Thomas Jefferson National Accelerator Facility

Medium-Energy Comparative Research Review

June 12, 2013

SM Tests/BSM Searches

Roger Carlini
(JLab)

Outline: SM Tests/BSM Searches

- Precision Tests of the SM
  - The Qweak Experiment – Hall C
- Long Lead Time Technical Activities for Future Precision Measurements
- BSM Searches at Jlab
  - APEX – Hall A
  - HPS – Hall B
  - Dark Light – ERL at the FEL
- Future Programs
  - The Moller Experiment – Hall A
  - PVES with SOLID – Hall A

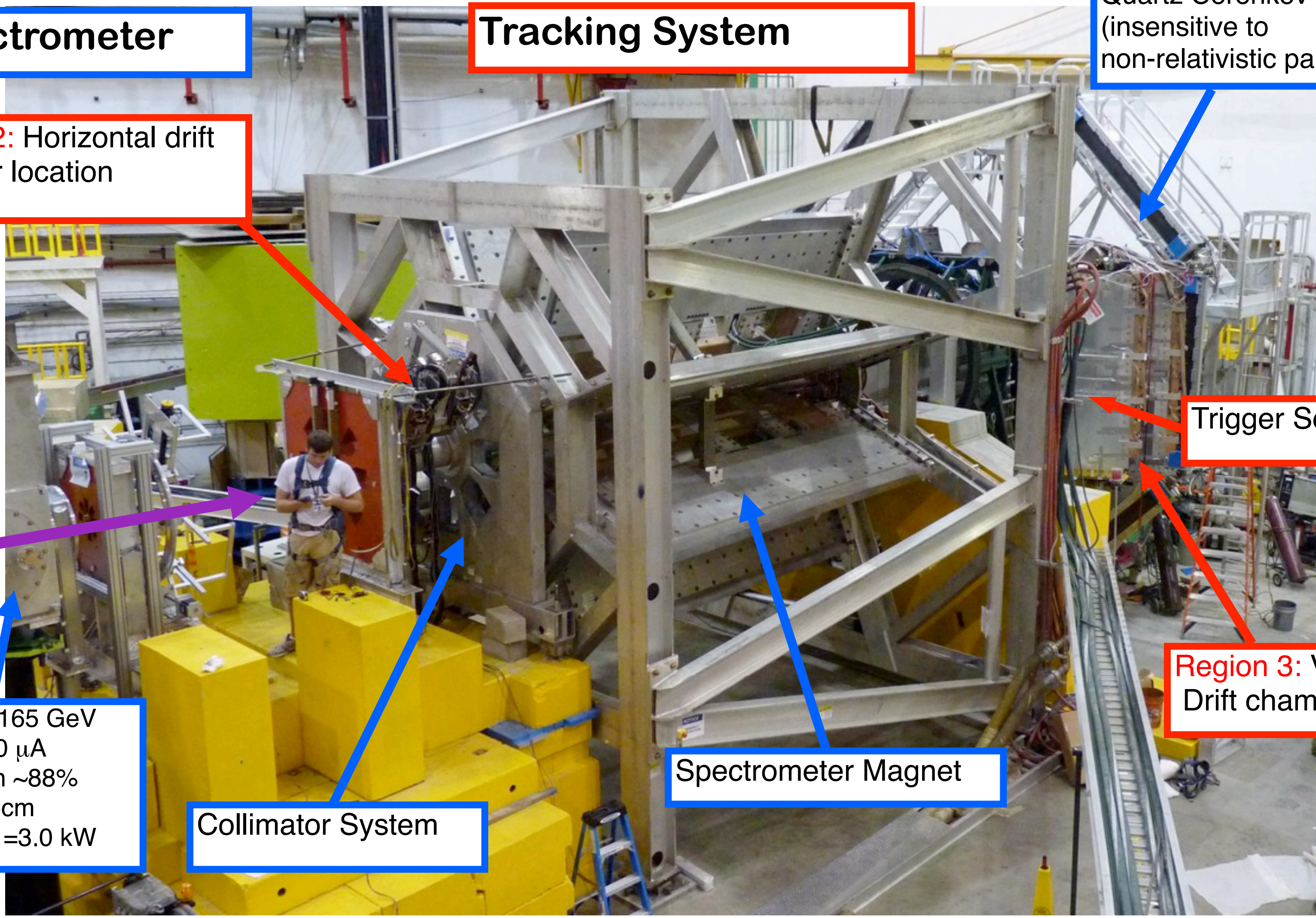
Q-Weak: A Search for Parity Violating New Physics at the TeV Scale via Measurement of the Proton's Weak Charge.

10 years of development + 2 years on floor (~1 year beam time)
International Collaboration: 24 institutions (23+ grad students ,10+ post docs)

Spokesperson	Project Manager	Polarimetry	LH_2 - target	Detectors
R. D. Carlini	G. Smith	D. Gaskell	S. Covrig	D. Mack

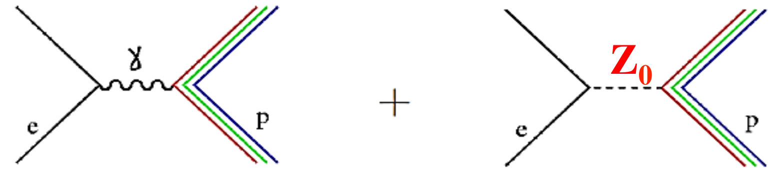
- Parity-violating e-p analyzing power to high precision with high precision at $Q^2 \sim 0.025\ (GeV/c)^2$. Allows determination of: Q^p_W, C_{1u}, C_{1d}, Q^n_W, & $\sin^2\theta_W$
- Parity-violating and conserving e-C and e-Al analyzing powers.
- Parity-allowed analyzing power with transverse-polarized beam on H and Al.
- Parity-violating and allowed analyzing powers on H in the $N\rightarrow\Delta(1232)$ region.
- PV asymmetries in pion photo-production.
- Transverse asymmetries in pion photo-production.
- Non-resonant inelastic measurement at 3.3 GeV to constrain γ-Z Box uncertainty.
- Transverse asymmetry in the PV inelastic scattering region (3.3 GeV).
- Knowledge base on high precision PV technology and methodology.

