Electroweak Physics
At
eRHIC

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BROOKHAVEN
NATIONAL LABORATORY

Physics Case

eRHIC will primarily be a Nuclear/QCD Facility

Structure functions (pol., PV)), small x gluons…

Properties of quarks in nuclei (EMC effects)…

Sum rules (Bj) etc, $\alpha(Q^2)_{QCD}$…

HERA(ep): $L \sim 10^{31} cm^{-2} s^{-1} \rightarrow 10^{33,34,35} cm^{-2} s^{-1}$

polarized e,p,D,^{3}He; Heavy Ions

What about Electroweak Physics?

Major Second Dedicated Detector?

Broadens & Complements Program!

JLAB Evolution

Fixed Target polarized ep, eN scattering

E_e=6GeV→12GeV→? $L\sim10^{38}cm^{-2}s^{-1}$!

Mainly QCD/Nuclear Physics

But Flagship A_{LR}: ep, ee, eD Experiments

Precision $\sin^2\theta_W$ and "New Physics" Effects

3 Dark Photon Searches

Future? Polarized ep, eD, e^3He, ***EIC***

Goal $L\sim10^{35}cm^{-2}s^{-1}$! High Q^2 (staged)

BNL/LDRD 2009-12

Electroweak Physics with an Electron-Ion Collider

(Deshpande, Kumar, Marciano, Vogelsang)

Postdoc: Yingchuan Li

DIS & Nuclear Structure Functions (γ,*Z,W*)

beyond HERA(ep) L~$10^{31}cm^{-2}s^{-1} \rightarrow 10^{33,34,35}cm^{-2}s^{-1}$

PV Structure Functions… (*see M. Stratmann talk*)

Polarized EMC, EW Bj Sum Rule

(Very Attractive Program)

- **A_{RL}, $sin^2\theta_W(Q^2)$ *running*, Radiative Corrections,**
  Probe "*New Physics*" *L~$10^{34}cm^{-2}s^{-1}$*
- Lepton Flavor Violation: eg ***ep*$\rightarrow\tau$*X*** (≥100fb^{-1})
  Leptoquark Sensitivity (100-1000 x better than HERA)

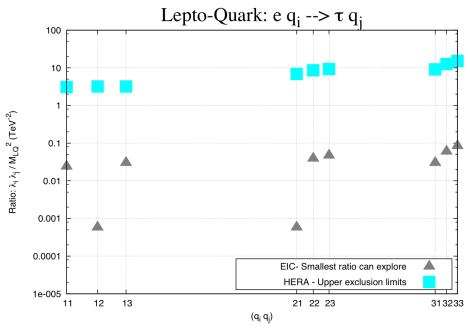
Search for Leptoquarks at EIC: A feasibility study

C. Faroughy, S.Taneja, A. Deshpande
Stony Brook University

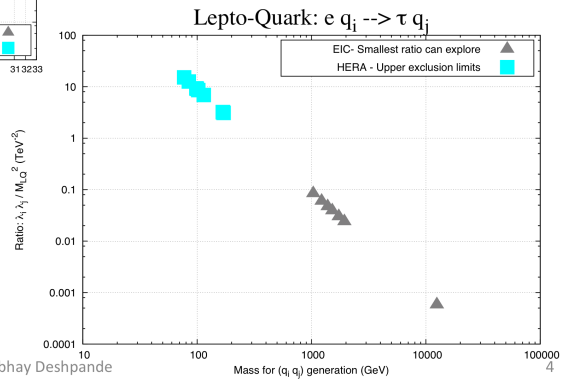
Much Input and help from:
M. Gonderinger, M. Ramsey-Musolf
University of Wisconsin

K. Kumar
U. Of Mass at Amherst

How does this compare with HERA?



Private communications: M. Gonderinger



Various Issues That Need Thorough Study

What are the Machine and Detector Requirements?

Inclusion of Electroweak Radiative Corrections

Weak Ampitudes Squared vs Photon-Z Interference

High Precision & Polarization(±0.5%?, ±0.25%?)

Proton, D, ^{3}HE Polarization (Spin Content-Other?)

