The Q^{p}_{Weak} Experiment at Jefferson Laboratory: A search for physics beyond the Standard Model via a measurement of the proton's weak charge

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for the Q-Weak Collaboration

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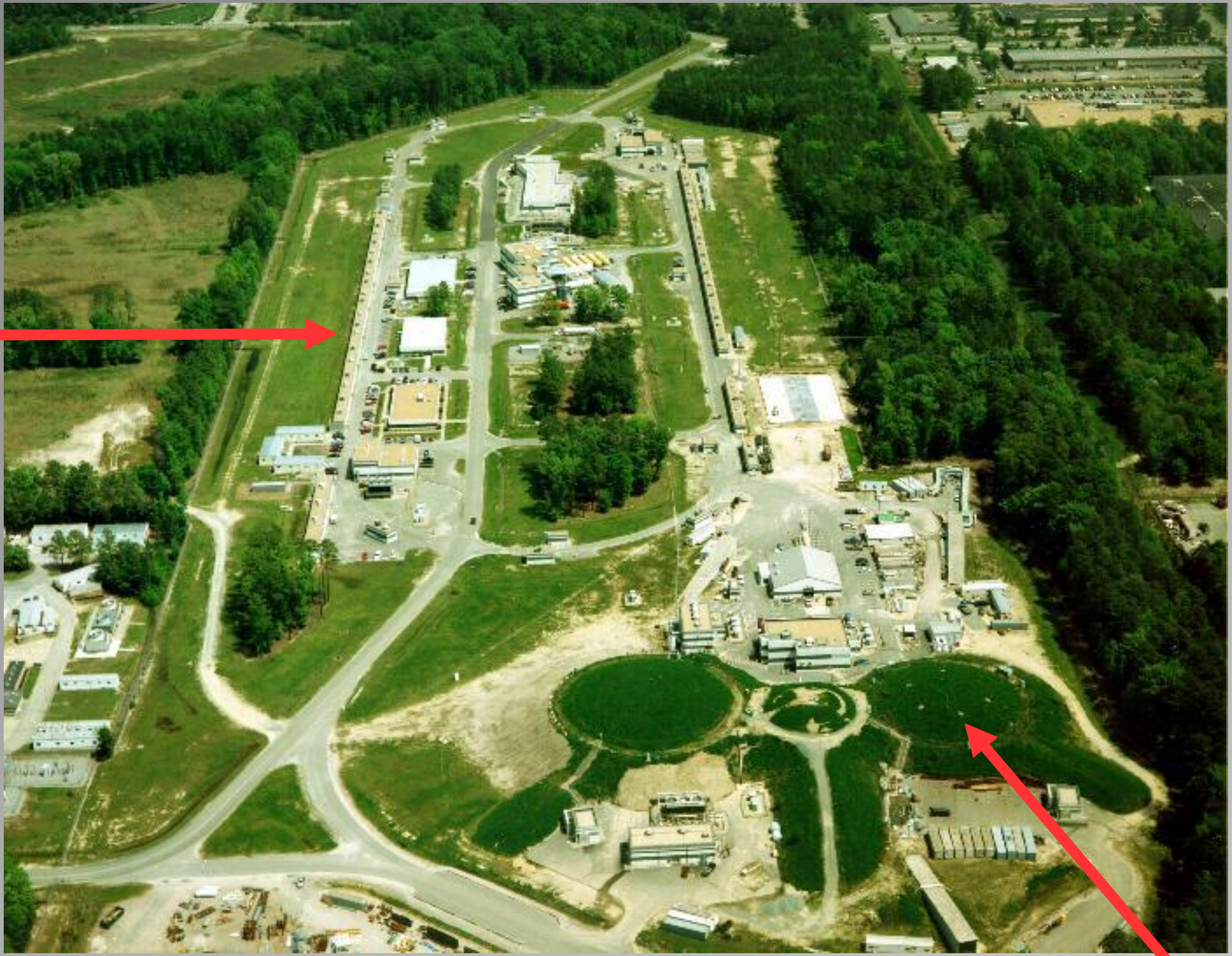
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Office of Nuclear Physics · Department of Energy

NATIONAL SCIENCE FOUNDATION NSF

NSERC CRSNG

Jefferson National Laboratory



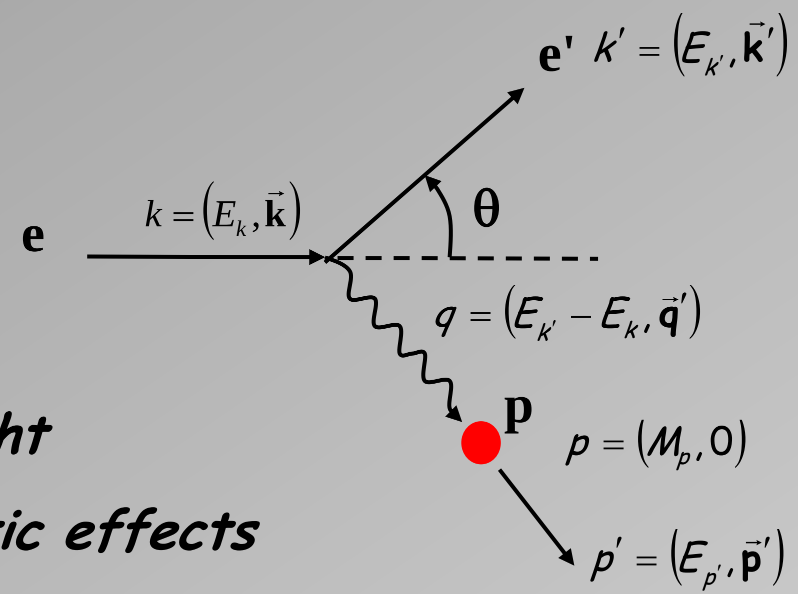
Racetrack Linear Accelerator

Hall C

The Measurement

Elastic scattering of polarized electrons from protons in a liquid hydrogen target:

- *Prepare electron beam with a given helicity (spin)*
- *Scatter electrons from protons and measure cross-section*
- *Flip spin and measure cross-section again*
- *Calculate the difference for the period of measurement*
- *Repeat (obsessively)*
- *Extract an asymmetry*



- *The rest is all about picking the right kinematics and controlling systematic effects*

$$Q^2 = -(k - k') \approx 4E_k E_{k'} \sin^2\left(\theta/2\right) = 0.026 \text{ GeV}^2$$

The Measurement

Central scattering angle:	$8.4° \pm 3°$
Phi Acceptance:	53% of 2π
Average Q^2:	0.026 GeV^2
Acceptance averaged asymmetry:	– 0.23 ppm
Integrated Rate (per detector):	800 MHz (6.4 GHz total)
Beam Energy:	1.165 GeV
Beam Current:	165 μA – 180 μA
Beam Polarization:	89%
Target Power:	2.5 kW

The Observable

$$A_{LR}(\vec{e},p) = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_{Q_W^p} + A_{H,V} + A_{H,A}$$

$$k = -\frac{G_F}{4\pi\alpha\sqrt{2}}$$

$$A_{Q_W^p} = kQ^2 Q_W^p$$

Quantity of interest ≈ -0.15 ppm

$$A_{H,V} = kQ^2 Q_W^n \frac{\varepsilon G_E^{p,\gamma} G_E^{n,\gamma} + \tau G_M^{p,\gamma} G_M^{n,\gamma}}{\varepsilon (G_E^{p,\gamma})^2 + \tau (G_M^{p,\gamma})^2} + kQ^2 Q_W^s \frac{\varepsilon G_E^{p,\gamma} G_E^{s} + \tau G_M^{p,\gamma} G_M^{s}}{\varepsilon (G_E^{p,\gamma})^2 + \tau (G_M^{p,\gamma})^2}$$

$$A_{H,A} = kQ^2 Q_W^e \frac{\varepsilon' G_A^{p,Z} G_M^{p,\gamma}}{\varepsilon (G_E^{p,\gamma})^2 + \tau (G_M^{p,\gamma})^2}$$

Nucleon structure.
Know this from world data:
$A_{H,V}$ ~ -0.07 ppm
$A_{H,A}$ ~ -0.01 ppm

hadronic:
(30% of asymmetry)
- contains $G^{\gamma}_{E,M}$ $G^{s}_{E,M}$
Constrained by
HAPPEX, G^0, MAMI PVA4

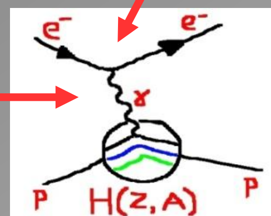
axial:
(4% of asymmetry) -
contains G^{p}_{A},
has large electroweak radiative corrections.
Constrained by
G^0 and SAMPLE

Amounts to a 1.5% error contribution in Q_{Weak}

Connection to Theory

$$\mathcal{H}_I^e = -eJ^{\mu}_{e,EM}A_{\mu} - \frac{g_W}{4\cos\theta_W} J^{\mu}_{e,W} Z_{\mu}$$

$$S_{fi}^{EM} = i\,\frac{4\pi\alpha}{q^2} J^{\mu}_{e,EM} J^{N,EM}_{\mu}$$



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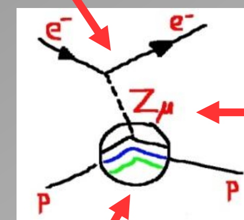

$$S_{fi}^{W} = i\,\frac{G_F}{2\sqrt{2}} J^{\mu}_{e,W} J^{N,W}_{\mu}$$

$$S_{fi}^{W} \rightarrow S_{fi}^{W} + i\,\frac{g_W^2}{4\Lambda^2} J^{\mu}_{e,W}{}' J^{N,W'}_{\mu}$$

$$\mathcal{H}_I^N = -eJ^{\mu}_{N,EM}A_{\mu} - \frac{g_W}{4\cos\theta_W} J^{\mu}_{N,W} Z_{\mu}$$

$$\sigma \propto \left|S_{fi}\right|^2 = \left|S_{fi}^{EM}\right|^2 + \left|S_{fi}^{W}\right|^2 + S_{fi}^{EM} S_{fi}^{W\dagger} + S_{fi}^{EM\dagger} S_{fi}^{W}$$

PV Signal

Standard Model Parameters

Weak Current $J_W^\mu = \sum_f \overline{\psi}_f \gamma^\mu \left(g_V^f + g_A^f \gamma_5\right)\psi_f$

$$S_{fi}^{EM} S_{fi}^{W\,\dagger} + S_{fi}^{EM\,\dagger} S_{fi}^{W} \rightarrow \frac{G_F}{\sqrt{2}} \sum_{i=u,d,s} \left[C_{1i}\, \bar{e}\gamma_\mu \gamma^5 e\, \bar{q}_i \gamma^\mu q_i + C_{2i}\, \bar{e}\gamma_\mu e\, \bar{q}_i \gamma^\mu \gamma^5 q_i \right]$$

Q_{Weak} picks out this

Weak Charges From the PDG:

	Tree Level	Rad. Corr. + New Phys.
C_{1u}	$-\frac{1}{2}\left(1-\frac{8}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(1-\frac{8}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1u}$
C_{1d}	$-\frac{1}{2}\left(-1+\frac{4}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(-1+\frac{4}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1d}$
C_{1s}	$-\frac{1}{2}\left(1-\frac{8}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(1-\frac{8}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1s}$
C_{2u}	$-\frac{1}{2}\left(1-4\sin^2\theta_W\right)$	$-\frac{1}{2}\rho_{eq}\left(1-4\kappa_{eq}\sin^2\theta_W\right)+\lambda_{2u}$
C_{2d}	$\frac{1}{2}\left(1-4\sin^2\theta_W\right)$	$\frac{1}{2}\rho_{eq}\left(1-4\kappa_{eq}\sin^2\theta_W\right)+\lambda_{2d}$
C_{2s}	$\frac{1}{2}\left(1-4\sin^2\theta_W\right)$	$\frac{1}{2}\rho_{eq}\left(1-4\kappa_{eq}\sin^2\theta_W\right)+\lambda_{2s}$

Standard Model Parameters

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C_{1u}	$-\frac{1}{2}\left(1-\frac{8}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(1-\frac{8}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1u}$
C_{1d}	$-\frac{1}{2}\left(-1+\frac{4}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(-1+\frac{4}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1d}$
C_{1s}	$-\frac{1}{2}\left(1-\frac{8}{3}\sin^2\theta_W\right)$	$-\frac{1}{2}\rho'_{eq}\left(1-\frac{8}{3}\kappa'_{eq}\sin^2\theta_W\right)+\lambda_{1s}$
C_{2u}	$-\frac{1}{2}\left(1-4\sin^2\theta_W\right)$	$-\frac{1}{2}\rho_{eq}\left(1-4\kappa_{eq}\sin^2\theta_W\right)+\lambda_{2u}$
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Strongly suppressed by design kinematics (C_{1s}, C_{2u}, C_{2d}, C_{2s} crossed out)

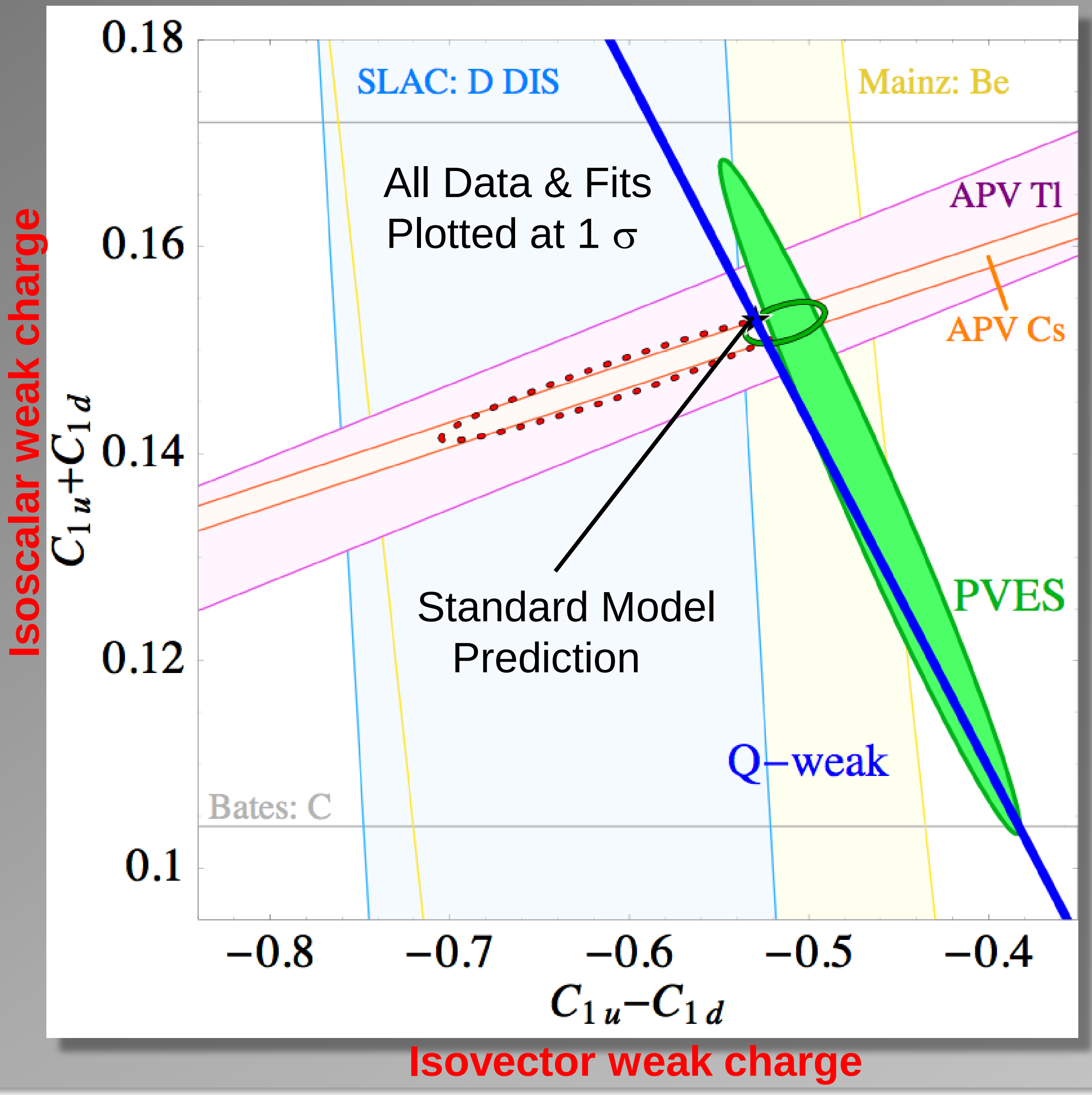
$$g_V^f = -2C_{1f} \qquad g_A^f = \frac{2C_{2f}}{1-4\sin^2(\theta_W)}$$

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

$$Q^p_{Weak} = 1-4\sin^2\theta_W = 0.075$$

Standard Model Parameters

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



HAPPEx: H, He
G^0: H,
PVA4: H
SAMPLE: H, D

Standard Model Parameters

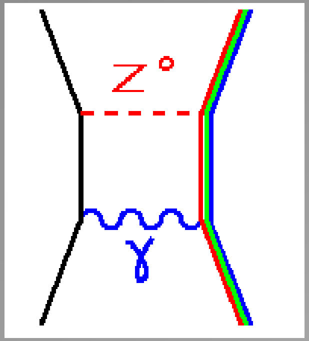
Including radiative corrections (Kurylov, Musolf, Su Phys. Rev. D 68, 035008 (2003)):

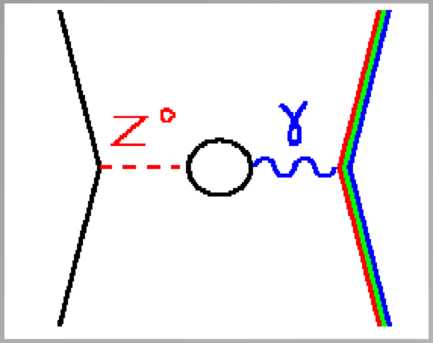
$$Q_W^p = \rho_p\left(1 - 4\kappa_p \sin^2(\theta_W)\right) + \lambda_p$$

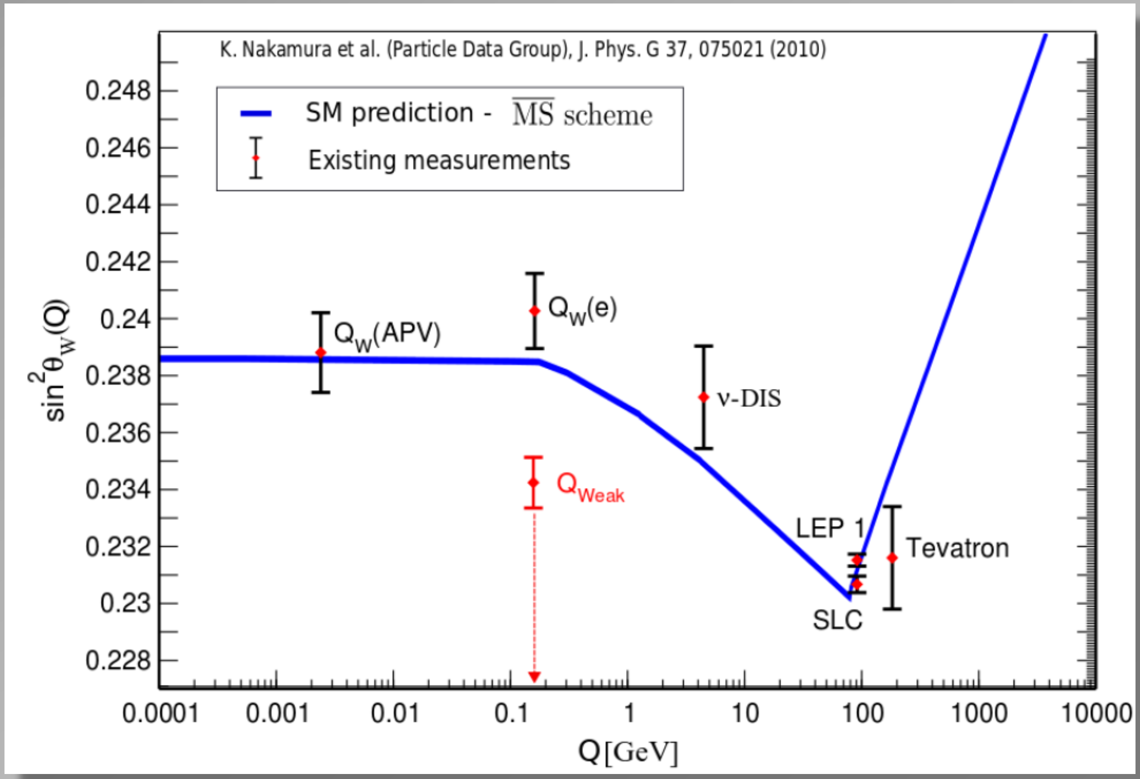
$$\rho_p \Rightarrow 1 + \delta\rho_p^{RC} + \delta\rho_p^{NP}$$

$$\kappa_p \Rightarrow 1 + \delta\kappa_p^{RC} + \delta\kappa_p^{NP}$$

$$\lambda_p \Rightarrow \delta\lambda_p^{RC} + \delta\lambda_p^{NP}$$







Proposal Error Budget

	$\Delta A_{phys} / A_{phys}$	$\Delta Q^p_{weak} / Q^p_{weak}$
Statistical (2200 hours production)	2.1%	3.2%
Systematic:		
Hadronic structure uncertainties	--	1.5%
Beam polarimetry	1.0%	1.5%
Absolute Q^2 determination	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated Beam Properties	0.5%	0.7%
Total	**2.5%**	**4.1%**

