# The Qweak : Precision Measurement of the Proton's Weak Charge by Parity Violating Experiment

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# The Qweak Collaboration


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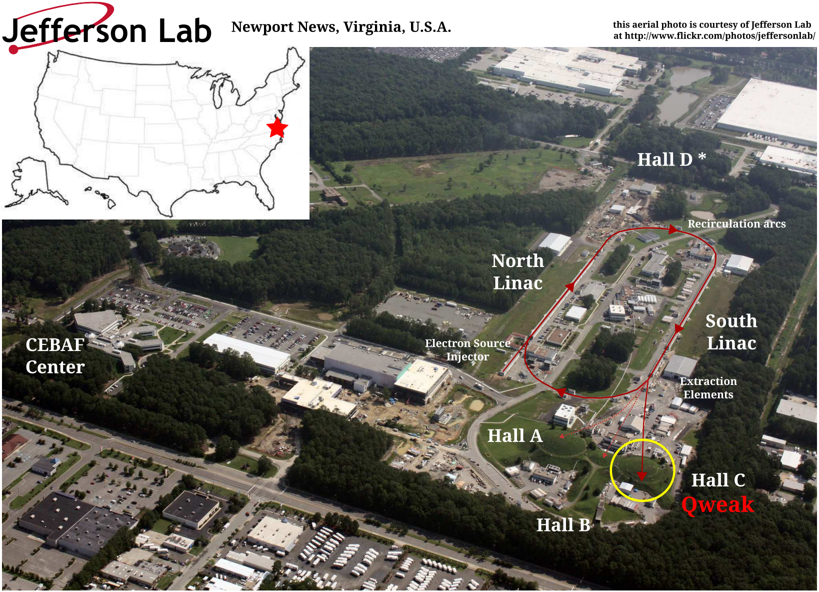
# Parity Violating Experiments

- Parity Violation (PV) experiments in electron scattering measure the PV asymmetry arising from the **interference** between one-$\gamma$ and one-$Z$ exchange
- $\vec{e}D$ experiment at SLAC Phys. Lett. B77, (1978) 347, B84 (1979) 524
  - the **first** PV experiment confirmed the electroweak theory after the weak neutral current found by Gargamelle experiment at CERN Phys. Lett. B46, (1973) 138
- the Qweak experiment at Jefferson Lab measures the same quantity


Jefferson Lab
Newport News, Virginia, U.S.A.
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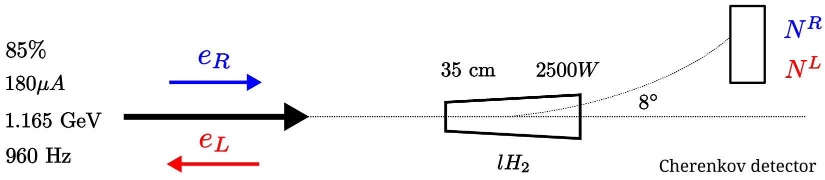
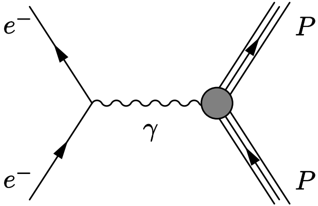
Hall D *
Recirculation arcs
North
Linac
South
Linac
CEBAF
Center
Electron Source
Injector
Extraction
Elements
Hall A
Hall C
Qweak
Hall B

# The Qweak Experiment at Hall C, Jefferson Lab

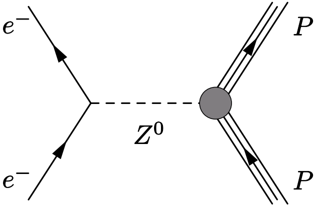



- 85% longitudinally polarized electron beam with 960 Hz Helicity flip
- 35 cm and 2.5 kW liquid Hydrogen target (fixed and unpolarized)
- elastic scattering at forward angle (8°)
- low momentum transfer $Q^2 = 0.026\ (\mathrm{GeV}/c)^2$
- 8 Cherenkov radiation bars for elastic scattered electrons
- measure the PV asymmetry $A_{\mathrm{RL}}^{\mathrm{exp}} = \frac{N^R - N^L}{N^R + N^L}$
- expected $A_{\mathrm{RL}}^{\mathrm{exp}} \approx -230 \times 10^{-9} = -230\ \mathrm{ppb}$
- running time : $\approx$ 2200 hours for 5 $\mathrm{ppb}$ statistical error