Qweak Apparatus Overview (without shielding installed)



Q^p_{Weak} : Extraction from Parity-Violating Electron Scattering

- $A_{ep} = \left[\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}\right] \sim \frac{|M^{PV}_{weak}|}{|M_{EM}|}$



EM (PC) neutral-weak (PV)

- $A_{ep} = \left[\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{\epsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1-4\sin^2\theta_W)\epsilon' G_M^\gamma G_A^Z}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2}$
  - where $\varepsilon = [1 + 2(1+\tau)\tan^2(\theta/2)]^{-1}$, $\varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}$,
    $\tau = Q^2/4M^2$, $G^\gamma_{E,M}$ are EM FFs, $G^Z_{E,M}$ & G^Z_A are strange & axial FFs,
    and $\sin^2\theta_W = 1 - (M_W / M_Z)^2$ = weak mixing angle

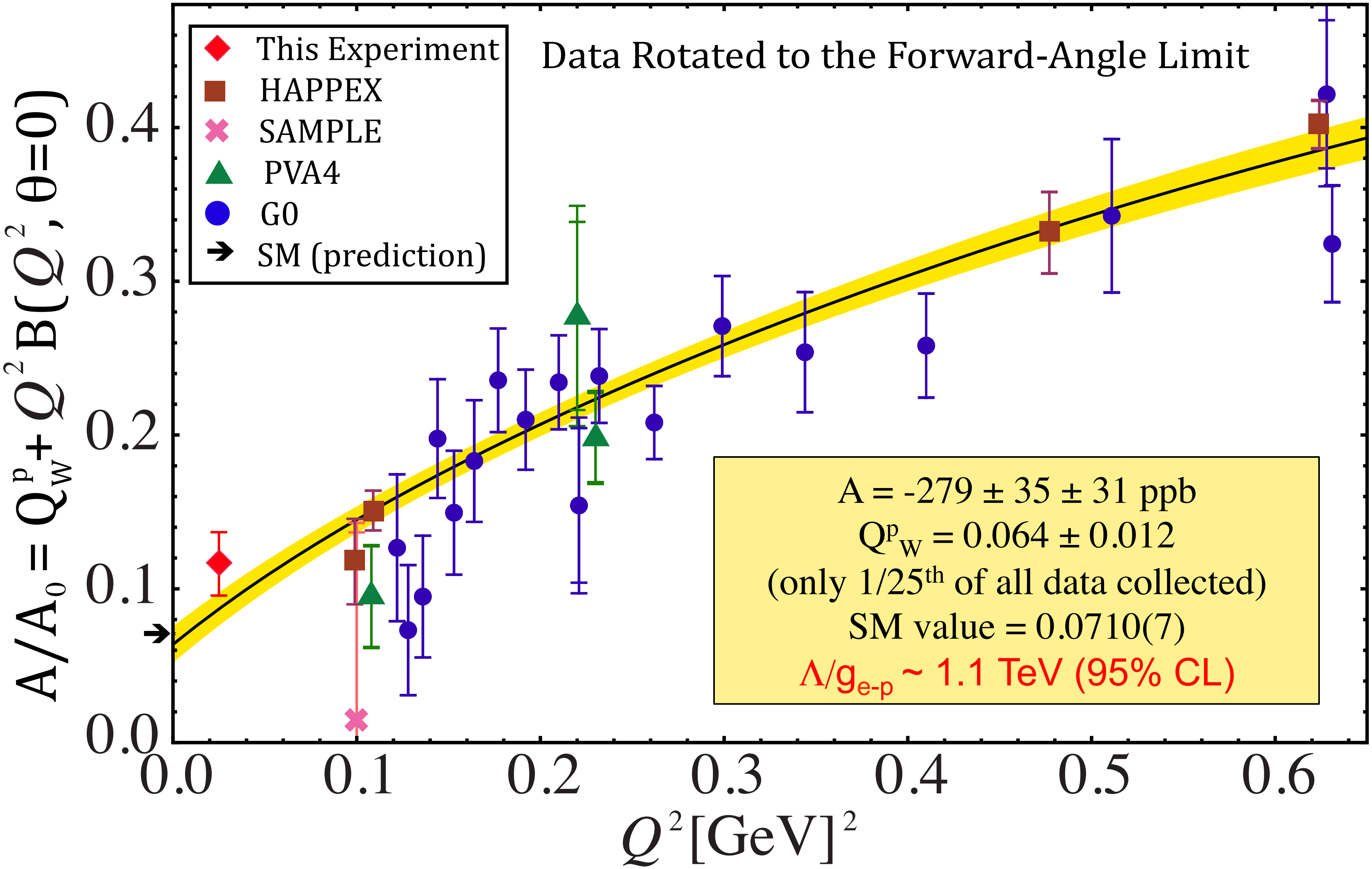
- Recast $A_{ep} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[Q^p_w + Q^2 B(Q^2,\theta)\right]$
  - So in a plot of $A_{ep}/\left[\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\right]$ vs Q^2:
    - ***Q^p_w* is the *intercept*** (anchored by precise data near Q^2=0)
    - $B(Q^2,\theta)$ is the ***slope*** (determined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

This Experiment

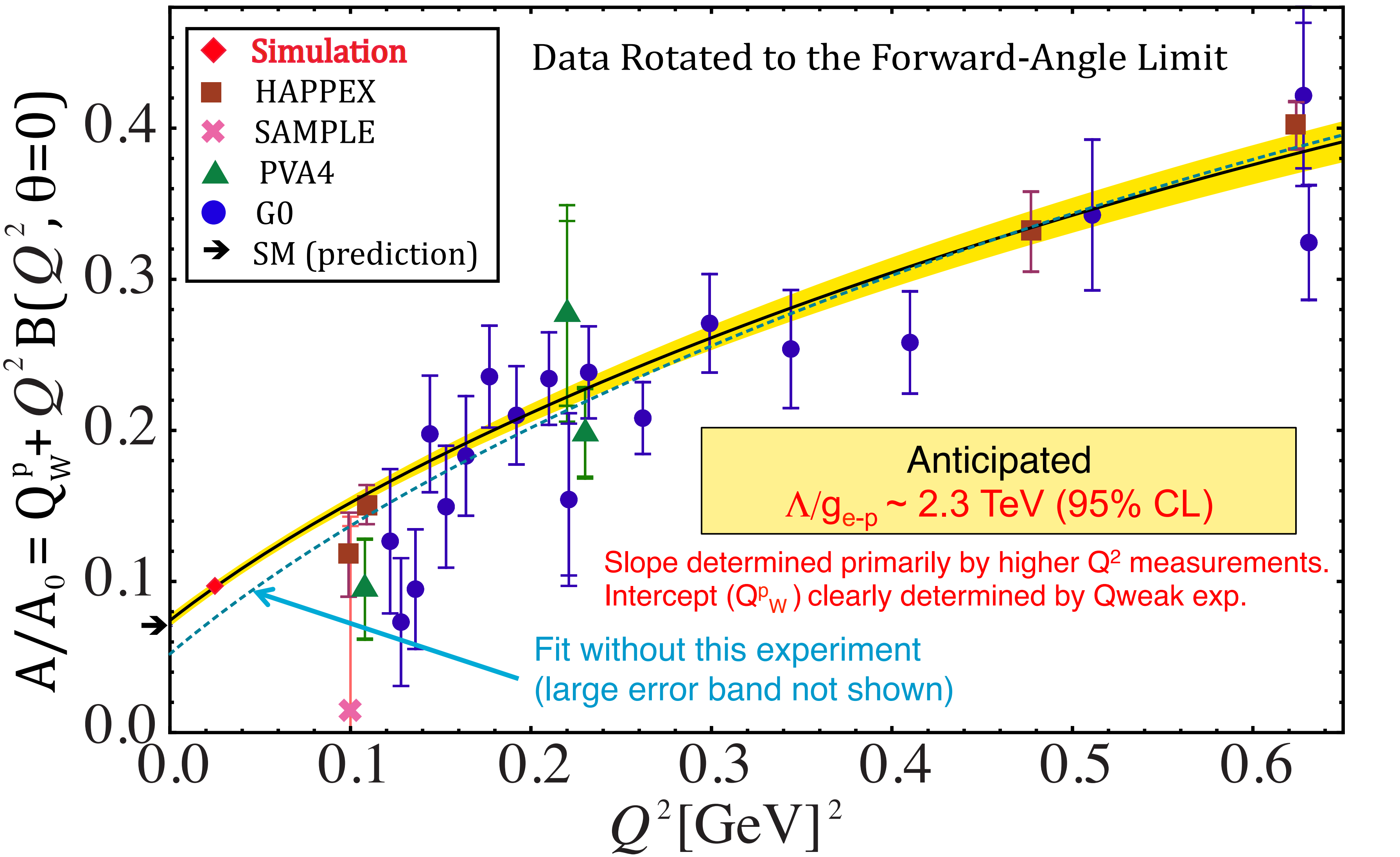
$$Q^p_W = [\rho_{NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_W(0) + \Delta'_e] + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

Extraction also requires “modern” calculations of energy dependent corrections
- recently completed.