Model independent physics reach:

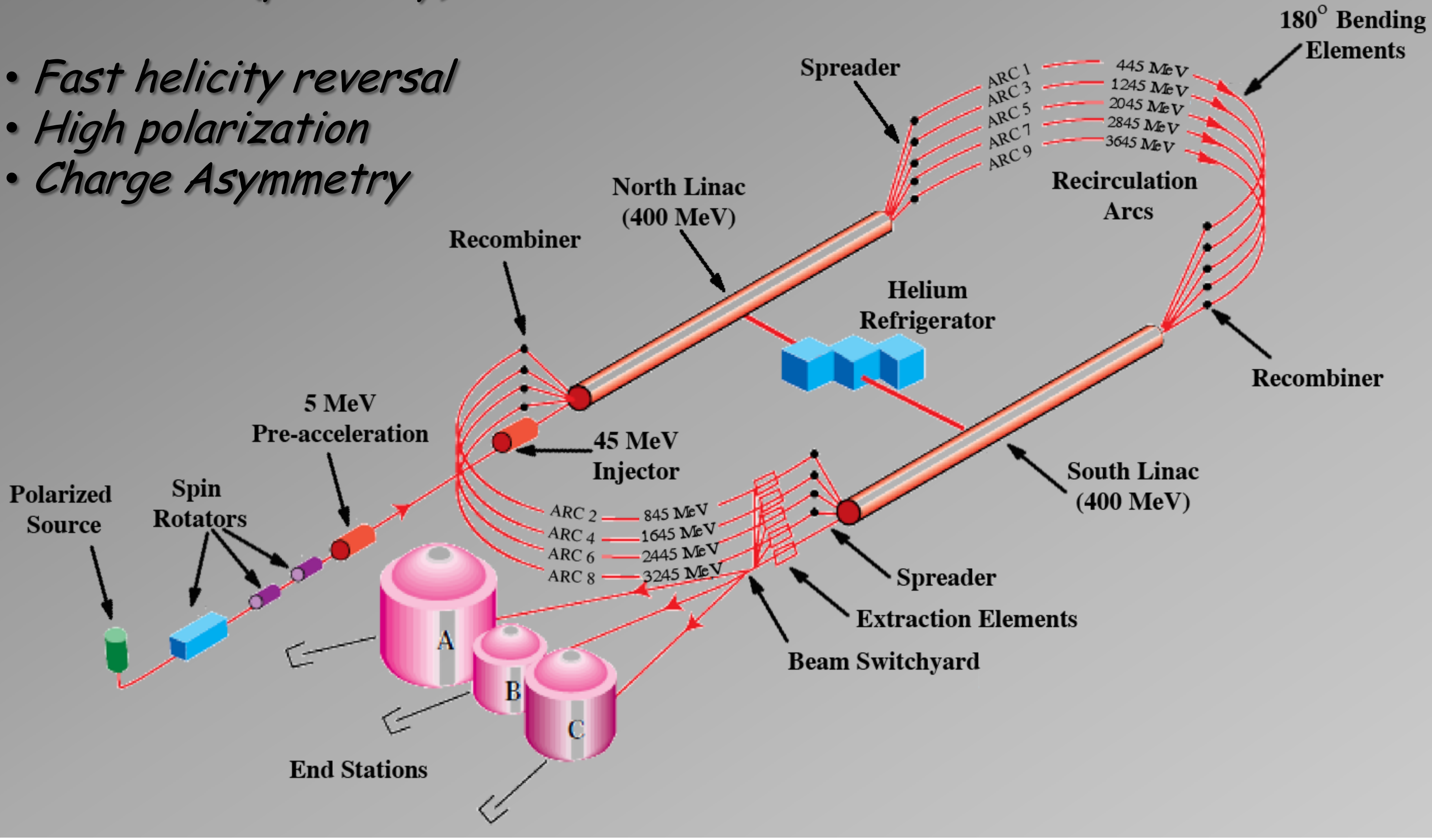
$$\frac{\Lambda}{g} \sim \frac{1}{2\sqrt{\sqrt{2} G_F \left|\delta Q^p_W\right|}} \approx 2.3 \text{ TeV}$$

Experiment Overview

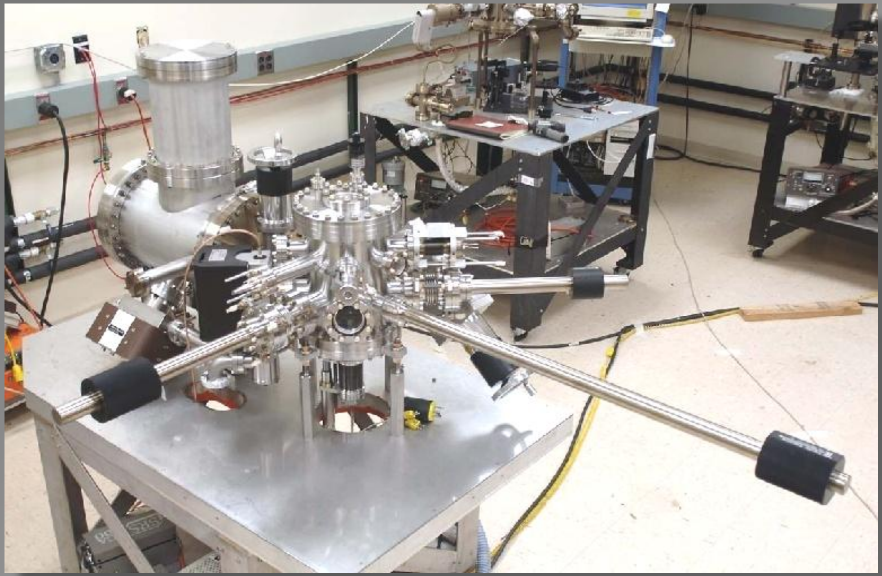
For Q-Weak the facility is an integral part of the experiment!

Determined (primarily) at the source:

- *Fast helicity reversal*
- *High polarization*
- *Charge Asymmetry*

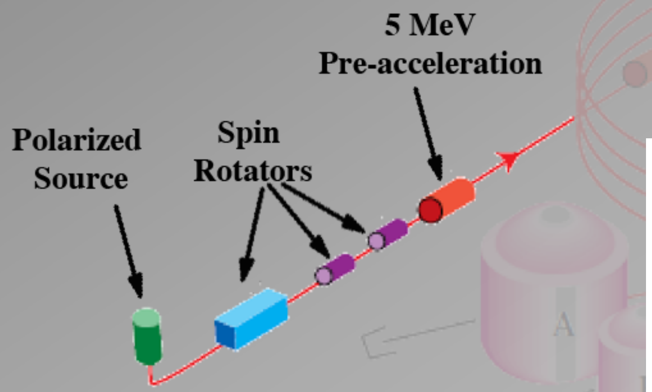


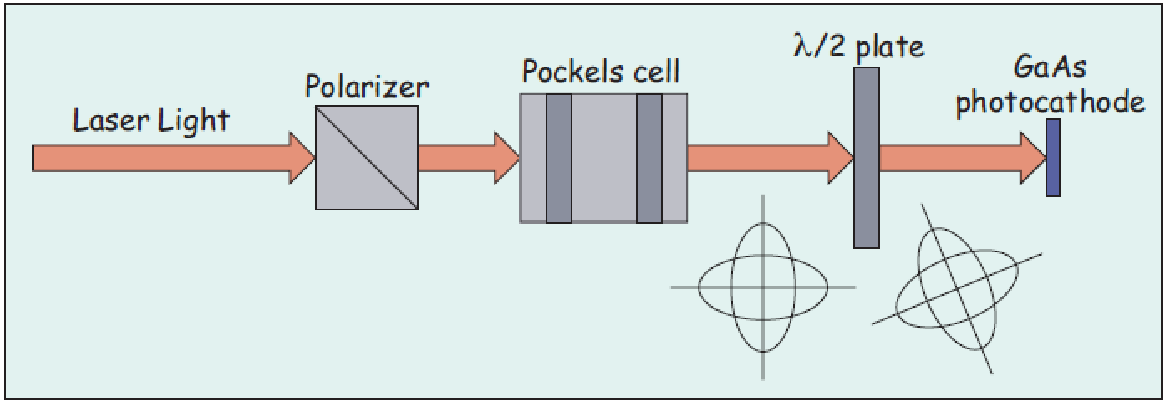
Experiment Overview



Helicity reversal:

- *Continuously at 1 kHz, with Pockels cell*
- *Every 4 to 8 hours with insertable half-wave plate*
- *Every Couple of weeks with a spin rotation (Wein flip)*





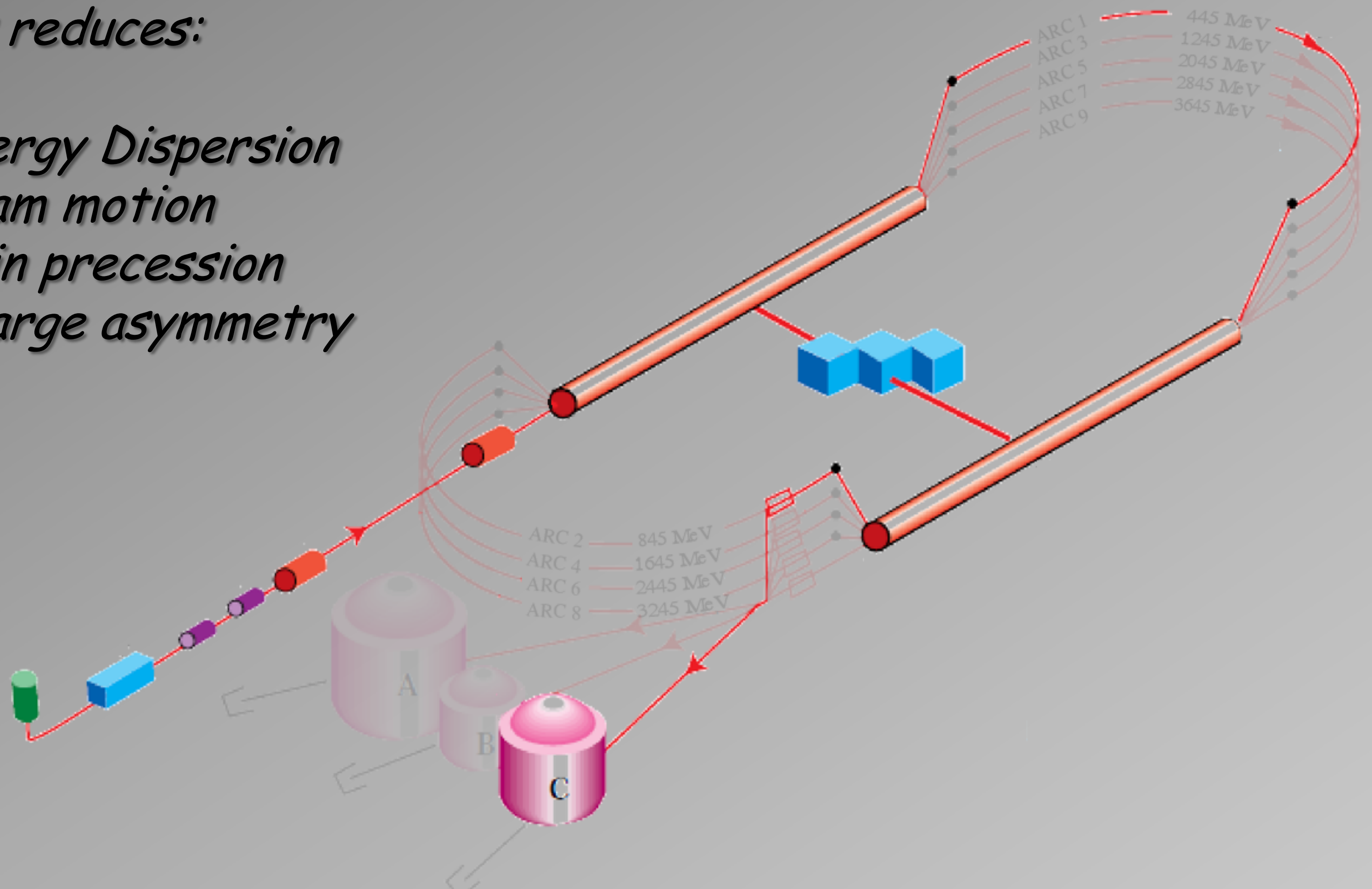
Experiment Overview

For Q-Weak the facility is an integral part of the experiment!

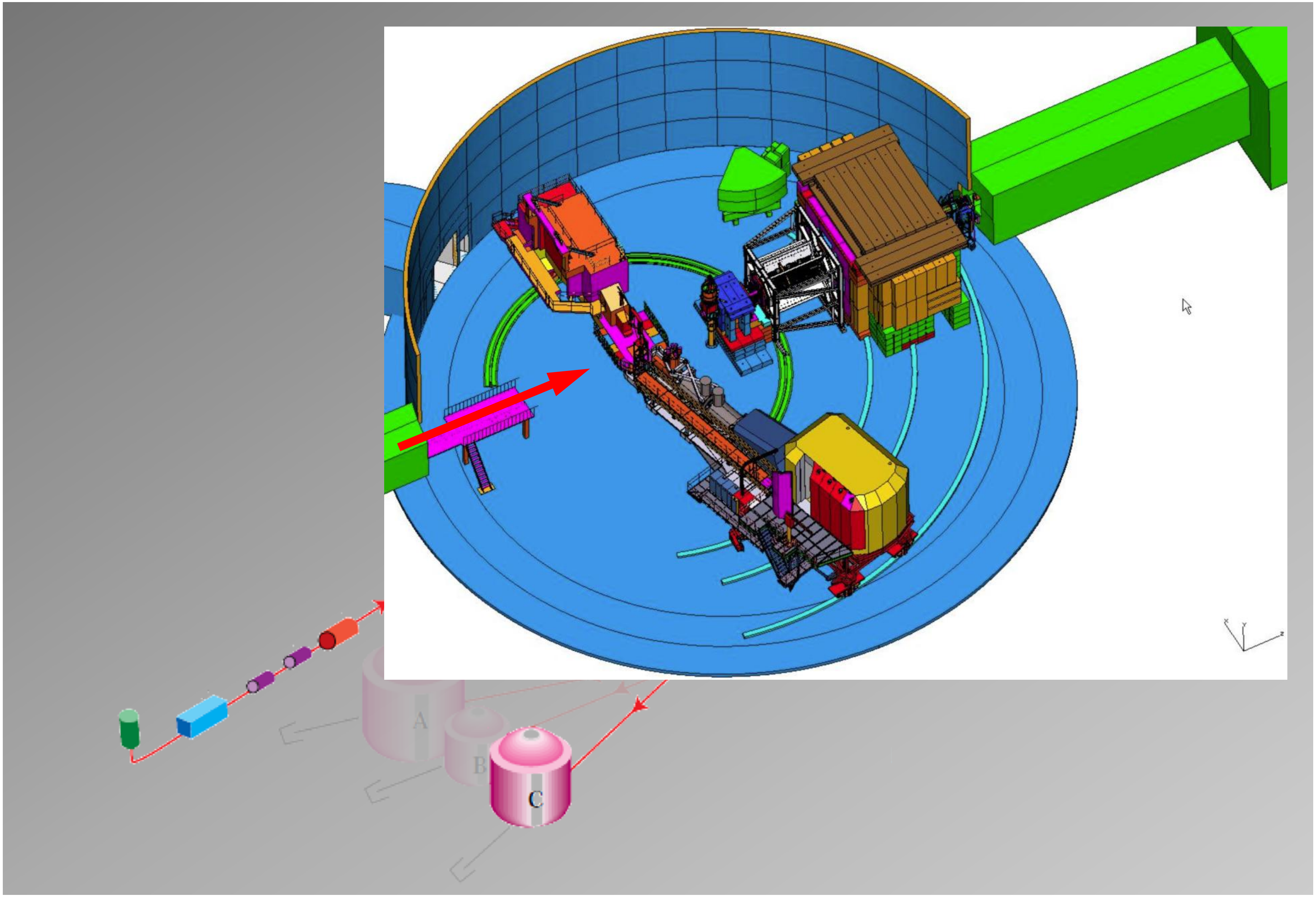
Q-weak routinely uses only one-pass.

This reduces:

- *Energy Dispersion*
- *Beam motion*
- *Spin precession*
- *Charge asymmetry*



Experiment Overview



Experiment Overview

Q-Weak is a high precision and high accuracy experiment!

Statistical accuracy requires high luminosity:

- *High beam current (routinely ~ 180 μA)*
- *Long high-power LH_2 target (35 cm, 2.5 kW)*
- *High event rate in the main detectors (in excess of 800 MHz)*

Experimental precision requires :

- *Accurate polarimetry (1%)*
- *Accurate determination of mometum transfer (0.5%)*
- *Control of helicity correlated beam properties (0.5%)*
- *Suppression of background (dilution and asymmetries) (0.5%)*

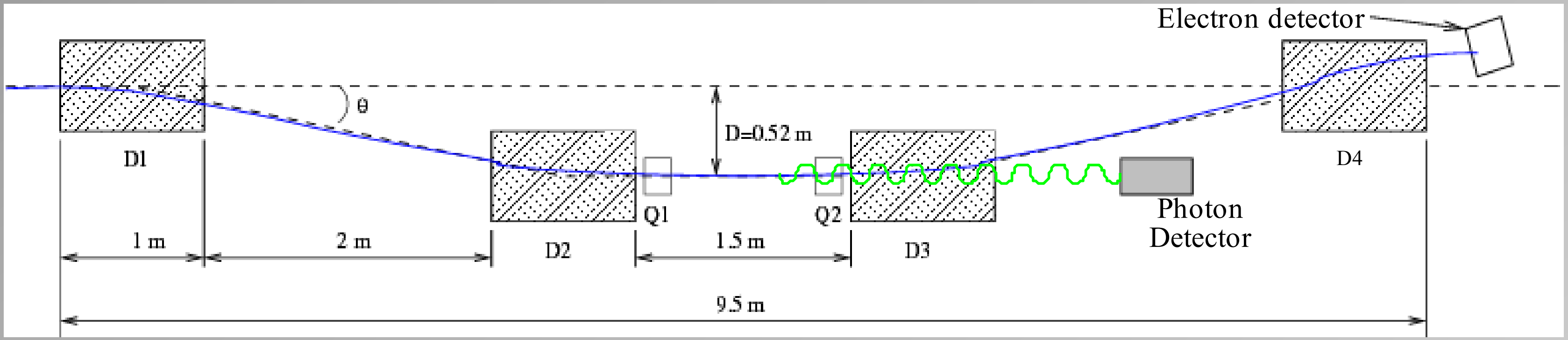
Experiment Overview

Polarimetry:

Standard Hall C Møller polarimeter:

Periodic invasive measurement at lower current.