# How to extract $Q^p_{\rm weak}$



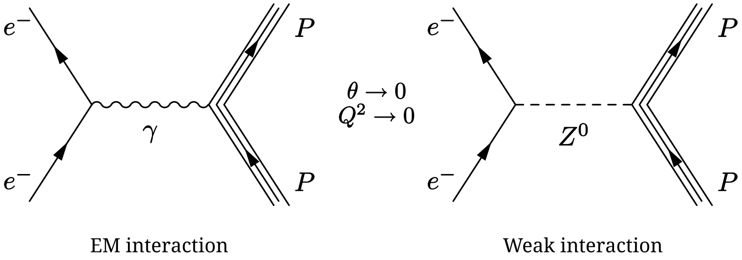

EM interaction




Weak interaction

$$A^{phy}_{\rm PV} = \frac{A^{\rm exp}_{\rm RL}}{P_e} = A_0 \left[ Q^p_{\rm weak} Q^2 + F^p(Q^2, \theta) \right]$$

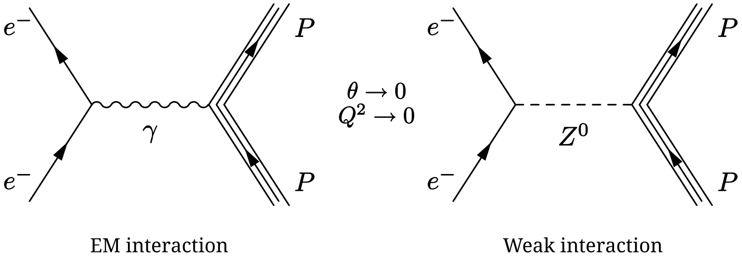
## How to extract $Q^p_{\rm weak}$




$$A^{phy}_{\rm PV} = \frac{A^{\rm exp}_{\rm RL}}{P_e} = A_0 \left[ Q^p_{\rm weak} Q^2 + B \cdot Q^4 + \cdots \right]$$

- $A_0 = -\frac{G_F}{4\sqrt{2}\pi\alpha}$ : constants
- $A^{\rm exp}_{\rm RL}$ : is measured by so-called **Parity Mode** with Cherenkov Detectors, Luminosity Monitors, and Beam Current and Positions Monitors
- $Q^2$ : is measured by so-called **Tracking Mode** by Trigger Plastic Scintillator, Horizontal and Vertical Drift Chambers

## How to extract $Q^p_{\text{weak}}$



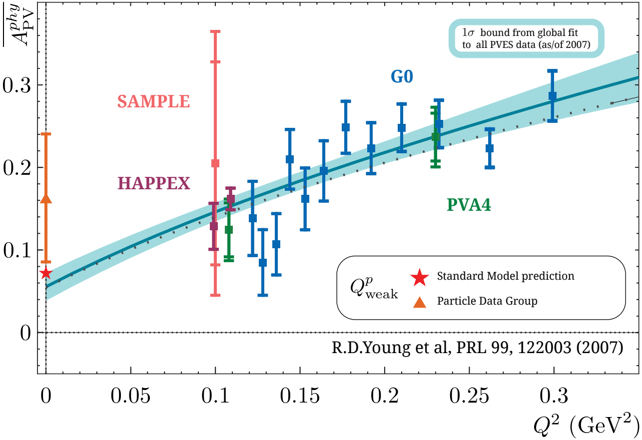

$$A^{phy}_{\text{PV}} = \frac{A^{\text{exp}}_{\text{RL}}}{P_e} = A_0 \left[ Q^p_{\text{weak}} Q^2 + B \cdot Q^4 + \cdots \right]$$