. **$\sin^2\theta_W(Q^2)$ Collider Requirements**

Utility of Both Beams Polarized **?**

WEAK NC PARITY VIOLATION

- **1978 SLAC Polarized eD Asymmetry (Prescott, Hughes…)**
  e+D→e+X γ-Z Interference

$A_{RL} = \sigma_R - \sigma_L / \sigma_R + \sigma_L \propto 2x10^{-4} Q^2 GeV^{-2}(1-2.5\sin^2\theta_W) \sim 10^{-4}$ Expected

Exp. Gave $A_{RL}^{exp} = 1.5x10^{-4} \rightarrow \sin^2\theta_W = 0.21(2)$

Atomic Parity Violation (APV)

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

θ_W=Weak Mixing Angle

$Q_W(Cs)^{exp}$=**-73.16(28)(20)**$\rightarrow \sin^2\theta_W(m_Z)_{MS}$=0.2312(16)

$\sin^2\theta_W(0)$ = 0.2387(16) (runs ~3%)

$\sin^2\theta_W(Q^2)$ = Physical Running Angle

Incorporates γZ mixing loops: quarks, leptons, $W^{\pm}$

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Precision measurements at the Z Pole ($e^+e^- \rightarrow Z \rightarrow ff$)

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!)

Leptonic vs Hadronic Z Pole Averages

$\sin^2\theta_W(m_Z)_{MS} = 0.23085(21)$ Leptonic

$\sin^2\theta_W(m_Z)_{MS} = 0.23194(27)$ Hadronic

(Also differ by > 3sigma)

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

IS IT CORRECT?

(Major Implications)

$\alpha^{-1}=137.035999$, $G_\mu=1.1663788(7)\times10^{-5}\text{Gev}^{-2}$, $m_Z=91.1875\text{GeV}$
+ $m_W=80.398(25)\text{GeV}\rightarrow\sin^2\theta_W(m_Z)$ = <u>0.23104(15)</u>

<u>Implications</u>: $114\text{GeV}<m_{\text{Higgs}}<150\text{GeV}$.
New Physics Constraints From: m_W, $\sin^2\theta_W$, α,& G_μ
$S=N_D/6\pi$ (N_D=# of heavy new doublets, eg 4th generation$\rightarrow N_D=4$)
m_{W^*}= Kaluza-Klein Mass (Extra Dimensions)
$G_\mu\rightarrow G_\mu(1+0.0085S+O(1)(m_W/m_{W^*})^2+\ldots)$

	$\sin^2\theta_W(m_Z)_{MS}$	S	N_D&m_{W^*}
<u>Average</u>	0.23125(16)	+0.11(11)	2(2), $m_{W^*}\geq3\text{TeV}$
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
			Fourth Generation…

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

E158 at SLAC Pol ee→ee Moller)

$E_e \approx 50$GeV on fixed target, $Q^2=0.02\text{GeV}^2$

$A_{LR}(ee)=-131(14)(10)\times10^{-9}\ \alpha\ (1-4\sin^2\theta_W)$

Measured to ±12% $\rightarrow \sin^2\theta_W$ to ±0.6%

$\rightarrow \sin^2\theta_W(m_Z)_{MS}=$0.2329(13) slightly high

Best Low Q^2 Determination of $\sin^2\theta_W$

$A_{LR}(ee)^{exp}=A_{LR}(ee)^{SM}(1+0.13T-0.20S+7(m_Z/m_{Z\chi})^2\ldots)$

Constrains "New Physics" eq $m_{Z\chi}>0.6$TeV, H^{--},S, Anapole Moment, …

Together APV(Cs) & E158→ $\sin^2\theta_W(Q^2)$ running (6 sigma)

$\sin^2\theta_W(m_Z)_{MS}=$0.2320(10) about ±0.5%

Goals of Future Experiments

- Several High Precision: $\Delta\sin^2\theta_W \sim 0.0004$ or better
- Compare High and Low Q^2
- Different Q^2 Sensitivity to "New Physics"

  $m_{Z'}$ >1TeV, SUSY Loops, 4th Generation….

