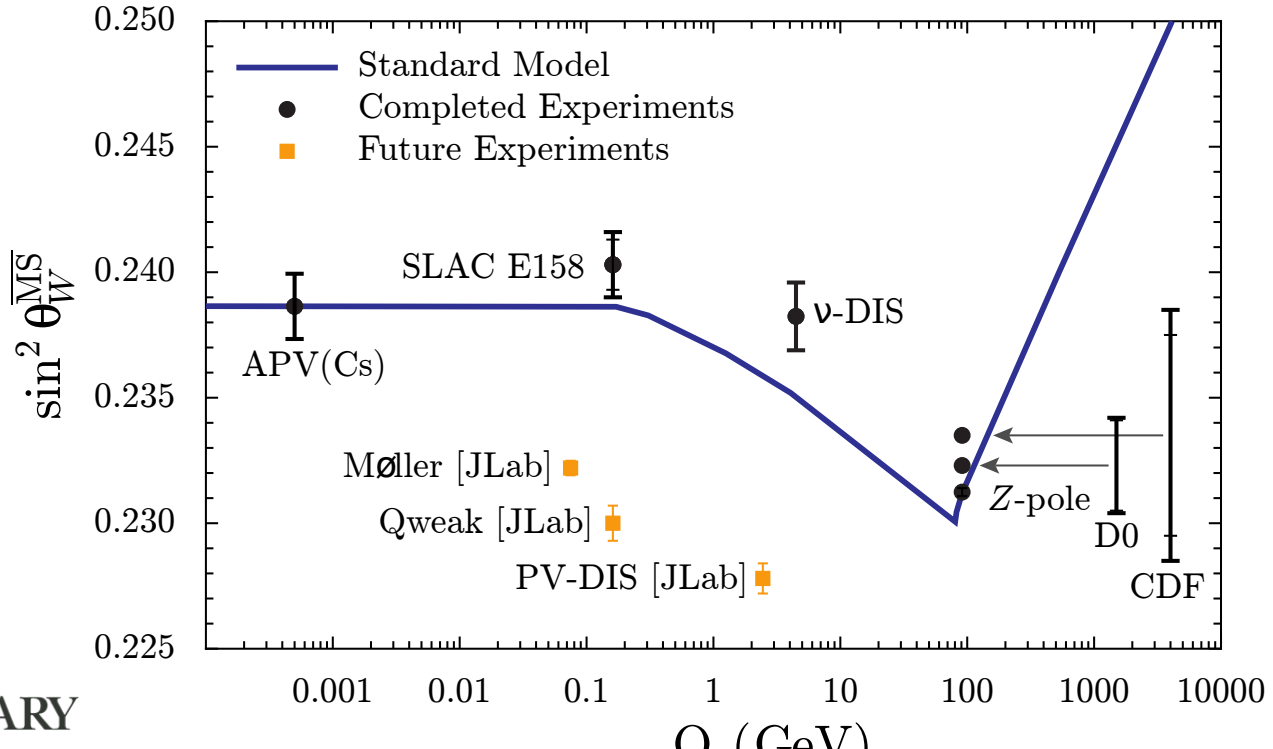
- Originally, $3\,\sigma$ deviation from Standard Model
- Erler, Langacker: strange quark PDFs
- Londergan, Thomas: charge symmetry violation, $m_u \neq m_d$
- Cloet, Bentz, Thomas: in-medium modifications to PDFs, isovector EMC-type effect
- Entire anomaly accounted for (everybody stops looking. . .)