- $P_e$ : is done by Polarization Measurements with offline Møller and online Compton Polarimeters
- $B$ : contains $G^{\gamma}_{E,M}$ and $G^{Z}_{E,M}$ and can be determined by the recently completed PV electron scattering Experiments
- So, we can obtain $Q^p_{\text{weak}}$

# Contribution of the Qweak to $Q^p_{\rm weak}$

bs

$$Q^p_{\rm weak} = 1 - 4\sin^2\theta_W = -2(2C_{1u} + C_{1d})$$




$$\overline{A^{phy}_{PV}} = \frac{A^{phy}_{PV}}{A_0 Q^2} = \left[Q^p_{\rm weak} + B \cdot Q^2\right]$$

bs

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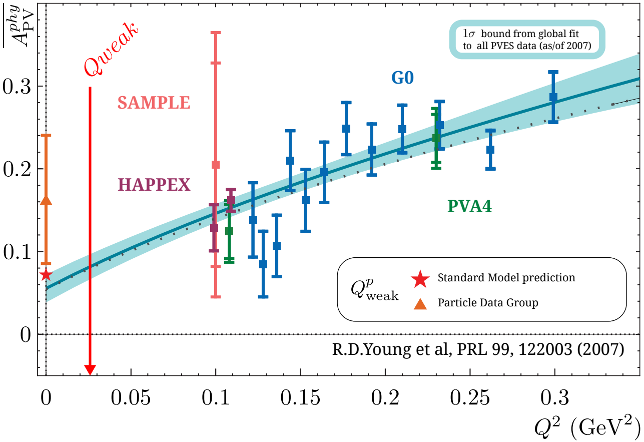
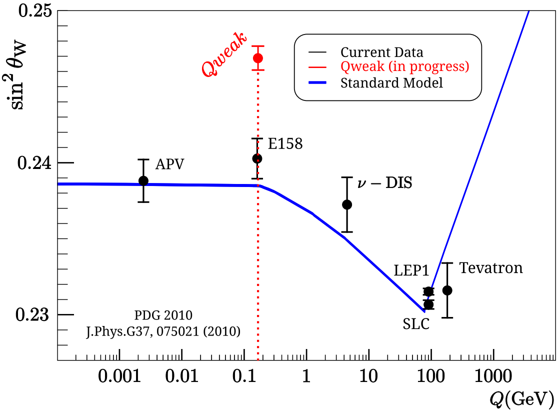



Qweak will improve the results of the fit

by a factor of 5 under the assumption of agreement with SM

# Running of Weak Mixing Angle in the Electroweak Standard Model

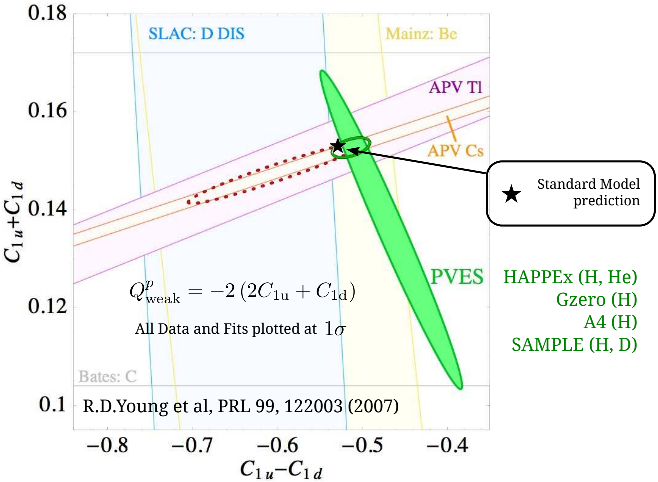
Return




- SLAC E158 : weak charge of electron (pure leptonic)
- APV : weak charge of Cs (semi-leptonic, $d$-quark dominated)
- Qweak : weak charge of proton (semi-leptonic, $u$-quark dominated)