New Hall C Compton :
(Diamond Strip e$^-$ and scintillator photon Detectors)
Continuous non-invasive measurement at full current.

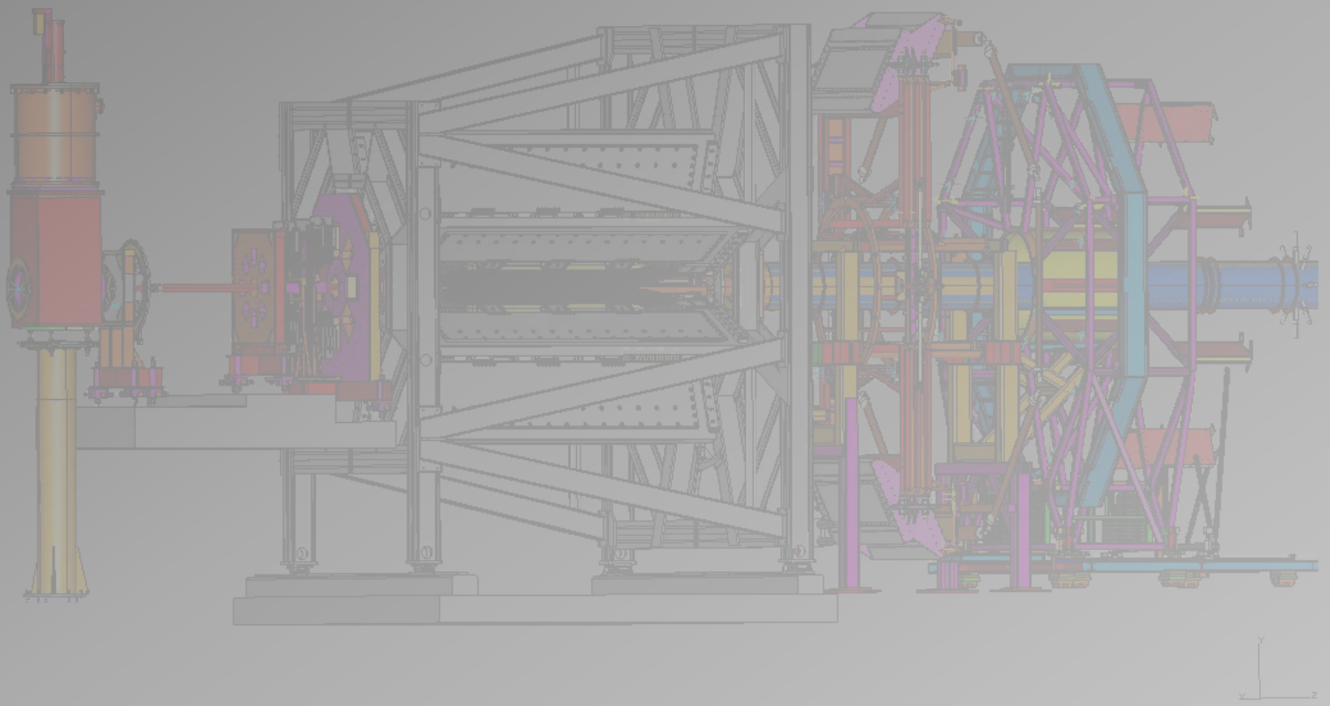


Experiment Overview

Q-Weak is a two mode experiment!

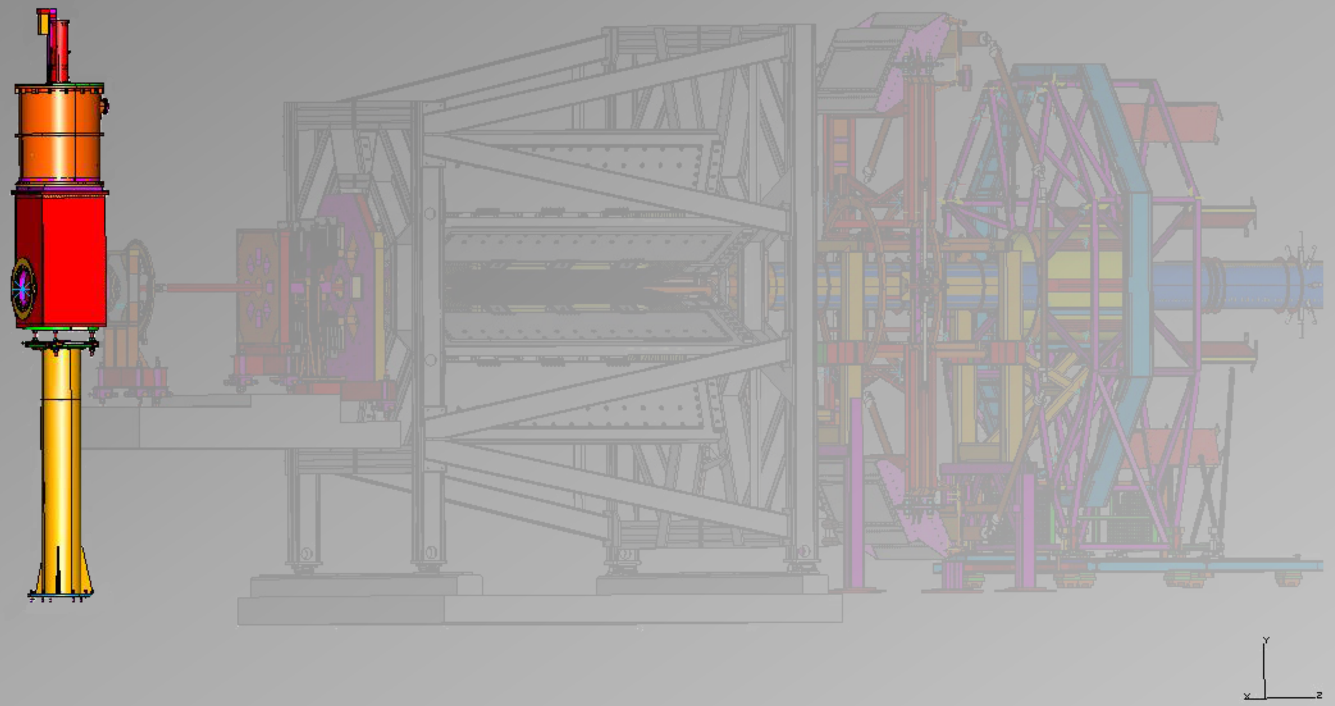
- *Current Mode*
- *Tracking or Event Mode*

Different components of the experiment are used in combination during the different running modes:



Experiment Overview

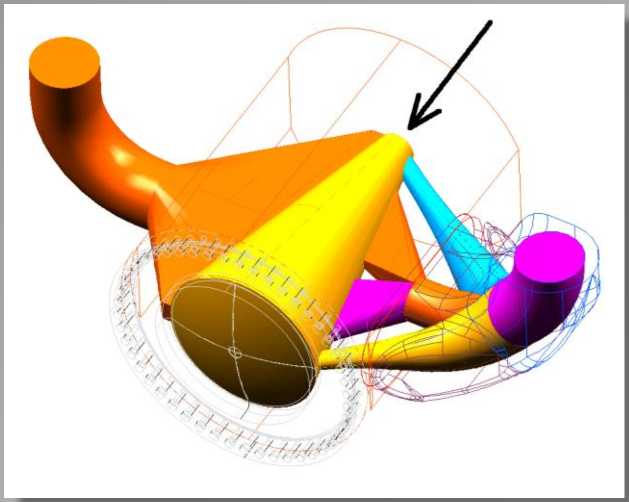
High Power LH_2 Target:

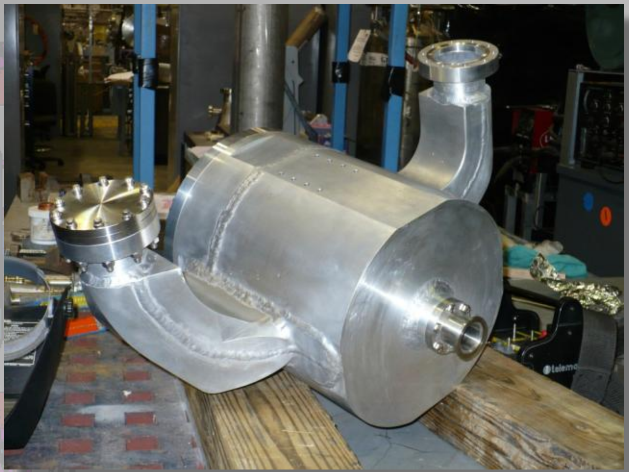


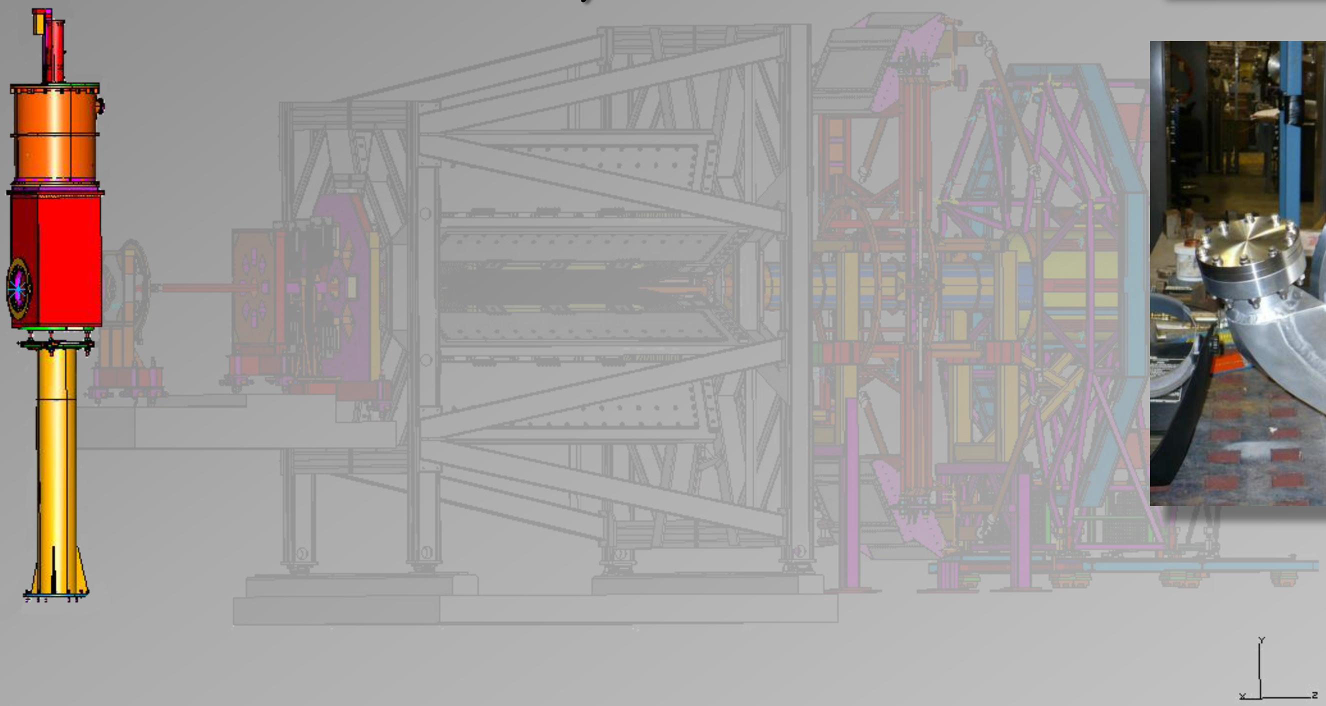
Experiment Overview

High Power LH_2 Target:

- *up to 180 μA with a 3x3 or 4x4 mm raster*
- *2.5 kW*
- *35 cm long*
- *2.8 m/s flow rate*
- *Density fluctuations (at 960 Hz) < 57×10^{-5}*
- *→ run at 1 kHz helicity reversal rate*

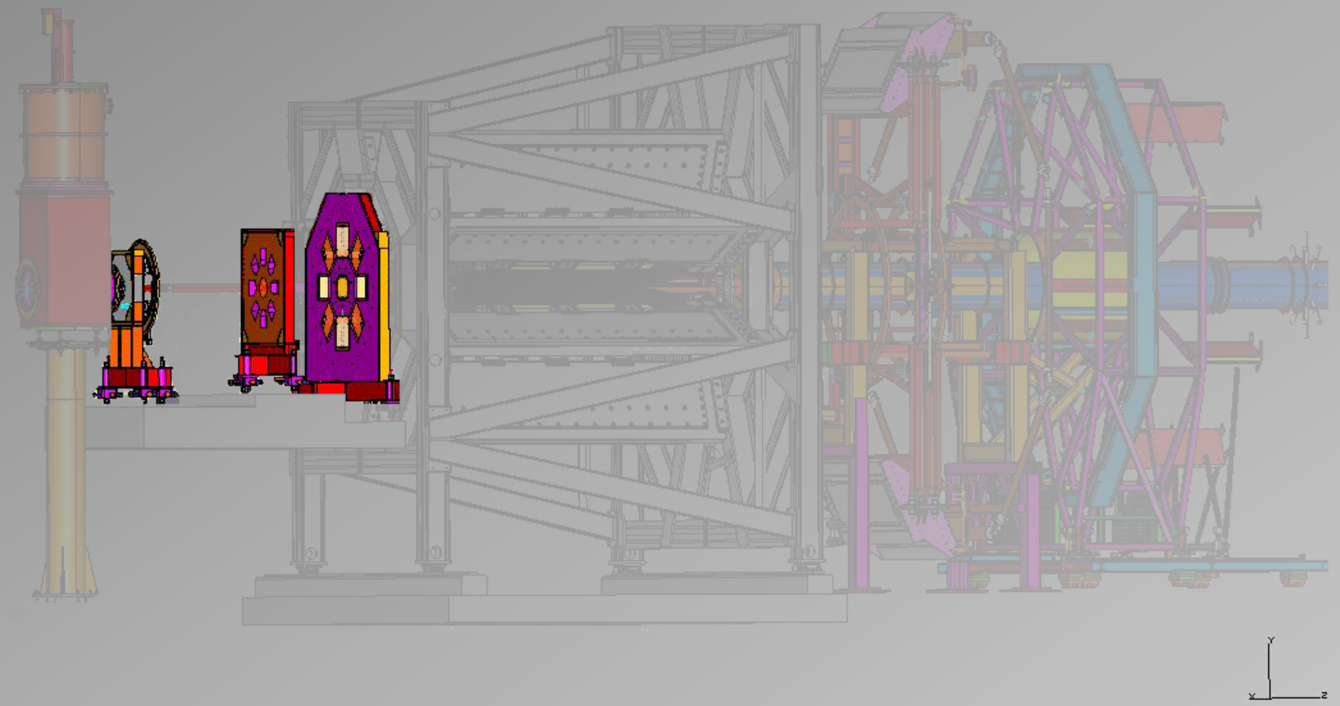






Experiment Overview

3 Collimator System:

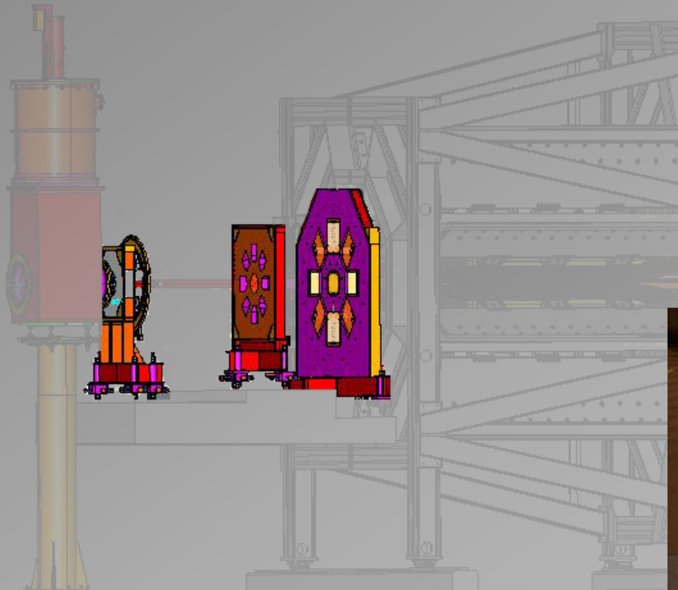


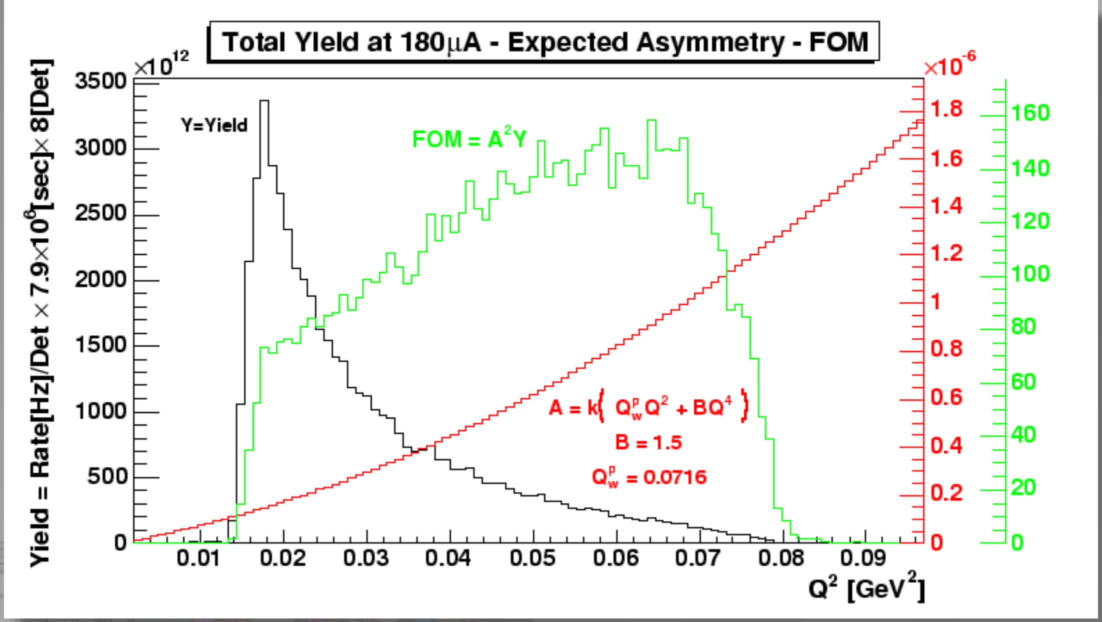
Experiment Overview

3 Collimator System:

Primary definition of Q^2
Based on:

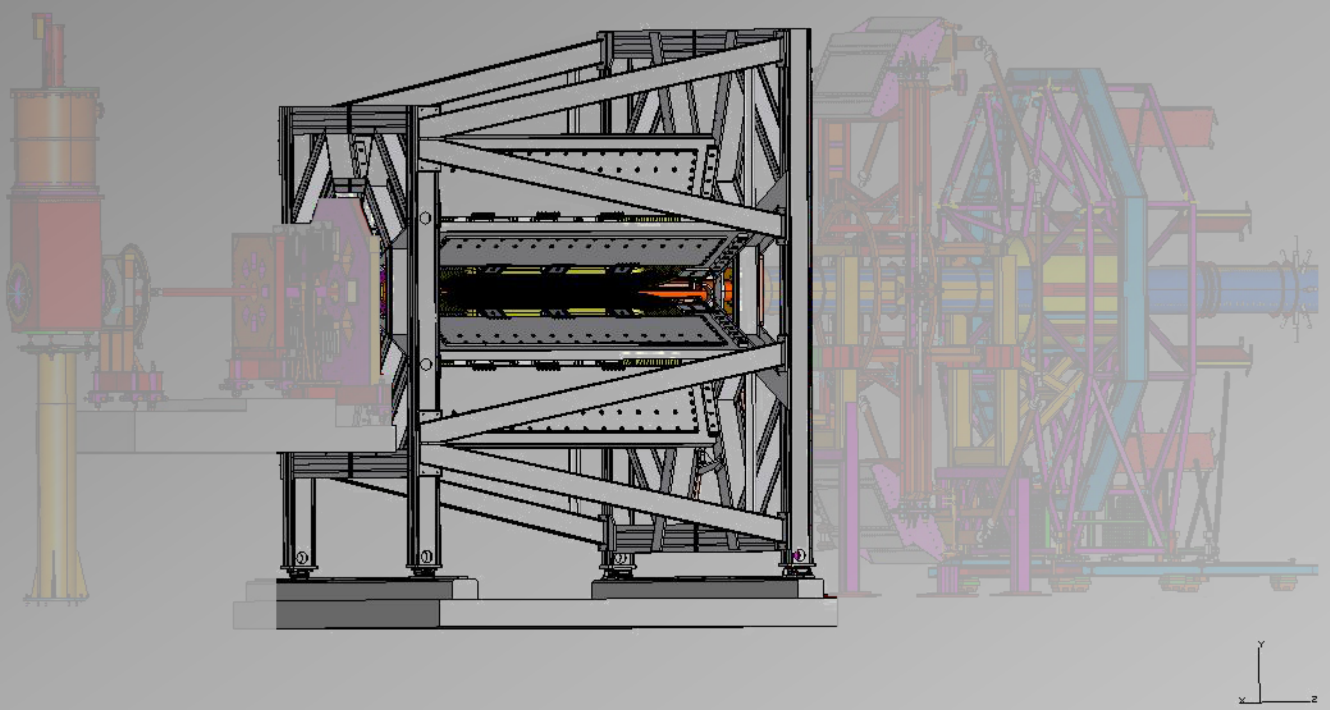
- *event rate maximization*
- *asymmetry maximization*
- *minimization of hadronic dilution.*





Experiment Overview

Spectrometer (QTOR):

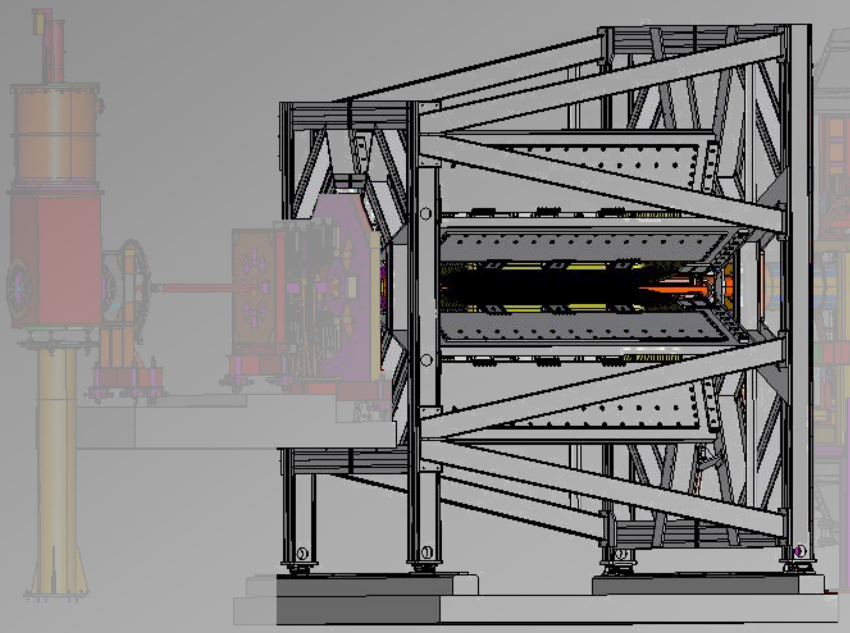


Experiment Overview

Spectrometer (QTOR):

- 8 Sector Room Temperature Toroidal Magnet
- 9500 A, 1.5 MW maximum
- 4.3 m long, 1.5 m wide coils (simple racetrack shape)
- water cooled copper coils

$$\int \vec{B}\cdot d\vec{l} = 0.89 \ \mathrm{T\cdot m}$$



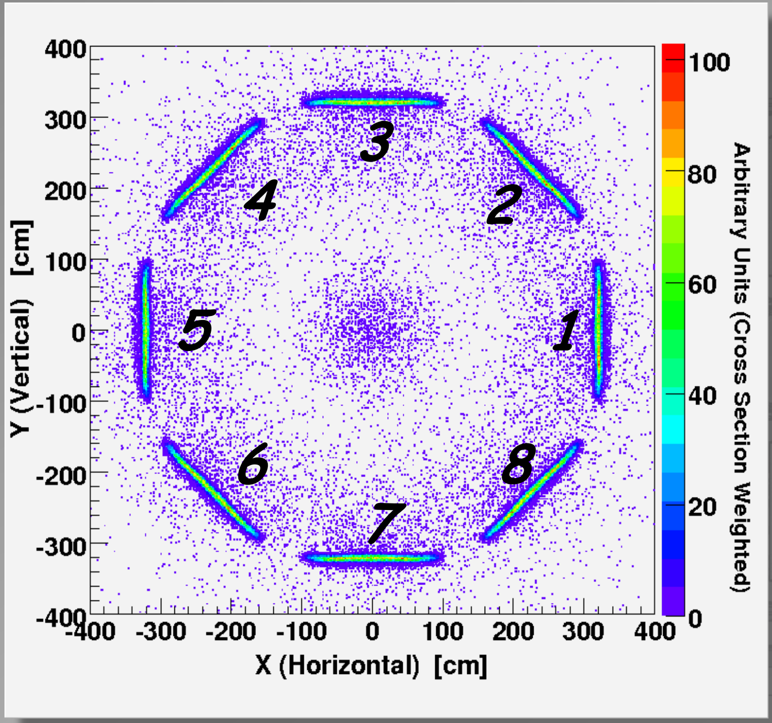
Experiment Overview

Main Detectors:

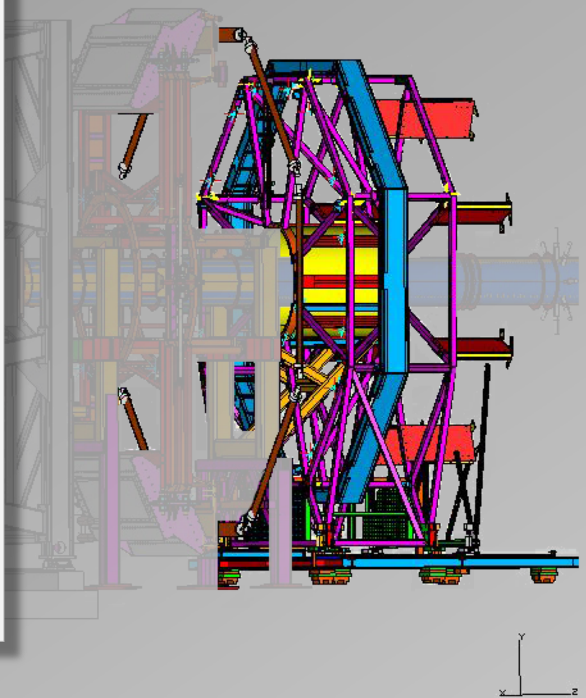
Experiment Overview

Main Detectors:

- 8 fused silica (quartz) radiators 200 cm x 18 cm x 1.25 cm
- Spectrosil 2000 (Rad-hard & low luminescence)
- 800 MHz e^- per bar (Current mode readout $I_a = 6\ \mu A$)
- Light collection by TIR (5 inch S20 photocathodes $I_{kD} = 3\ nA$)



Beam out of page



Experiment Overview

Main Detectors:

- *8 fused silica (quartz) radiators 200 cm x 18 cm x 1.25 cm*
- ***Spectrosil 2000** (Rad-hard & low luminescence)*
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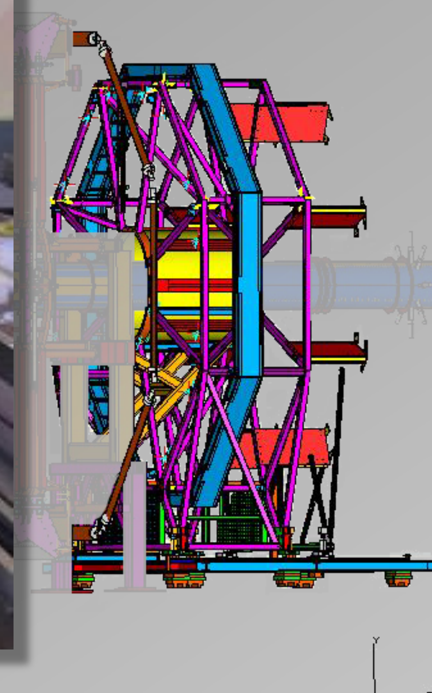
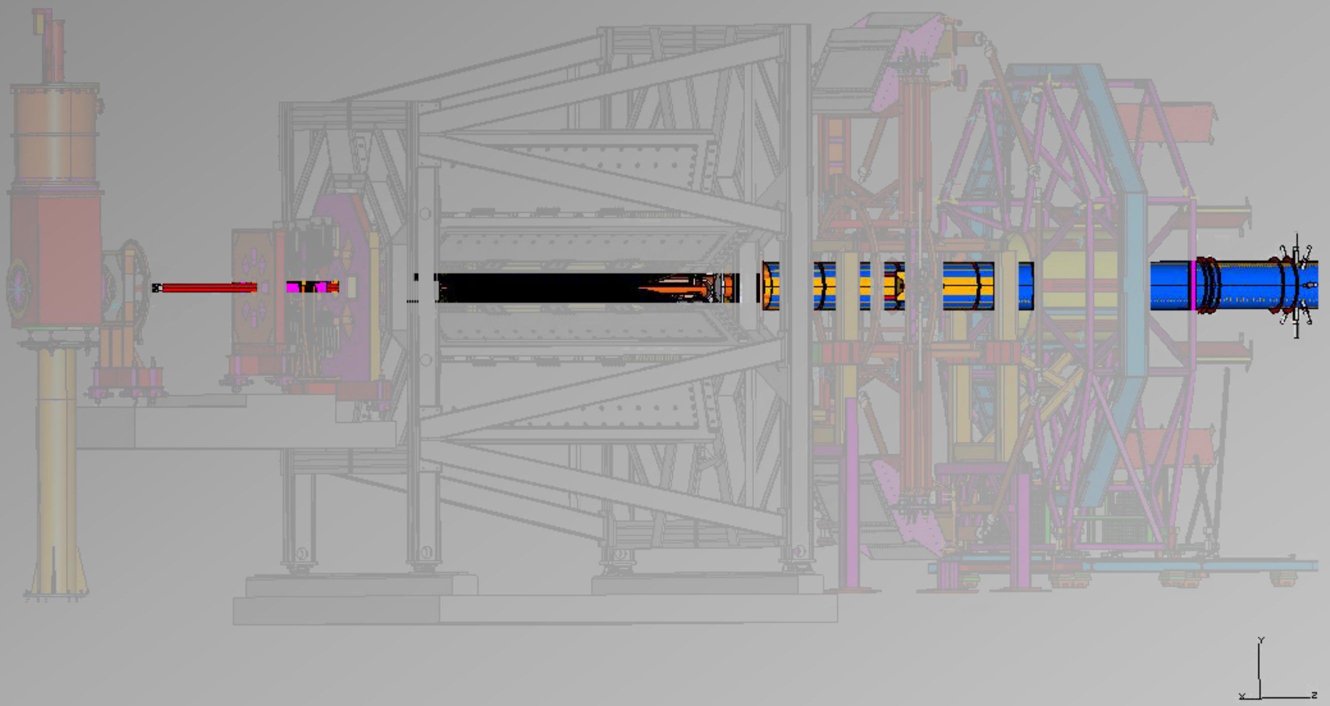
- *Light collection by TIR (5 inch S20 photocathodes I_{kD} = 3 nA)*



Experiment Overview

Beam Line and Luminosity Monitors:

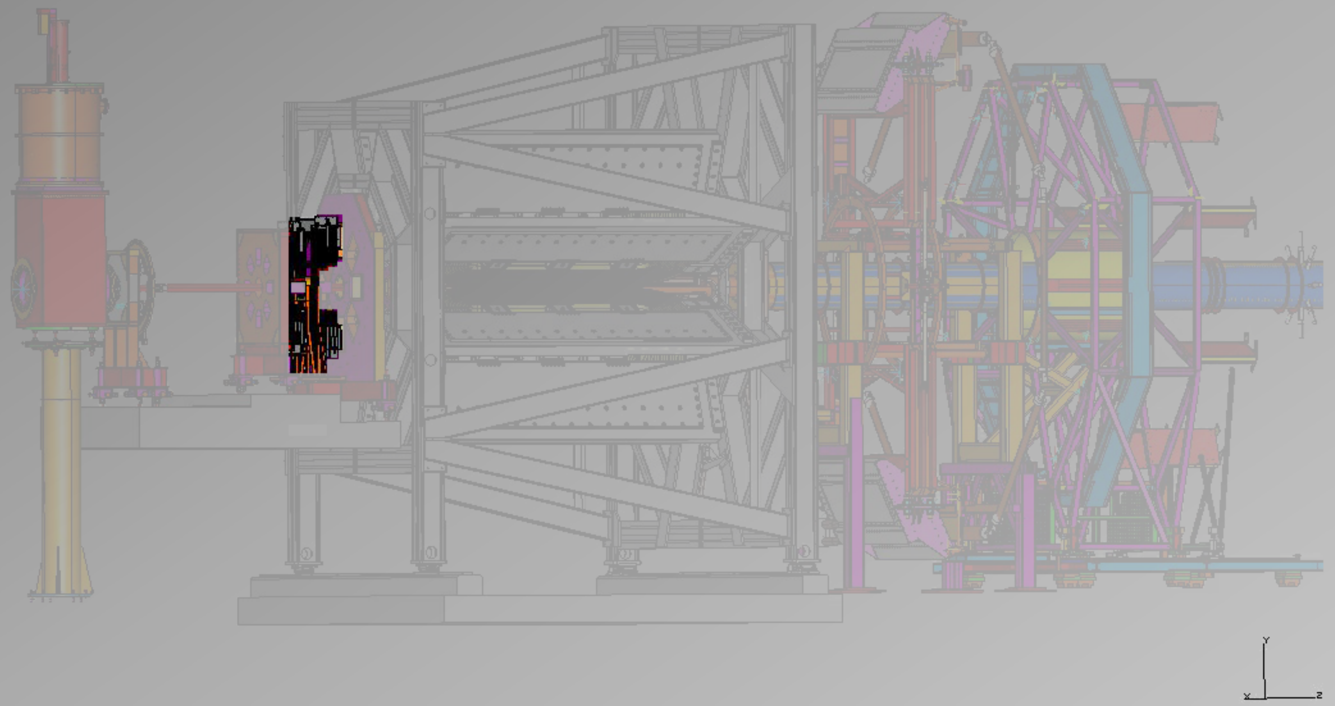
- *Beam line designed to reduce backgrounds (flares)*
- *Monitors primarily used to monitor sensitivity to beam motion and halo*
- *forward scattered beam very well collimated with a tungsten ring in the primary collimator*



Experiment Overview

Tracking Mode Detectors.

Horizontal Drift Chambers:

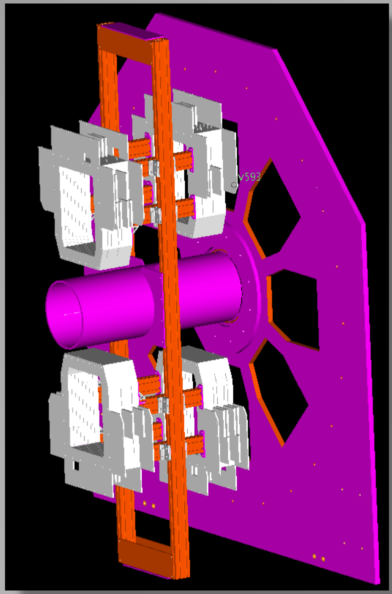


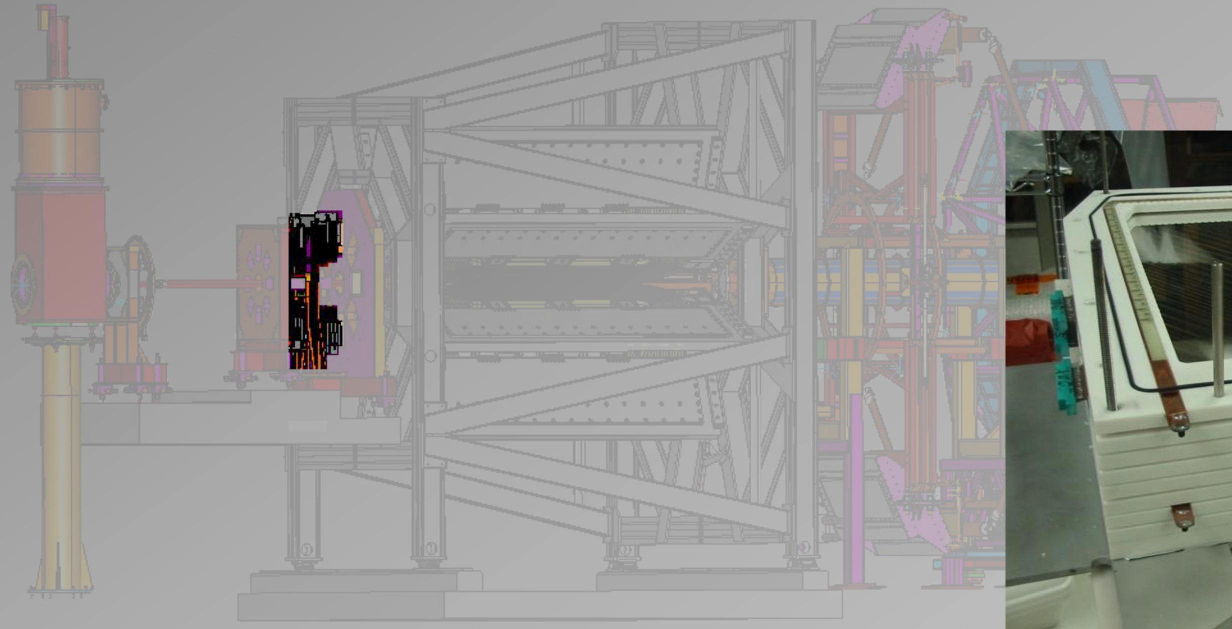
Experiment Overview

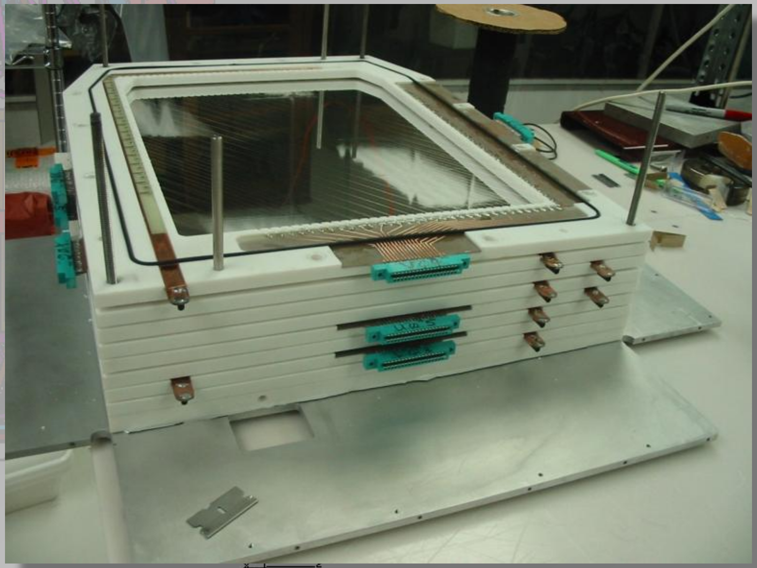
Tracking Mode Detectors.

