

The Qweak Experiment at Jefferson Lab



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For the Qweak Collaboration

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Jefferson Lab



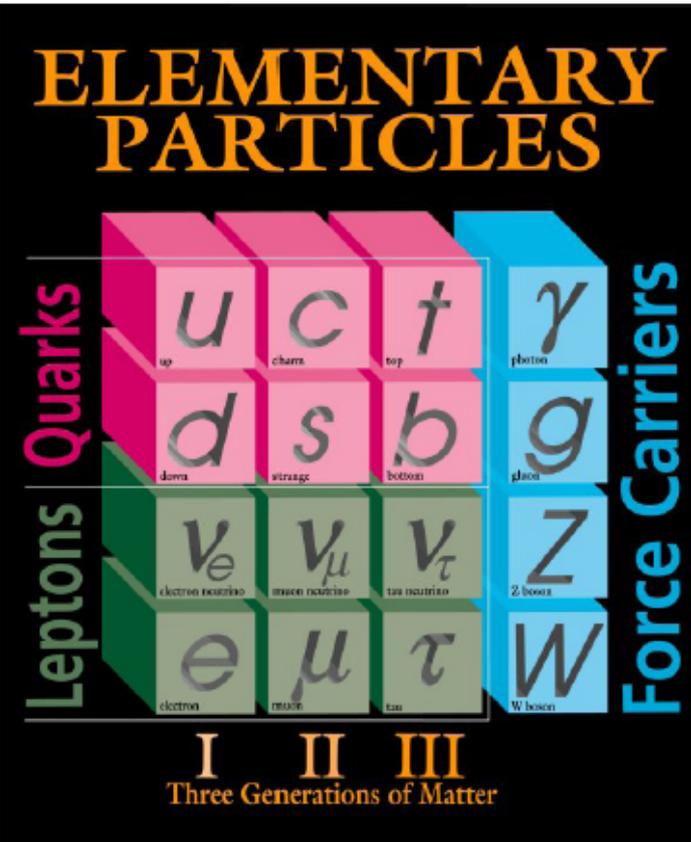
Outline

- Brief Introduction and Motivation
- Overview of the Experiment
- Look at Data Quality

Introduction to Qweak

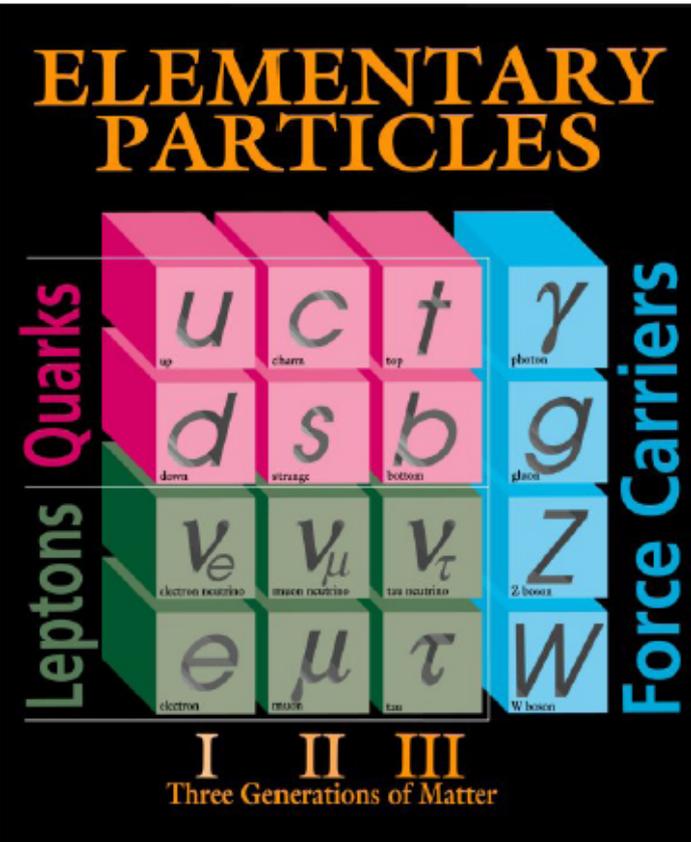
- Parity-violating elastic electron-proton scattering at Jefferson Lab
- First direct measurement of the proton's weak charge Q_W^p (4% goal)
- New determination of $\sin^2\theta_W$ at low Q^2 (0.3% goal)
- Sensitive to new PV electron-quark interactions at the TeV scale
- Complementary to Atomic Parity Violation
(ratio of isotopes measures Q_W^p if neutron skin is under control)

Introduction



	Electromagnetic Charge	Weak Vector Charge
u	+2/3	$-2C_{1u} = 1 - \frac{8}{3}\sin^2 \theta_W \approx 1/3$
d	-1/3	$-2C_{1d} = -1 + \frac{4}{3}\sin^2 \theta_W \approx -2/3$
uud	+1	$Q_W^p = 1 - 4\sin^2 \theta_W \approx 0.07$
udd	0	$Q_W^n = -1$
		$(C_{1i} = 2g_{AG}^e g_V^i)$

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Q_W^p suppressed in SM \rightarrow sensitive to new physics

Quark Couplings

- Qweak will fully constrain the vector quark couplings:

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

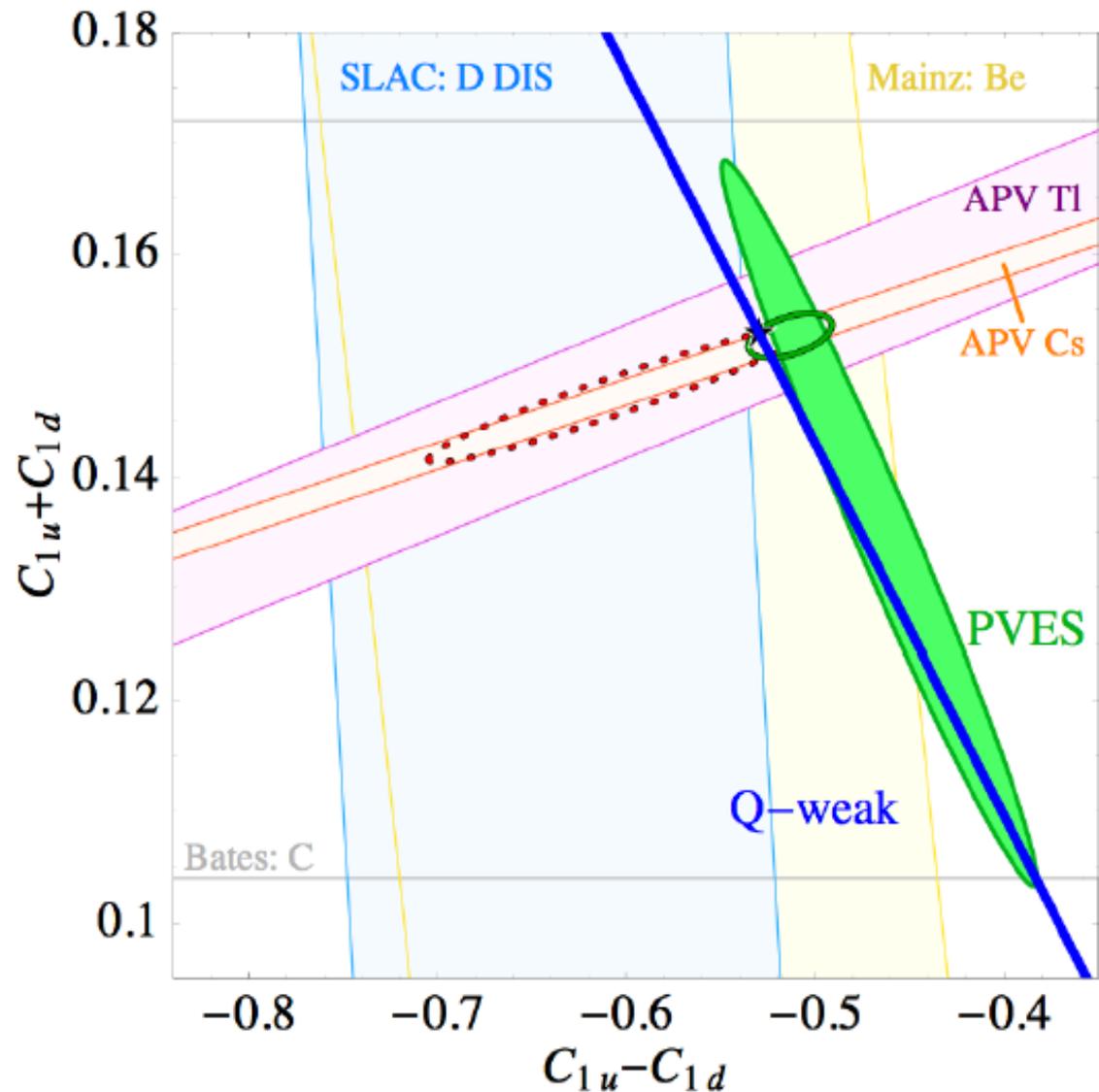
PVES ellipse:
HAPPE_x, G0, PVA4, SAMPLE

Q_{weak} : Anticipated error

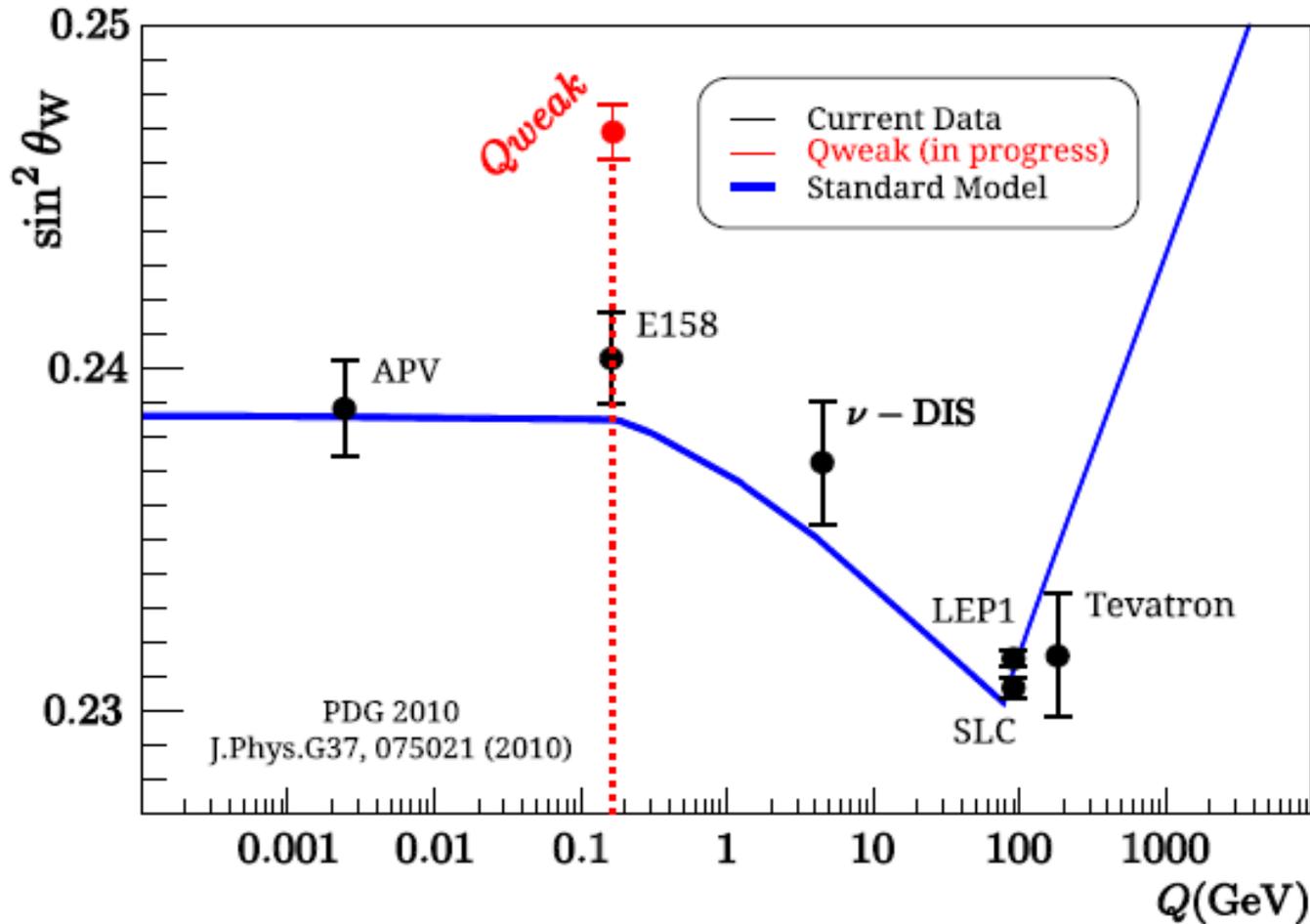
band assuming SM

★ = SM prediction

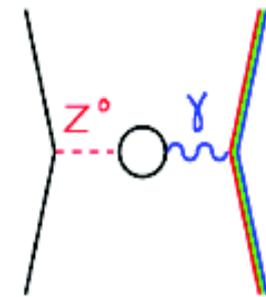
Plot from Young, Carlini, Thomas & Roche, PRL **99**, 122003 (2007)