# Constraints on the low energy neutral weak couplings

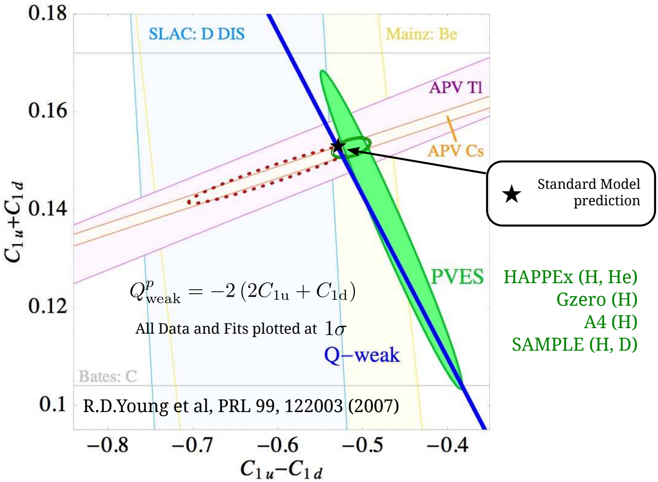




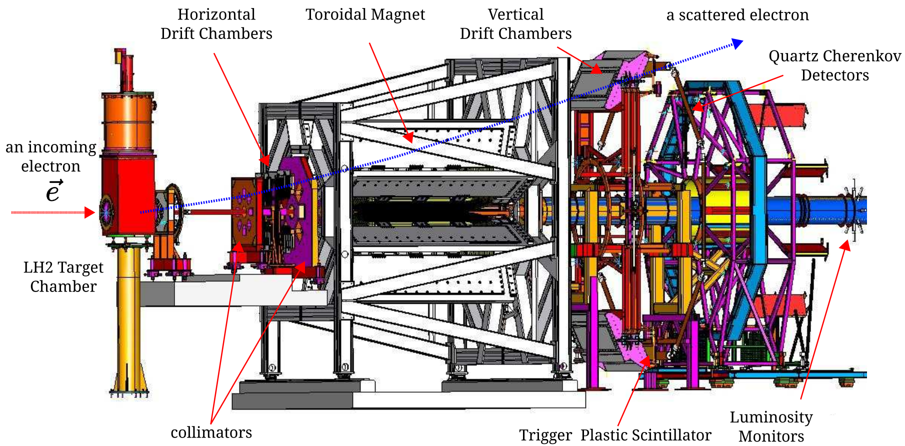

HAPPEx (H, He)
Gzero (H)
A4 (H)
SAMPLE (H, D)