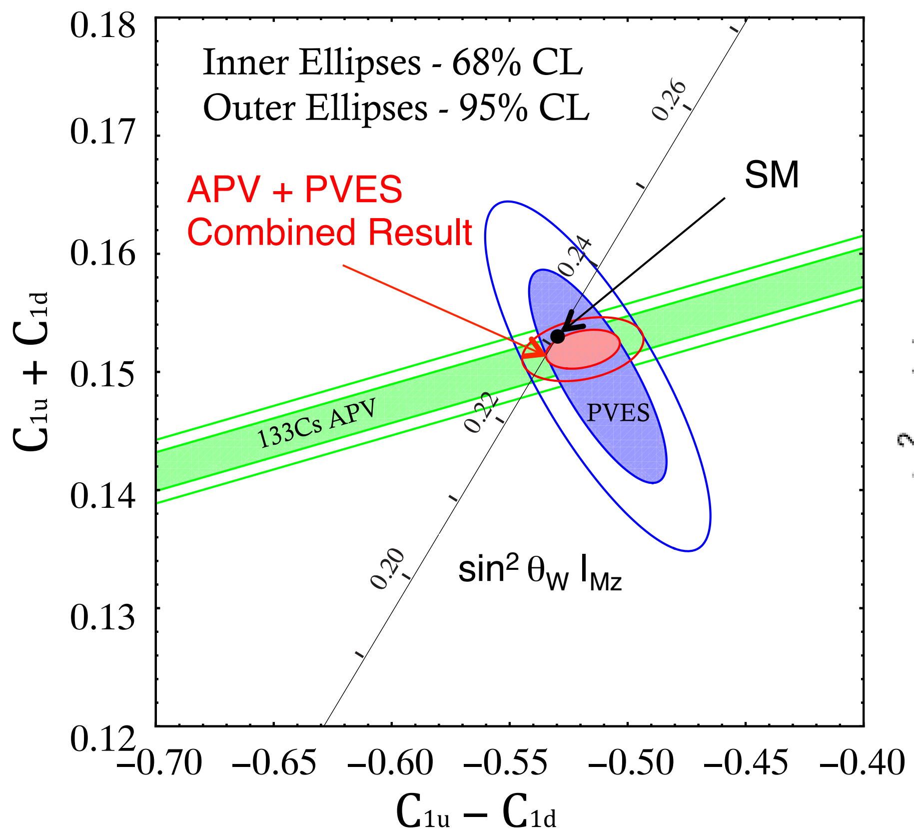
Global fit of $Q^2 < 0.63\ (GeV/c)^2$ - PVES +1/25th of Qweak Data

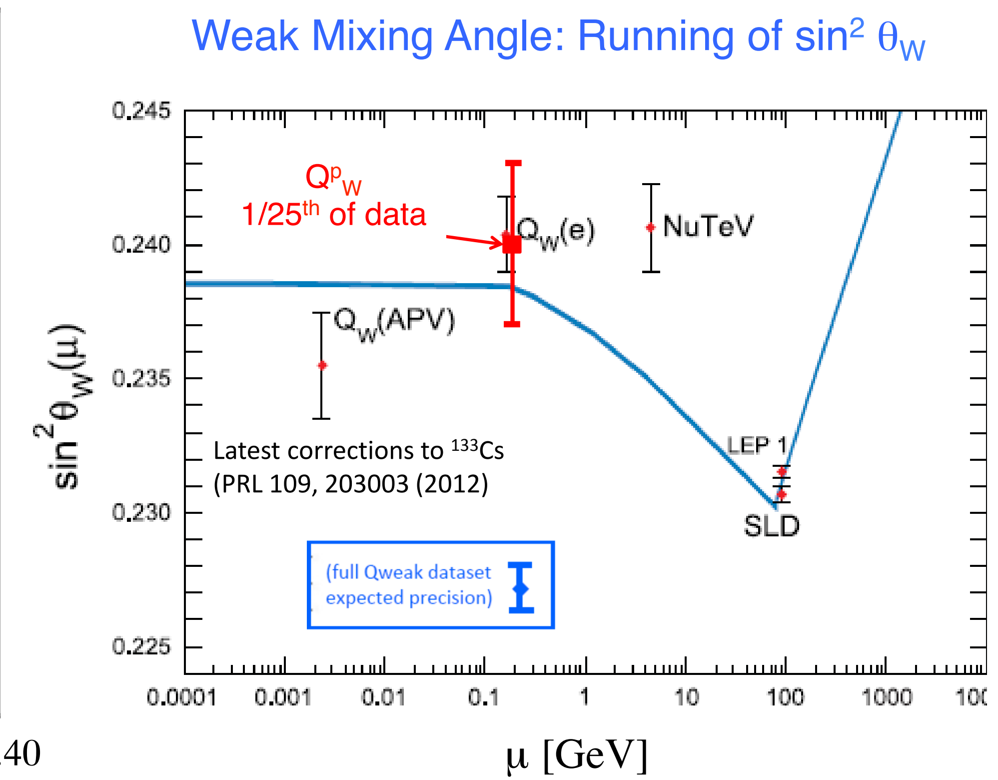


Estimated Fit Uncertainties for Final Result (Assuming SM)



Combined Analysis: 1/25th of Qweak Data + other PVES + APV





$C_{1u} = -0.184 \pm 0.005$
$C_{1d} = 0.336 \pm 0.005$

$Q^n_W = -2(C_{1u} + 2C_{1d})$
$= -0.975 \pm 0.010$

$Q^p_W = -2(2C_{1u} + C_{1d})$
$= 0.064 \pm 0.012$
SM value = 0.0710(7)

Remainder of experiment still being analyzed, final result before end of 2014. Expect final $\Delta A_{e\text{-}p}$ result will have ~5 x better precision.