Electroweak Interaction

Running of $\sin^2\theta_W$

- Higher order loop diagrams
- $\sin^2\theta_W$ varies with Q^2





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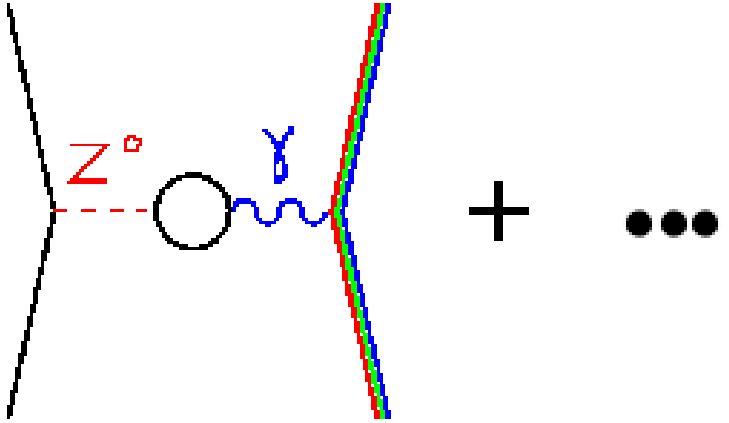
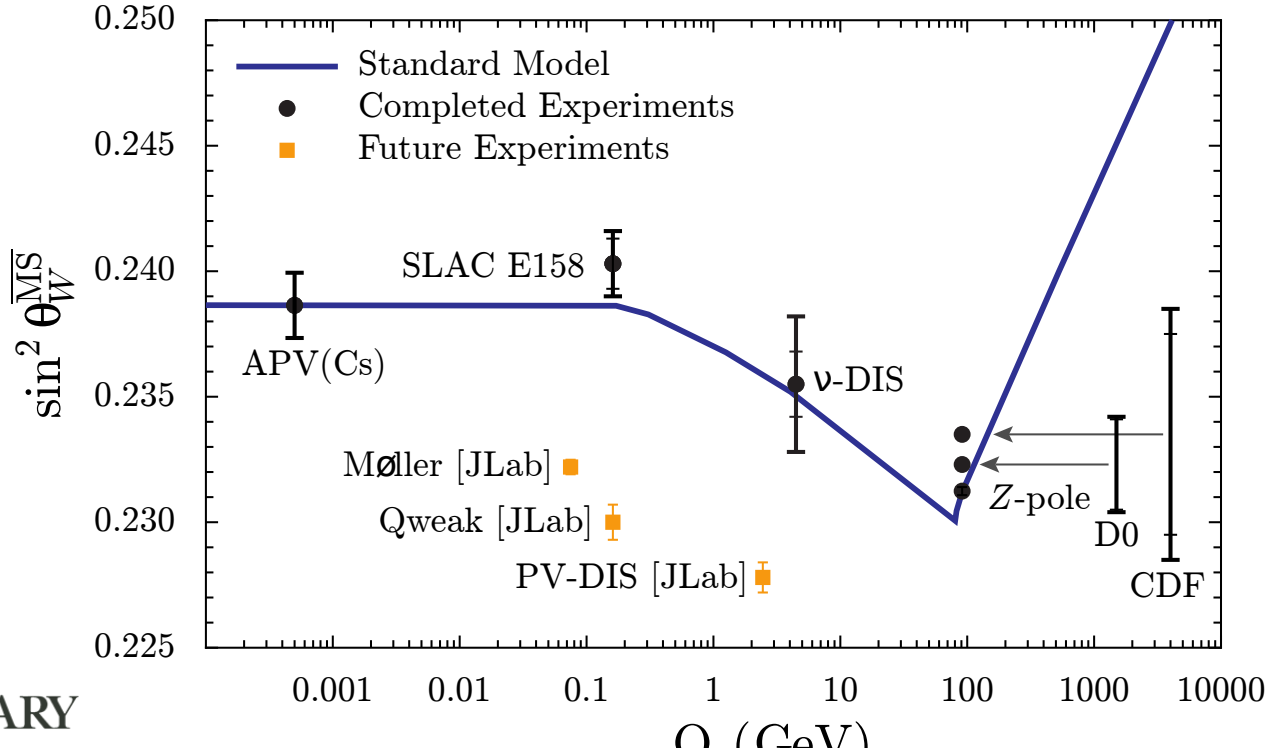