# Constraints on the low energy neutral weak couplings

Return



# Experimental Layout in Hall C at Jefferson Lab



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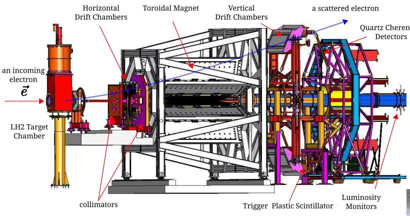
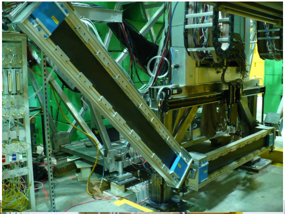
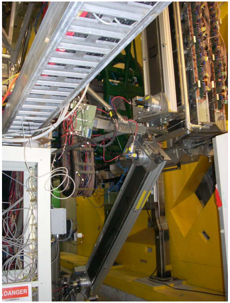
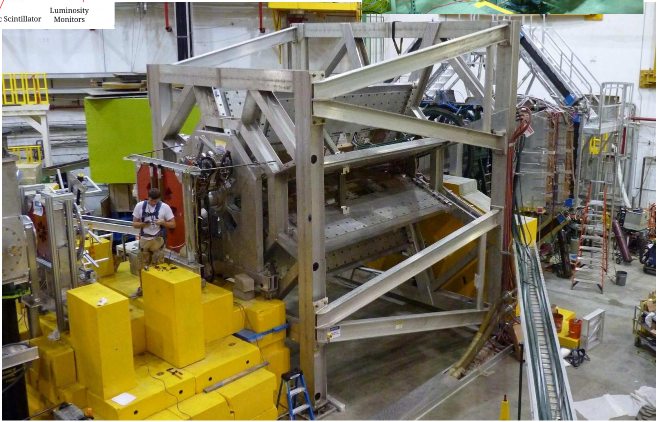
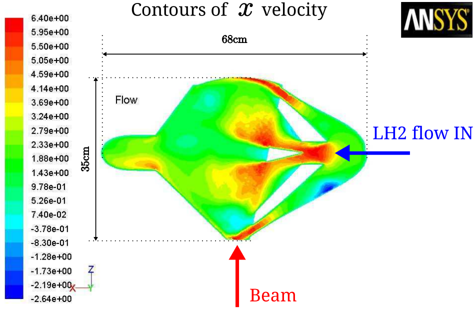




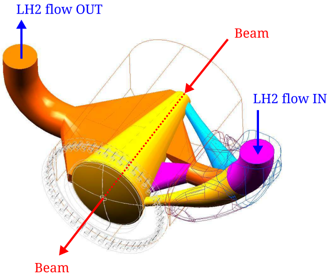



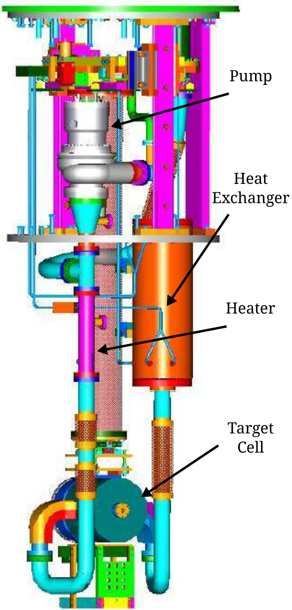
# The Highest Power $\mathcal{L}H_2$ Target




Designed by using
Computational Fluid Dynamics (CFD)

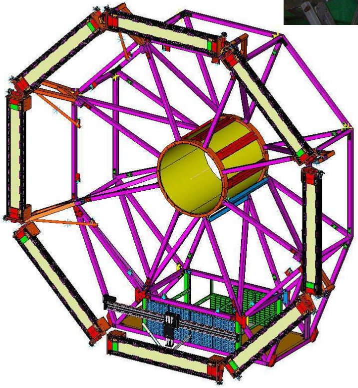
- 2500 W Power
- up to 180 $\mu A$
- transverse flow design by CFD (smaller $\Delta T$ in fluid and $\Delta\rho$ across target cell



## Main Detectors

- Cherenkov Radiator $200 \times 18 \times 1.25\ cm^3$ Spectrosil 2000 : radiation hardness, non-scintillating, and low-luminescence
- lightguide $18 \times 18 \times 1.25\ cm^3$ attached to each end (fused silica)
- Two 5 inch PMTs per bar
- Parity Mode up to 180 $\mu A$
- Tracking Mode 50 $pA$