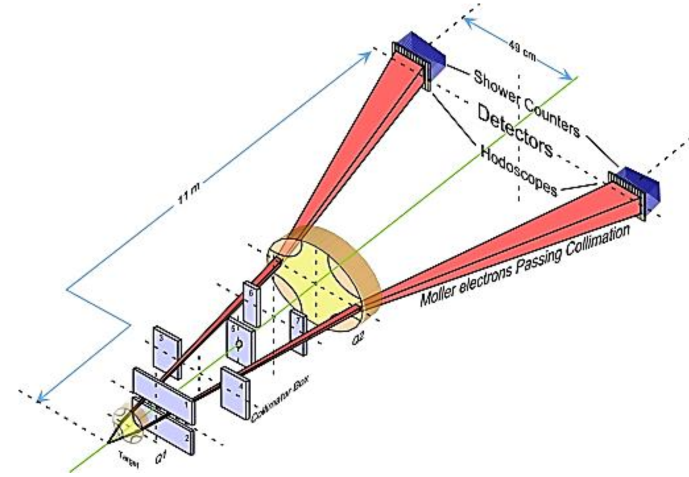
Precision Polarimetry – D. Gaskell (Jlab)

<u>Strategy: use 2 independent polarimeters</u>

Qweak achieved design goal of ΔP/P ≤ 1%

Existing < 1% Hall C Møller polarimeter:
- Low beam currents, invasive
- Known analyzing power provided by polarized Fe foil in a 3.5 T field.

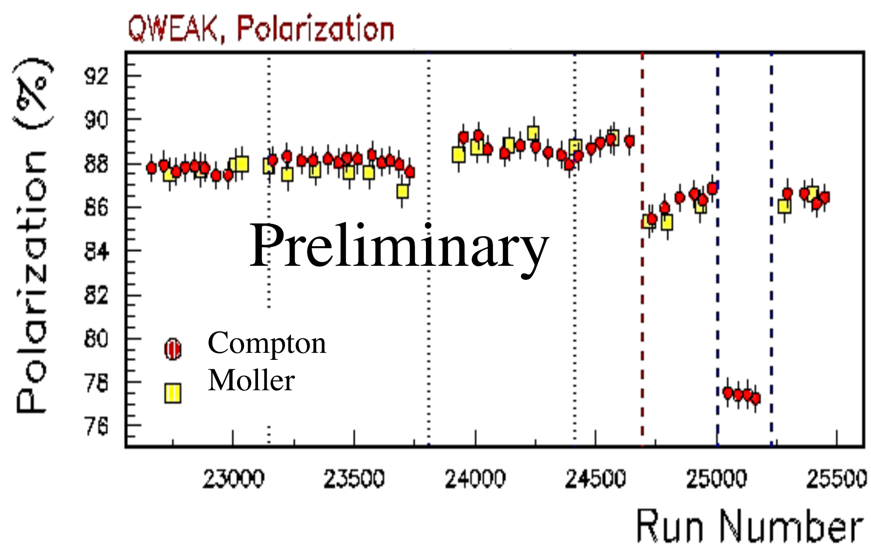
→ Møller polarimetry systematic uncertainty (relatively) energy independent, higher precision may require new technology.

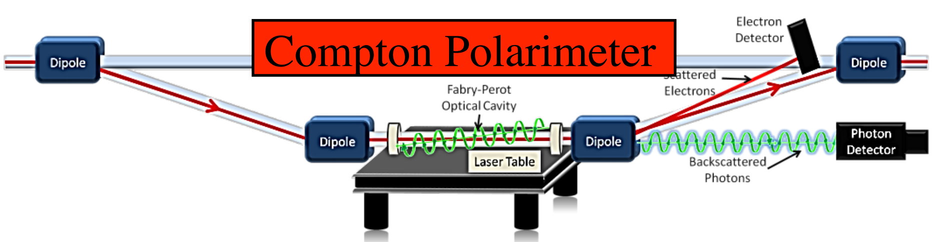


Møller Polarimeters in Halls A & C

New Hall C Compton polarimeter (1% / h)
- Continuous, non-invasive
- Known analyzing power provided by circularly-polarized laser

→ Compton polarimetry benefits from larger analyzing power at higher energy – dP/P < 0.5% within reach with existing techniques at 11 GeV.



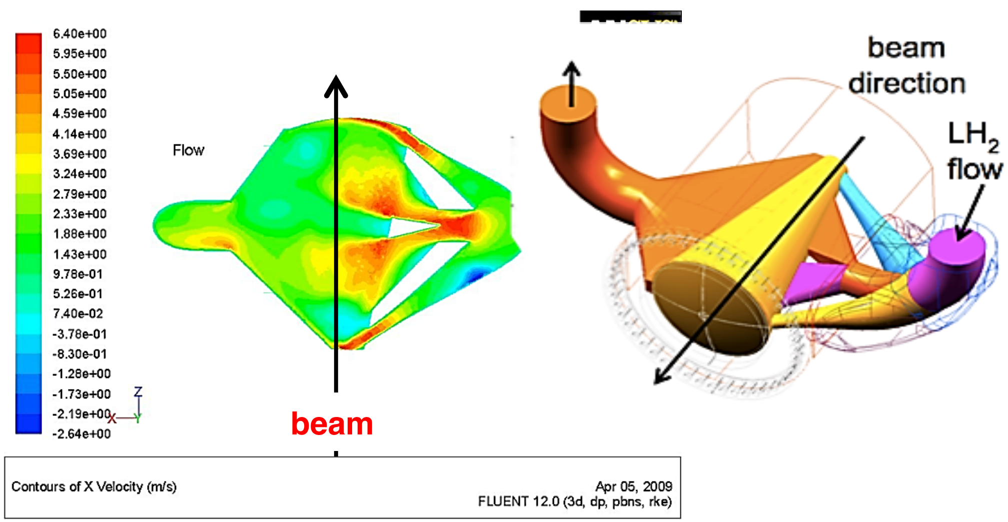


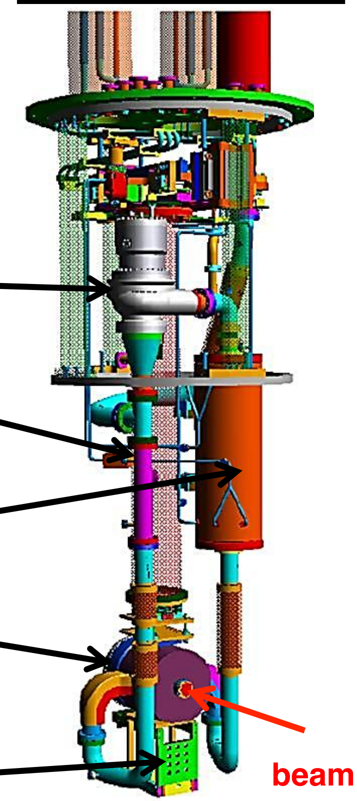
First LH_2 Target Designed with Computational Fluid Dynamics (CFD)

S. Covrig – (D.O.E. early career award) & G. Smith

- KHz scale helicity reversal rate greatly suppresses "boiling noise" and is critical for PV experiments, but does nothing for beam current dependent density reductions.
- CFD-Capability & goals going from 6 GeV era to 11 GeV era:
  - ✓ Qweak LH_2 target world's highest power cryogenic target ~3 kW (< 0.8% density loss @ 2,500 W) with 46 ppm/reversal pattern @960 Hz.
  - ➢ Standardize performance of LH_2 targets: 1% luminosity loss over 20 cm at 100 μA with a raster of 2 mm (at least 10X better than 6 era GeV LH_2 previous "standard" Jlab targets").
  - ➢ Designing a MOLLER-class LH_2 target (5,000 W) with 25 ppm/reversal pattern @2 KHz helicity flip rate.