Horizontal Drift Chambers:

- *Pairs of 6-layer Chambers per tracking octant*
- *Mounted on a rotator to tracking in each octant*
- *Used to measured Q^2 and extract scattering vertex*



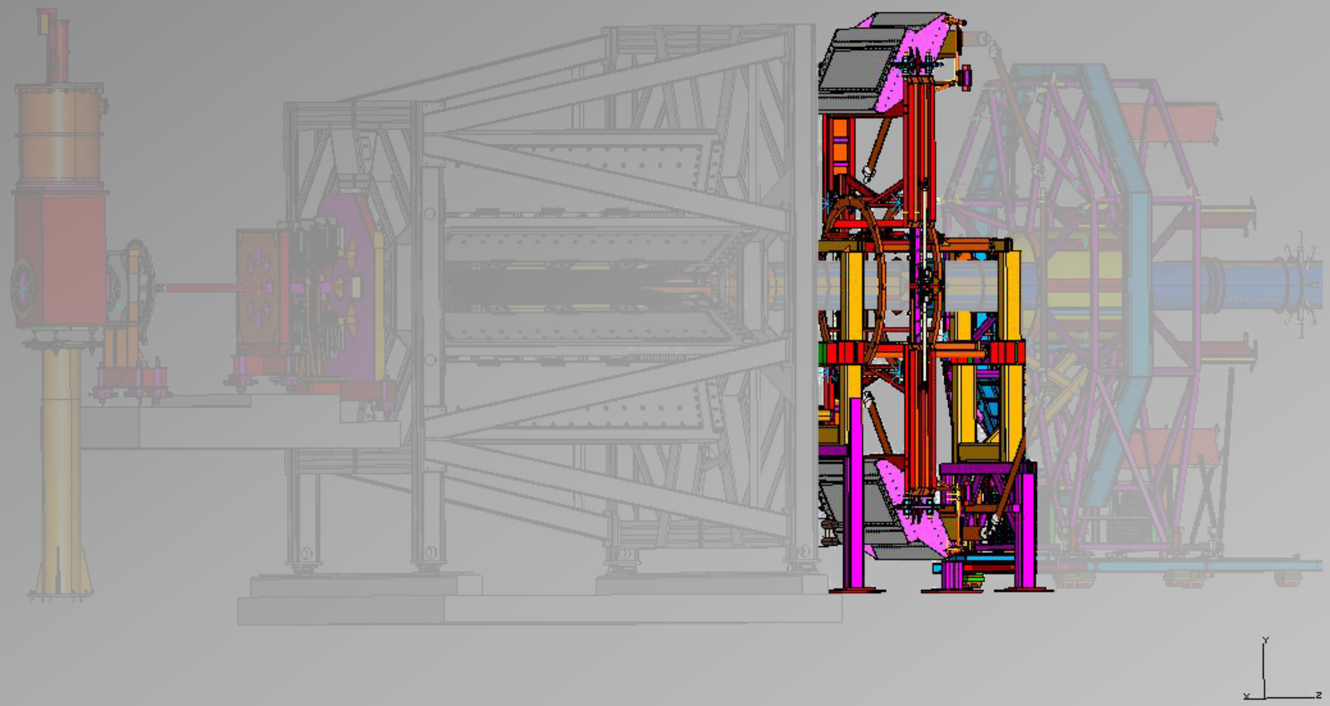




Experiment Overview

Tracking Mode Detectors.

Vertical Drift Chambers and trigger scintillators:

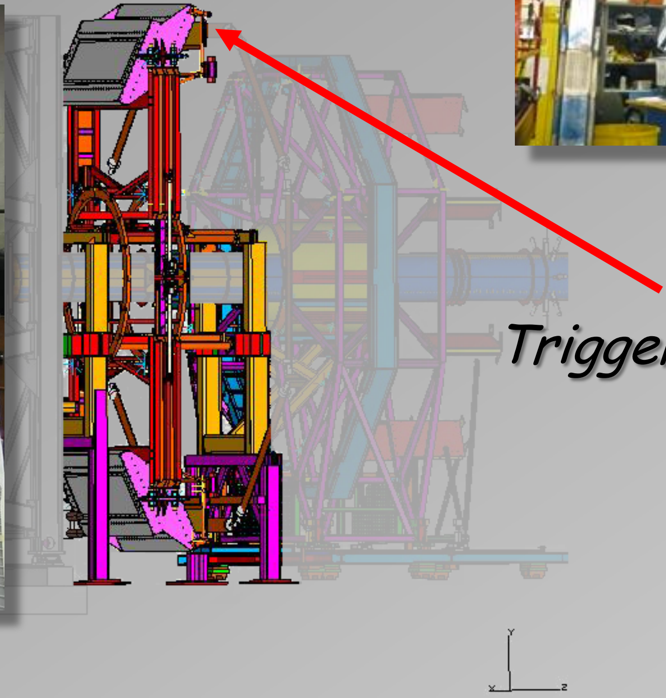


Experiment Overview

Tracking Mode Detectors.

Vertical Drift Chambers and trigger scintillators:

- *Four 2 meter long wire planes per octant*
- *Mounted on a rotator to tracking in each octant*
- *Used for independent measurement of Q^2*

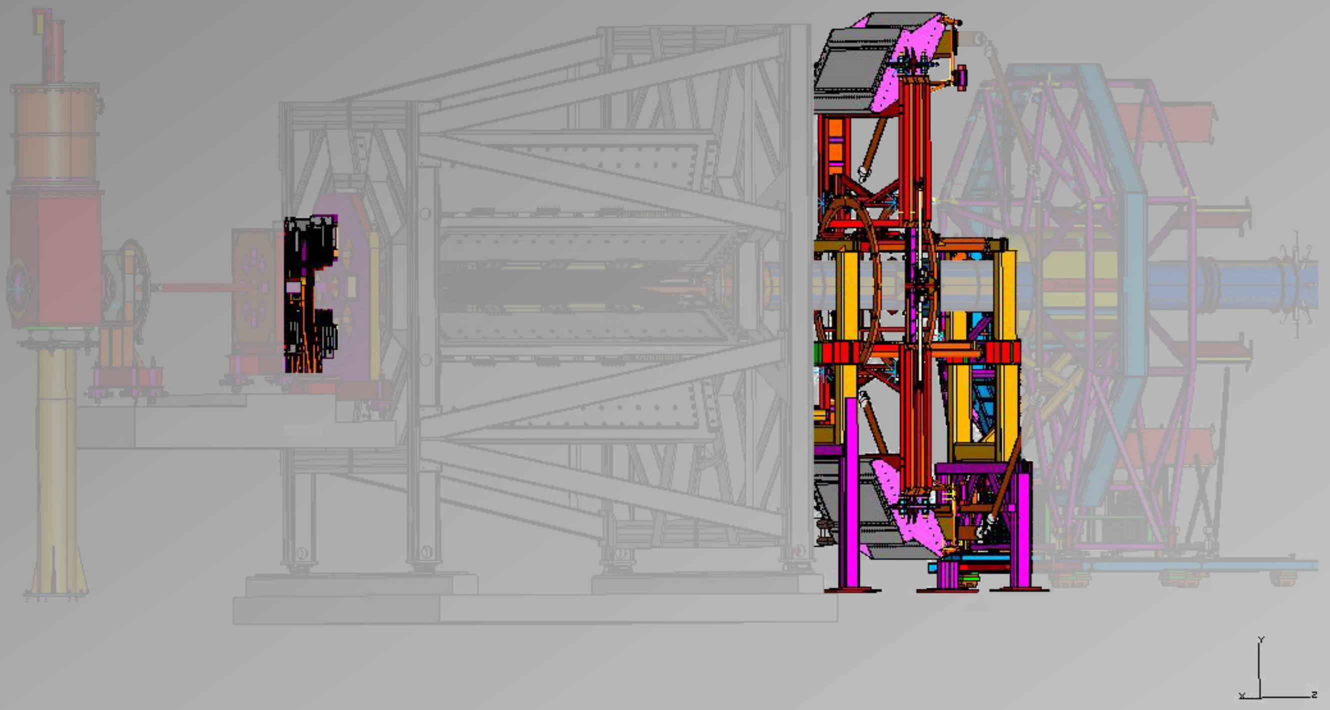


Trigger Scintillator

Experiment Overview

Tracking Mode Detectors.

Tracking measurements: *Do low current (nA) event counting mode runs*

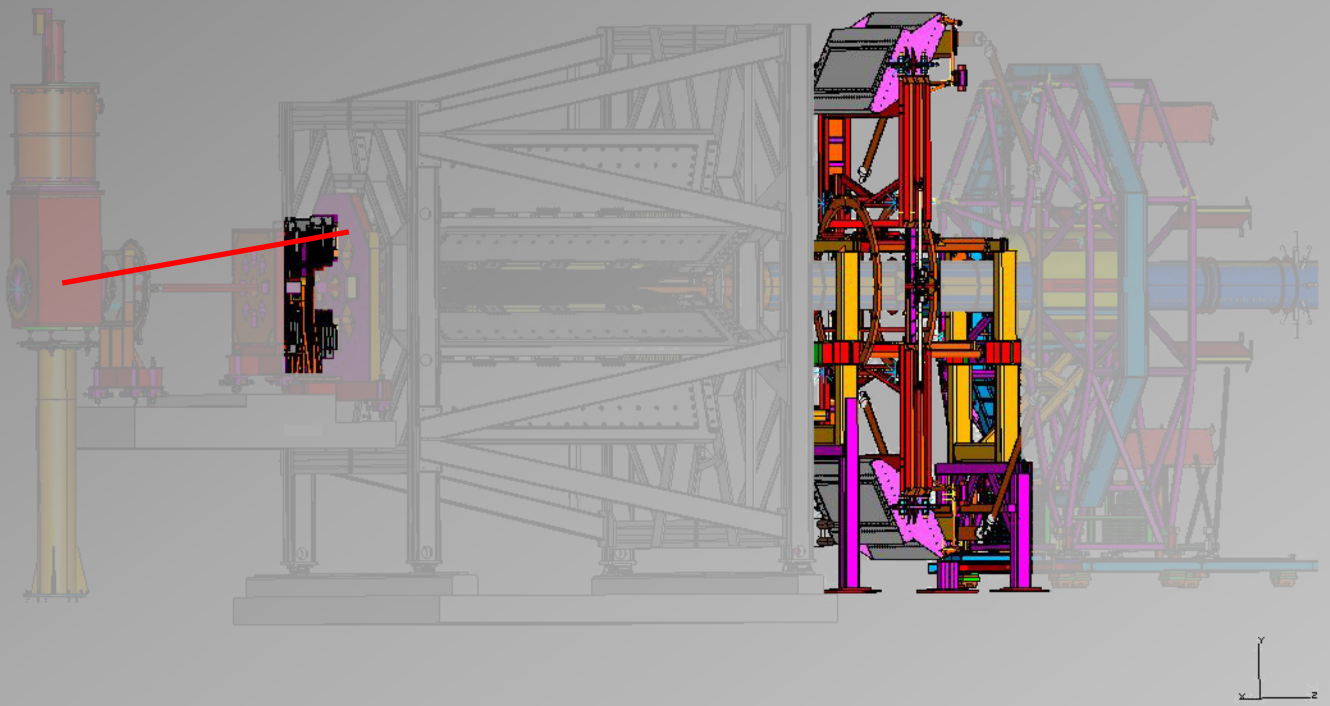


Experiment Overview

Tracking Mode Detectors.

Tracking measurements: *Do low current (nA) event counting mode runs*

- *Get partial track from target to QTOR entrance – calculate Q^2*

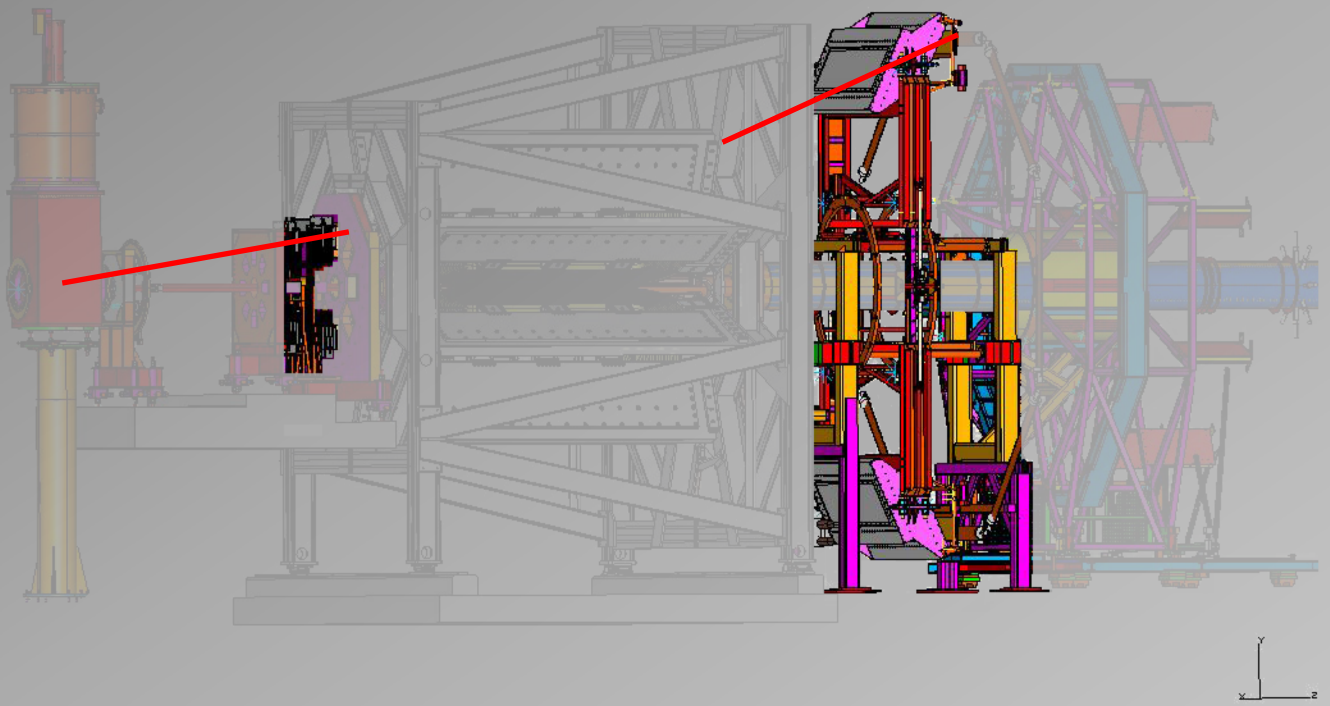


Experiment Overview

Tracking Mode Detectors.

Tracking measurements: *Do low current (nA) event counting mode runs*

- ❑ *Get partial track from target to QTOR entrance – calculate Q^2*
- ❑ *Get partial track from QTOR exit to detector – calculate Q^2*

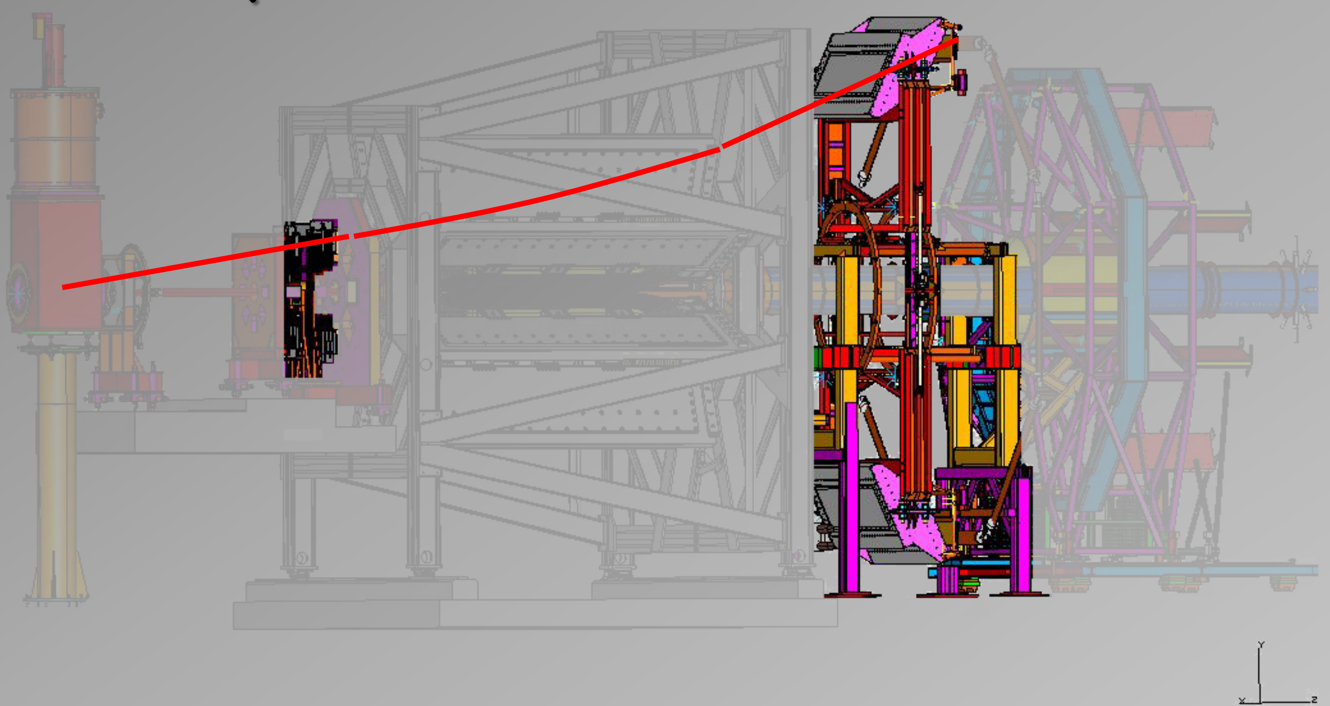


Experiment Overview

Tracking Mode Detectors.

Tracking measurements: *Do low current (nA) event counting mode runs*

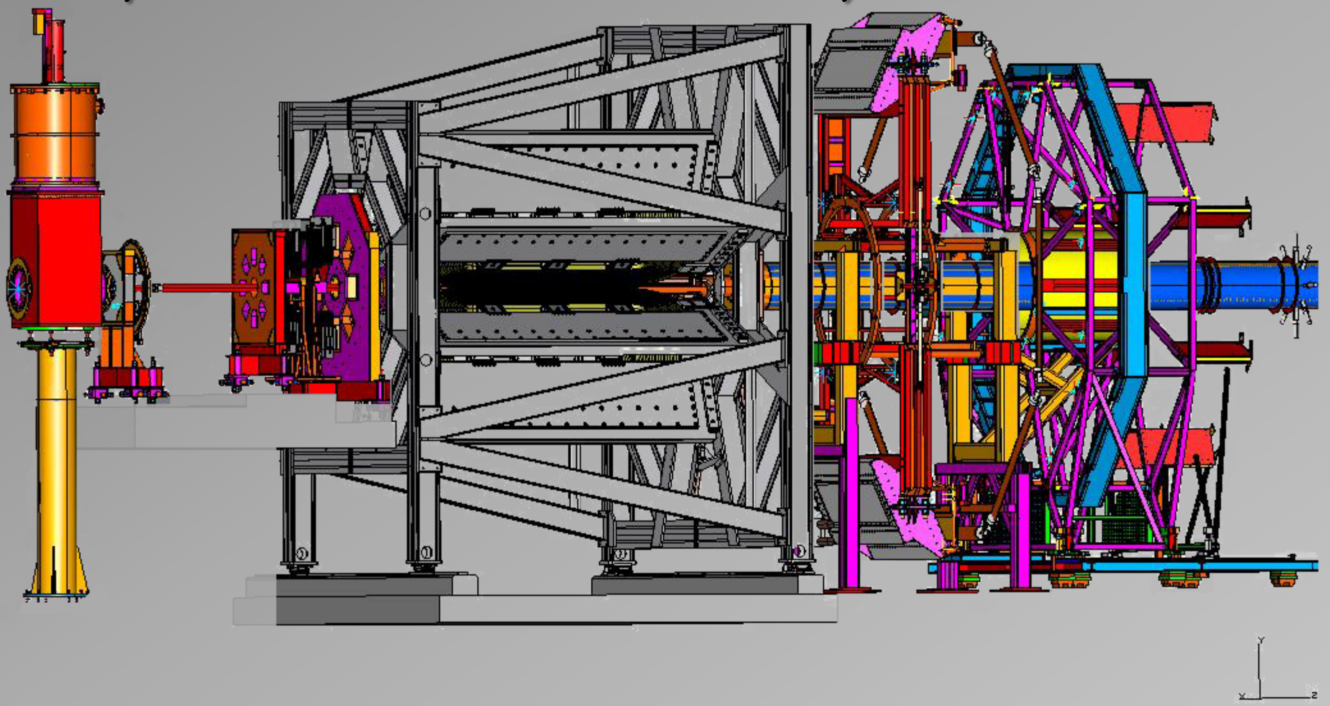
- *Get partial track from target to QTOR entrance – calculate Q^2*
- *Get partial track from QTOR exit to detector – calculate Q^2*
- *Perform consistency check by connecting partial tracks, using the measured QTOR field.*



Experiment Overview

The Q-Weak Experiment

- Design started in ~2000
- Was installed in 2009 and 2010
- Commissioned September - November 2010
- Had a phase I from 12/2010 – 05/2011
- Had a phase II from 11/2011 – 05 /2012
- Completed data collection on May 18, 2012



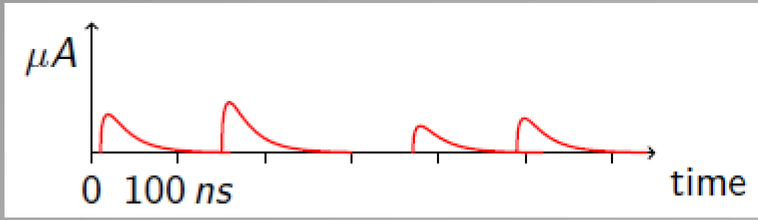
Qweak Data

W. Deconinck W&M

Event Mode vs. Current Mode Measurement

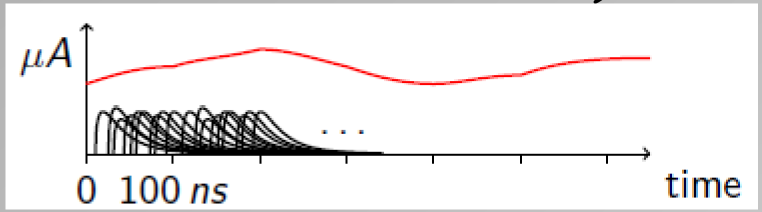
Event mode:

- ❑Each event individually registered
- ❑Event selection / rejection is possible (either PID or discrimination)



Current mode:

- ❑ Very high event rates possible (one every nanosecond)
- ❑ No event selection / background rejection (experiment must be designed to suppress backgrounds and this must be verified with dedicated measurements)



Qweak Data

Asymmetry measurement in current mode:

- Statistical width on individual measurements is 200 ppm (from sampling resolution/frequency of integrating ADC – pure counting statistics)

- Current mode measurements are never at counting statistics but need to be dominated by counting statistics to avoid systematic corrections to resulting asymmetry

- Any Noise in excess of 200 ppm (target, detectors) increases running time to get to the same limit.