# Error Budget

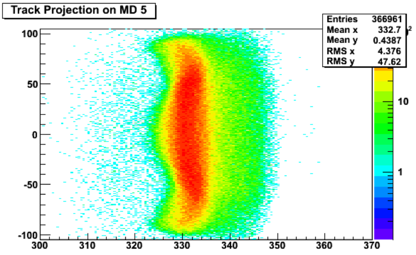
- 4.1% on $Q^p_{\rm weak}$

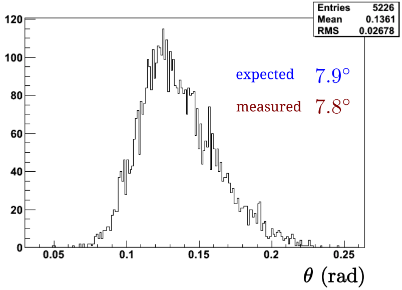
| Source of error | $\frac{\Delta A^{phy}_{\rm PV}}{A^{phy}_{\rm PV}}$ | $\frac{\Delta Q^p_{\rm weak}}{Q^p_{\rm weak}}$ |
|---|---|---|
| Statistics (2.5k hours with 150 $\mu A$) | 2.1% | 3.2% |
| Systematic | | 2.6% |
| Hadronic structure | - | 1.5% |
| Polarimetry* | 0.5% | 1.0% |
| Absolute $Q^{2*}$ | 0.5% | 1.0% |
| Backgrounds* | 0.5% | 0.7% |
| Helicity-correlated beam properties | 0.5% | 0.7% |
| Total | 2.5% | 4.1% |

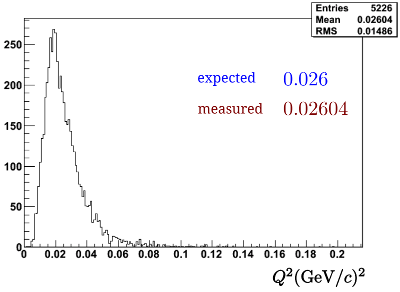
$*$ : dedicated measurements

# Tracking Mode : $Q^2$ Measurement

- 50 pA and $\mathcal{L}H_2$ target
- first measured rate (projected tracks), $\theta$, and $Q^2$ distributions live up to Qweak's expectation
- $Q^2$ error will be due entirely to systematic, because of $< 0.5\%$ statistical error on $Q^2$ obtained in 10 mins of data

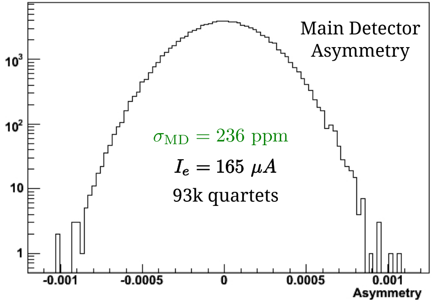


### main detector asymmetry width $\sigma_{\mathrm{MD}}$

- important to monitor $\sigma_{\mathrm{MD}}$, because an uncertainty $\propto \sigma_{\mathrm{MD}}/\sqrt{N}$
- 165 $\mu$A, $\mathcal{L}H_2$ target, and 5.83 GHz detected rate
- expected $\sigma_{\mathrm{MD}} \Rightarrow$ 235 ppm
  - ♫ pure counting statistics $\rightarrow$ 215 ppm
  - ♫ $+$ detector energy resolution $\rightarrow$ 232 ppm
  - ♫ $+$ beam current normalization $\rightarrow$ 235 ppm
- measured $\sigma_{\mathrm{MD}} \Rightarrow$ 236 ppm with 6.5 minutes of data

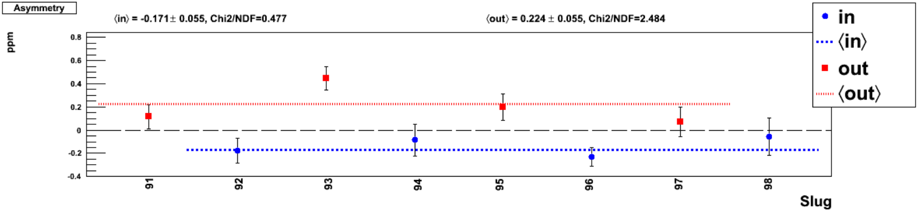


## systematic check by optically reversing beam helicity

- change overall helicity pattern by insertable $\lambda/2$ plate

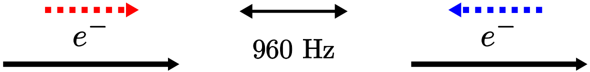
$$+ - - + \quad \Longleftrightarrow \quad - + + -$$