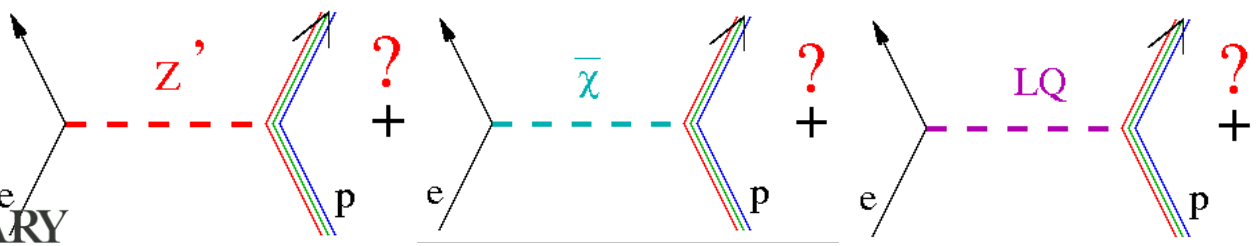
Sensitivity to New Physics

New physics

- Consider effective contact interaction
- Coupling constant g, mass scale Λ
- Effective charges $h_V^u = \cos\theta_h$ and $h_V^d = \sin\theta_h$

Effective Lagrangian

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



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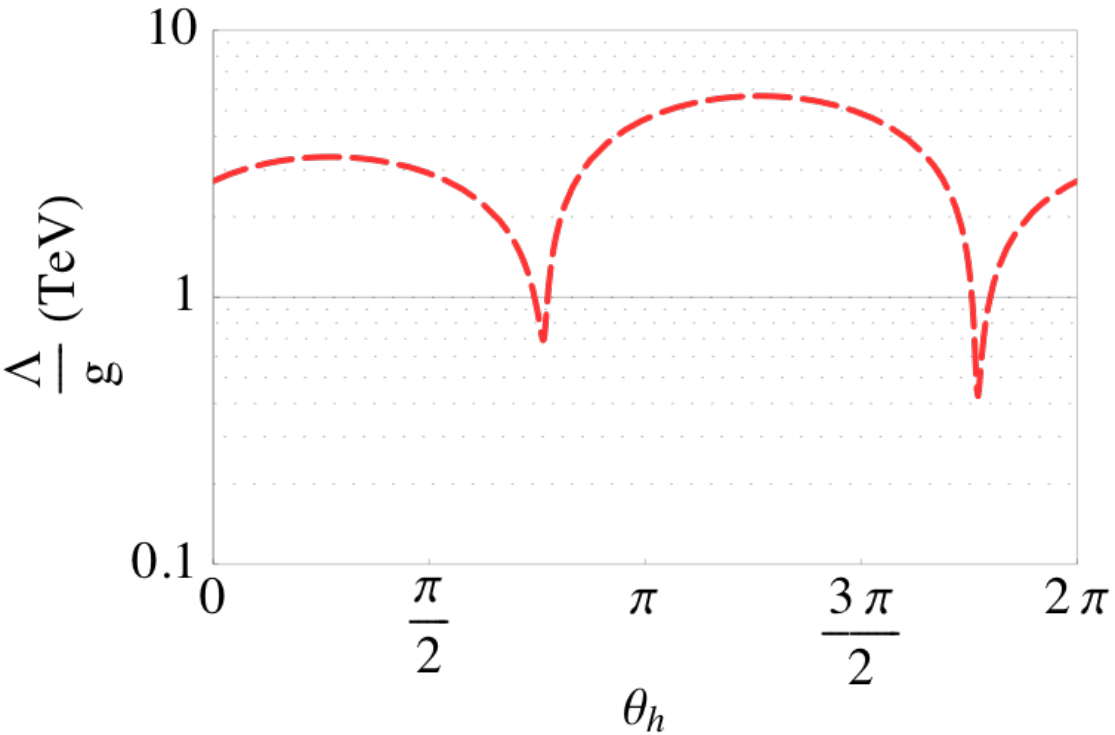