Important:

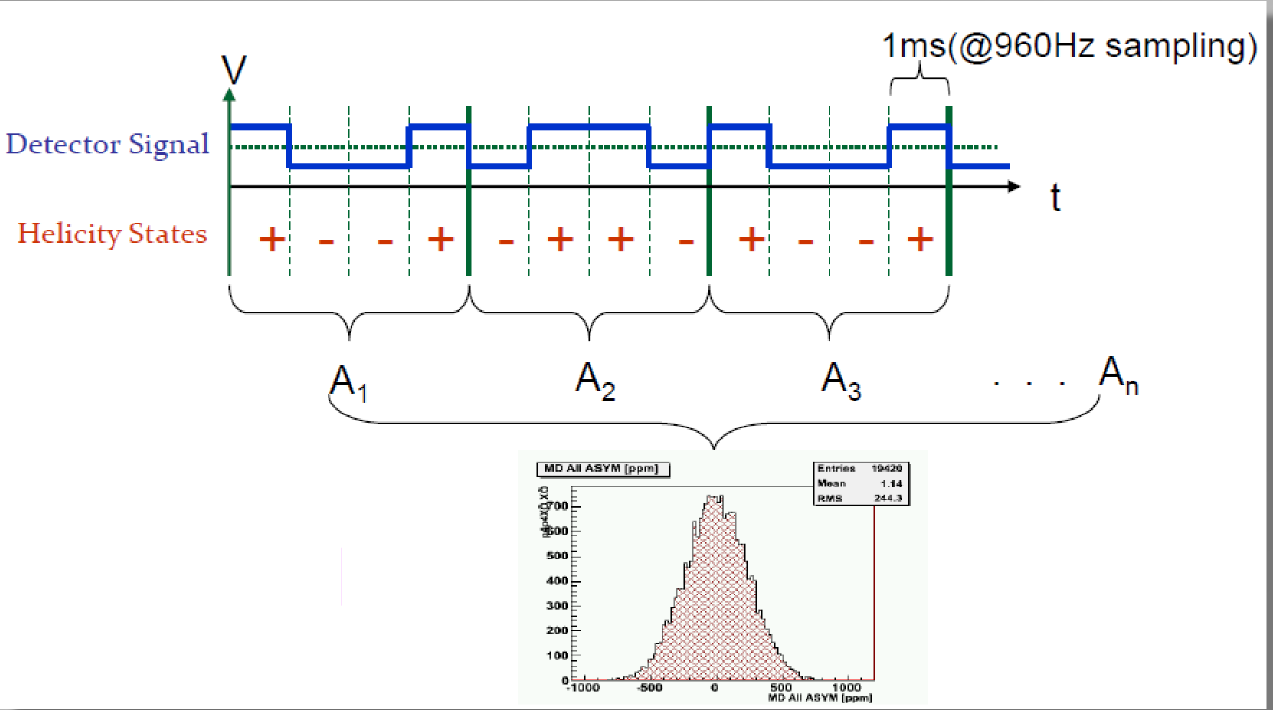
- Keep the noise down!
- Avoid false asymmetries!
- Correct for systematic effects!

Qweak Data

Asymmetry Data Collection:

- *Detector yields are integrated over 1 ms for each helicity state*
- *Raw asymmetries are formed from differences between positive and negative helicity states within a quartet*
- *Quartet asymmetries are histogrammed*

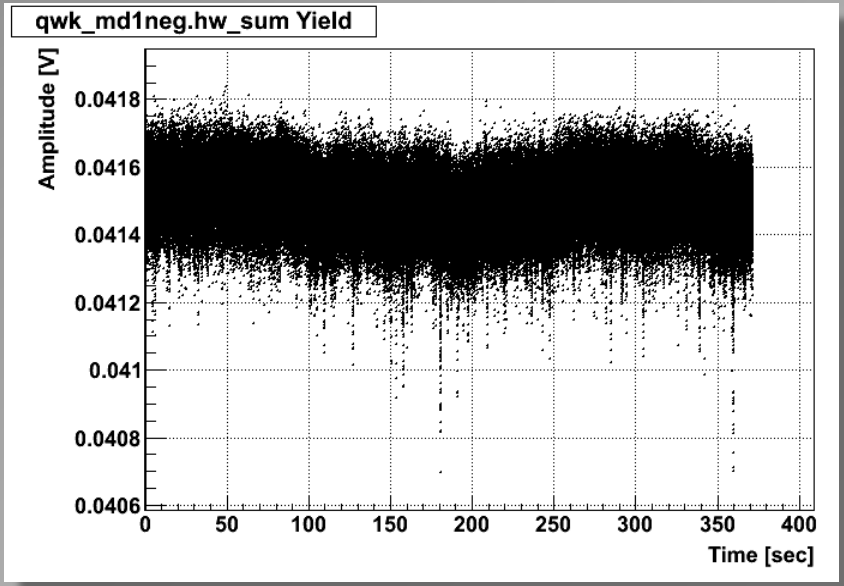
$$A_{Raw}(\vec{e},p) = \frac{\sum_{+} N_{+} - \sum_{-} N_{-}}{\sum_{+} N_{+} + \sum_{-} N_{-}}$$

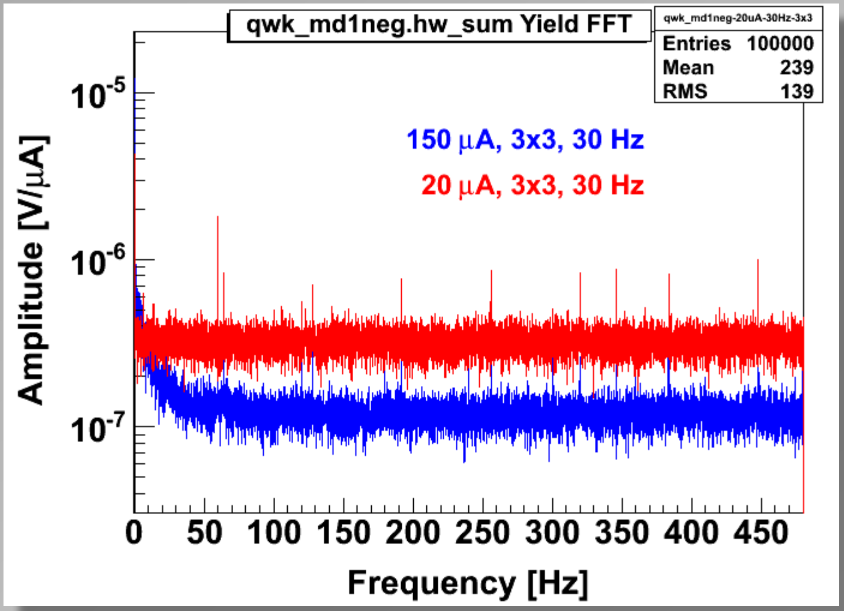


Qweak (Diagnostic Data Examples)

Target boiling:

- ❑ *With high beam power target boiling is inevitable*
- ❑ *Starts around 100 µA*
- ❑ *But this has a 1/f frequency dependence and dominates at low frequency*
- ❑ *Fast helicity (960 Hz) reversal (240 Hz quartet) reduces the effect.*



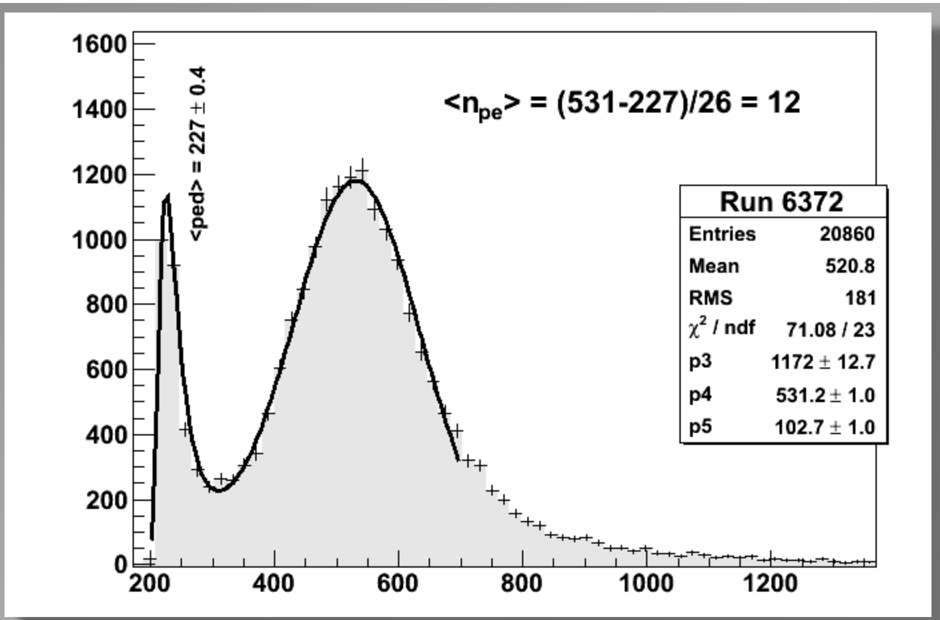


Qweak (Diagnostic Data Examples)

Main Detectors:

Bare bar:

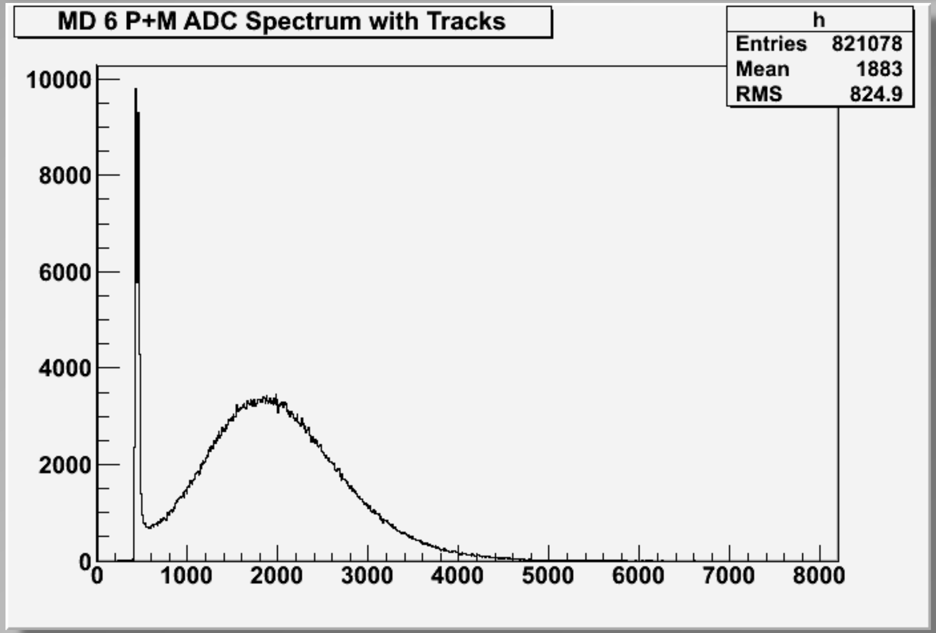
The simulated efficiency was about 16 PE.



Pre-radiated bar:

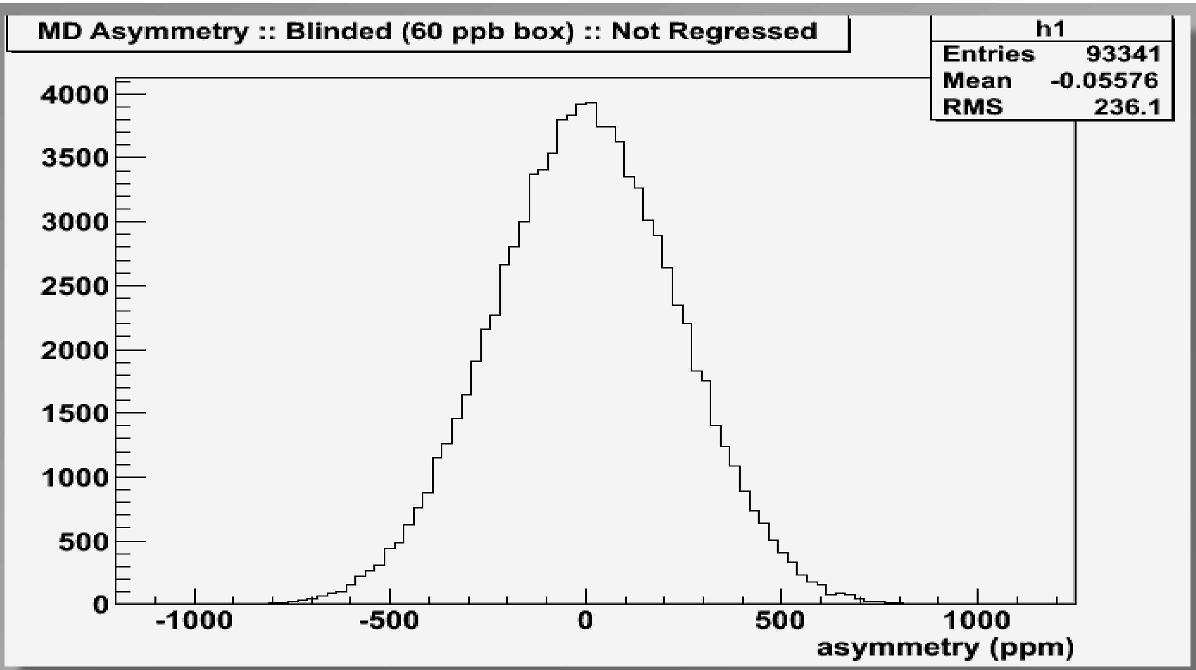
Increase of mean yield and RMS consistent with shower activity in a 2 cm lead radiator (3 cm is shower max):

~ 85 PE/electron



Qweak (Diagnostic Data Examples)

Main Detectors:



Observed RMS width in main detector yield:

~ 240 ppm

Pure counting statistics:	*≈ 200 ppm*
Detector Resolution:	*+ 90 ppm*
Current monitor resolution	*+ 50 ppm*
Target boiling	*+ 57 ppm*
Total	*≈ 233 ppm ≈ observed*

Qweak Preliminary Asymmetry Sample

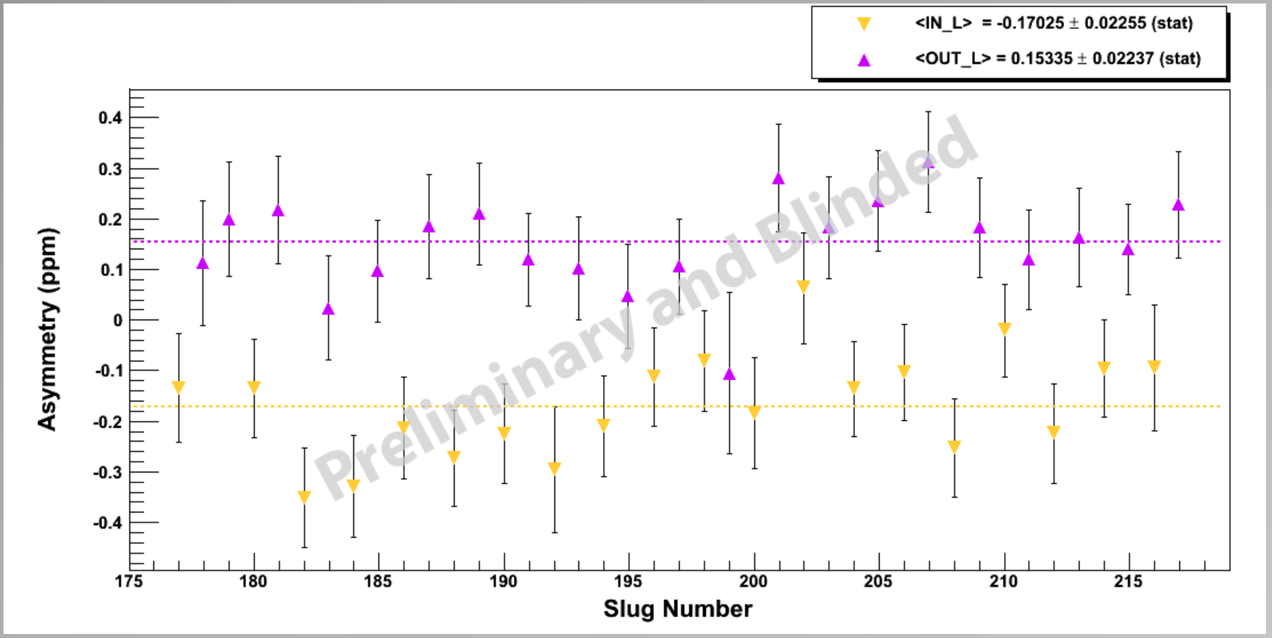
Asymmetry Data:

Insertable λ/2-plate (IHWP) in injector allows "analog" helicity flipping (on the time scale of a few hours – a slug)

Wien filter: Another way of flipping helicity (several weeks time scale)