Absolute measurement of $\sin^2\theta_W(m_Z)_{ave} = \pm 0.00008!$

Vs G_F, α, m_Z & m_W ➔ $|\Delta S| < \pm 0.05$

Extra Dim.,≈ 5TeV

Complements LHC

Future Efforts

QWEAK exp at JLAB

Will measure forward $A_{LR}(ep \rightarrow ep) \alpha (1-4\sin^2\theta_W)=Q_W(p)$

$E=1.1GeV$, $Q^2 \approx 0.03GeV^2$, $Pol=0.80 \pm 1\% \rightarrow A_{RL}(ep) \approx 3x10^{-7}$

small A_{RL} requires long running

Goal $\Delta\sin^2\theta_W(m_Z)_{MS}=0.0008$ via ±4% measurement of A_{LR}

Will be best low energy measurement of $\sin^2\theta_W$

$A_{LR}(ep)^{exp}=A_{LR}(ep)^{SM}(1+4(m_Z/m_{Z\chi})^2+\ldots)$

eg $m_{z\chi}$~0.9TeV Sensitivity (Not as good as APV)

Mainz ERL at E≈0.1GeV $\Delta\sin^2\theta_W(m_Z)_{MS}=0.0002!$

Other Future Efforts: Polarized **Moller** at JLAB

After 12GeV Upgrade

$A_{LR}(ee \rightarrow ee)$ to ±2.5%

$\Delta \sin^2\theta_W(m_Z)_{MS} = \pm 0.00025$!

Comparable to Z pole studies!

$A_{LR}(ee)^{exp} = A_{LR}(ee)^{SM}(1+7(m_Z/m_{Z\chi})^2+\ldots)$

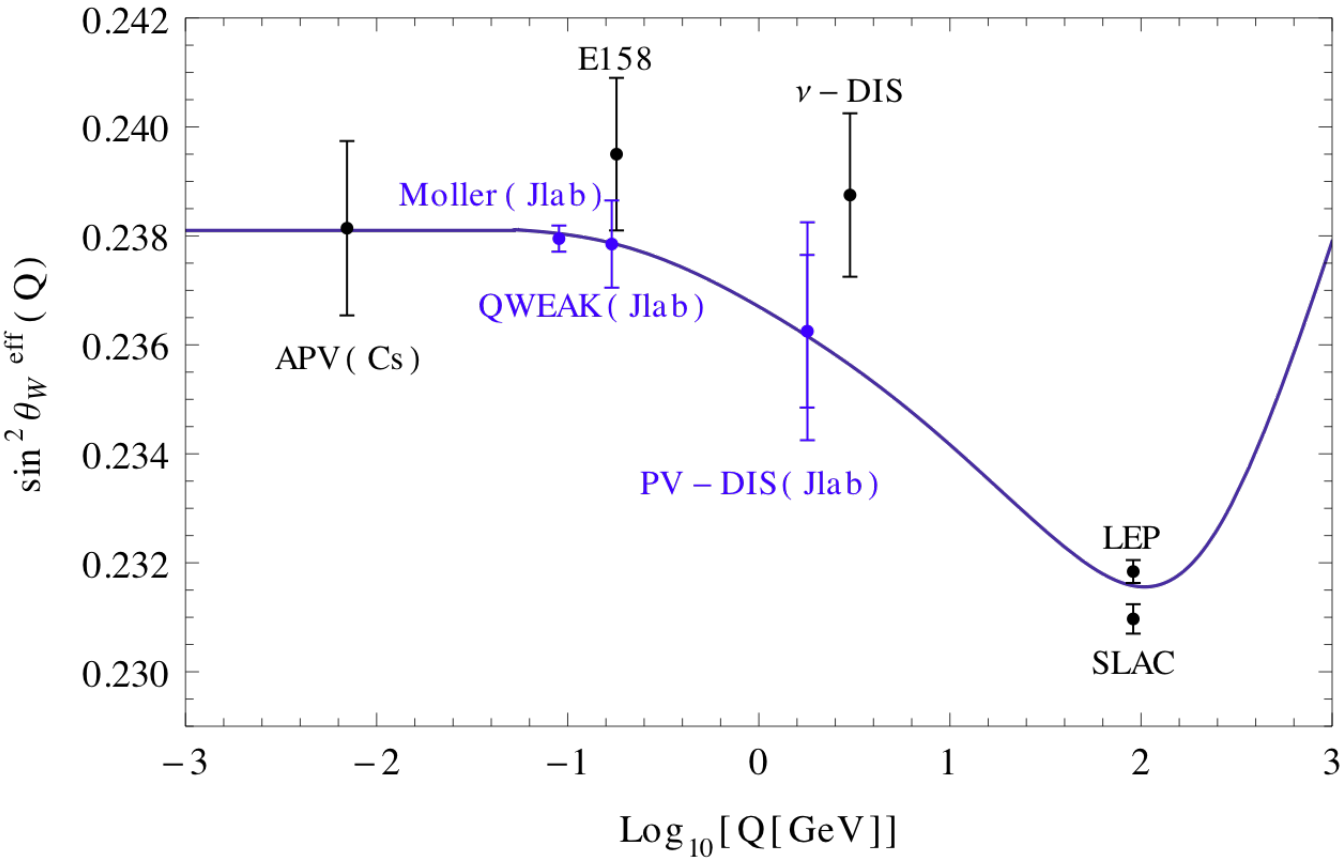
Explores $m_{Z\chi} \rightarrow 1.5$TeV Better than APV, S~0.1 etc.

