Atomic Parity Violation

(*History and Update*)

or

How Jon and I spent

Summer 1990 in Colorado

William J. Marciano

(April 1, 2011)

BROOKHAVEN
NATIONAL LABORATORY

Parity Violating Weak Neutral Currents

By 1975 the $SU(2)_L xU(1)_Y$ structure of the Glashow-Weinberg-Salam Model was nearly established. Predicted Weak Neutral Currents seen in neutrino scattering at CERN! But did the NC have the right coupling?

$$g/\cos\theta_W Z^\mu f \gamma_\mu (T_{3f} - 2Q_f \sin^2\theta_W - T_{3f}\gamma_5) f$$

θ_W=*Weak Mixing Angle*

A New Form of Parity Violation!

Non Maximal but Distinctive

γ-Z Interference → Parity Violation Everywhere!

Atomic Parity Violation (APV)

- **$Q_W(Z,N) = Z(1-4\sin^2\theta_W)-N$** Weak Charge

$Q_W(p)=1-4\sin^2\theta_W \approx 0.07$ Hydrogen

$Q_W(^{209}Bi_{83}) = -43 - 332\sin^2\theta_W \approx -\underline{127}$

Bi Much Larger but Complicated Atomic Physics

<u>Originally APV not seen in Bi (1977)→ SM Ruled Out?</u>

$-29 \leq Q_W(^{209}Bi_{83}) \leq 16$ (Washington)

$-20 \leq Q_W(^{209}Bi_{83}) \leq 74$ (Oxford)

Note $-230 \leq Q_W(^{209}Bi_{83}) \leq -87$ ***(Novosibirsk 1978)***

(Later APV clearly seen in Tl, Bi, **<u>Cs</u>**…)

But Meanwhile…

1978 SLAC Polarized eD Asymmetry (Prescott, Hughes…)

$e+D \rightarrow e+X$ γ-Z Interference

$A_{RL} = \sigma_R - \sigma_L / \sigma_R + \sigma_L \propto 2 \times 10^{-4} Q^2 \text{GeV}^{-2} (1 - 2.5 \sin^2\theta_W)$

$\sim 10^{-4}$ Expected

Exp. Gave $A_{RL}^{exp} = 1.5 \times 10^{-4} \rightarrow \sin^2\theta_W = \underline{0.21(2)}$

Confirmed $SU(2)_L \times U(1)_Y$ SM!

$\pm 10\%$ Determination of $\sin^2\theta_W$ Precision!

Major Discovery - Nobel Prize Material

- **L. Wolfenstein**: "*Eventually, Atomic Physicists will make extremely precise APV measurements*"

words of encouragement

- 1982-84 A. Sirlin and WJM calculate radiative corrections to atomic parity violation

Theoretically very clean

Precise Q_W Predictions! ±0.2%!

Wait for Experiment

Atomic Parity Violation Becomes Precise

1985-1988 $Q_W(Cs)^{exp}$=**-71.04(1.38)(0.88)**

C. Wieman et al. PRLs

Techniques developed later used to create Bose-Einstein Condensation → "Nobel Prize"!

Theory → $Q_W(Cs)^{SM}$ =**-73.20(13) very precise**

Good Agreement at ±2-3%

Snowmass, Colorado Summer 1990

- J. Rosner seminar on S, T & U parameters loop corrections of Peskin & Takeuchi

Emphasized the importance of

$S \approx +N_D/6\pi$ (N_D=# of heavy new doublets,

eg 4th generation$\rightarrow N_D=4$, $S=+0.2$)

Enhanced in Technicolor x 2 if QCD like

$S \approx 0.1 x N_{TC} x N_D$

Many doublets! $\rightarrow$ **$S \geq +2$** expected

Constraint from APV?

Following Week: Separate Seminars

- WJM Aspen Center for Physics
- J. Rosner Second Snowmass Talk

  (Carl Wieman in attendance)

Join Forces → Very Enjoyable & Productive Collaboration

Atomic Parity Violation Sensitive to S!

Essentially no T dependence! (α, G_μ & m_Z input)

$Q_W(Cs)=Q_W(Cs)^{SM}(1+0.011S)$

Experiment → $S=-2.7\pm2.0\pm1.1$

Was S really Negative? What did it mean?

Large N_{TC} & N_D Technicolor Unlikely - Ruled Out?

Supersymmetry ($S\approx0$) Wins by Default!