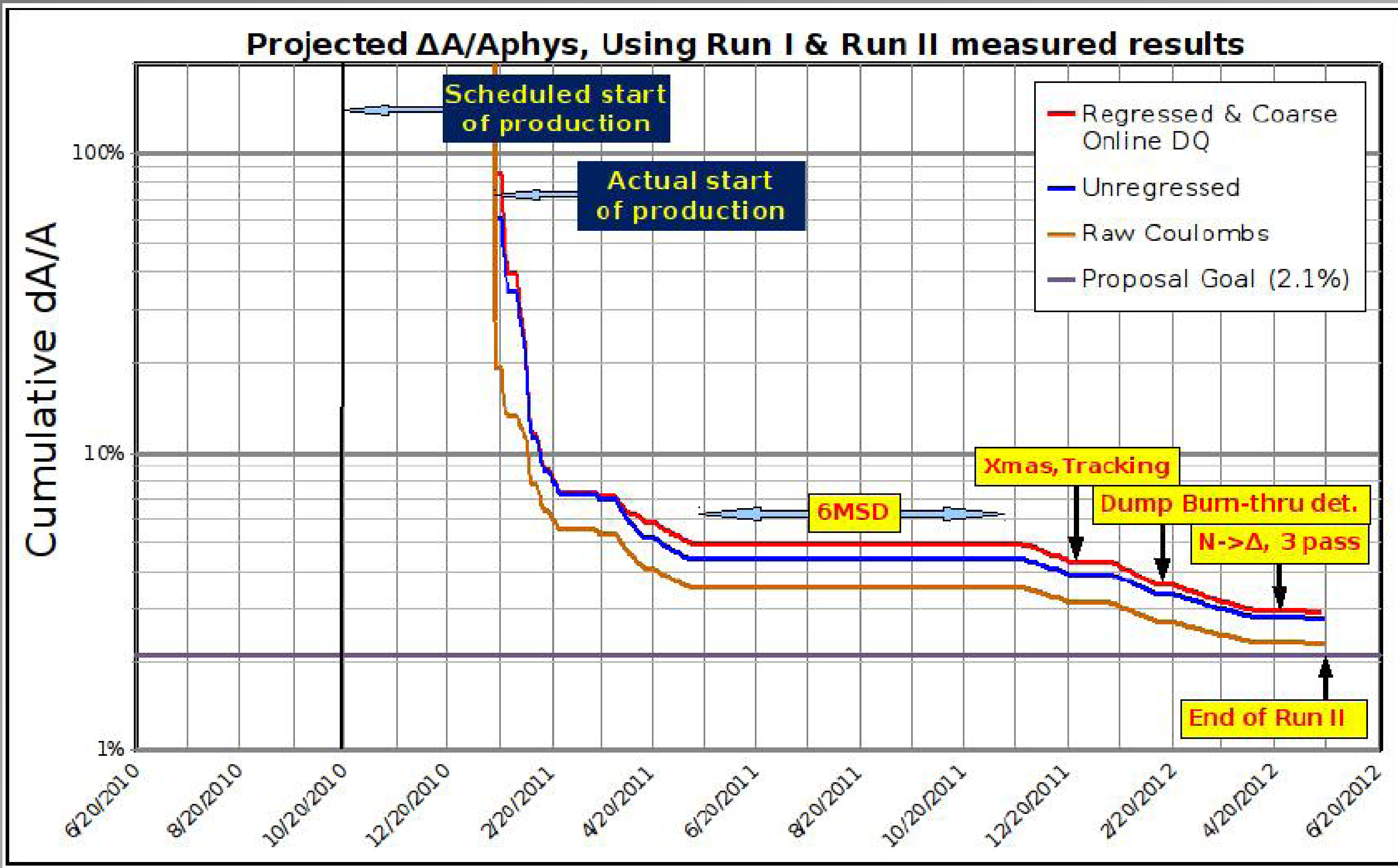
This is a partial Wien with 21 slugs of data

We have many hundreds of these.



Average asymmetries are consistent with sign change!

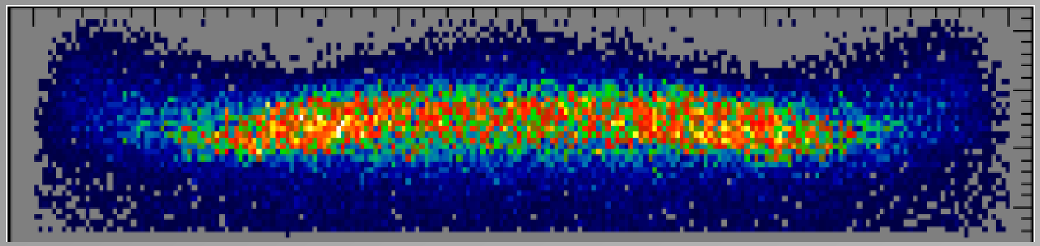
Qweak Statistics Performance



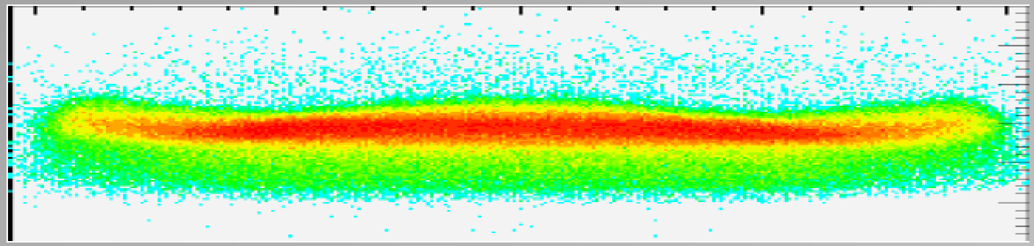
Qweak Tracking Data

Tracking Mode Data:

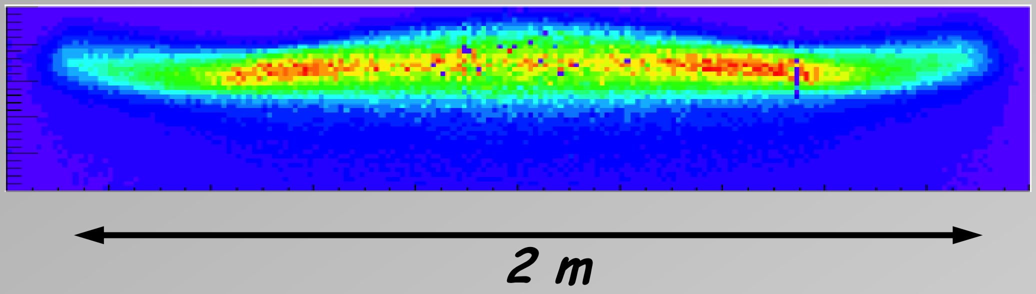
Simulated event yield profile on the main detector:



Reconstructed profile from VDC chamber events:

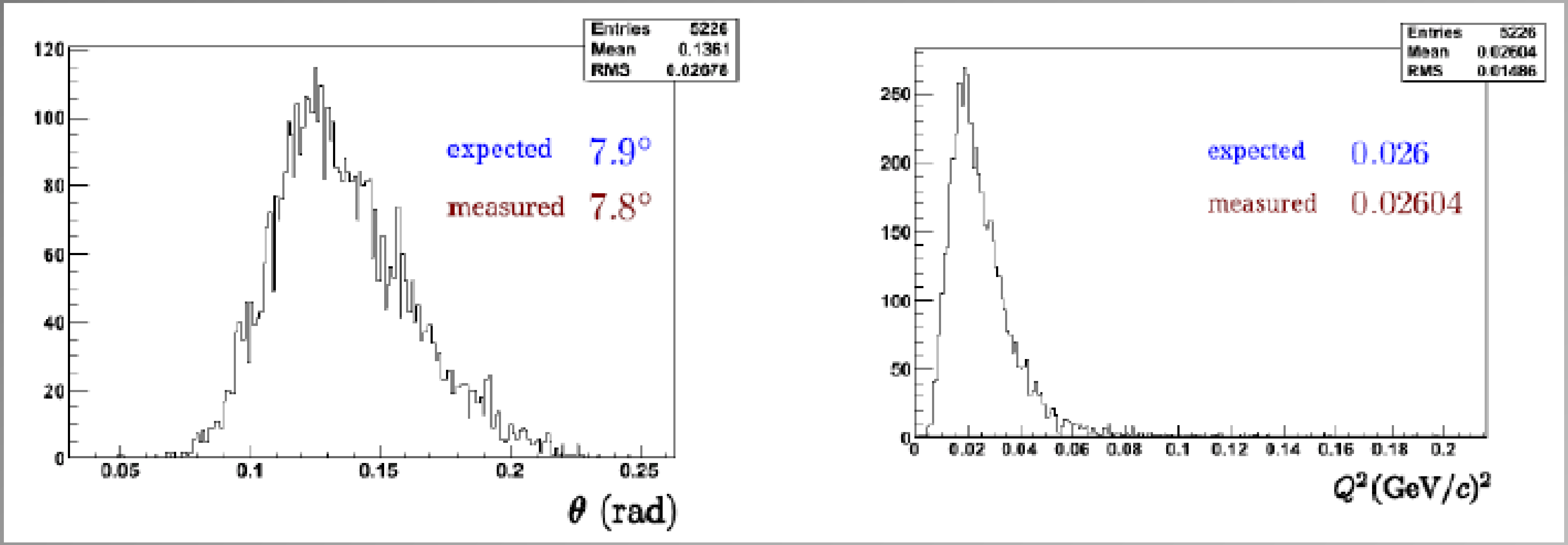


Event profile measured by focal plane scanner at full current:



Qweak Tracking Data

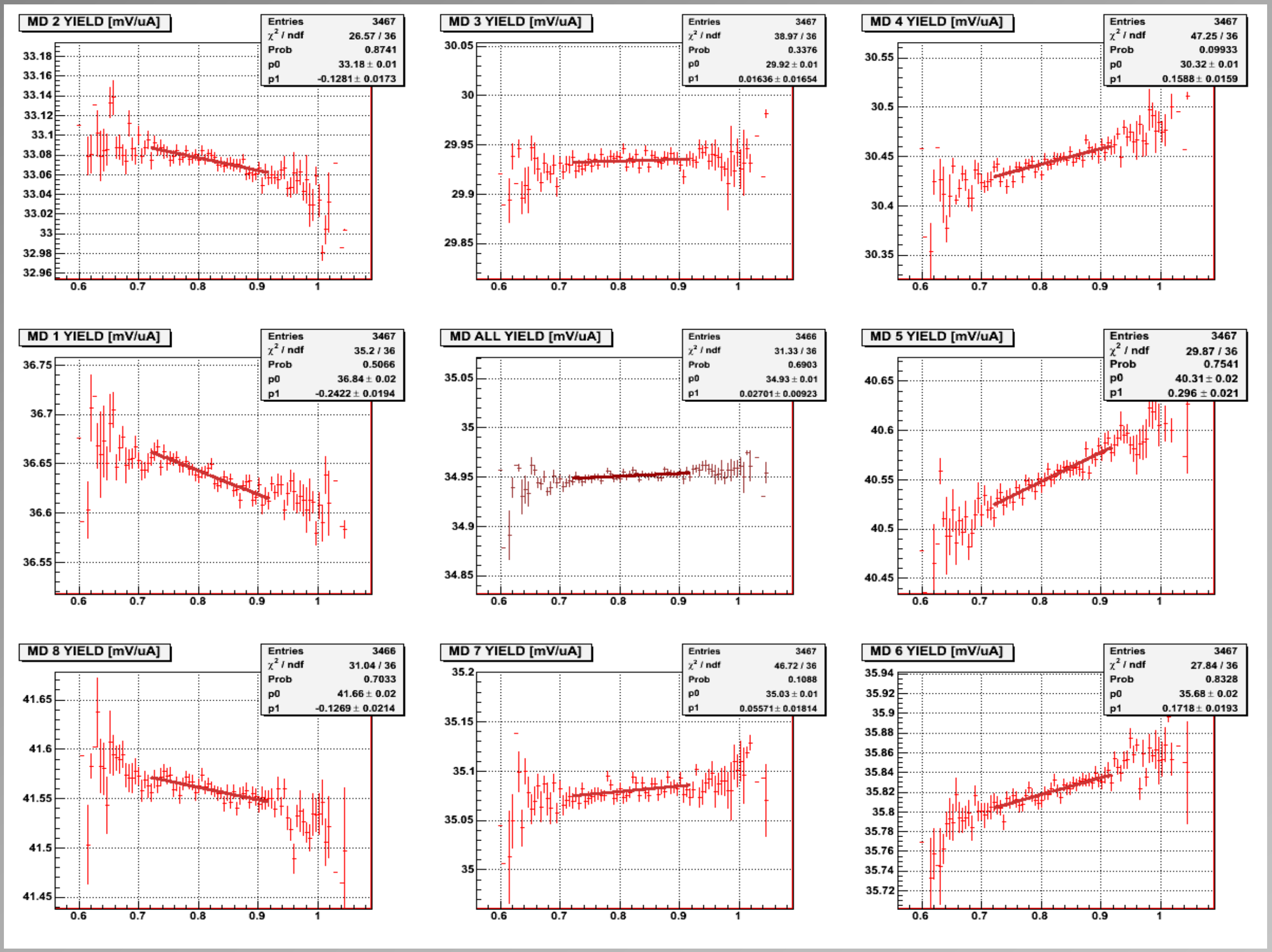
Preliminary reconstruction of scattering angle and Q^2



Qweak Beam Sensitivities

Natural beam motion:

- *Measured asymmetry correlated with beam position and angles.*
- *False asymmetries*
- *Need to do linear regression to remove effect:*



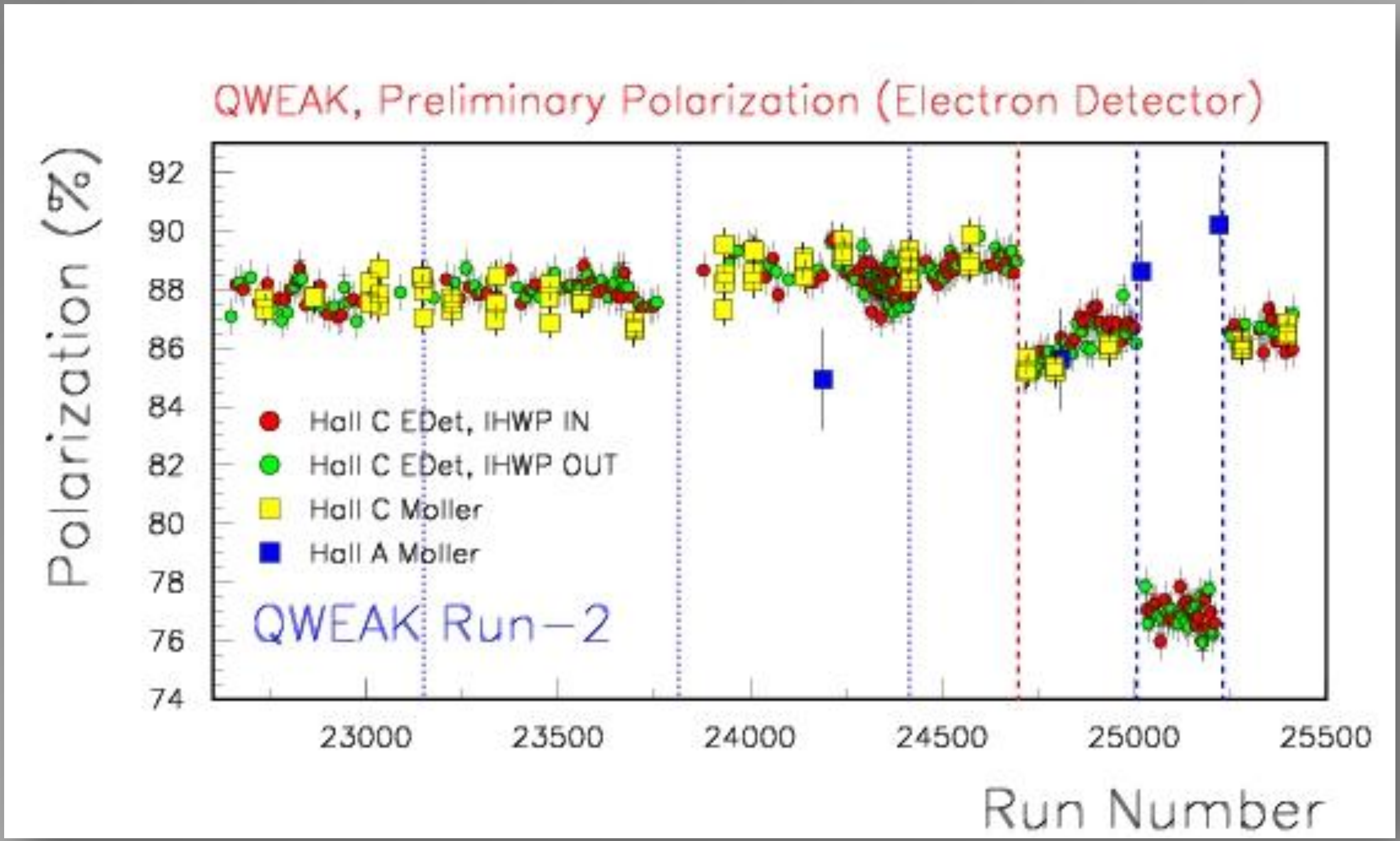
YIELD [mV/μA]

Target X [mm]

$$A_{Corr}(\vec{e},p) = \sum_i \frac{\partial A_{Raw}}{\partial x_i}\Delta x_i \qquad x_i = x, y, x', y', E$$

Qweak Polarimetry

Comparison of the Moller and Compton polarimeter results:



Qweak Background / Systematics

Potential false asymmetries:

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

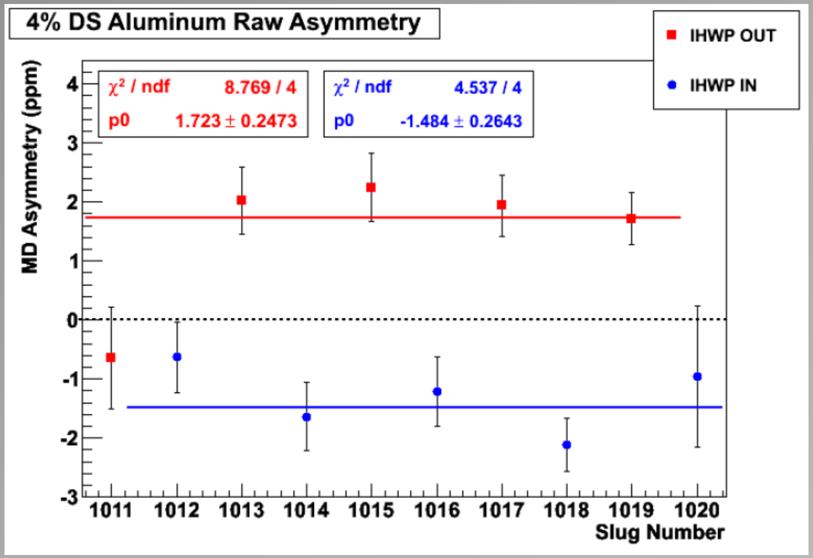
Processes:

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

Qweak Background / Systematics

Aluminum Asymmetry:

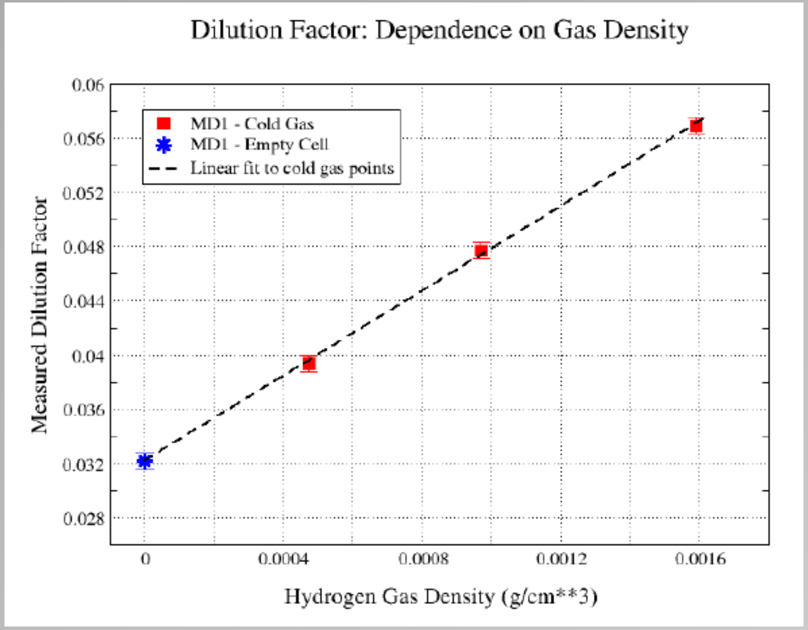
Preliminary 4% measurement consistent with order of magnitude expected from theory.