- expected the sign change of a measured PV asymmetry
- good systematic check of the main detector
- Slug is roughly 8 hours
- unregressed and uncorrected plot



## what the helicity-correlated beam parameters are

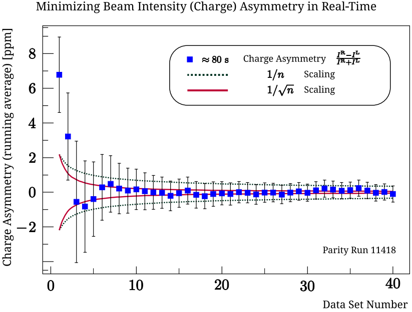
- characterize one polarized electron by energy, position, direction, charge, and helicity
- we want to change only the helicity, but it is possible to change them all
- these changes modify the PV asymmetry
- mandatory to monitor and minimize such helicity correlated differences as well as to measure the sensitivities of the PV asymmetry to these changes.

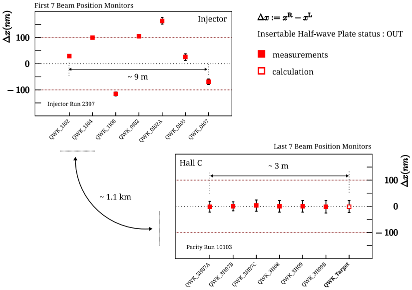


# Monitor Helicity-correlated Beam Parameters (two examples)

## Charge Asymmetry

- run a beam intensity feedback program during a data taking simultaneously
- keep the helicity-correlated beam intensity below 0.1 ppm
- the right result during one run period, which is usually 1 hour.




## Position Differences

- monitor and record the beam position differences between two helicity states
- recorded data are used to extract the position sensitivities to the PV asymmetry
- have achieved the position sensitivities contribution to the asymmetry below 0.2 ppm

# Experiment Status

## schedule

- first commissioning beam : July 2010
- commissioning run : Fall 2010
- Run I : Jan-May 2011
- **Run II** : **Nov 2011 - May 2012**

## achievement

- Beam : 150 - 180 $\mu$A with 86%-88% polarization (more than our proposals)
- all helicity-correlated properties are acceptable
- At present, we have **in hand 24%** of proposed statistics for $Q^p_{\mathrm{weak}}$
- done initial Auxiliary measurements ($A_{\mathrm{PV}}$ for Aluminum target windows and for $N \to \Delta$, Parity-conserving transverse asymmetry)

## teething problems

- target pump, beam dump vacuum leakage, QTor Magnet power supply, and so on

# Summary

- The Qweak will make a precision measurement of the proton's weak charge in the simplest system by Parity Violation experiment
- Experiment well underway, data-taking ends May 2012
- No show-stoppers found, on track for proposed 4% precision on $Q^{p}_{\mathrm{weak}}$

감사합니다!

Thank you!

Dankeschön!

ありがとう!

謝謝!

¡Gracias!

Merci!

☺

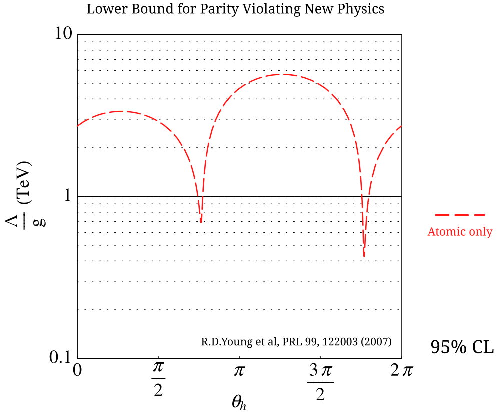
Backup Slides....