Weak Mixing Angle

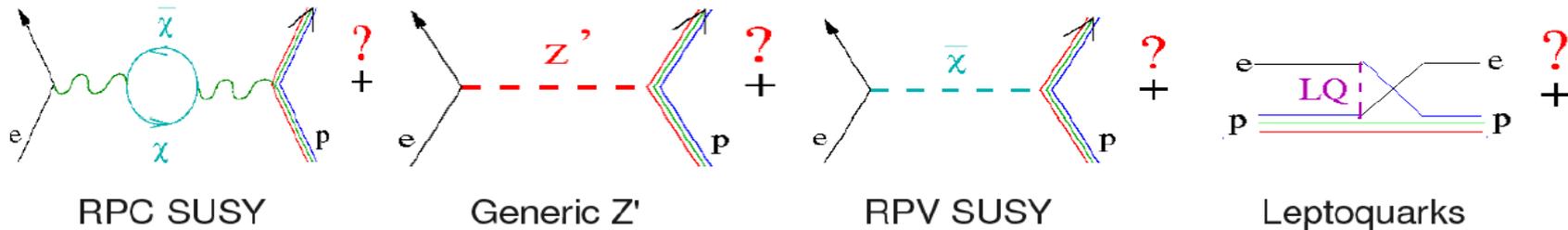


- Running of $\sin^2\theta_W$ with momentum transfer



- Array of existing measurements with different sensitivities to new physics

New Physics



Parameterize new physics with a new contact interaction in the Lagrangian:

$$\mathcal{L}_{\text{NP}}^{\text{PV}} = -\frac{g^2}{4\Lambda^2} \bar{e} \gamma_\mu \gamma_5 e \sum_q h_V^q \bar{q} \gamma^\mu q$$

g=coupling
Λ=mass scale

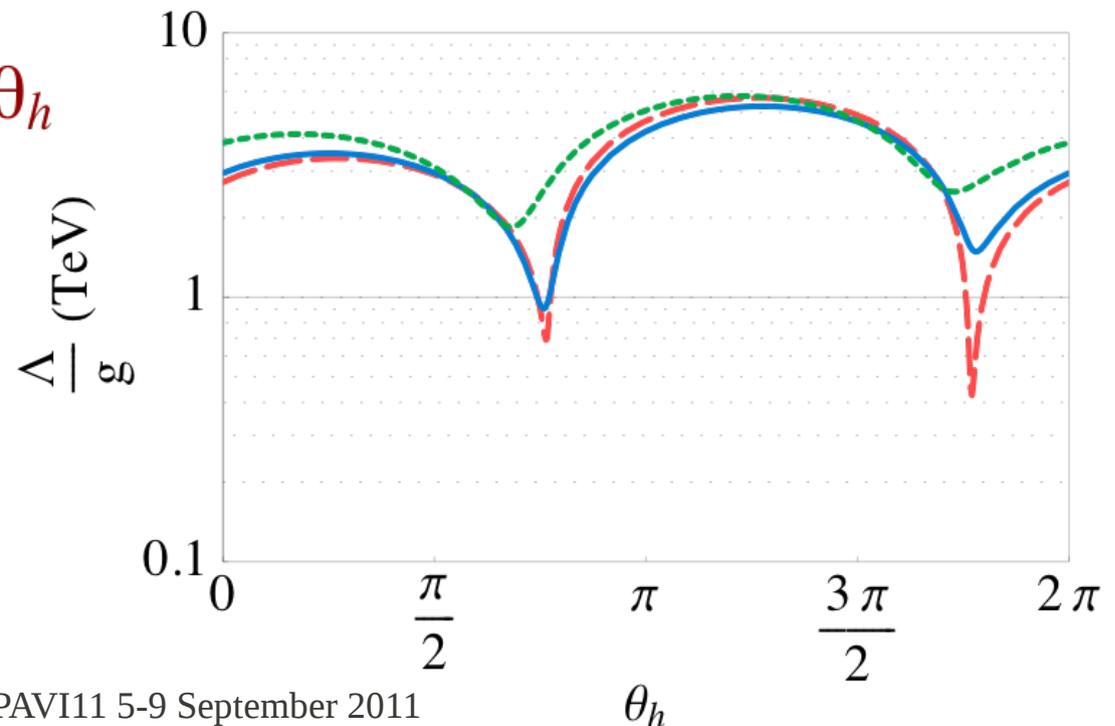
Arbitrary quark flavor dependence of new physics:

$$h_V^u = \cos \theta_h \quad h_V^d = \sin \theta_h$$

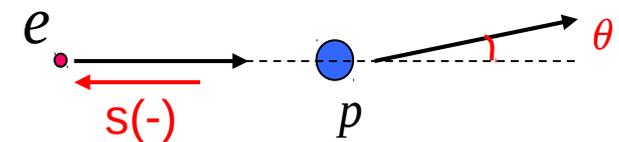
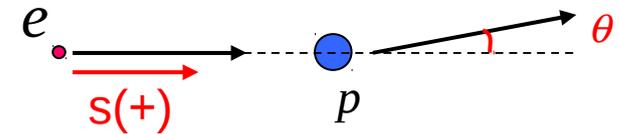
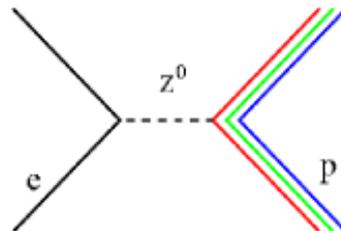
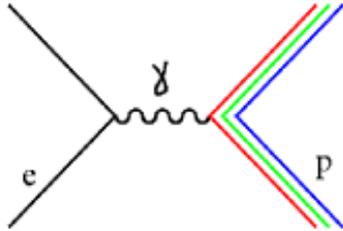
Qweak (4%) → ~2 TeV

with PVES

Atomic only



Parity-Violating Asymmetry

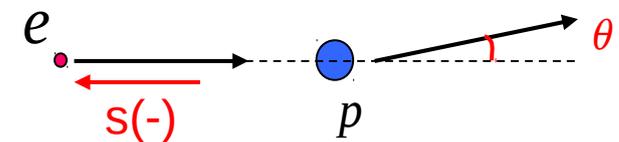
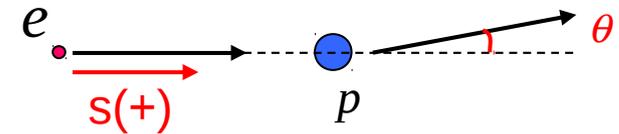
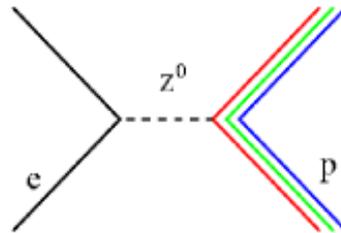
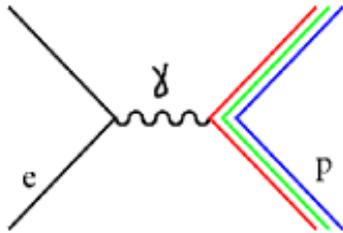


Electromagnetic (PC) + Neutral-weak (PV)

Parity-Violating Asymmetry: $A_{PV} \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$

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

Parity-Violating Asymmetry



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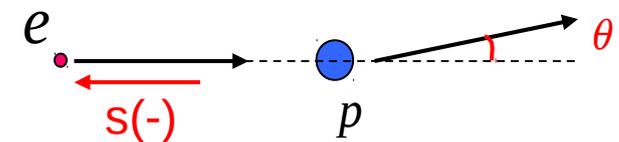
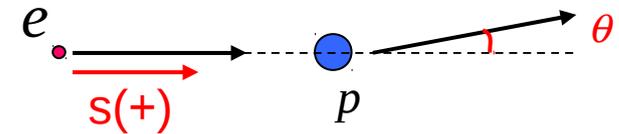
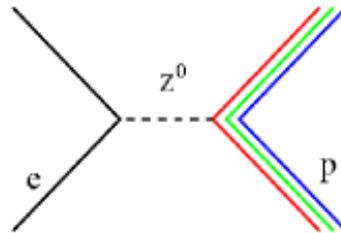
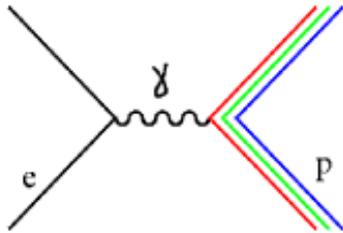
As $Q^2 \rightarrow 0$, $\theta \rightarrow 0$:

$$A_{PV}(p) \Rightarrow \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} [Q_W^p + Q^2 B(Q^2)]$$

Leading order term: $Q_W^p(E)$

$B(Q^2)$: contains $G_{E,M}^\gamma, G_{E,M}^Z$ which are constrained by previous PC and PV form factor measurements

Parity-Violating Asymmetry



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$$A_{PV}(p) \Rightarrow \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} [Q_W^p + Q^2 B(Q^2)] \quad \sim 230 \text{ ppb}$$

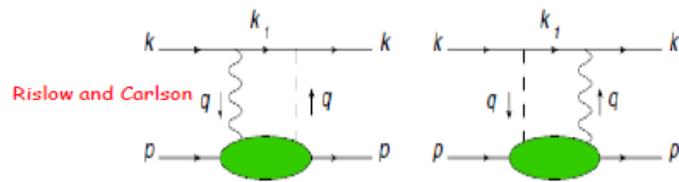
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Radiative Corrections

Several corrections: $\Delta \sin^2 \theta_w(M_Z)$, WW and ZZ box - but these have small uncertainties

Focus on: **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 $\pm 1.1\%$ to $\pm 2.8\%$.

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

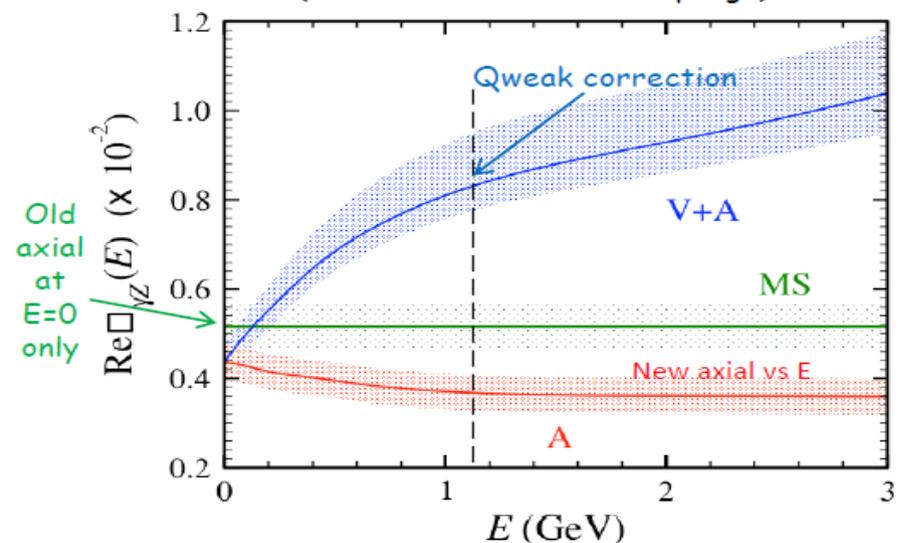
PV Amplitude	Authors	Correction* @ E=1.165 (GeV)
$A^{e \times V^p}$ (vanishes as $E \rightarrow 0$)	GH	0.0026 \pm 0.0026**
	SBMT	0.0047 ^{+0.0011} _{-0.0004}
	RC	0.0057 \pm 0.0009
	GHR-M	0.0054 \pm 0.0020
$V^{e \times A^p}$ (finite as $E \rightarrow 0$)	MS (as updated by EKR-M)	0.0052 \pm 0.0005***
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

* Does not include a small contribution from the elastic.

** 5.7% \times $Q_w^p(\text{LO}) = 0.0026$. $Q_w^p(\text{LO}) = 0.04532$.

*** Included in Q_w^p . For reference, $Q_w^p = 0.0713(8)$.

Blunden, Melnitchouk, Thomas (2011)
(V and A are hadronic couplings)



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

1

Uncertainties

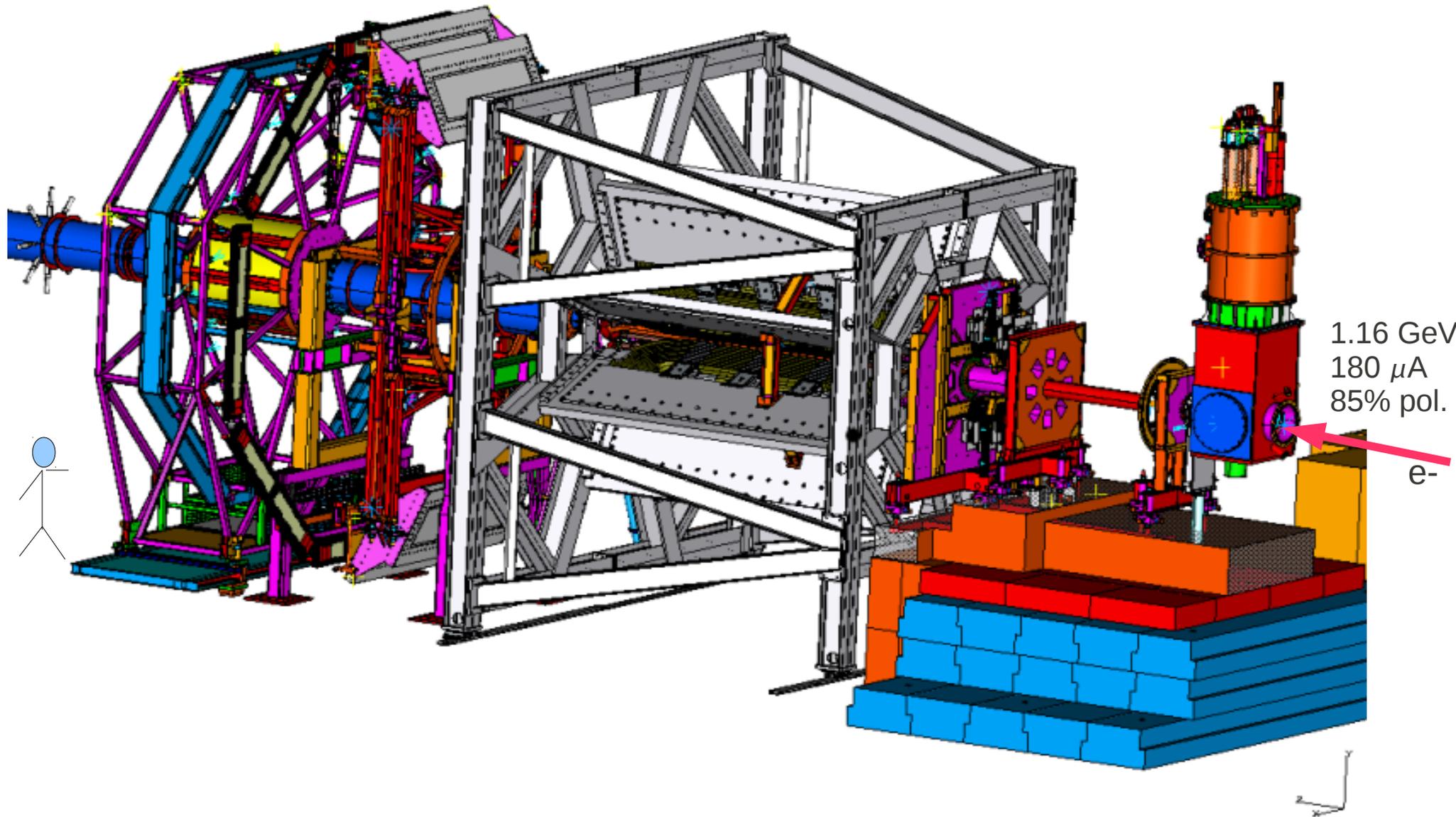
- Anticipated uncertainties with ~2500 hours of production running:

	$\Delta A_z/A_z$	$\Delta Q_w/Q_w$
Statistical (2500 hours)	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	0.7%	1.0%
Helicity correlated beam properties	0.5%	0.8%
Total:	2.5%	4.2%