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





Centrifugal pump (15 l/s, 7.6 kPa)

3 kW Heater

3 kW HX utilizing 4K & 14K He coolant

35 cm cell (beam interaction volume)

Solid Targets

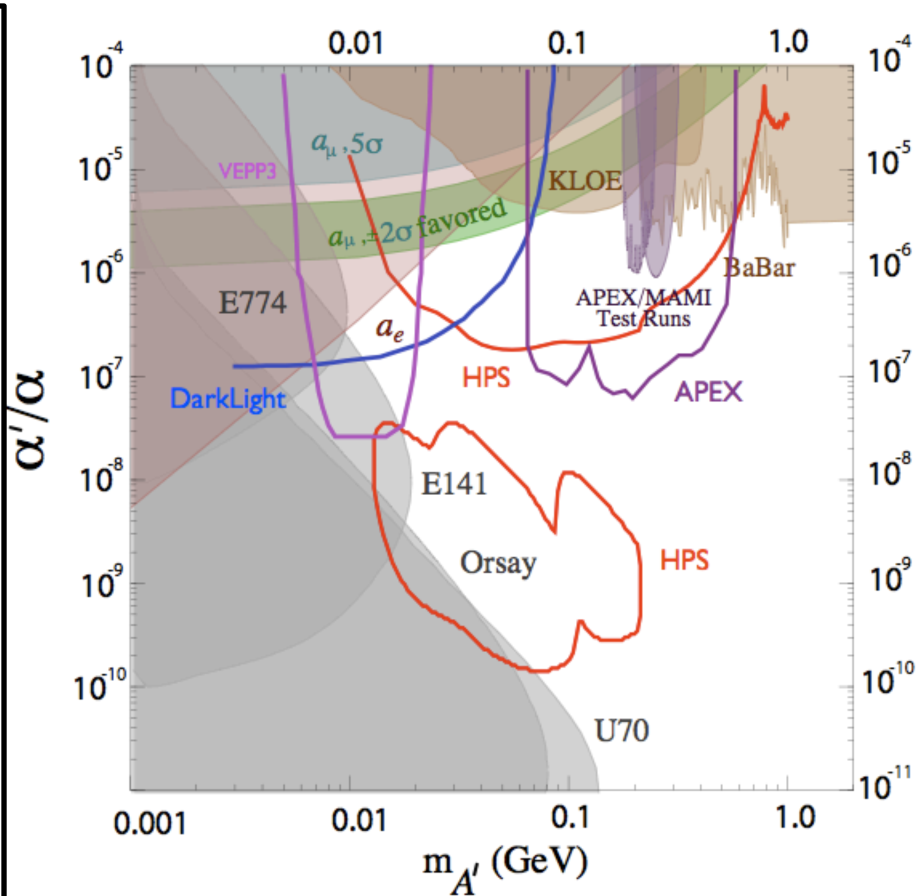
Motivation from BSM physics at JLab

The Heavy Photon (A') is:

- a massive vector gauge boson, which kinetically mixes with the SM γ, inducing a weak coupling εe to electric charge, $\alpha'/\alpha \equiv \varepsilon^2$
- present in many extensions of the Standard Model below weak scale and is natural for string theories

A' candidate might explain the discrepancy between the measured and calculated value of the anomalous magnetic moment of the muon, $a_\mu = g - 2$, (*among the simplest new physics explanations is the existence of a new force mediator that couples to muons*)

Might be responsible for the discrepancy in PCR measured in muon and electron experiments

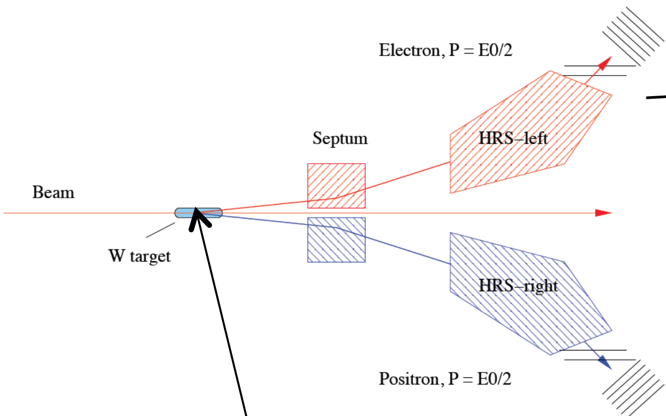


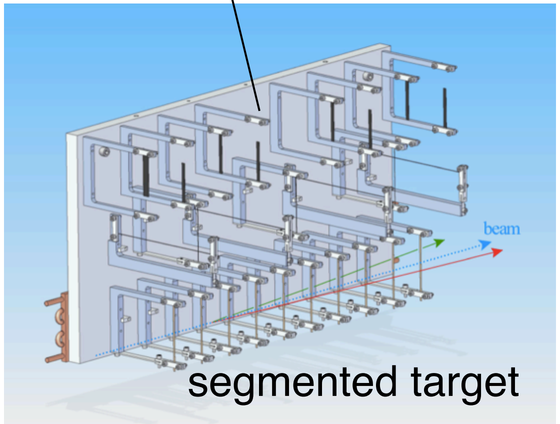
Existing constraints on heavy photons (A′) - 90% confidence level limits from the beam dump experiments E141, E774, Orsay, and U70, the muon anomalous magnetic moment, KLOE, the test run results reported by APEX and MAMI, an updated estimate using a BaBar result, a constraint from supernova cooling, and an updated constraint from the electron anomalous magnetic moment. In the green band, the A′ can explain the observed discrepancy between the calculated and measured muon anomalous magnetic moment.

The A′ Experiment in Hall-A (APEX)

- Bogdan Wojtsekhowski (JLab)

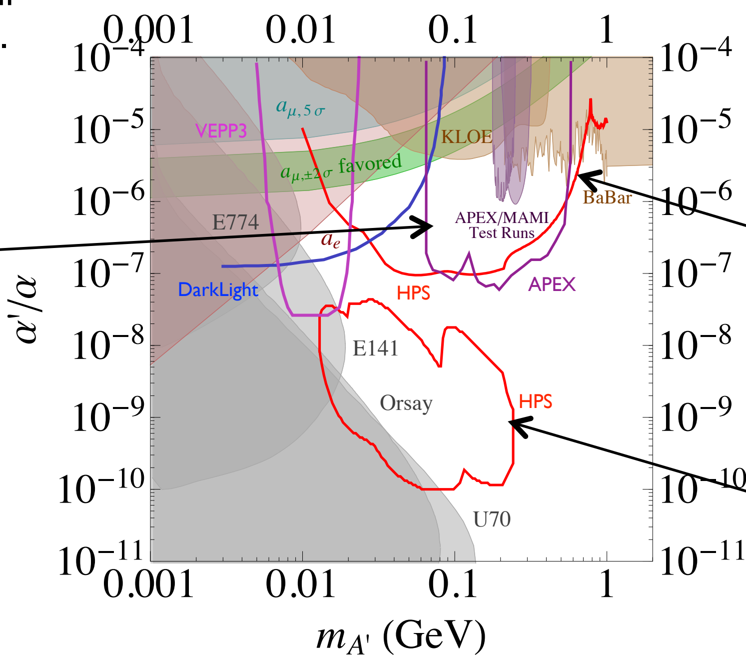
Electron-nucleus fixed-target, a e^+e^- pair in the two HRS focusing spectrometers. Search for 50-500 MeV A' decaying promptly to e^+e^- pairs.