# Constraints on new Physics beyond the SM

parametrize new physics via 4-fermion contact interaction

($\Lambda$ = mass, $g$ = coupling)

$$\frac{\Lambda}{g} = \frac{1}{\sqrt{\sqrt{2}G_F}} \cdot \frac{1}{\sqrt{\Delta Q^p_{\mathrm{weak}}}}$$



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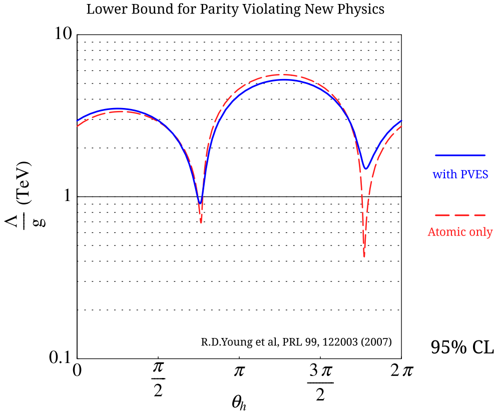

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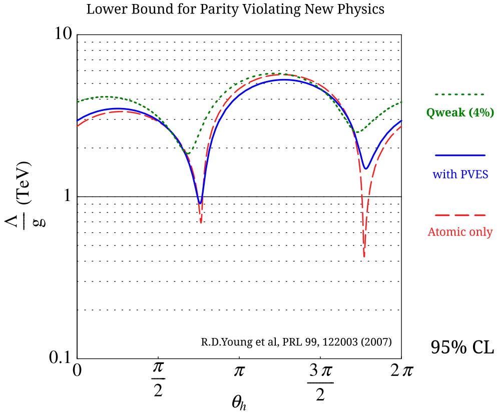
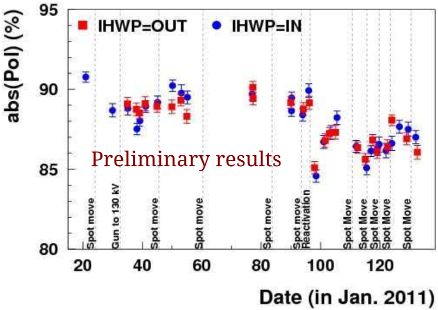


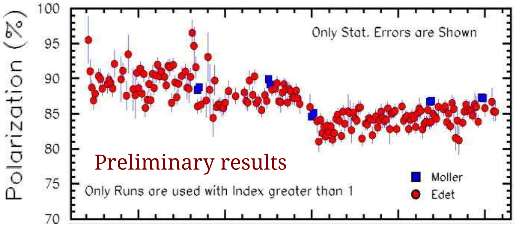
## Basel-Hall C Møller

- offline
- nominal operating current $\approx 1\ \mu A$
- pure Fe target
- three measurements per week

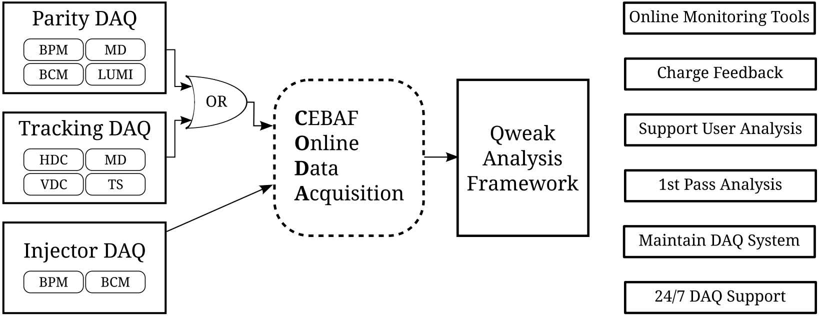



## Hall C Compton

- online
- full production current
- 10 W green laser
- continuous measurement



# Qweak Data Acquisition System (DAQ)




- Cherenkov Detector rate 800MHz each, total 6.4GHz in Parity Mode
- Parity Mode Raw data is about 20GiB/hr or about 480GiB/day
- 22 sampling ADCs for Parity DAQ, 12 sampling ADCs for Injector DAQ, 18 TDCs for Tracking DAQ, and others ADCs and scalers.