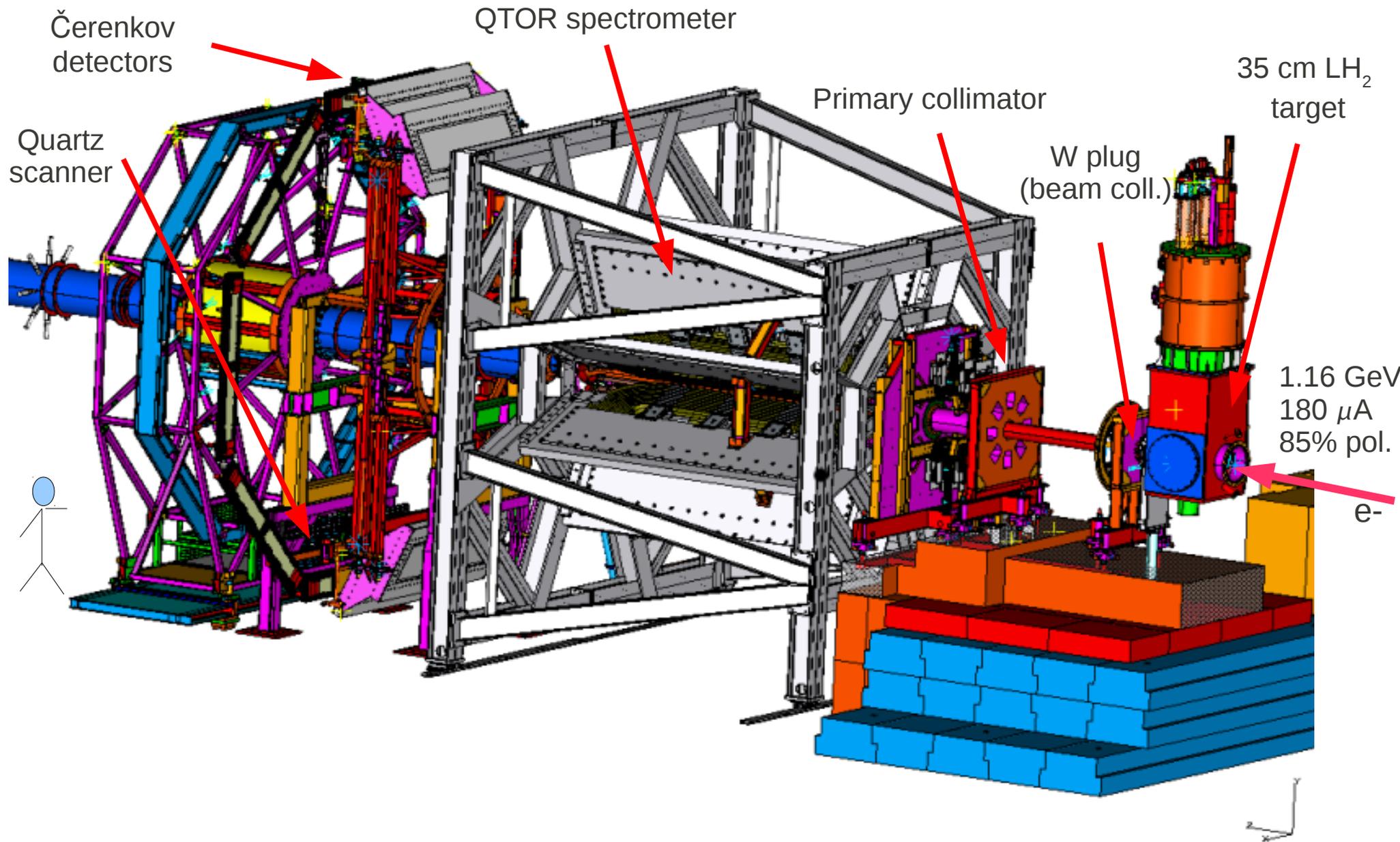
0.3% on $\sin^2\theta_w$

Additional error of 1.1% - 2.8% from the γZ box correction to Q_w^p leads to an error on Q_w^p of 4.3% - 5%

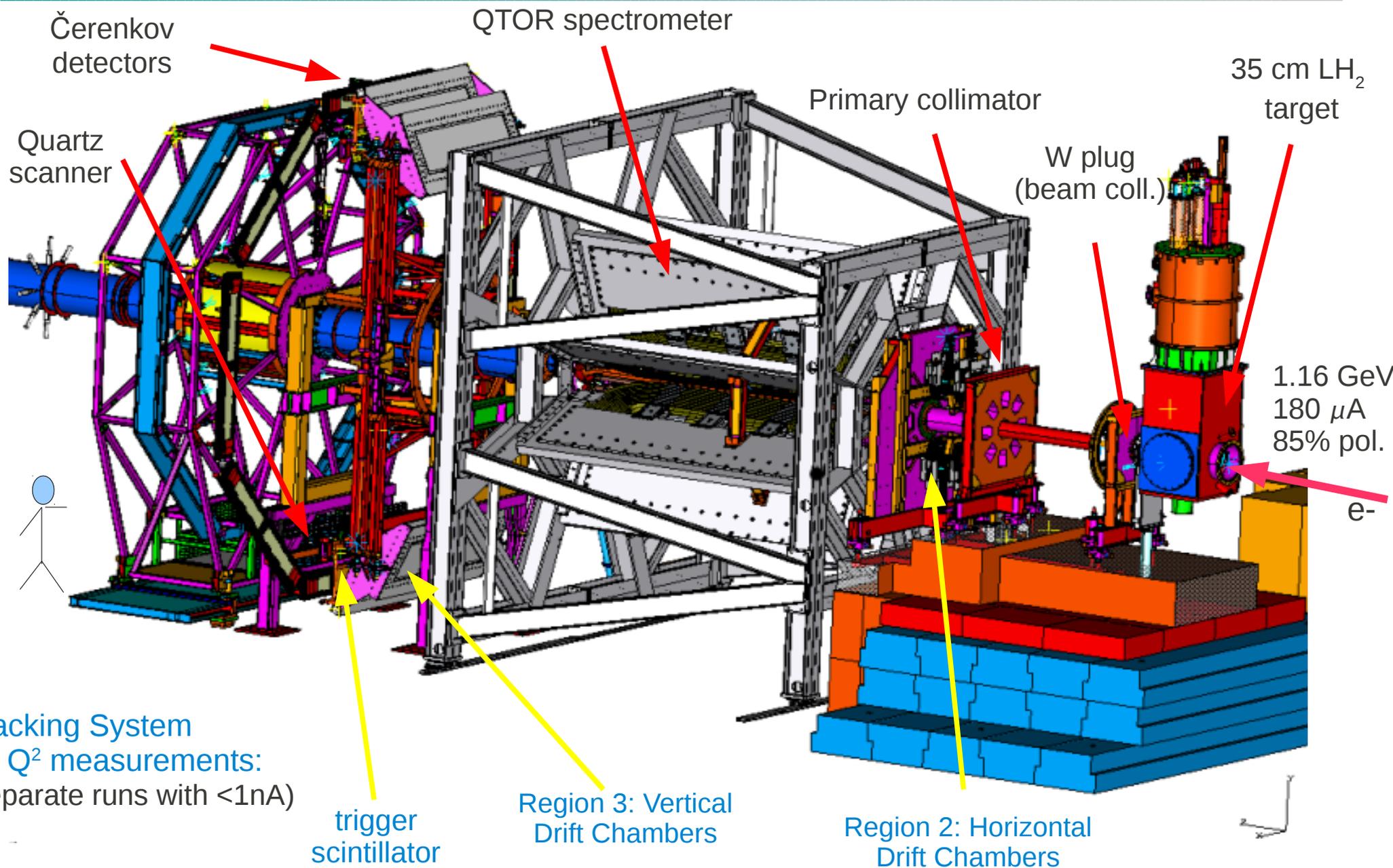
Qweak Overview



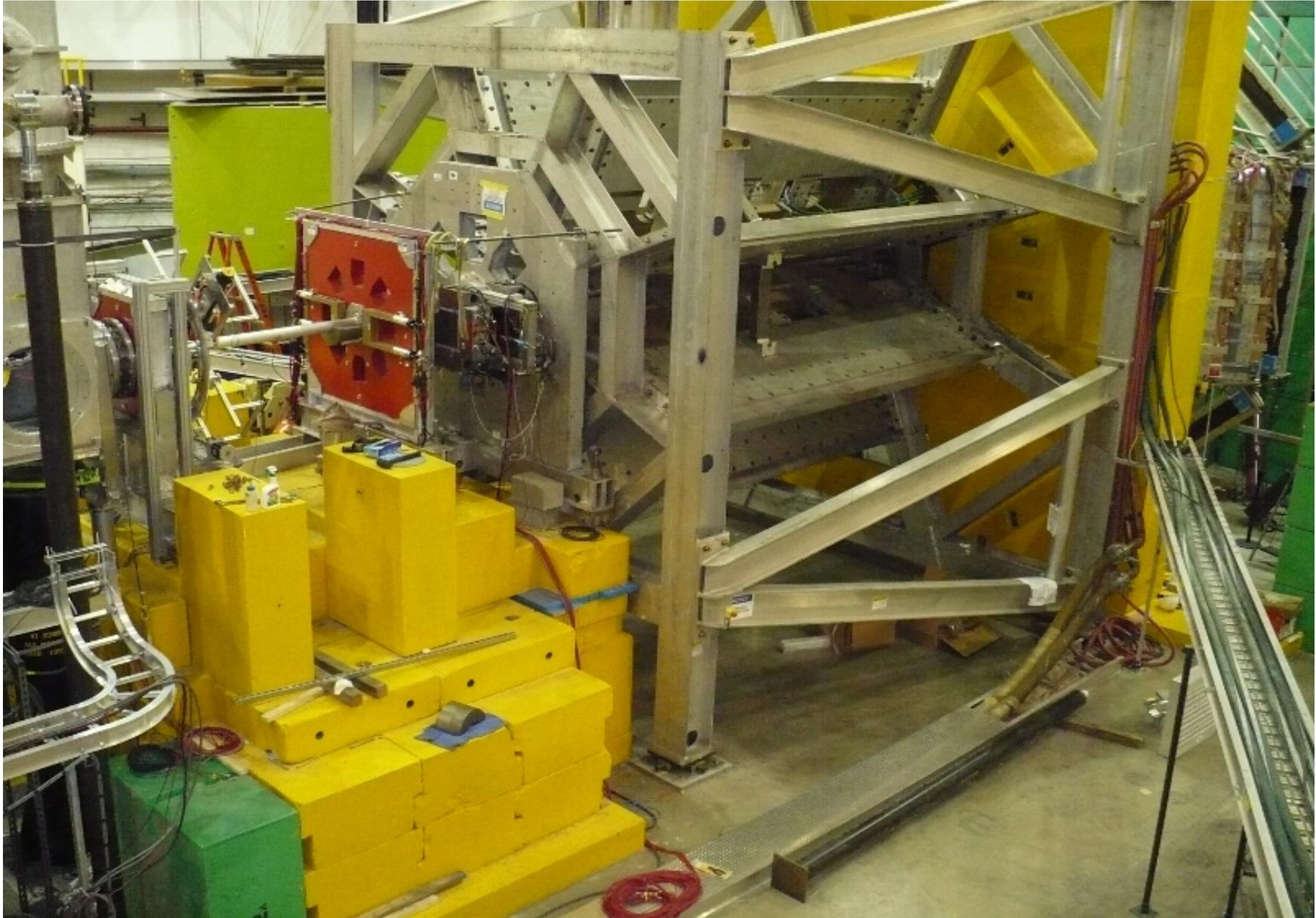
Qweak Overview



Qweak Overview



Qweak Status

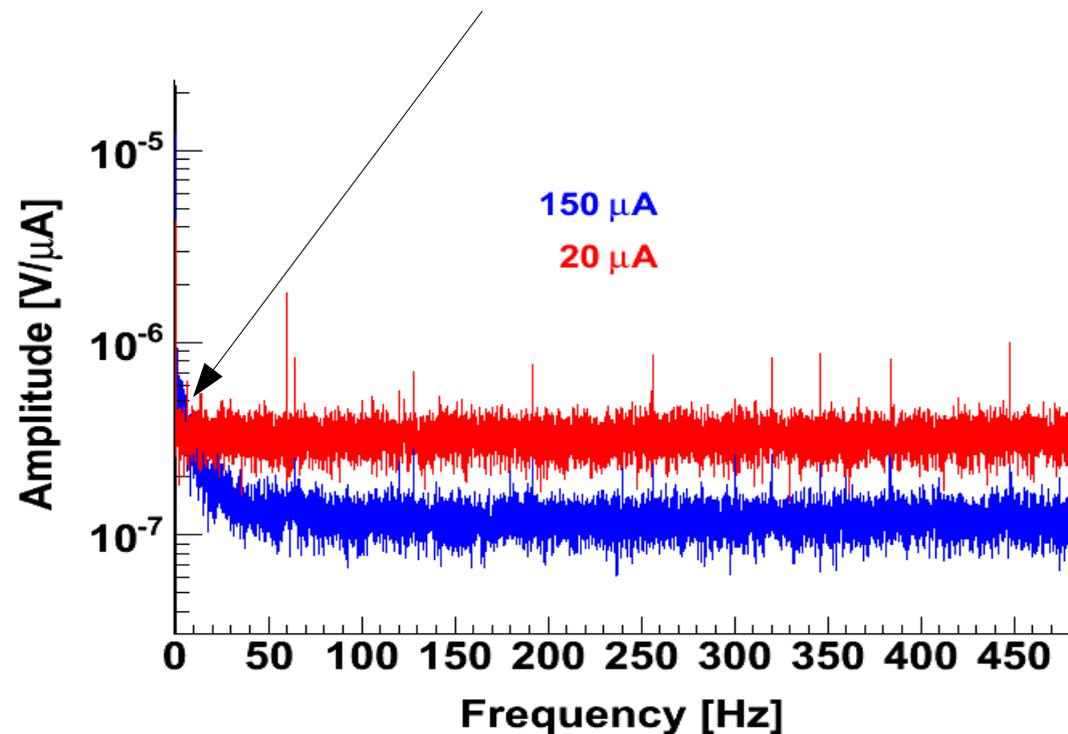


Target Performance

- Talk by Greg Smith

World's highest power cryotarget

Low frequency noise onsets at higher currents:



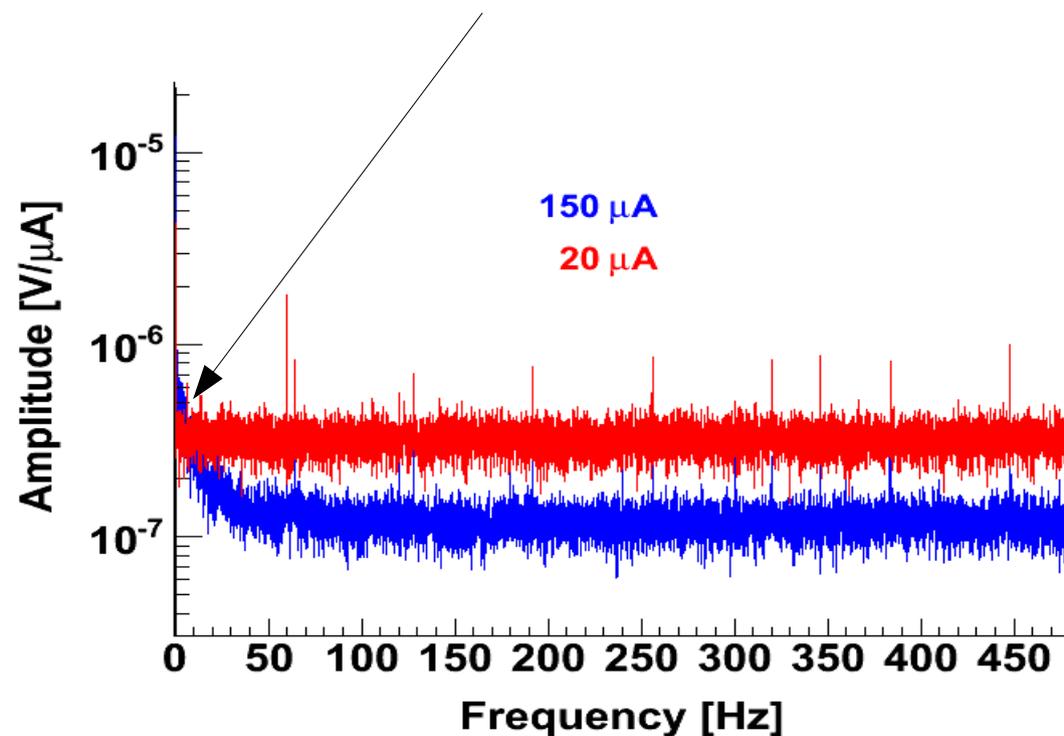
Flip Rate: 960Hz

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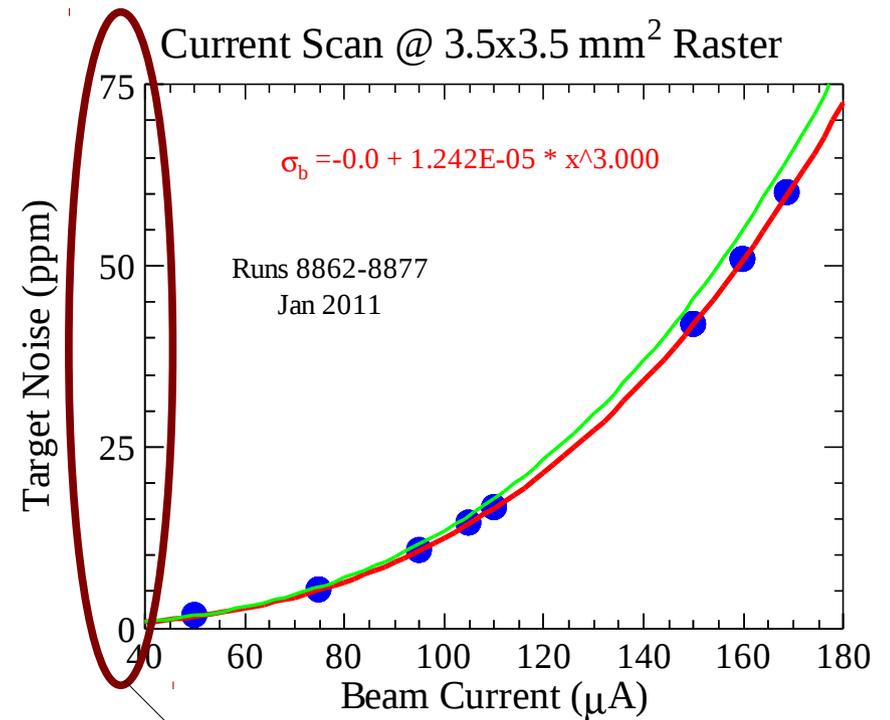
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Flip Rate: 960Hz

Boiling Noise versus Current:

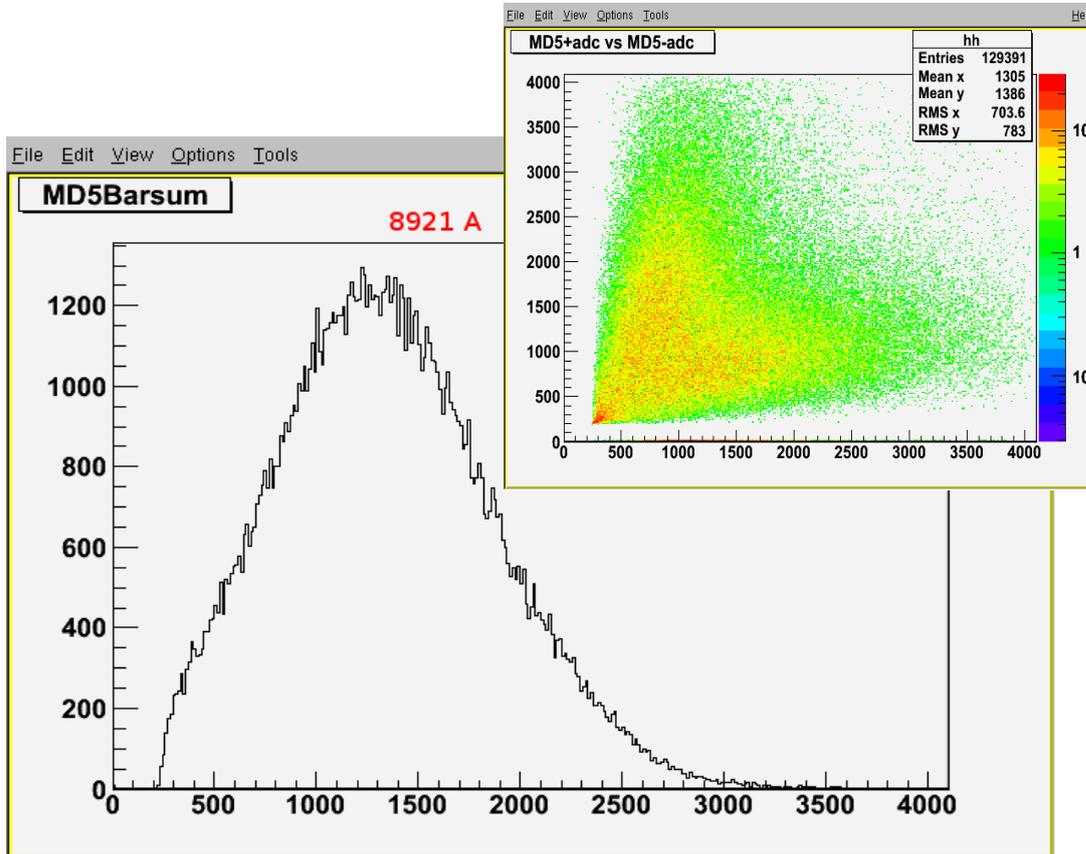
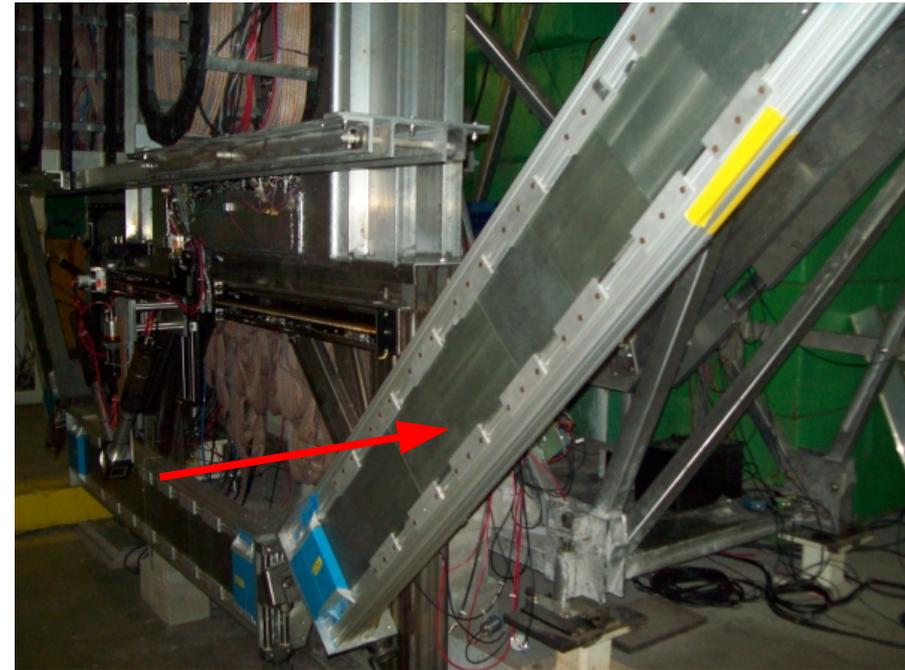


Small contribution added in quadrature with statistical width

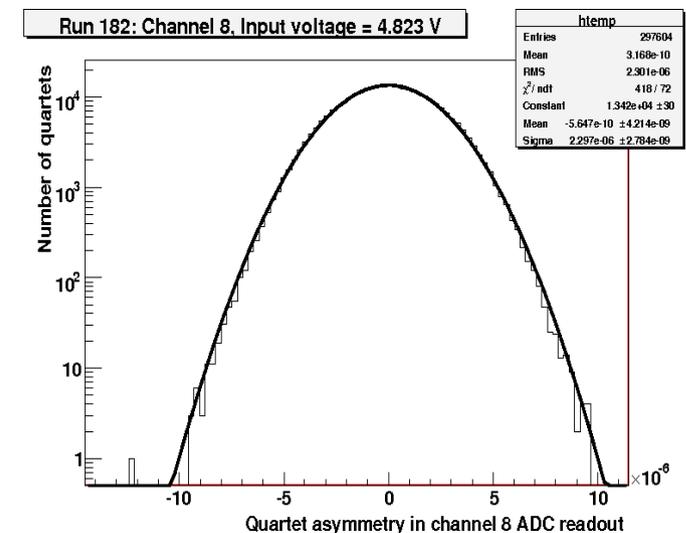
Detector Performance

- Talk by Dave Mack
 - Preradiated bars to reduce low energy backgrounds

Event Mode ADC Spectra: ~ 85 pe's:



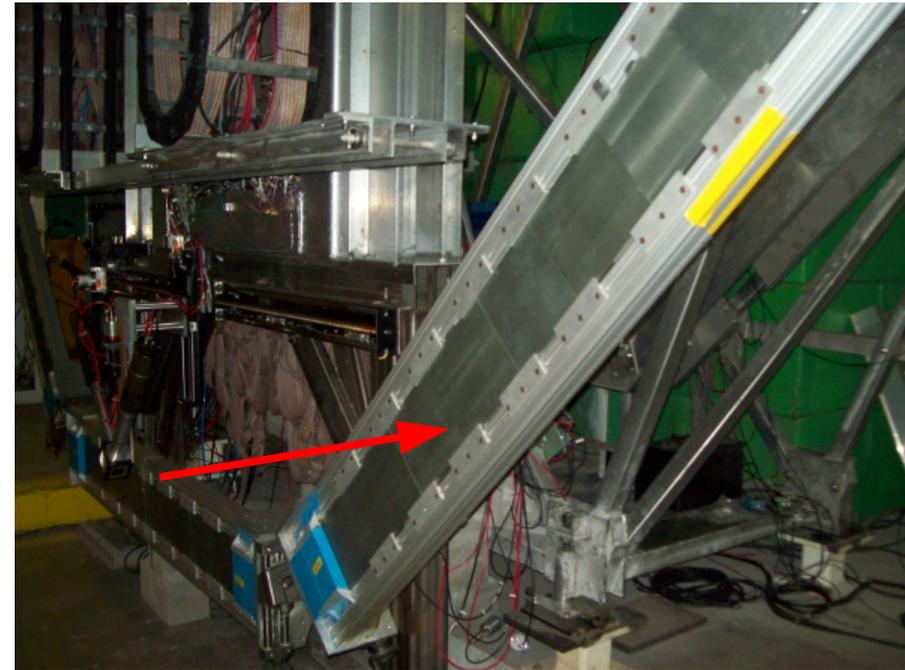
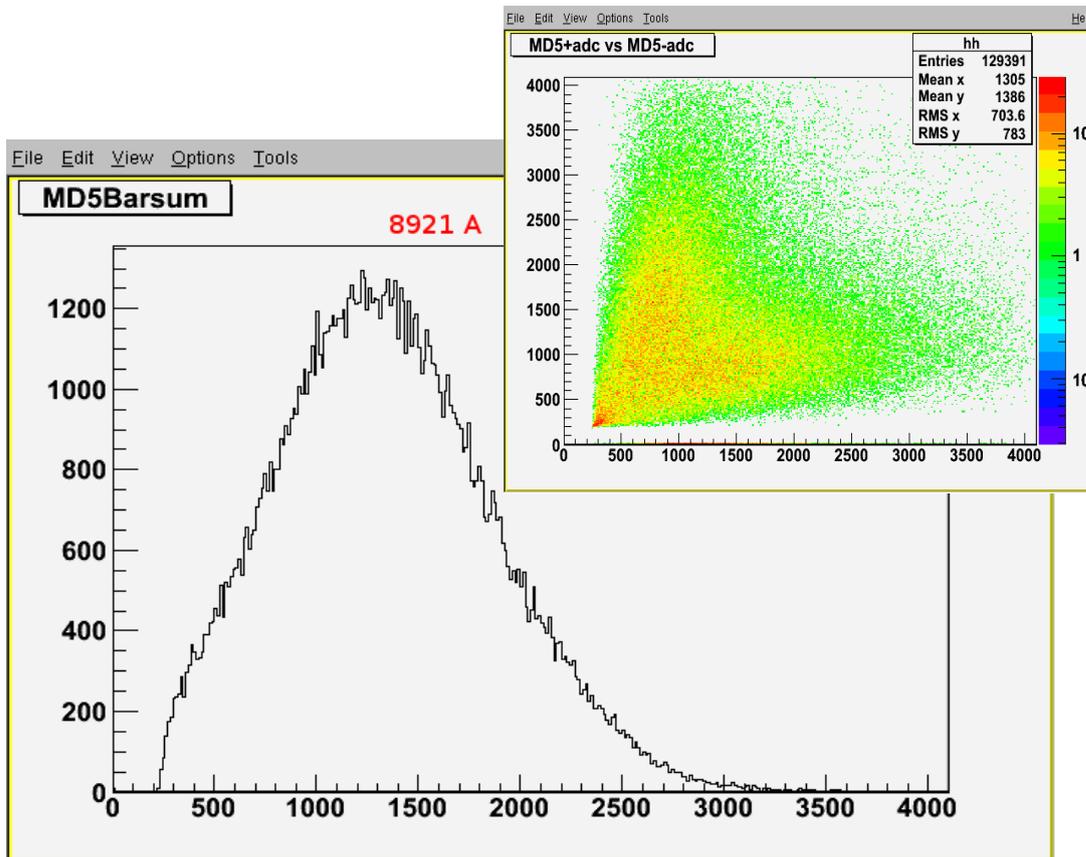
Battery noise tests of electronics chain:



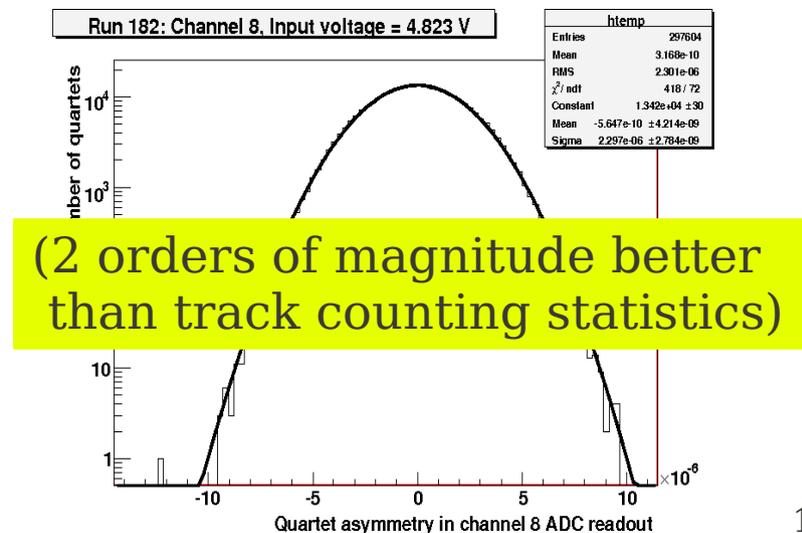
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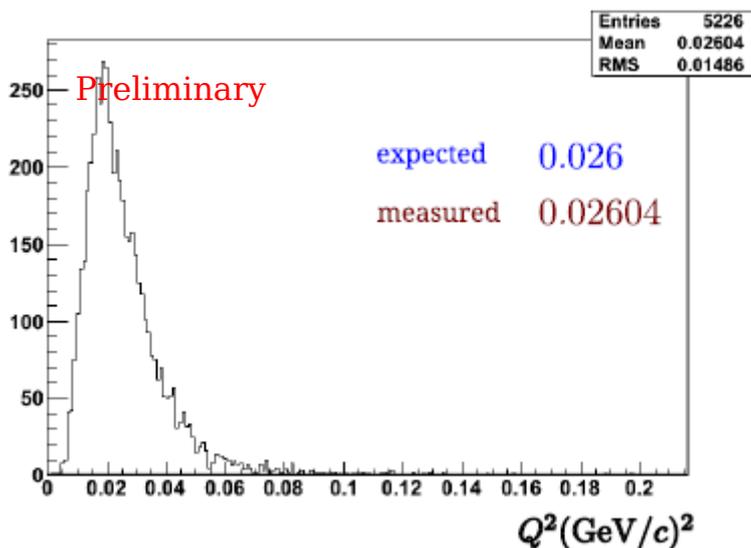
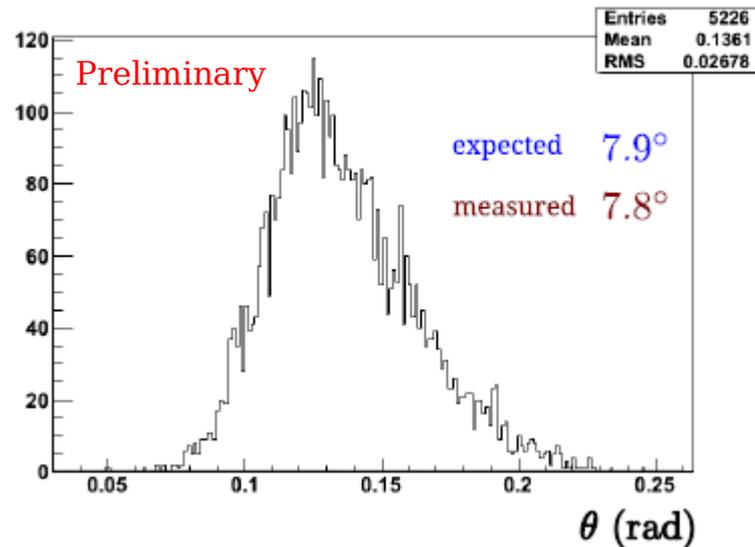


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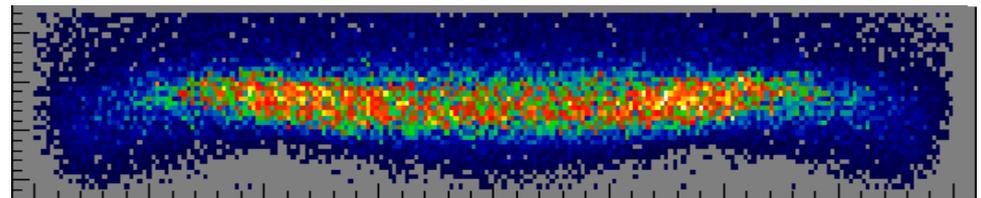
Tracking Performance

- Region 2 and Region 3 Drift Chambers at ~ 50 pA

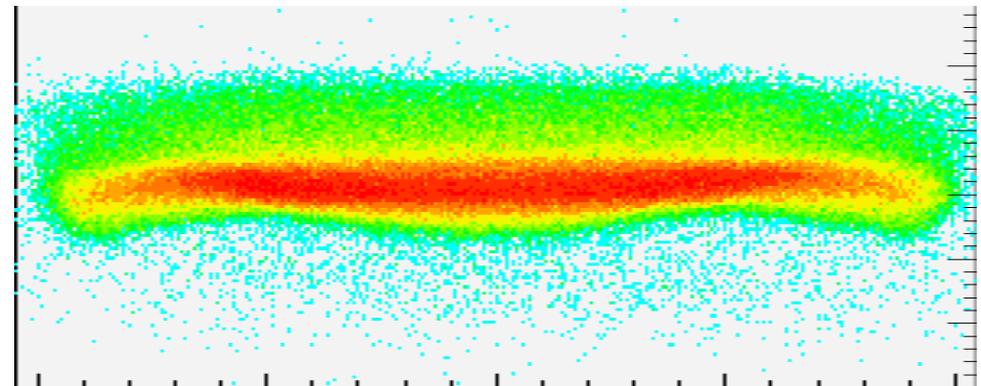


Electron Profile at Detector

Simulation



Region 3 Projection:



Position Resolution

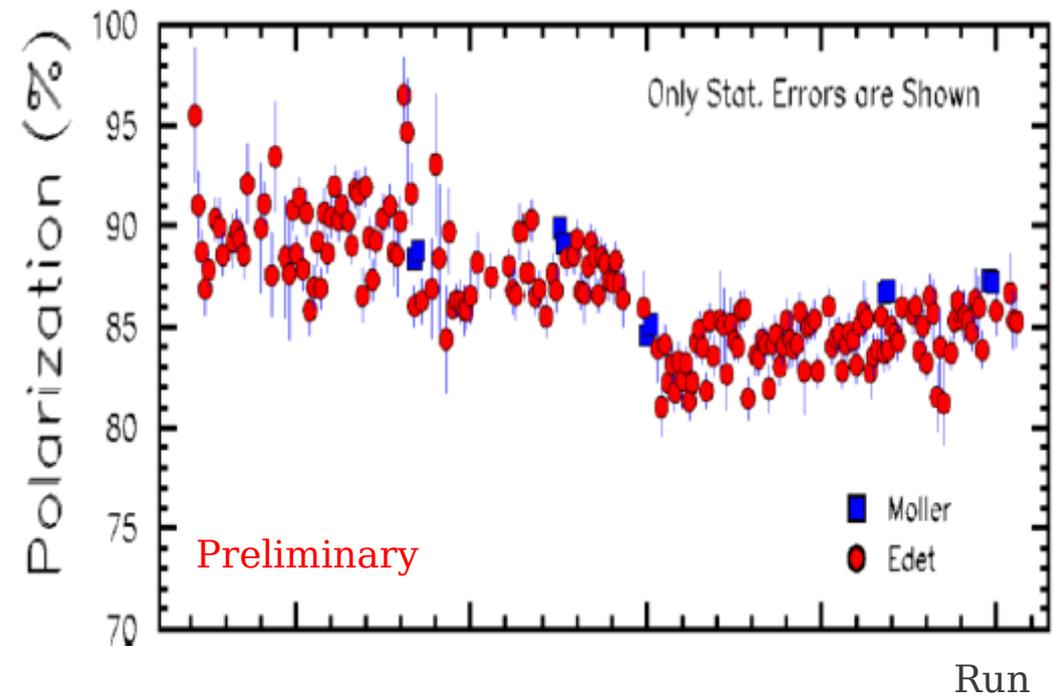
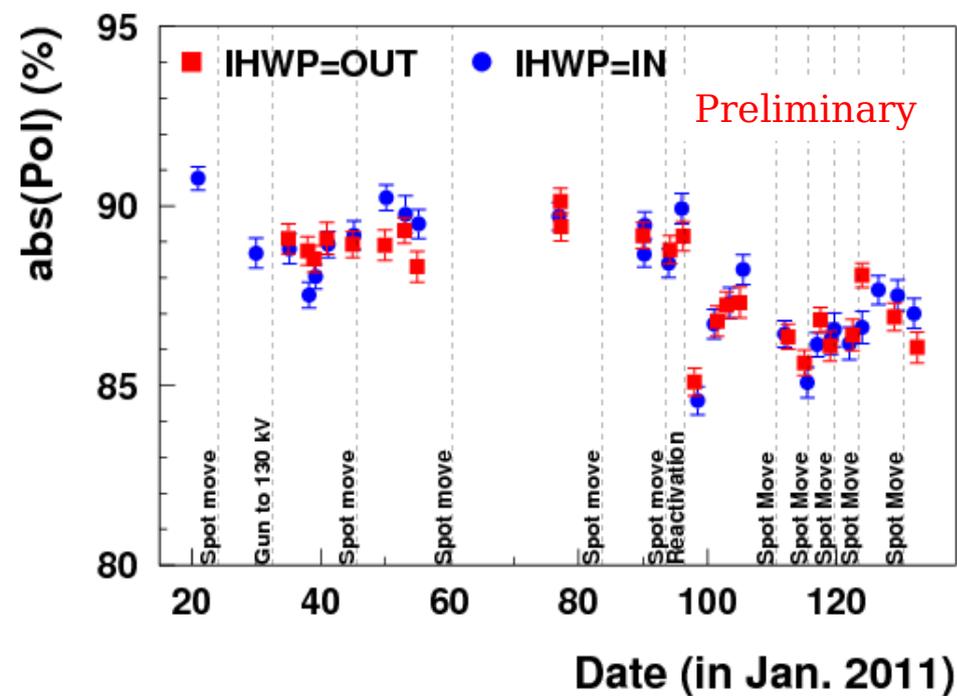
Region 2: 350 microns (software work underway)
Region 3: 250 microns (meets design goals)

Polarimetry

- Talk by Amrendra Narayan

Moller Polarimeter:
invasive measurement

Compton Polarimeter:
runs continuously



Polarization of 86%-88% achieved, systematic analysis still underway

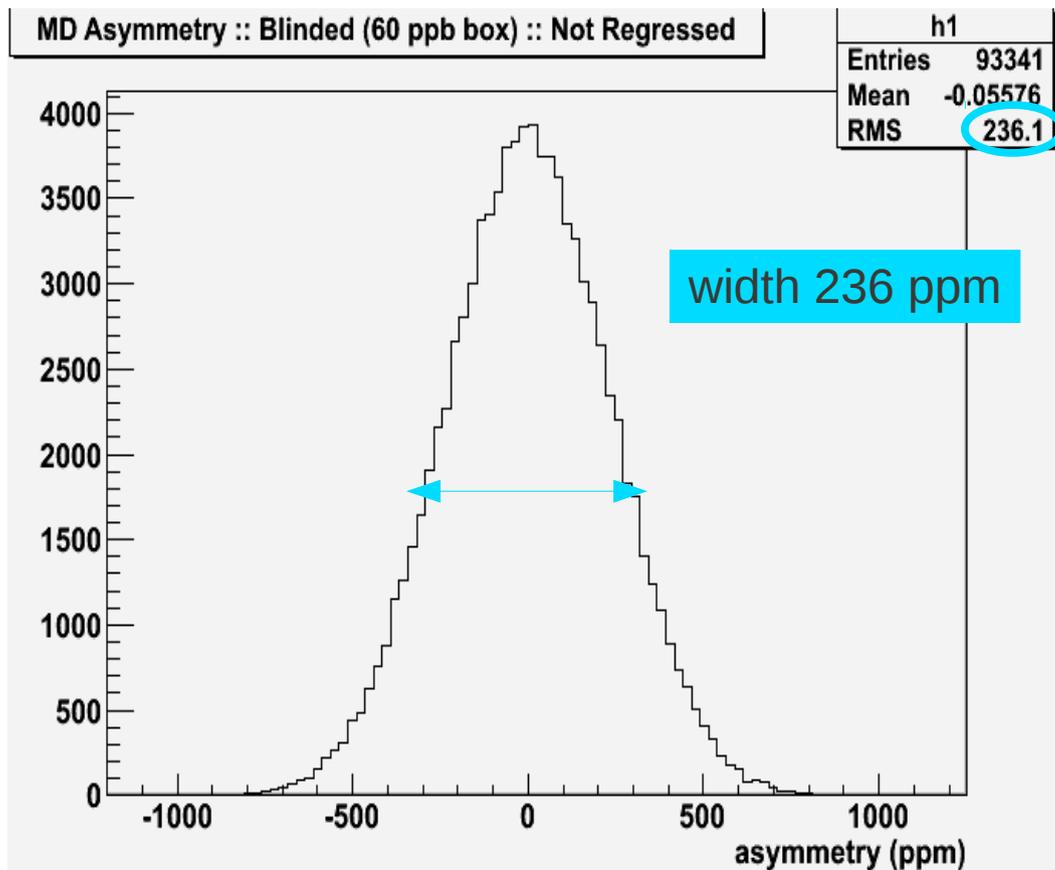
Data Quality

- Understanding the asymmetry width

Error: RMS/\sqrt{N}

Asymmetry measured in quartets at 240 Hz:

+--+ or -+-



We get a 1 ppm measurement every 4 minutes!

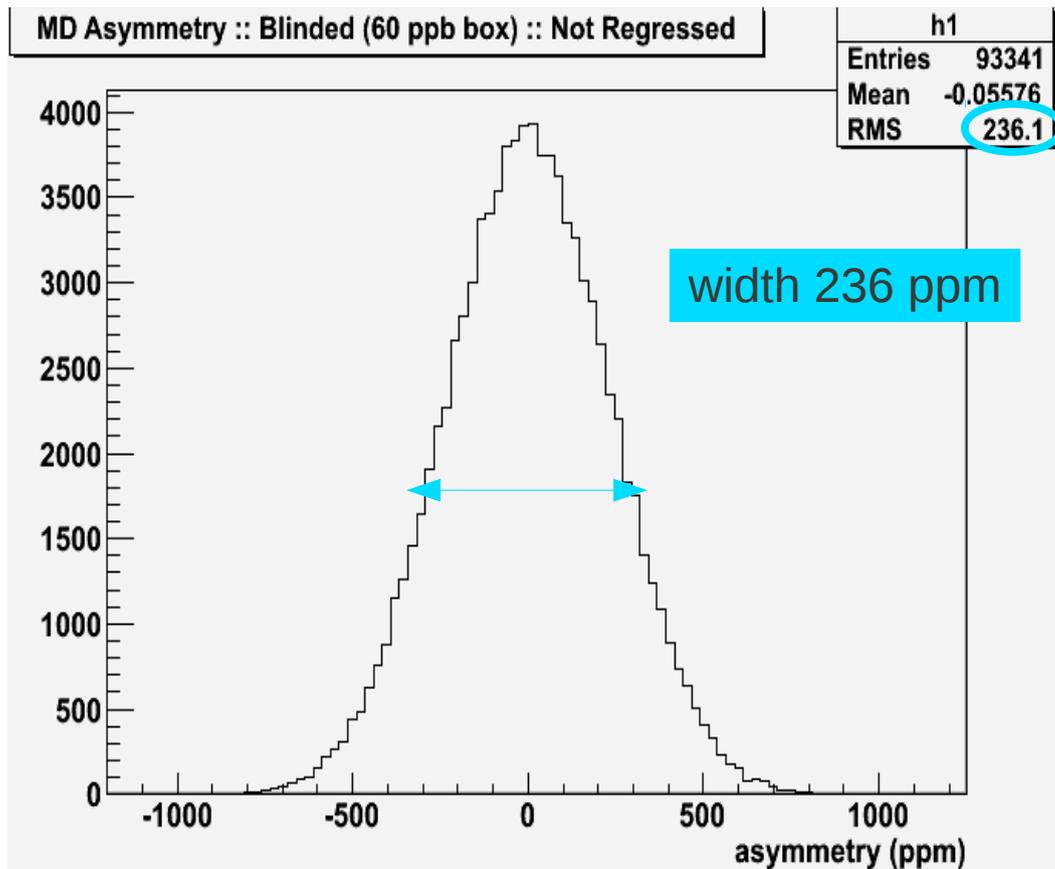
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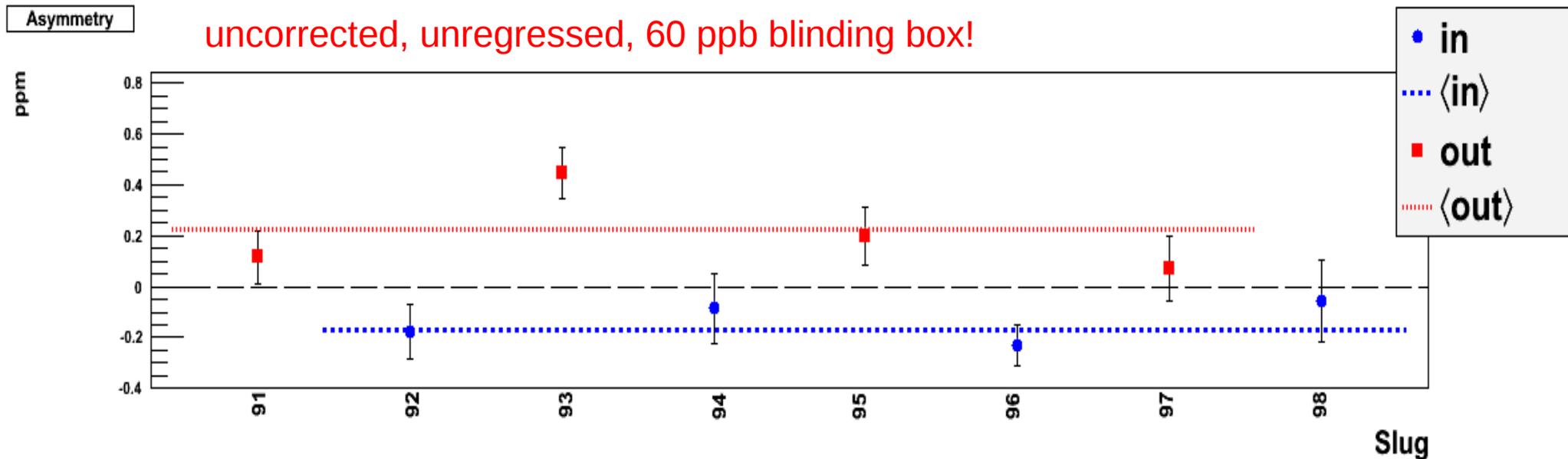
Accounting for the width: 170 μA