Spires: 367 citations (Famous but not Renowned)

VOLUME 65, NUMBER 24 PHYSICAL REVIEW LETTERS 10 DECEMBER 1990

Atomic Parity Violation as a Probe of New Physics

William J. Marciano
Physics Department, Brookhaven National Laboratory, Upton, New York 11973

Jonathan L. Rosner
Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637

(Received 30 August 1990)

Effects of physics beyond the standard model on electroweak observables are studied using the Peskin-Takeuchi isospin-conserving, S, and -breaking, T, parametrization of "new" quantum loop corrections. Experimental constraints on S and T are presented. Atomic parity-violating experiments are shown to be particularly sensitive to S with existing data giving $S = -2.7 \pm 2.0 \pm 1.1$. That constraint has important implications for generic technicolor models which predict $S \simeq 0.1 N_T N_D$ (N_T is the number of technicolors, N_D is the number of technidoublets).

If heavy $Z\chi$ boson of SO(10) exists

$$Q_W(Cs)=Q_W(Cs)^{SM}(1+0.011S-0.9(m_Z/m_{Z\chi})^2+\ldots)$$

Suggested $m_{Z\chi} \approx$ 500GeV

(positive evidence for $Z\chi$?) Jon likes Z' Bosons

We also pointed out that S could be precisely obtained from

$\alpha^{-1}=137.035999$, $G_\mu=1.1663788(7)\times10^{-5}\text{Gev}^{-2}$

+ m_W & $\sin^2\theta_W(m_Z)$

$$S \simeq 118\left[2\left(\frac{m_W-80.2\ \text{GeV}}{80.2\ \text{GeV}}\right)+\frac{\bar{x}-0.2323}{0.2323}\right]$$

Expected experiments to reach $S \approx \pm 0.2$

Precision measurements at the Z Pole
($e^+e^- \to Z \to f\bar{f}$)

Best Determinations:

$\sin^2\theta_W(m_Z)_{MS} = 0.23070(26)$ A_{LR} (SLAC)

$\sin^2\theta_W(m_Z)_{MS} = 0.23193(29)$ $A_{FB}(bb)$ (CERN)

(3.2 sigma difference!)

World Average: $\mathbf{\sin^2\theta_W(m_Z)_{MS} = 0.23125(16)}$

IS IT CORRECT?

(Major Implications)

α^{-1}=137.035999, G_μ=1.1663788(7)x$10^{-5}$$Gev^{-2}$, m_Z=91.1875GeV

+ ***m_W=80.398(25)GeV & $\sin^2\theta_W(m_Z)_{MS}$=0.23125(16)***

Implications: 114GeV<m_{Higgs}<150GeV.

New Physics Constraints From: m_W, $\sin^2\theta_W$, α,& G_μ

$S=N_D/6\pi$ =0.1±0.1, 4th generation→N_D=4→S=0.2 (tension)

m_{W^*}= Kaluza-Klein Mass (Extra Dimensions)>3TeV

	$\sin^2\theta_W(m_Z)_{MS}$	S	N_D&m_{W^*}
Average	0.23125(16)	+0.11(11)	2(2), m_{W^*}≥3TeV
A_{LR}	0.23070(26)	-0.18(15)	(SUSY)
A_{FB}(bb)	0.23193(29)	+0.46(17)	9(3)! Heavy Higgs, m_{W^*}~1-2TeV 4th generation…

Very Different Interpretations. We failed to nail $\sin^2\theta_W(m_Z)_{MS}$!

Atomic Exp. & Theory Improve

Currently: $Q_W(Cs)^{SM}$ =-73.16(3)

1990 $Q_W(Cs)^{exp}=-71.04(138)(88)_{ATh}$ C. Wieman et al.

1997 $Q_W(Cs)^{exp}=-72.11(27)(89)_{ATh}$ Better Experiment

*1999 $Q_W(Cs)^{exp}=-72.06(28)(34)_{ATh}$ Exp.→Better ATh

2008 $Q_W(Cs)^{exp}=-72.69(28)(39)_{ATh} \rightarrow \sin^2\theta_W(m_Z)_{MS}=0.2290(22)$

2009 $Q_W(Cs)^{exp}=\mathbf{-73.16(29)(20)}_{ATh} \rightarrow \sin^2\theta_W(m_Z)_{MS}=0.2312(16)!$

Porsey, Beloy & Derevianko PRL

±0.5% → Major Constraint On "New Physics"

$Q_W(Cs)=Q_W(Cs)^{SM}(1+0.011S-0.9(m_Z/m_{Z\chi})^2+\ldots)$

→ **S=0.0±0.4** $m_{Z\chi} \geq 1.2$TeV, leptoquark bounds, …

No Sign of "New Physics" Wait for the LHC!