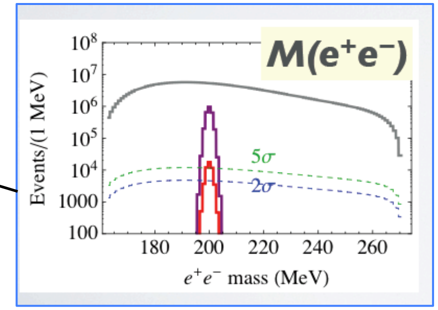


Heavy Photon Search Hall-B (HPS)

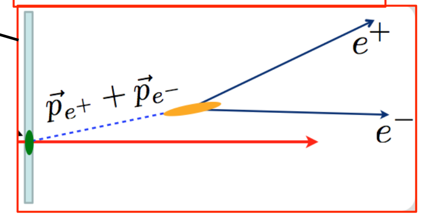
- Stepan Stepanyan (JLab)

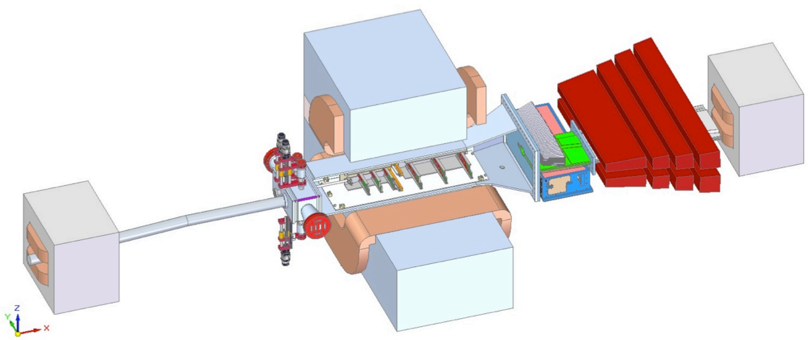


Bump hunt region



Displaced decay vertex search





1.1 GeV, 2.2 GeV & 6.6 GeV, ~500 nA e^- beams on tungsten target. Mass range 20 MeV – 1 GeV for couplings $e^2 > 10^{-7}$ with bump hunt and $e^2 < 5 \times 10^{-8}$ with displaced vertex.

e^+e^-, $\mu^+\mu^-$ pairs in custom Si-tracker magnetic spectrometer.

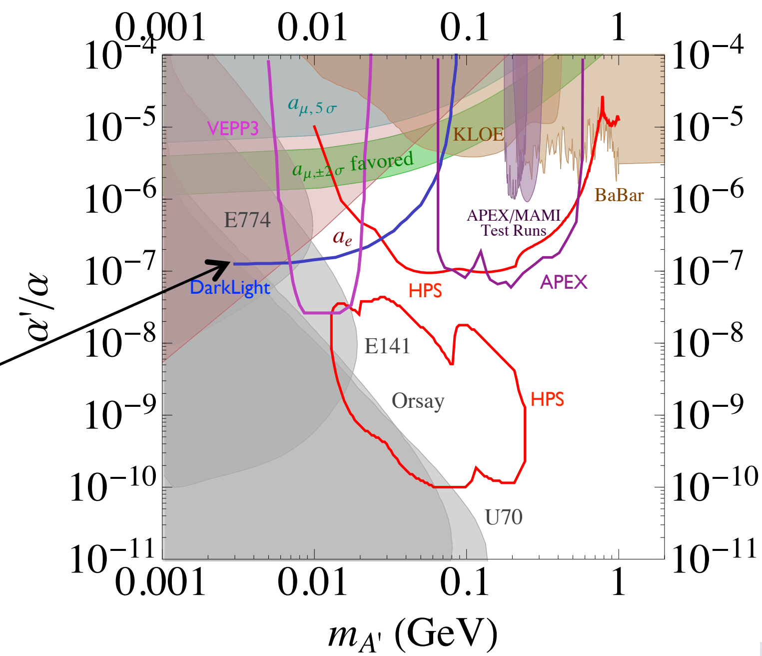
Search for A' in "visible" & "invisible" decay modes – at FEL / ELR

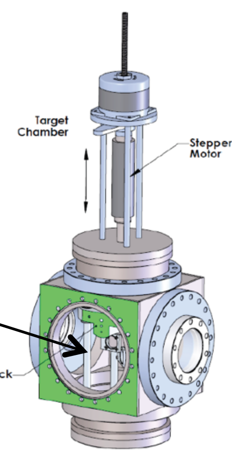
$e^- p \rightarrow e^- p A', A' \rightarrow e^+ e^-$ $\qquad$ $e^- p \rightarrow e^- p A', A' \rightarrow inv.$

MIT Collaboration: R. Milner, P. Fisher, C. Tschalaer,…

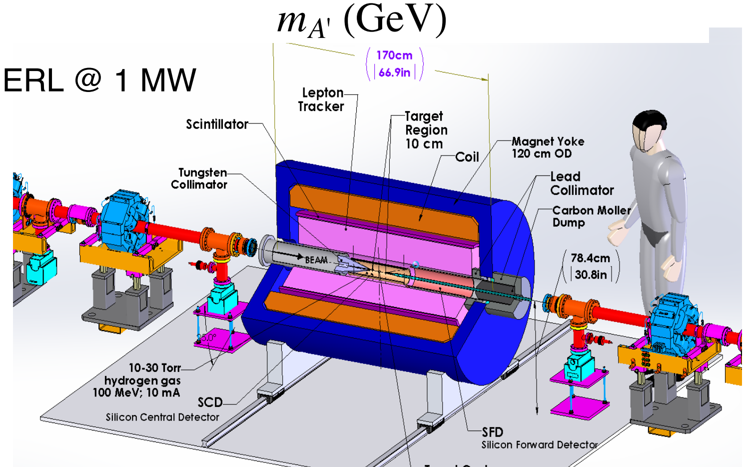
- Electron scattering off windowless hydrogen gas target, aggressively pumped.
- Gas thickness ~10^{19} cm^{-2} with 10mA beam yields ~0.5 ab^{-1}/month.
- Thin beryllium beam pipe.
- Si detector for proton recoil.
- TPC + 0.5 T magnet:
  - High track density
  - ~250 μm hit res.
  - Magnet confines low-p_T backgrounds (e-p and Moller).
- Scintillators serves as veto for invisibles search.

- Test target system was recently installed in the 3F region of the FEL IR beamline.
- ATest beam of 4.5 mA, 100 MeV (450 kWatt of e-beam power) successfully transmitted through a 2 mm hole, 10 cm long, with a maximum loss of < 3 ppm and demonstrated FEL/ERL has required stability.