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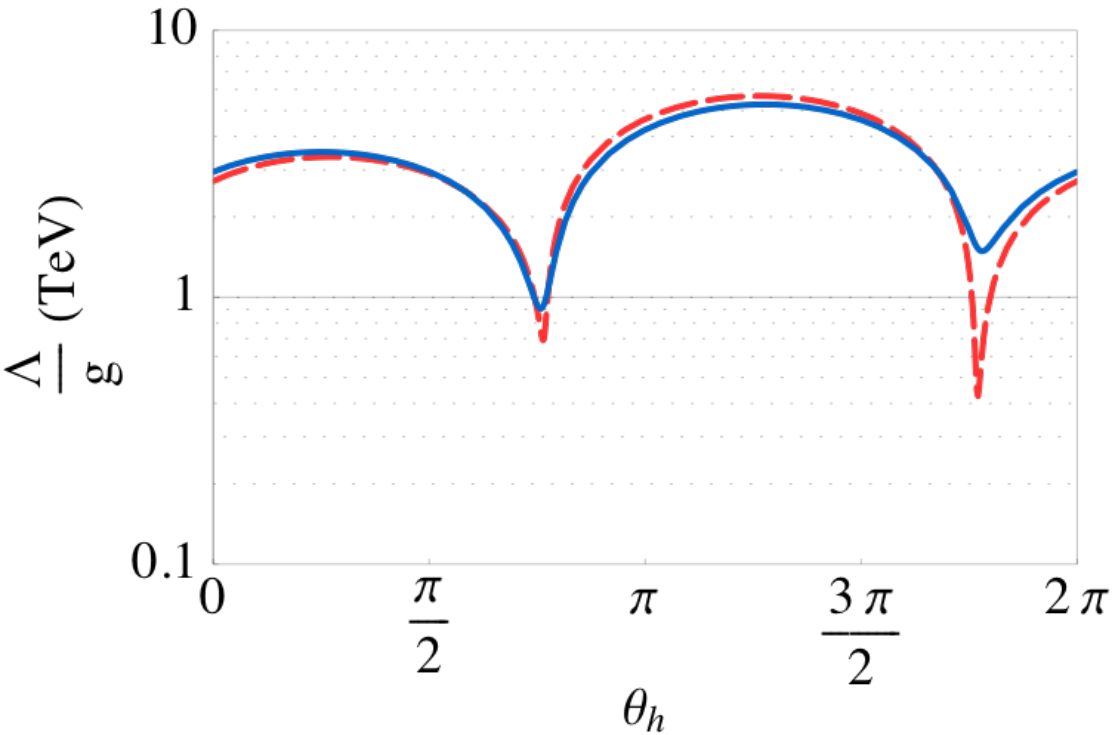