Asymmetry : A few ppm
Measured dilution: f = 3%

→ *Correction to asymmetry ≈ 20%*

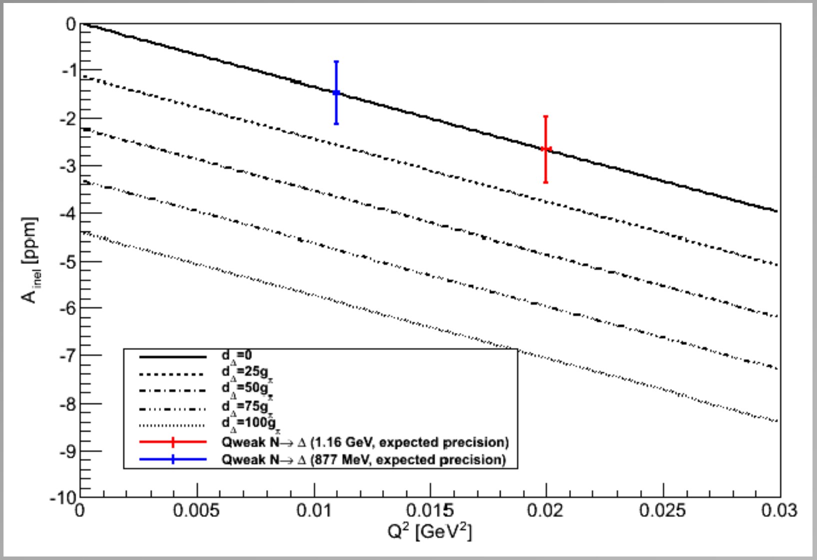
$$A_{phys}(\vec{e},p) = \frac{A_{Corr} - fA_{Al}}{1-f} \qquad f \equiv \frac{Y_{Al}}{Y_{Total}}$$



Qweak Background / Systematics

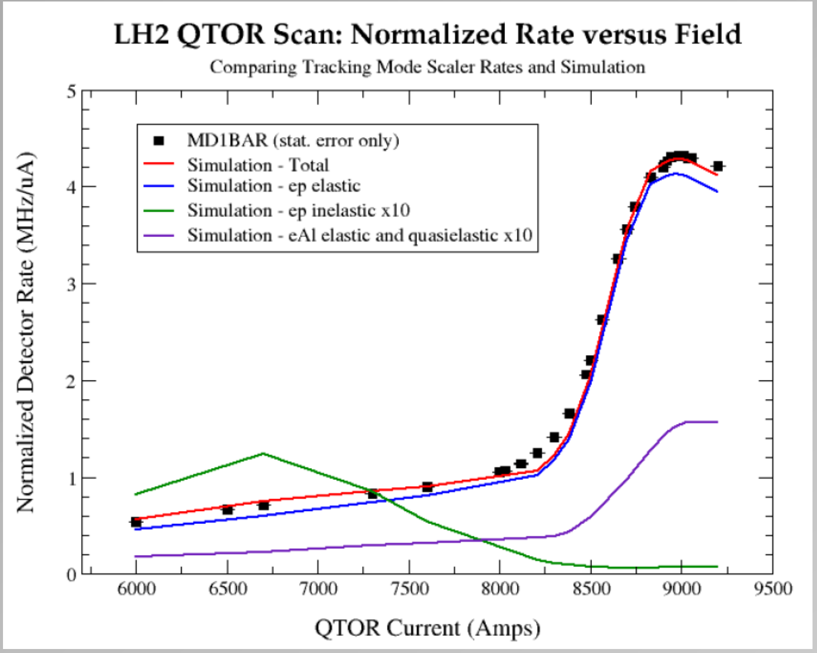
N → Δ:

Projected result only
(expected 1 ppm precision)



Asymmetry : A few ppm
Measured dilution: f = 0.1%

→ Correction to asymmetry ≈ 1%



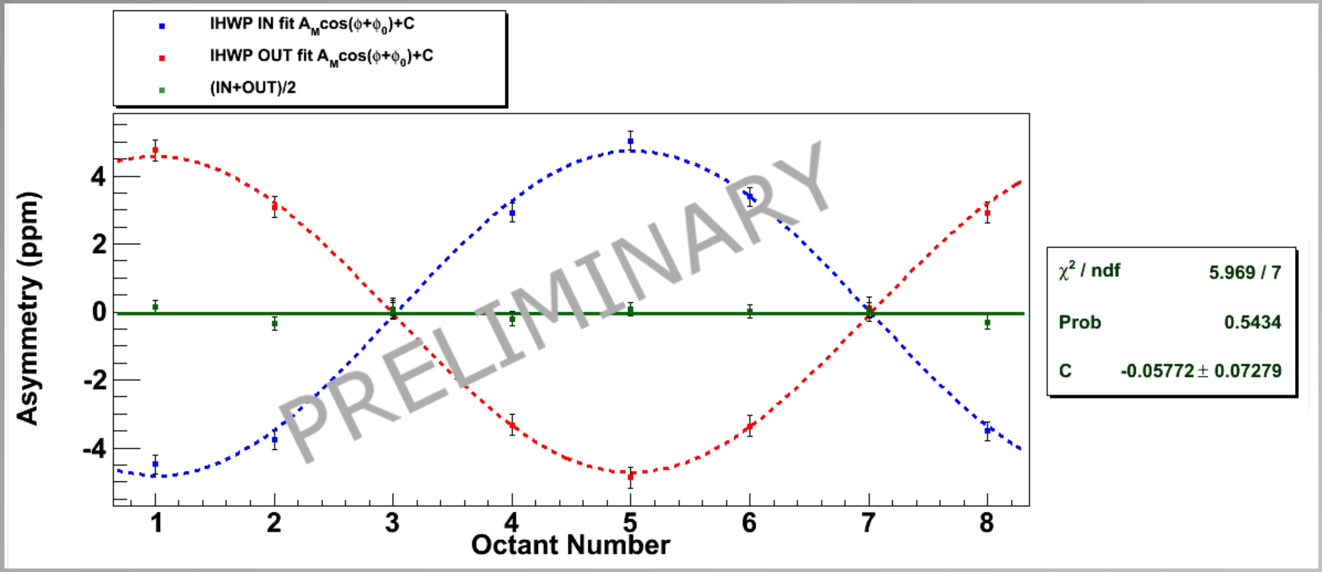
Qweak Background / Systematics

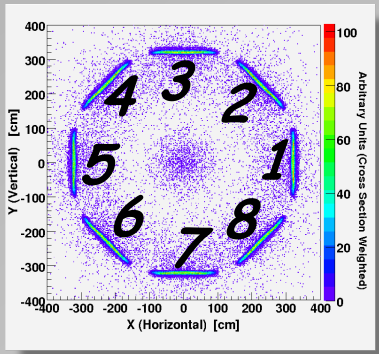
Transverse Asymmetry: $A_{Raw}(\phi_{det}) = |P_L|A_{PV} + |P_T|A_T \sin(\phi_{det} - \phi_s)$

Small transverse polarization component in the beam gives rise to a small false asymmetry. → *Do ancillary runs with transversely polarized beam on unpolarized target:*

Parity-conserving (T-odd) transverse Asymmetry: a few ppm

Cancellation with slow helicity reversal:





Qweak Background / Systematics

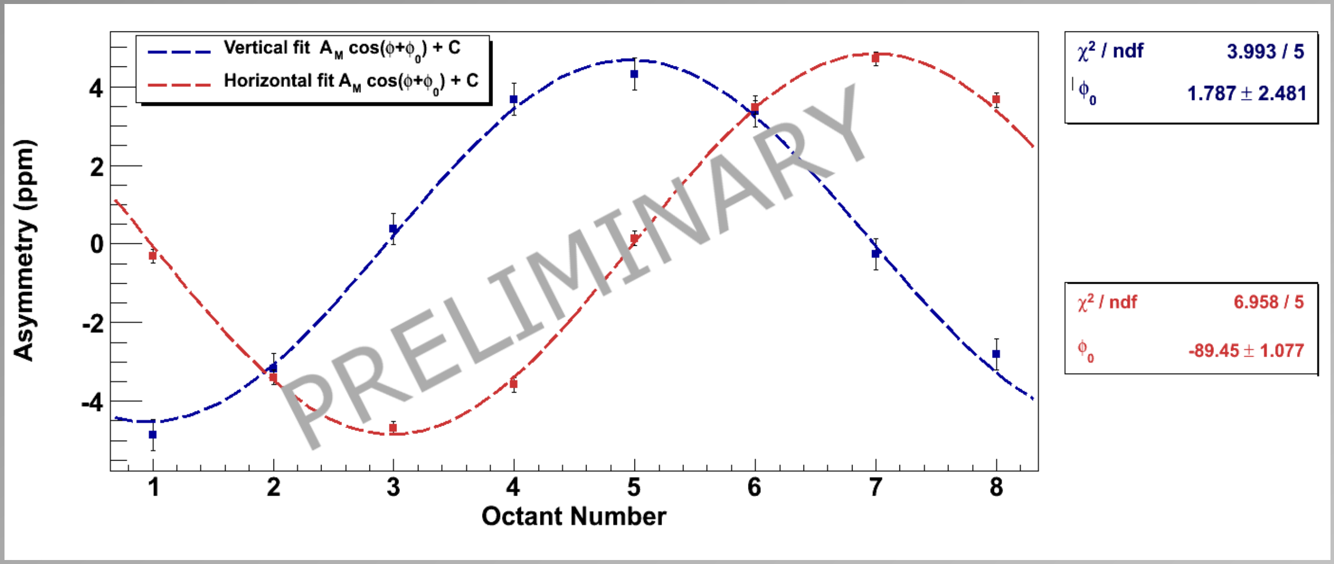
Transverse Asymmetry:

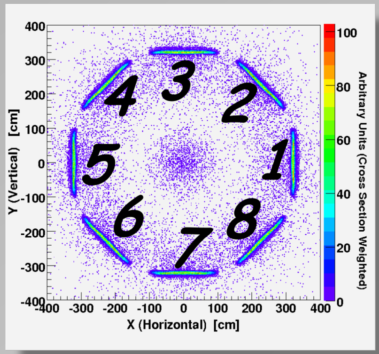
90 ° phase shift from vertical (Shown for horizontal polarization)

Shown asymmetries not corrected for backgrounds or polarization

Preliminary transverse asymmetry: (by B. Waidyawansa, Ohio Univ.)
A_T = -5.27 ± 0:07(stat) ± 0:14(syst) ppm

Transverse asymmetry leakage in A_{PV} < 2 ppb





Qweak Background / Systematics

Transverse Asymmetry:

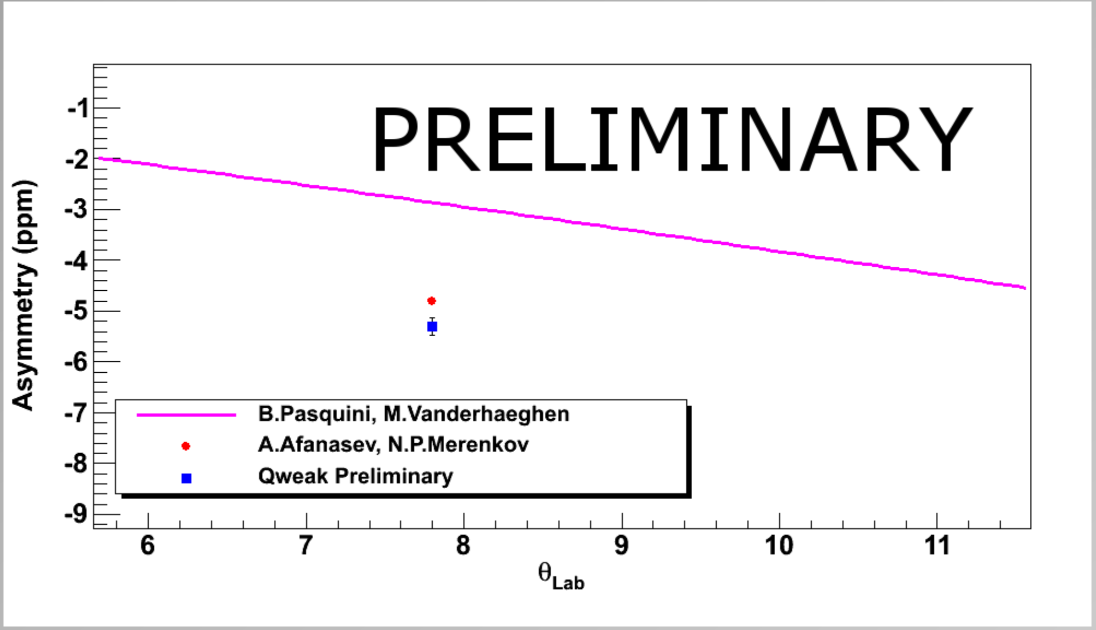
- *Pasquini & Vanderhaeghen: proton and N, resonance region with MAID, asymmetry dominated by inelastic contribution*

- *Afanasev & Merenkov: forward Compton amplitudes from real photo-production*

- *E = 1.160 GeV, θ = 7.8, Q^2 = 0.026 GeV^2*

- *Other measurements:*

  0.877 GeV
  3.36 GeV



Summary

Q-Weak completed data taking in May 2012

- Operated at very high luminosity of 2×10^{39} cm^{2} s^{-1}
- 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
- First preliminary results:

  Transverse asymmetry on hydrogen:
  $A_T = -5.27 \pm 0{:}07(stat) \pm 0{:}14(syst)$ ppm

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

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

Qweak Radiative Corrections and New Physics

$$Q_W^p = \rho_p\left(1 - 4\kappa_p \sin^2(\theta_W)\right) + \lambda_p \rightarrow + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

Q^p_{Weak}	Standard Model (Q^2 = 0)	0.0713 ± 0.0008
Q^p_{Weak}	experiment precision goal	± 0.003

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, Kurylov, Ramsey-Musolf, PRD 68(2003)016006.

Qweak Radiative Corrections and New Physics

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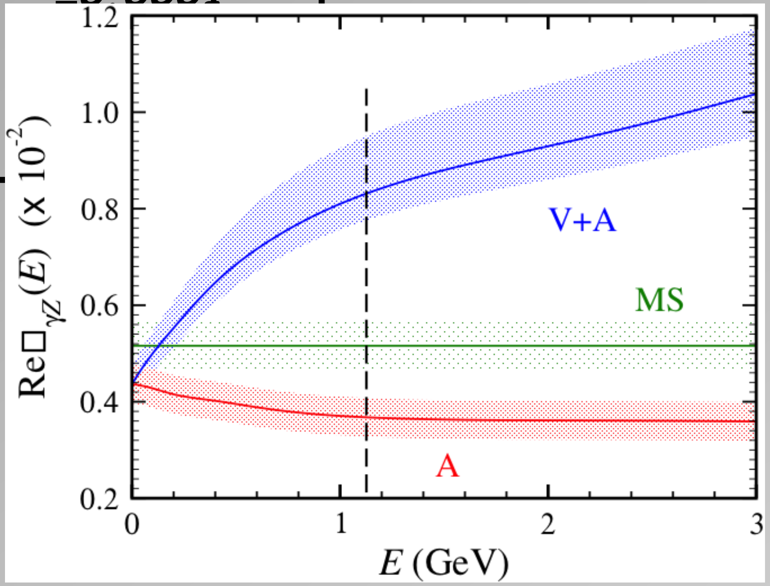
Charge symmetry	
Total	

Erler, Kurylov, Ramsey-Musolf, PRD 68(2003)016006.

New calculations:

γZ box: 8% correction with ≈1% uncertainty



Qweak Radiative Corrections and New Physics

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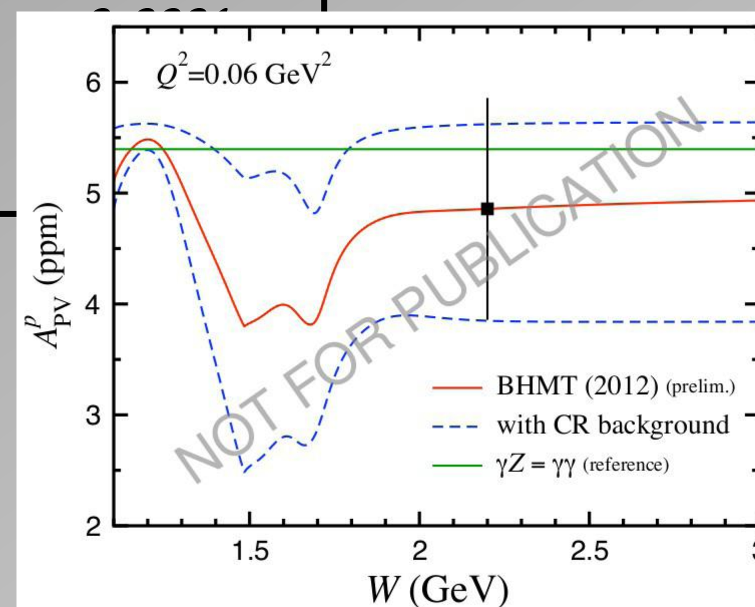
Total	

Erler, Kurylov, Ramsey-Musolf, PRD 68(2003)016006.



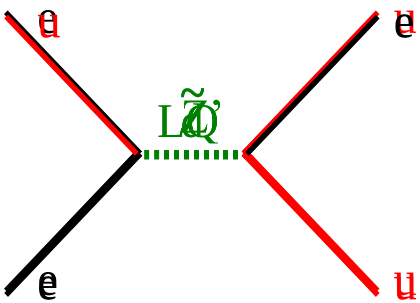
New calculations:

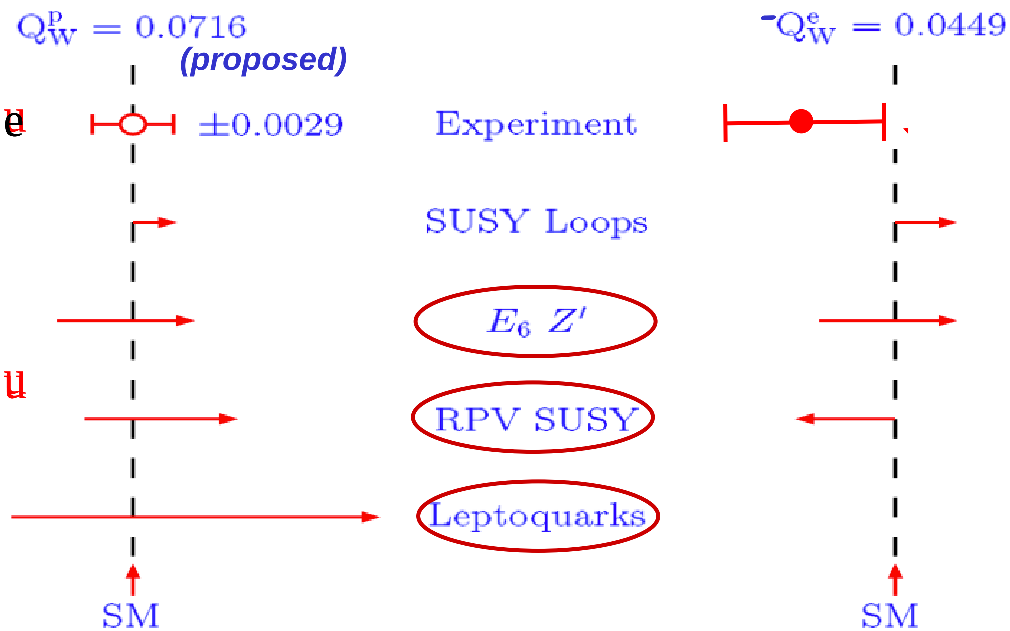
γZ box: 8% correction with ≈1% uncertainty

Verification in "DIS" region, calculation by Melnitchouk

Q^p_{weak} & Q^e_{weak} – Complementary Diagnostics for New Physics

JLab Qweak   SLAC E158





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

- *arrows show allowed "pull" of weak charges by new physics as constrained by previous experiments*
- *electron and proton weak charge experiments are complementary*