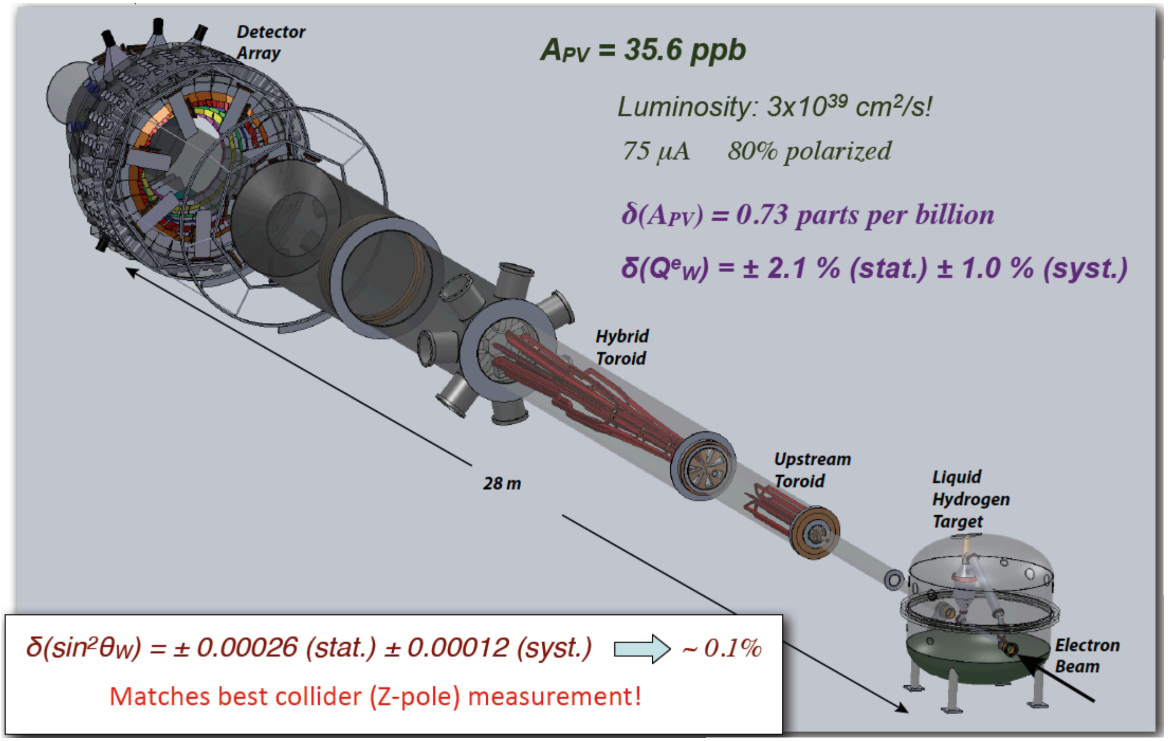


ERL @ 1 MW



The 11 GeV MOLLER Experiment – Hall A - Javier Gomez (project manager)

(an ultra precise measurement of the weak mixing angle using Møller scattering)



A_{PV} = 35.6 ppb

Luminosity: 3x10^{39} cm^2/s!

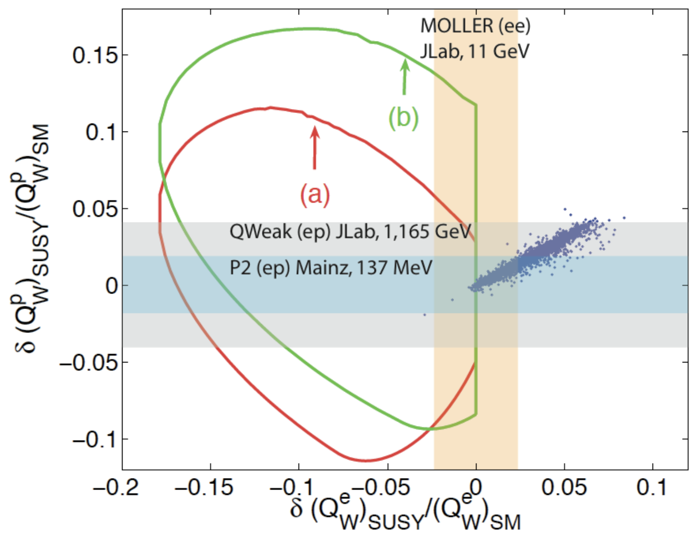
75 μA   80% polarized

$\delta(A_{PV})$ = 0.73 parts per billion

$\delta(Q^e_W)$ = ± 2.1 % (stat.) ± 1.0 % (syst.)

$\delta(\sin^2\theta_W)$ = ± 0.00026 (stat.) ± 0.00012 (syst.) ⇨ *~ 0.1%*

Matches best collider (Z-pole) measurement!

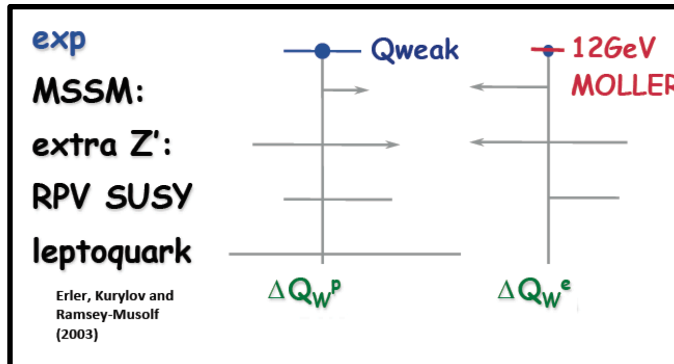


MOLLER: doubly-charged scalers

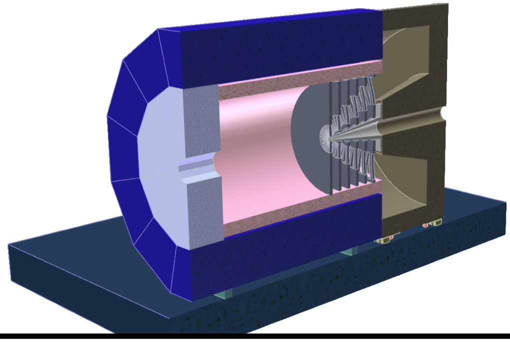
$$\mathcal{L}_{e_1e_2} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda^2}\bar{e}_i\gamma_\mu e_i\bar{e}_j\gamma^\mu e_j \quad \Rightarrow \quad \frac{\Lambda}{\sqrt{|g_{RR}^2 - g_{LL}^2|}} = 7.5\ \text{TeV}$$

best contact interaction reach for leptons at low OR high energy

To do better for a 4-lepton contact interaction would require:
Giga-Z factory, linear collider, neutrino factory or muon collider



PVES with SoLID – Hall A (measures C_{2u} & C_{2d})



SOLID
- Large acceptance spectrometer based on large solenoid (e.g. CLEO)
- High luminosity
- Tracking, calorimetry, Cerenkov detectors
- Precision polarimetry

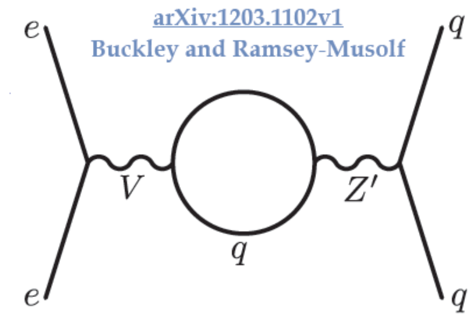
SoLID would fill unique corner of parameter space.

No other technique can provide comparable precision on axial hadronic weak neutral currents.