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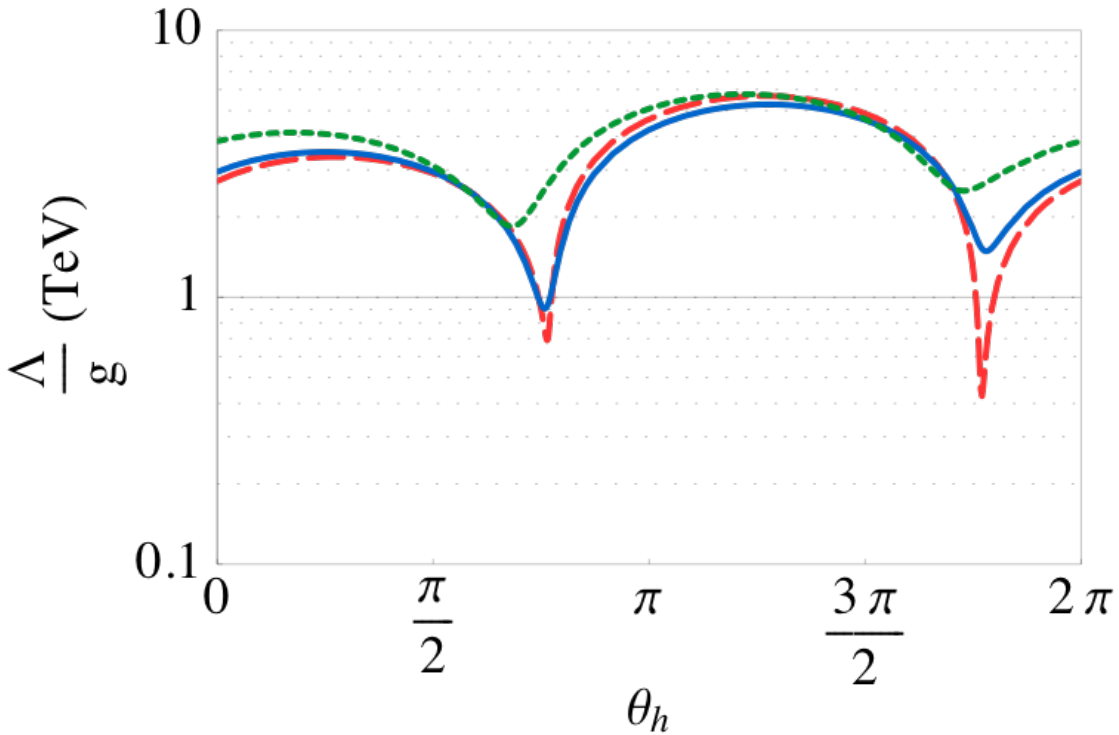