Future Atomic Parity Violation?

- **Do several (strings of) isotopes (C. Wieman idea)**

  Ratios Independent of Atomic Theory

  (Idea championed by Jon)

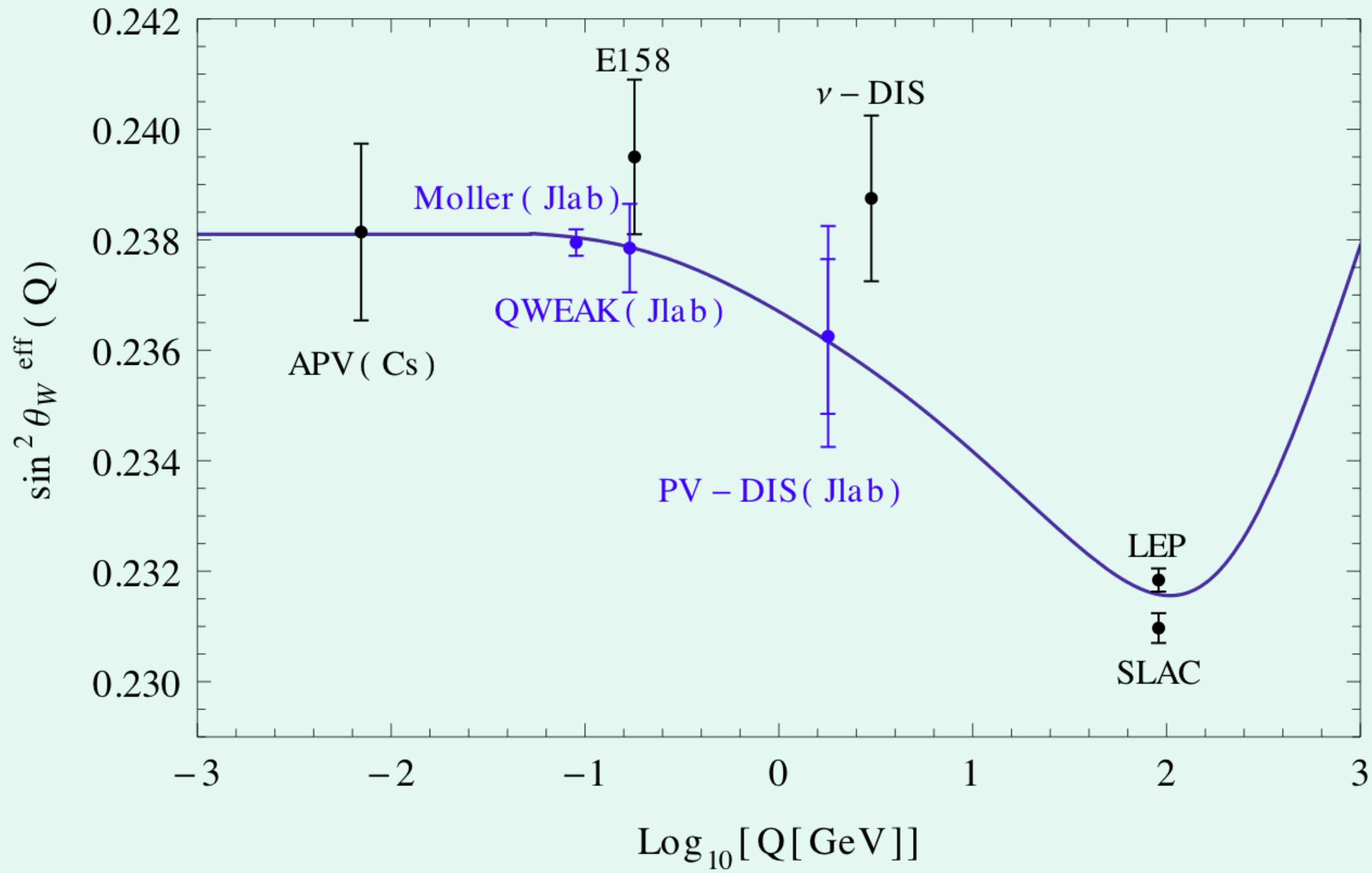
  Try Hydrogen Again? Challenging

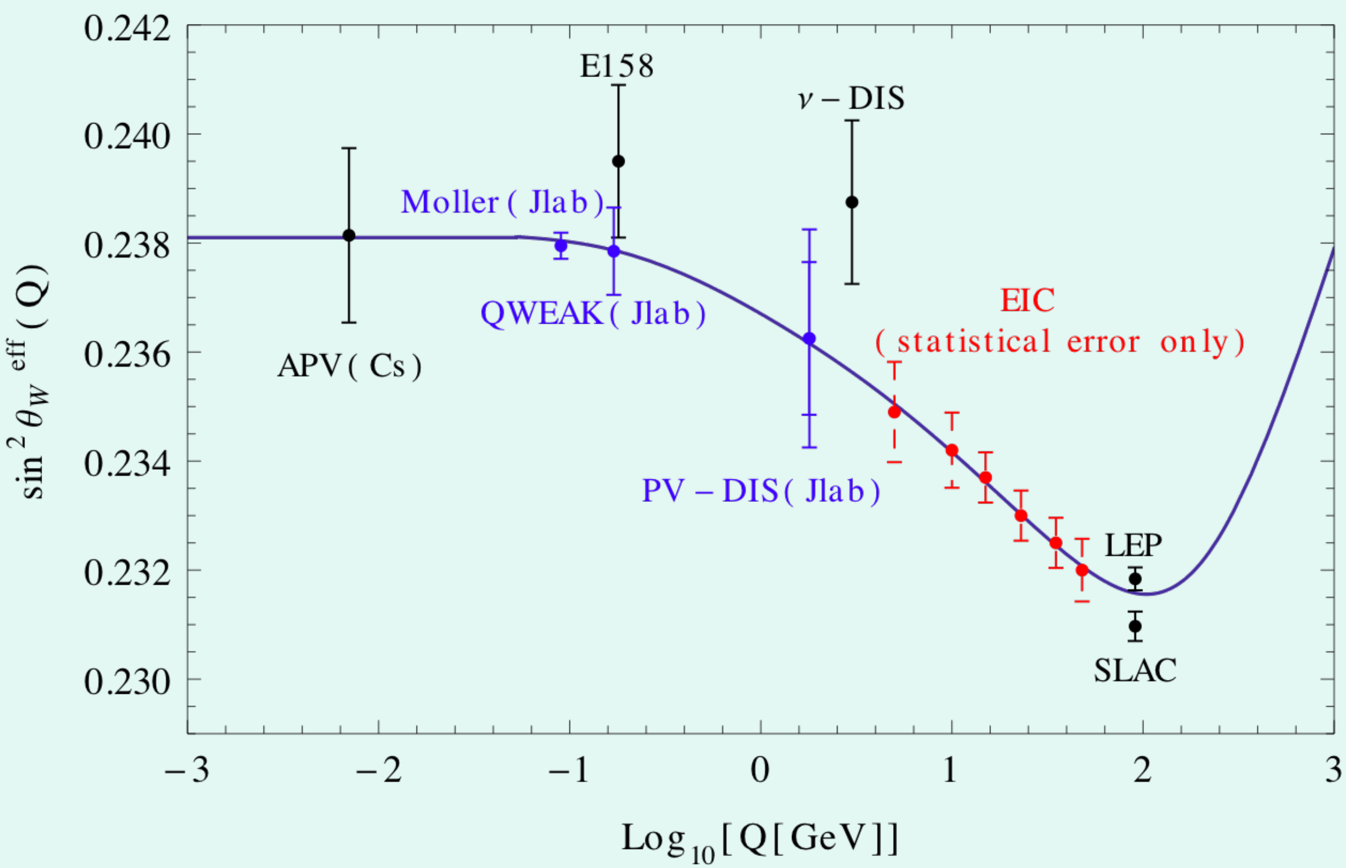
  (Q_W(p) better measured with elastic polarized ep scattering asymmetries – JLAB) (in Progress)

  Can low energy compete with Z pole studies?

  High vs Low Q^2 tests Running of $\sin^2\theta_W(Q)$

Running of $\sin^2\theta_W(Q)$ + future JLAB




0.242
0.240
0.238
0.236
0.234
0.232
0.230
$\sin^2\theta_W{}^{\rm eff}(Q)$
E158
ν – DIS
Moller (Jlab)
QWEAK (Jlab)
APV (Cs)
EIC
(statistical error only)
PV – DIS (Jlab)
LEP
SLAC
–3
–2
–1
0
1
2
3
$\mathrm{Log}_{10}[\mathrm{Q}[\mathrm{GeV}]]$

- *It was a pleasure to have crossed paths with Jon in Colorado*

We wrote a good/lasting paper

Shook up Technicolor

Participated in the Carl Wieman story

APV→Bose-Einstein Condensation

&

<u>Enjoyed Ourselves!</u>