- *LHC reach ~ 5 TeV, but....*
- *Little sensitivity if Z' doesn't couple to leptons*

Leptophobic Z'

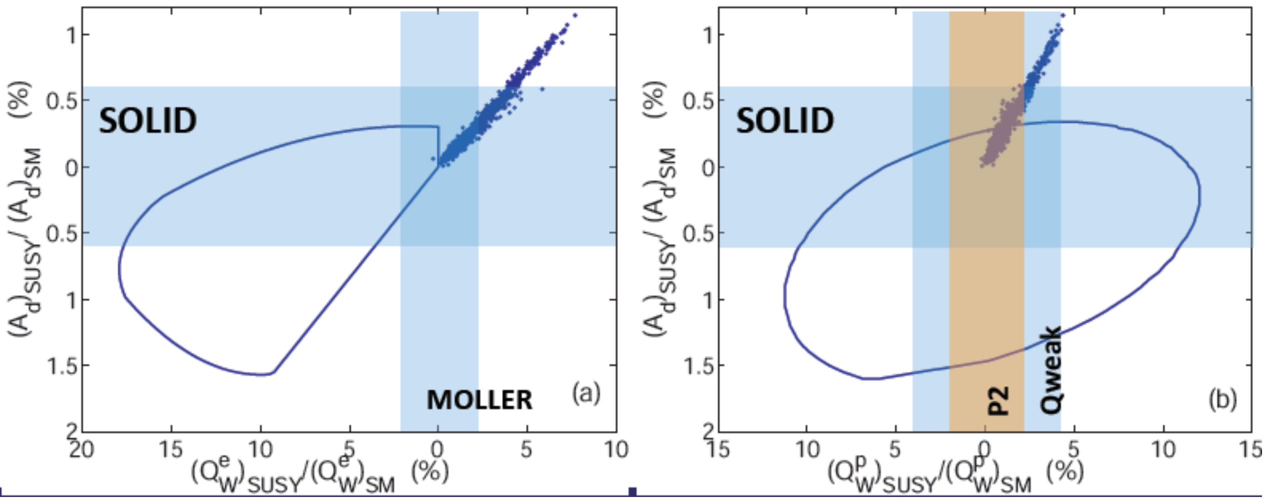
arXiv:1203.1102v1
Buckley and Ramsey-Musolf



Leptophobic Z' as light as 120 GeV could have escaped detection SoLID can improve sensitivity: 100-200 GeV range. (arXiv:1203.1102v1 Buckley and Ramsey-Musolf)

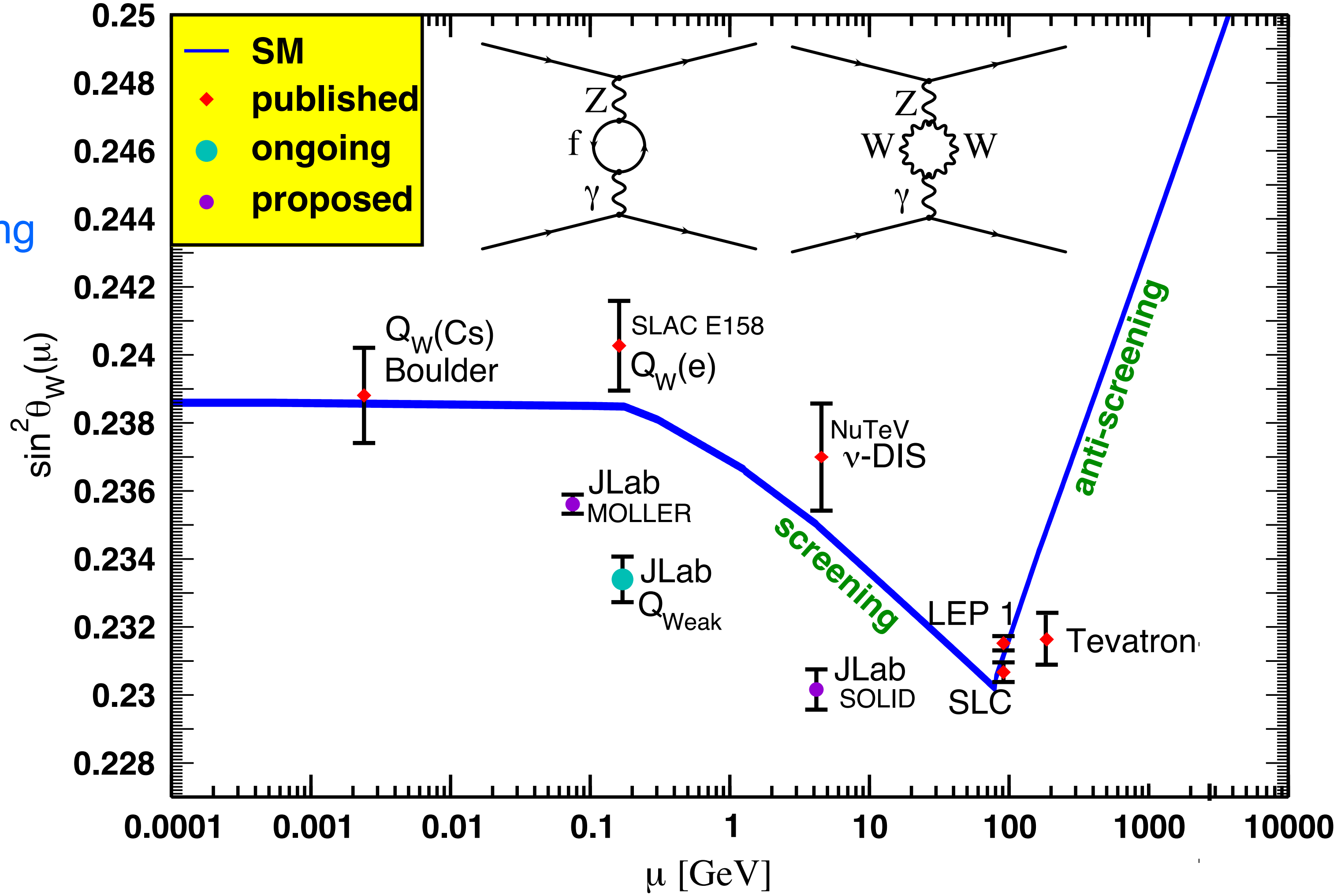
Since electron vertex must be vector, the Z' cannot couple to the C1q's if there is no electron coupling: can only affect C_{2q}'s

Complementary sensitivity to SUSY



Running of $\sin^2\theta_W$ Plot

Qweak decreasing



Jefferson Lab

Summary

- ✓ After more than a decade of effort, Jefferson Lab scientists have realized the completion of the Qweak experiment precision test of the SM.
  - **R. D. Carlini, G. Smith, D. Gaskell, D. Mack, S. Wood, B. Sawatzky, R. Michaels,**

    + ~90 collaborators, 24+ grad student & 10+ postdocs
- ✓ State-of-Art core technology in polarized beams, cryo-targets, precision control of beam properties, ultra-low noise electronics have been developed. All key to future precision PV and absolute cross-section measurements.
- ✓ Three cutting edge A' dark photon searches. Two of which are lead by Jlab scientists:
  - **B. Wojysekhowshi, Stepan Stepanyan**
- ✓ A next generation Moller experiment: An ultra-high precision test of the SM
  - **J. Gomez** (project manager) + many JLab staff scientists
- ✓ The next generation PVES experiment usind "SoLID" to measure the C_{2s}.