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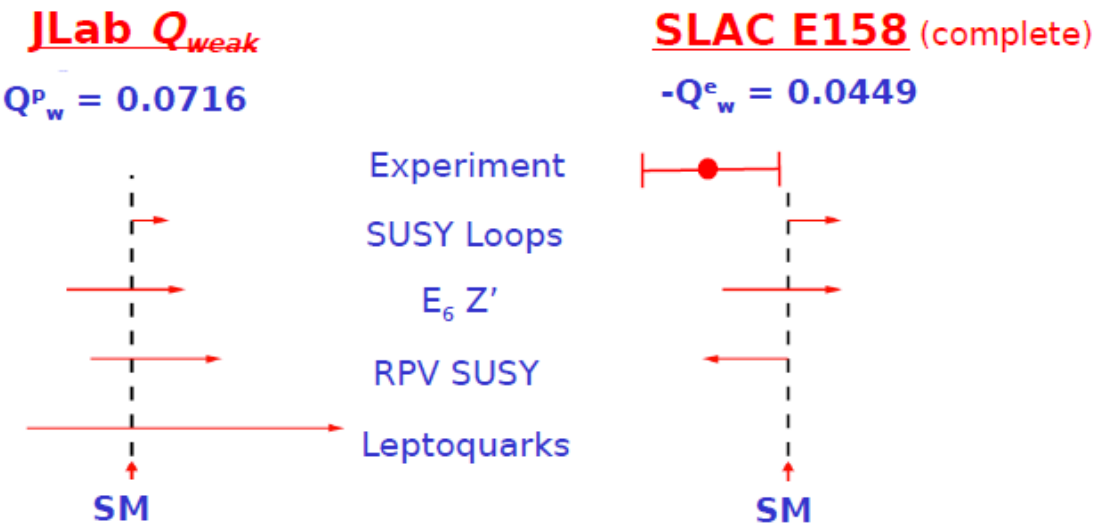
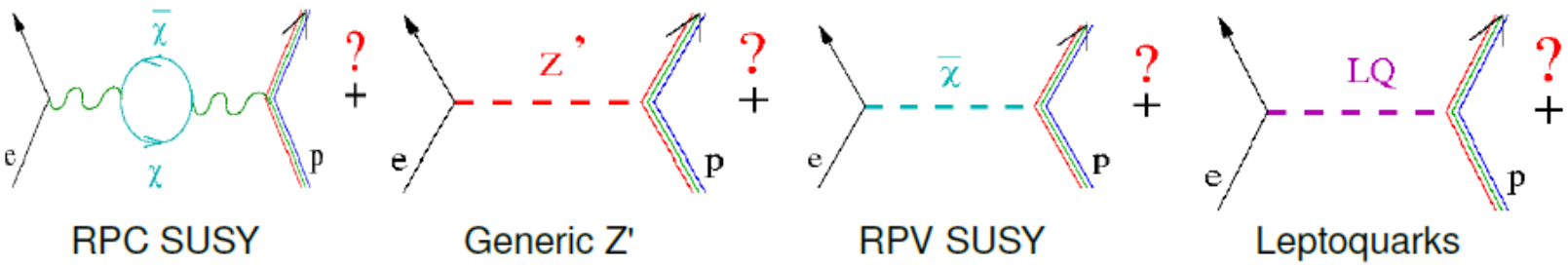
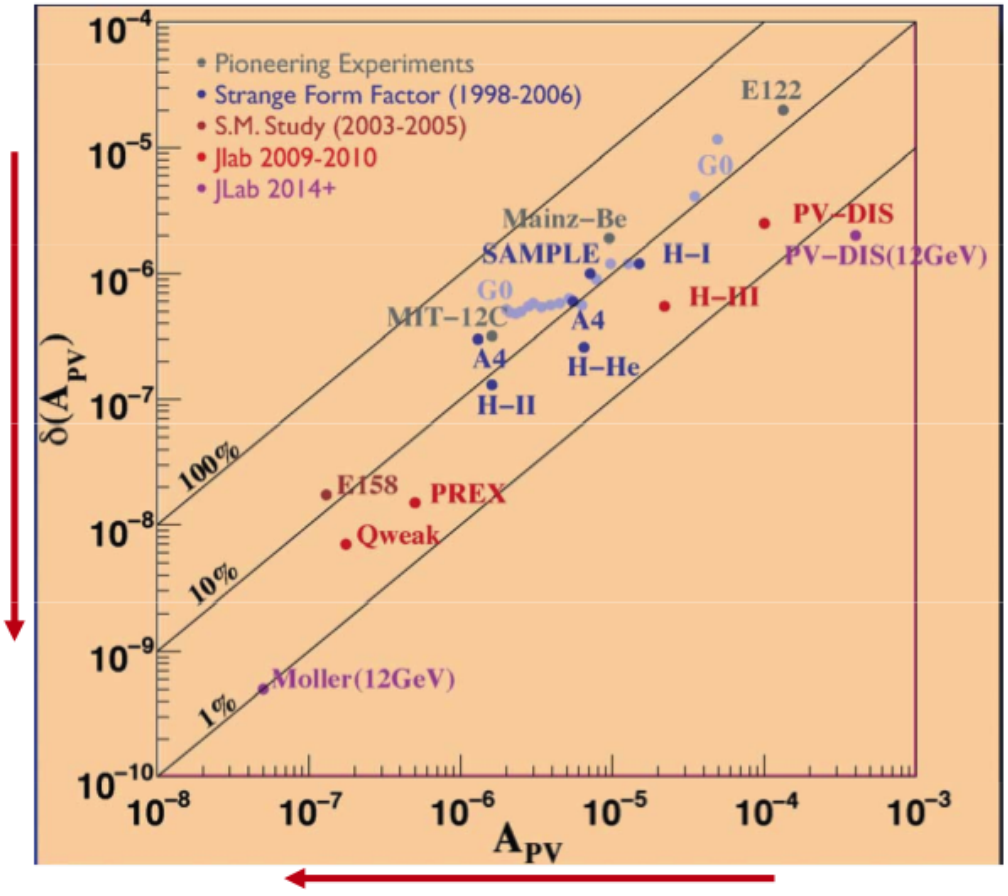
Different experiments sensitive to different extensions





Other Experiments