pure counting statistics: 215 ppm
+ detector resolution : 232 ppm
+ current normalization
and target boiling: 236 ppm

→ Well understood

Data Quality

- Slug Plots: 8 hour blocks of slow helicity reversal



Multiple methods for removing helicity correlated uncertainties through slow reversals:

IHWP: reversed each slug ~ every 8 hours

Wien flip: reversed 6 times over course of Run I (fairly new)

Helicity-Correlated Beam Properties

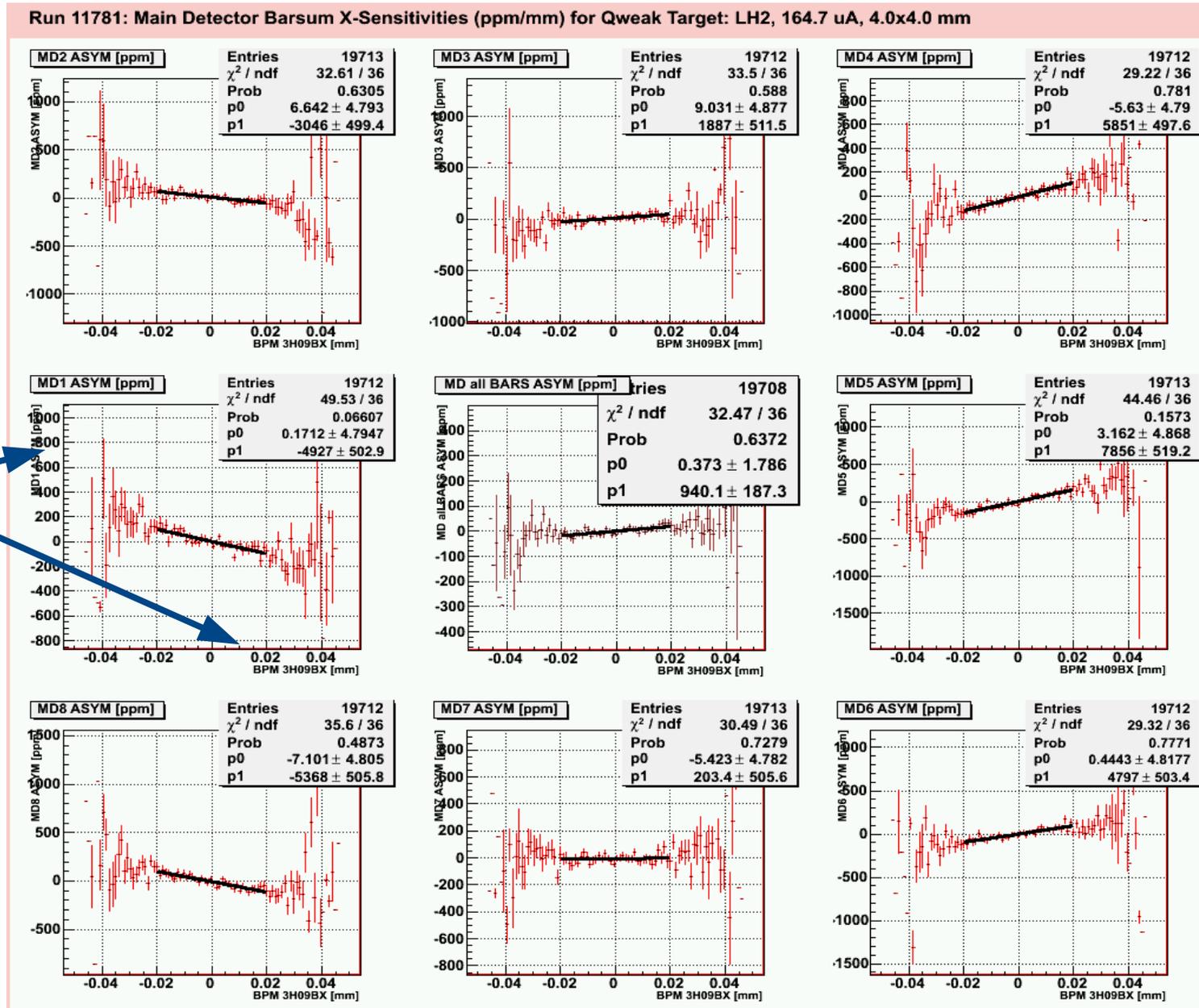
Detector sensitivity to helicity-correlated beam parameters can lead to a false asymmetry

Detector asymmetry
VS
Helicity-correlated position differences

slopes

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

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



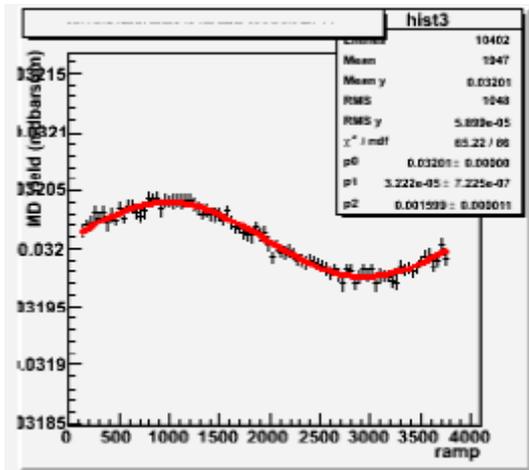
Regression/Beam Modulation

- Different methods to extract sensitivity slopes

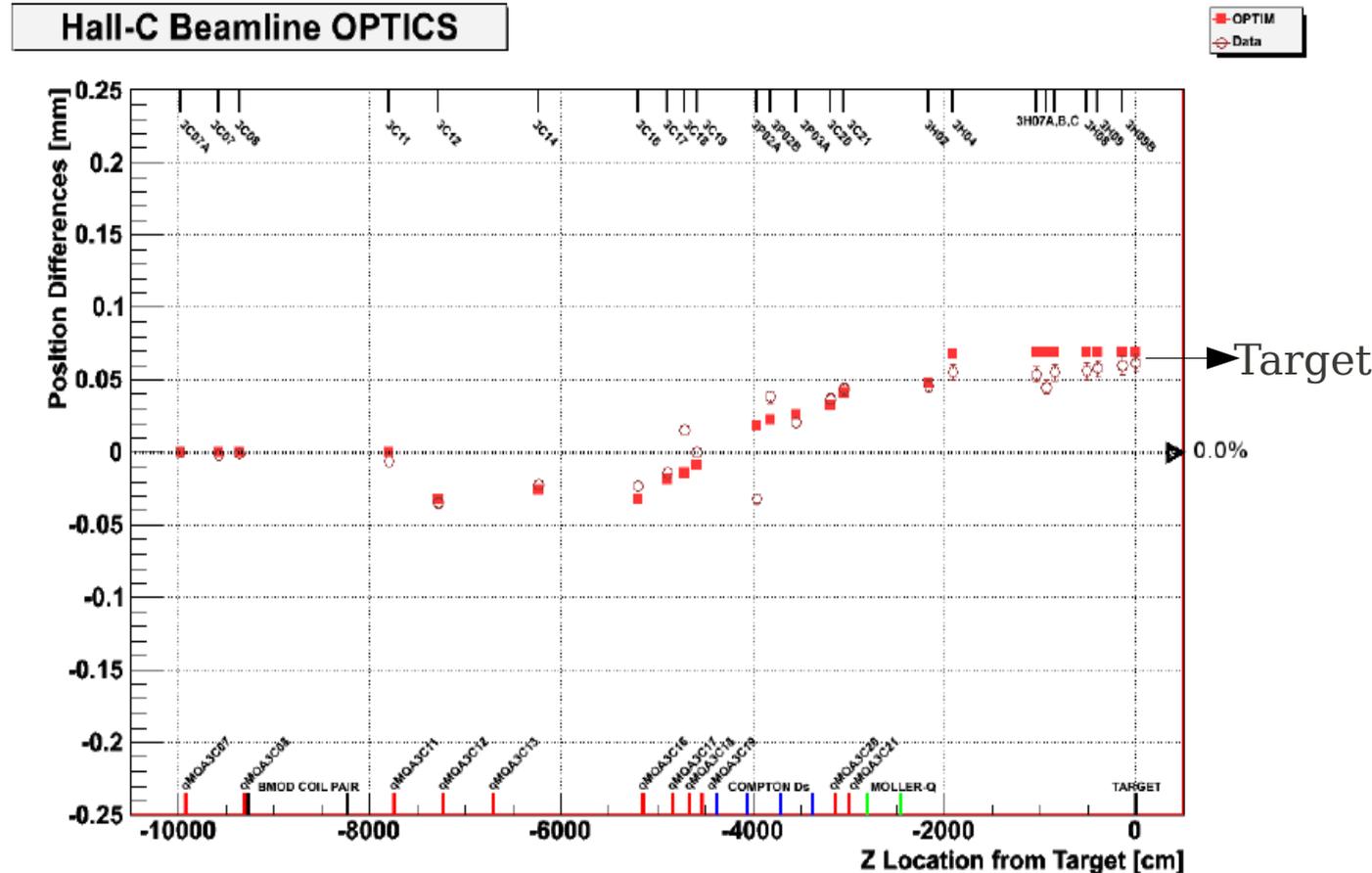
e.x. Beam Modulation:
deliberate modulation
of the beam using pair
of coils



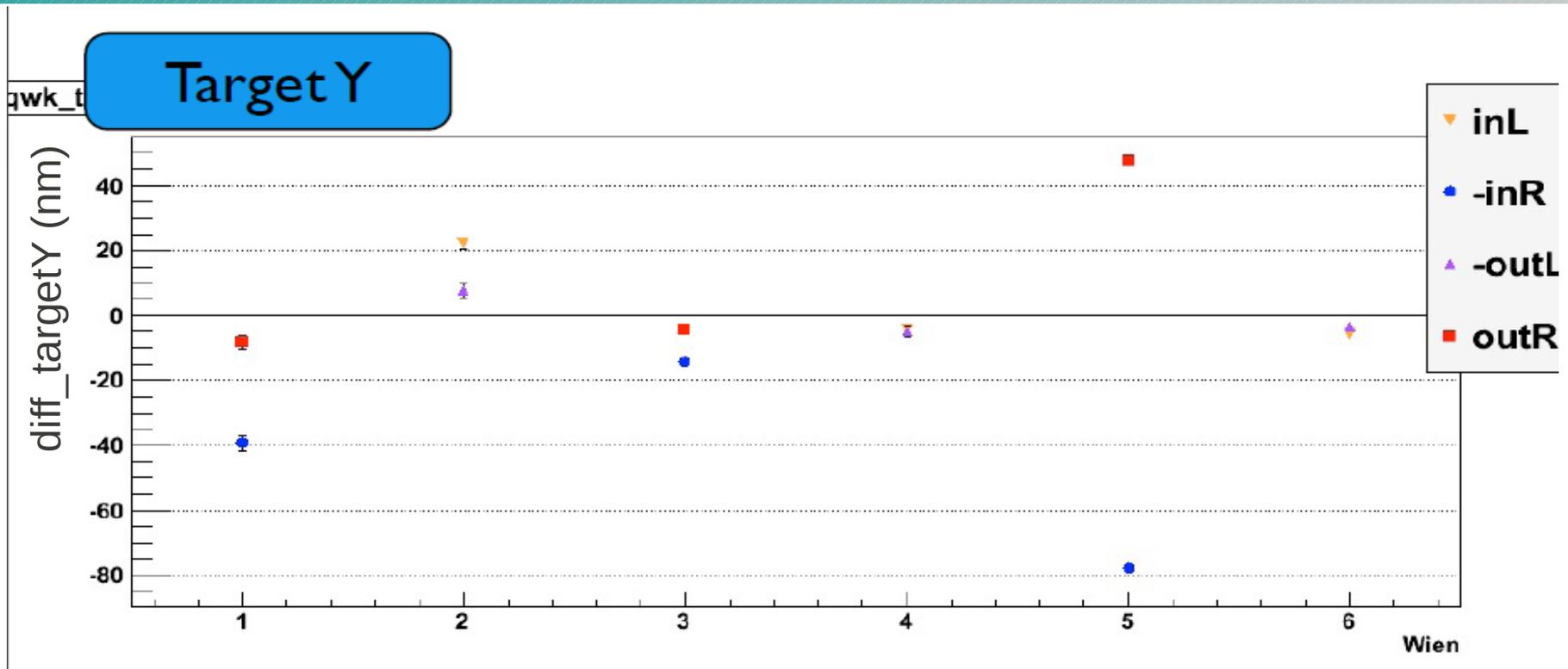
Measure detector response:



Run 11400: Hall-C BPM X Response of Modulation Signal FGX



Helicity-Correlated Beam Properties

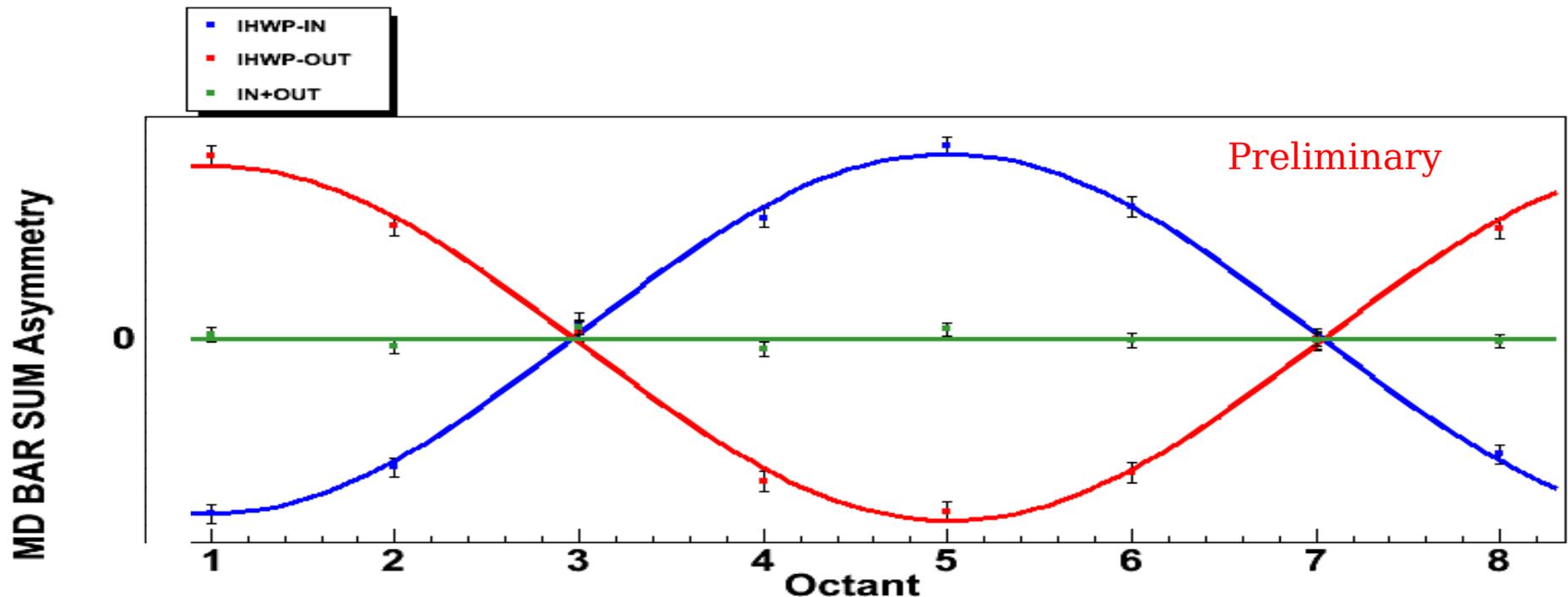


Property	Proposed Specification	Run I Achieved (preliminary)
Charge Asymmetry (ppm)	<0.1	0.008 ± 0.015
TargetX Differences (nm)	<2	3.9 ± 0.5
TargetY Differences (nm)	<2	-5.7 ± 0.5
TargetX Slope Differences (nrad)	<30	-0.11 ± 0.016
TargetY Slope Differences (nrad)	<30	-0.002 ± 0.016

Ancillary Measurements

- Transverse Asymmetry

- Large, parity-conserving asymmetry (ppm level) that leads to a false asymmetry due to residual transverse polarization and broken azimuthal symmetry
- Dedicated measurements with purely transverse polarization
- Preliminary data quality is good; correction considering transverse contamination and broken symmetry will be small (ppb level)



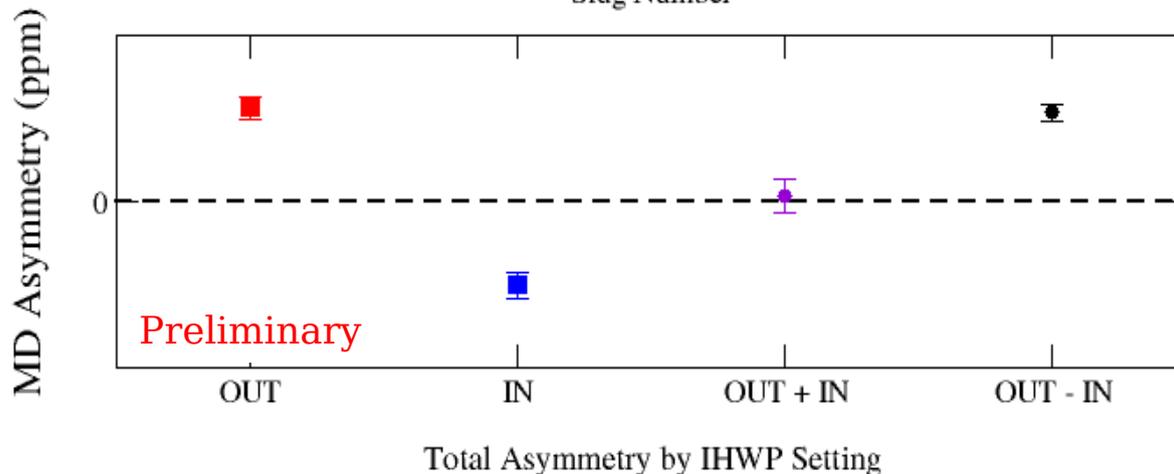
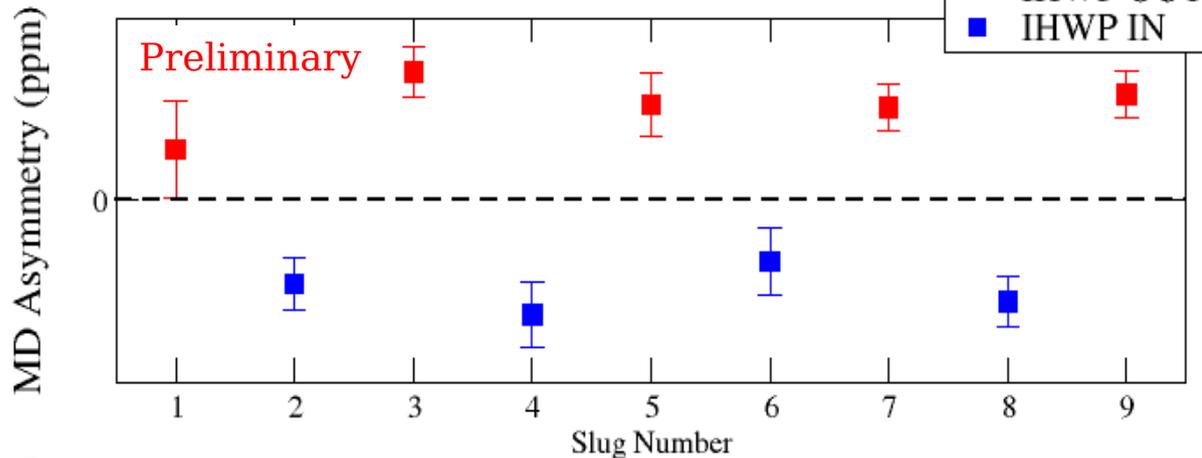
Ancillary Measurements

- Backgrounds Measurements

$$\frac{A_{measured}}{P} = (1 - f)A_{ep} + fA_{bkgd}$$

4% DS Aluminum Asymmetry

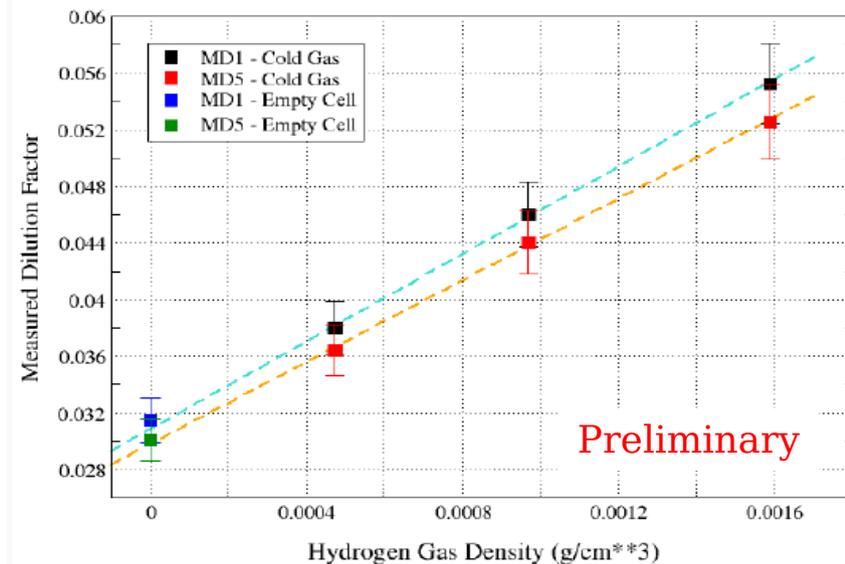
January 2011 Unregressed Data



Aluminum Target Windows:

- ~3% dilution
- ~20% correction due to few ppm asymmetry

Dilution Factor: Dependence on Gas Density



Ancillary Measurements

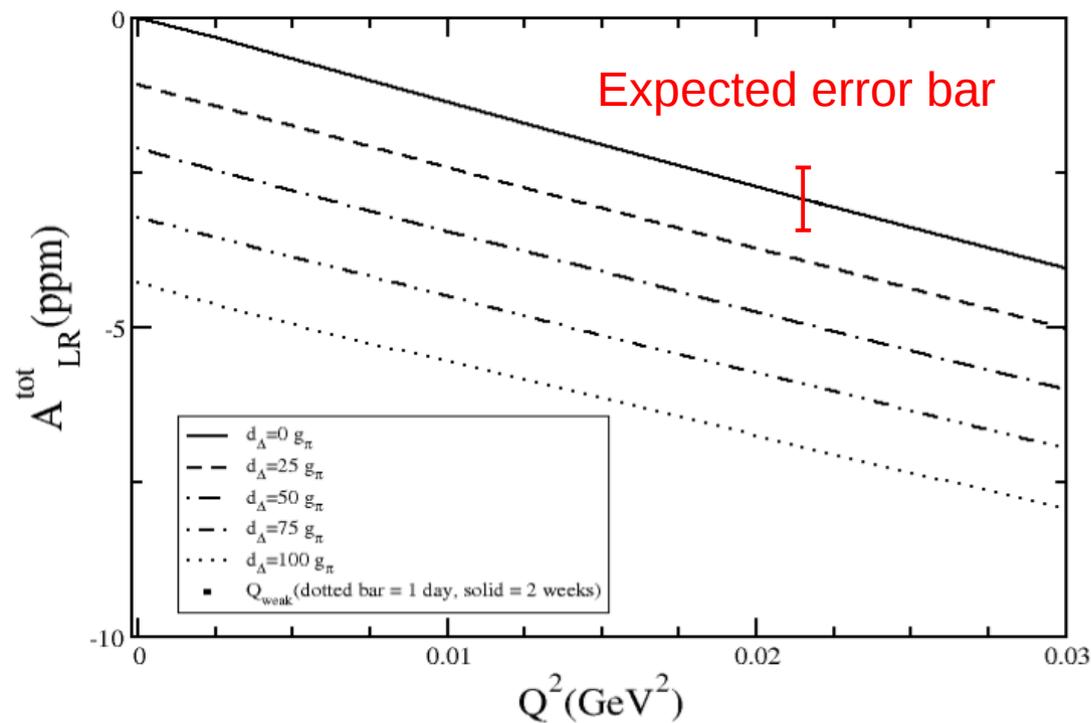
- Backgrounds Measurements

$$\frac{A_{measured}}{P} = (1 - f)A_{ep} + fA_{bkgd}$$

N → Δ Asymmetry: ~0.1% dilution, ~1% correction

$$A_{PV} = \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} [\Delta_{(1)}^\pi + \Delta_{(2)}^\pi + \Delta_{(3)}^\pi]$$

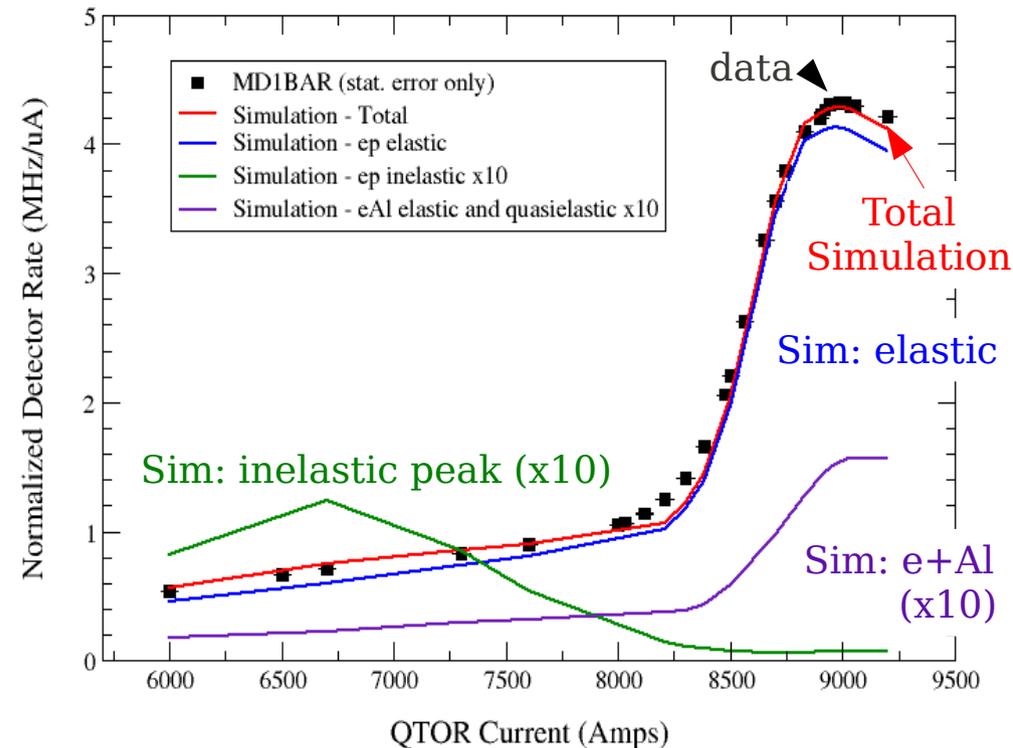
Does not have to vanish in $Q^2 \rightarrow 0$



QTOR Scan to benchmark simulation:

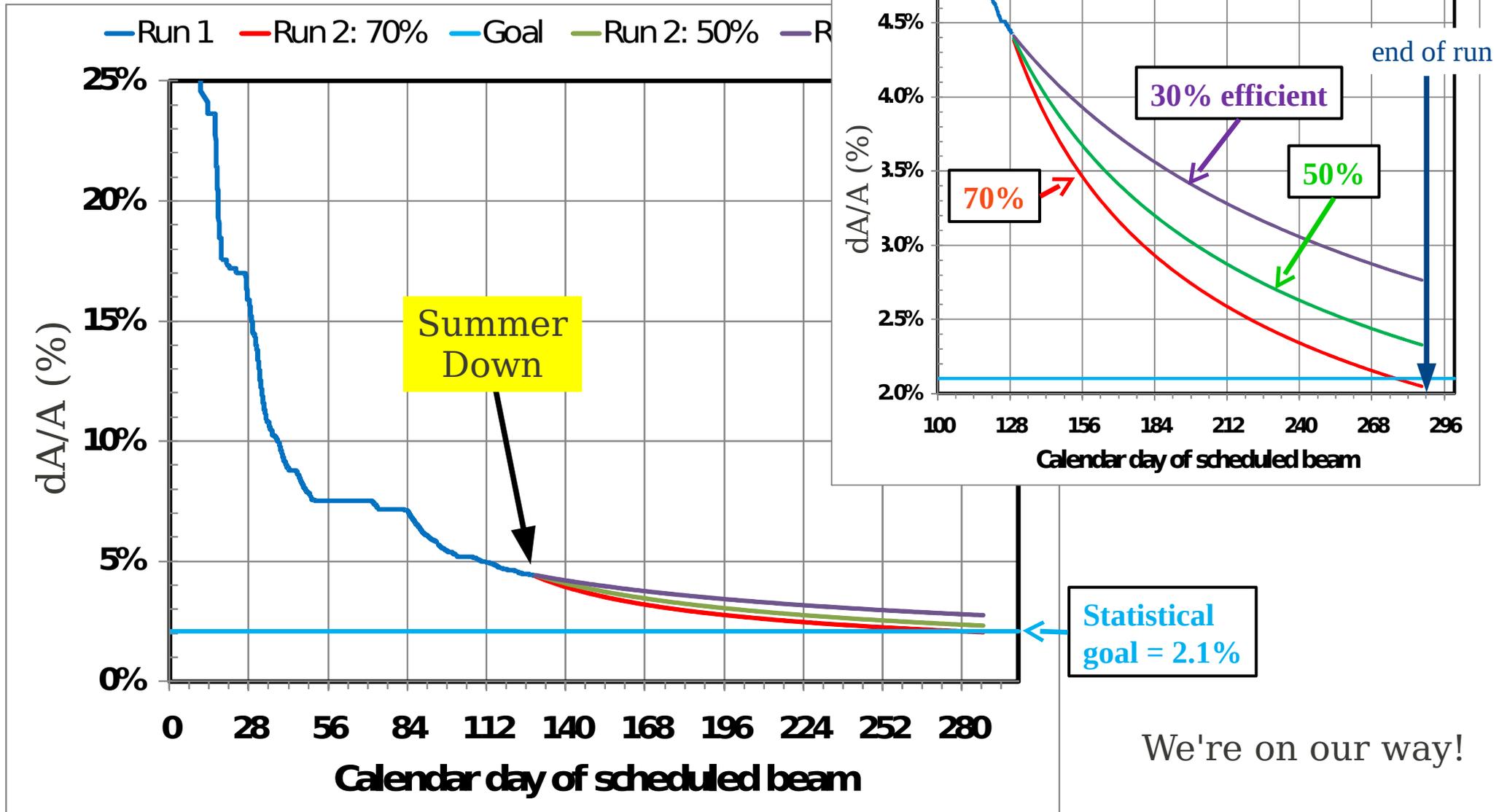
LH2 QTOR Scan: Normalized Rate versus Field

Comparing Tracking Mode Scaler Rates and Simulation



Outlook

- Statistics:



We're on our way!

Summary

First Commissioning Beam: July 2010

Commissioning Run: Fall 2010

“Run I” : Jan-May 2011

“Run II”: November 2011 - May 2012

Some teething pains:

- downstream beamline vacuum, target pump, 10 kA magnet power supply

But many more successes:

- $P^2 * I$ exceeds proposal (150-180 μA , 86-88% polarization)
- all critical subsystems fully commissioned
- several preliminary ancillary measurements complete (each valuable and competitive on its own)
- have 24% of proposed statistics on hand
- no show stoppers found: well prepared for Run II of Qweak which will start in November

Thank You!



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backups...

Radiative Corrections

γZ Box Corrections near 1.16 GeV A Partial Bibliography

PV Amplitude	Authors	Reference
$A^e_X V^P$ (vanishes as $E \rightarrow 0$)	GH	Gorchtein & Horowitz, PRL 102 , 091806 (2009)
	SBMT	Sibirtsev, Blunden, Melnitchouk, and Thomas, 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 $E \rightarrow 0$)	MS	Marciano and Sirlin, PRD 27 , 552 (1983), PRD 29 , 75 (1984)
	EKR-M	Erlener, Kurylov, and Ramsey-Musolf, PRD 68 , 016006 (2003)
	BMT	Blunden, Melnitchouk, and Thomas, PRL 107 , 081801 (2011)

Electroweak Radiative Corrections

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

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

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

(c.f. $Q^p_{weak} \approx 0.07$)

Estimates of Z γ box diagram on Q^p_{weak} (at our kinematics)

Gorchtein & Horowitz

Phys. Rev. Lett. 102, 091806 (2009)

$\sim 7\%$

Sibirtsev, Blunden, Melnitchouk, Thomas

Phys. Rev. D 82, 013001 (2010)

$6.6^{+1.5\%}_{-0.6\%}$

Rislow and Carlson

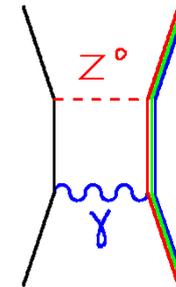
arXiv:1011.2397

$8.0 \pm 1.3\%$

Gorchtein, Horowitz, Ramsey-Musolf

arXiv:1102:3910

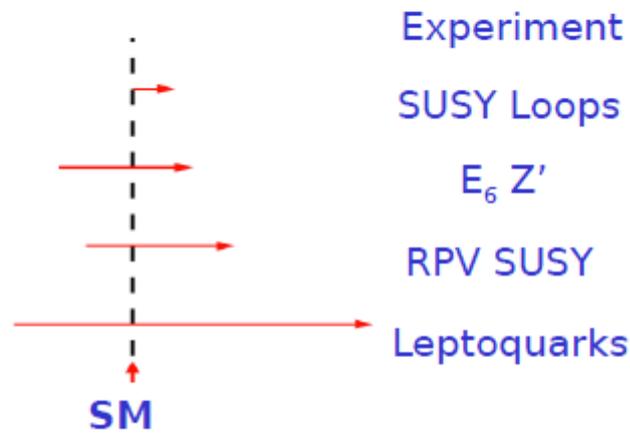
$7.6 \pm 2.8\%$



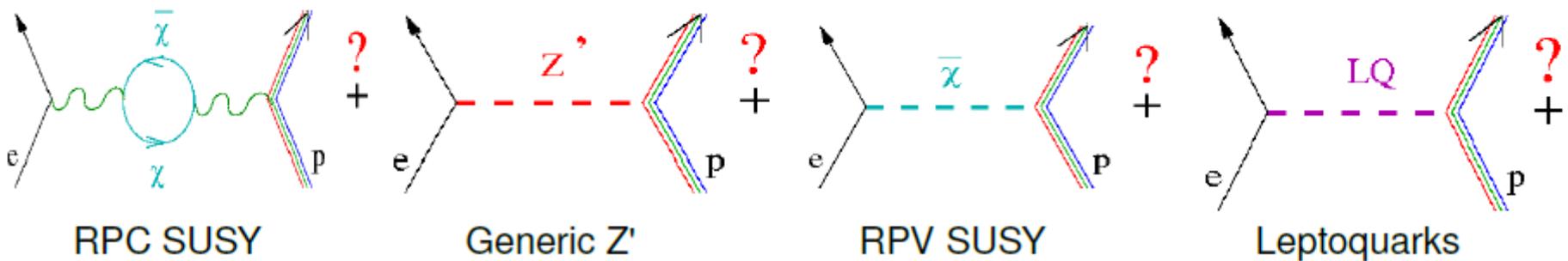
Sensitivity to New Physics

Different experiments sensitive to different extensions

JLab Q_{weak}
 $Q_w^p = 0.0716$



SLAC E158 (complete)
 $-Q_w^e = 0.0449$



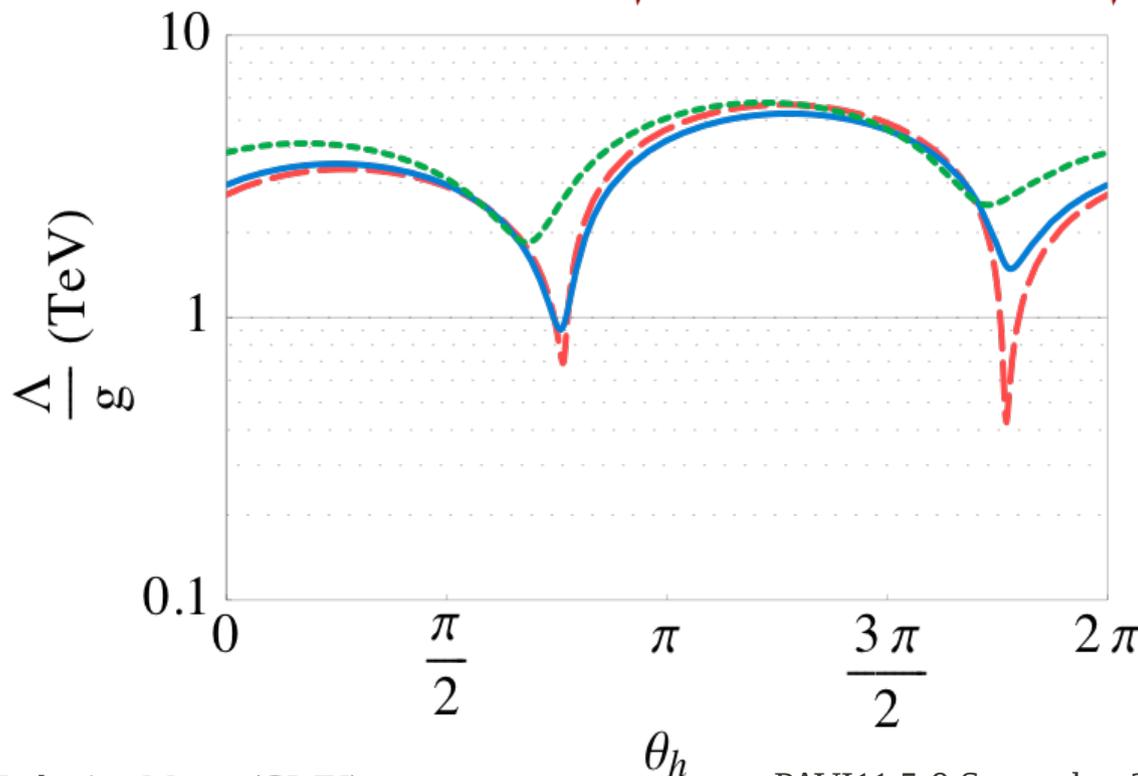
Constraints on New Physics

Parameterize new physics with a new contact interaction in the Lagrangian:

$$\mathcal{L}_{\text{NP}}^{\text{PV}} = -\frac{g^2}{4\Lambda^2} \bar{e} \gamma_\mu \gamma_5 e \sum_q h_V^q \bar{q} \gamma^\mu q$$

Arbitrary quark flavor dependence of new physics:

$$h_V^u = \cos \theta_h \quad h_V^d = \sin \theta_h$$



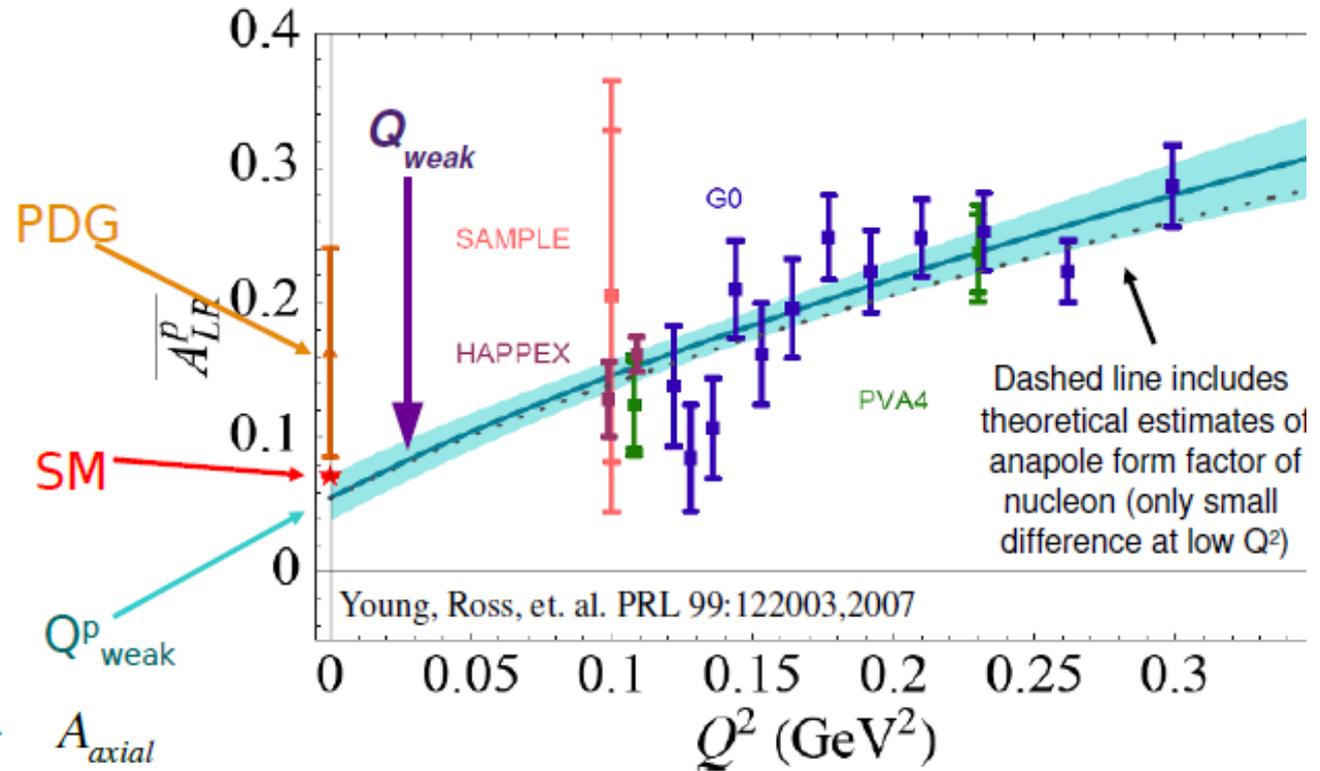
Qweak (4%)
with PVES
Atomic only

Parity-Violating Asymmetry Extrapolated to $Q^2 = 0$

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

Divide out leading Q^2 dependence:

$$\overline{A_{LR}^P} \approx Q_{weak}^P + B(Q^2)Q^2 + \dots$$



$$A = A_{Q_{weak}^P} + A_{hadronic} + A_{axial} = -0.17 \text{ ppm} - 0.07 \text{ ppm} - 0.01 \text{ ppm}$$

hadronic:
(31% of asymmetry)
contains $G_{E,M}^{\gamma}$ $G_{E,M}^Z$
Constrained by
HAPPEX, G^0 , MAMI PVA4

axial:
(4% of asymmetry)
contains G_A^e
large electroweak
radiative corrections
Constrained by G^0
and SAMPLE