Future JLAB Flagship Experiment!

Very Hard To Do Better!

ep Collider Goal: ±0.2% Better?

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



- $H_{PV}=G_\mu/\sqrt{2}[(C_{1u}u\gamma^\nu u+C_{1d}d\gamma^\nu d)e\gamma_\nu\gamma_5 e+$
  $(C_{2u}u\gamma^\nu\gamma_5 u+C_{2d}d\gamma^\nu\gamma_5 d)e\gamma_\nu e+\ldots]$

$Q_W(p)=2(2C_{1u}+C_{1d})$

$Q_W(Cs)=2(188C_{1u}+211C_{1d})$

Not renormalized by strong interactions at Q=0

What about the C_{2q}? Strongly renormalized at Q=0

Measure at high Q^2 EIC DIS Clean

C_{2q} small in SM ➔Sensitive to “New Physics”

What About C_{2u} and C_{2d}?

- Renormalized at low Q^2 by Strong Interactions

Measure in Deep-Inelastic Scattering (DIS), eD & ep

$A_{RL}(eD \rightarrow eX) \propto 2x10^{-4} GeV^{-2} Q^2 [(C_{1u} - C_{1d}/2) + f(y)(C_{2u} - C_{2d}/2)]$

$f(y) = [1-(1-y)^2]/[1+(1-y)^2]$

Standard Model: $C_{1u} = (1-8\sin^2\theta_W/3)/2 \approx 0.20$ Hadronic

$C_{1d} = -(1-4\sin^2\theta_W/3)/2 \approx -0.32$ Hadronic

$C_{2u} = (1-4\sin^2\theta_W)/2 \approx 0.04$ Leptonic

$C_{2d} = -(1-4\sin^2\theta_W)/2 \approx -0.04$ Leptonic

C_{2q} sensitive to RC & "New Physics" eg $Z\chi$ (SO(10))

Measure A_{RL} to ±1/2%?

Measure C_{2q} to ±1-2%?

JLAB 6 GeV DIS eD→eX Proceeding

JLAB 12 GeV DIS eD Future

Goals: Measure C_{2q}s, "New Physics", Charge Sym. Violation …

Effective Luminosity (Fixed Target) $10^{38}cm^{-2}sec^{-1}$!

What can ep and eD at e-Ion contribute?

Asymmetry F.O,M,~A^2N, $A \propto Q^2$, $N \propto 1/Q^2$ (acceptance?)

High Q^2 Better (but Collider Luminosity?)

→100fb^{-1} ($L \sim 10^{34}cm^{-2}s^{-1}$) Needed

Program can be started with lower luminosity

Do DIS ep, eD, eN at factor of 10 lower

(Polarized p & Nuclei)→Bjorken Sum Rule, Pol Structure Functions, Spin Distribution…

Single and Double Polarization Asymmetries

Polarized e: $A^e_{RL}=(\sigma_{RR}+\sigma_{RL}-\sigma_{LL}-\sigma_{LR})/(\sigma_{RR}+\sigma_{RL}+\sigma_{LL}+\sigma_{LR})\propto P_e$

Polarized p: $A^p_{RL}=(\sigma_{RR}+\sigma_{LR}-\sigma_{RL}-\sigma_{LL})/(\sigma_{RR}+\sigma_{LR}+\sigma_{RL}+\sigma_{LL})\propto P_p$

Polarized e&p $A^{ep}_{RRLL}= (\sigma_{RR}-\sigma_{LL})/(\sigma_{RR}+\sigma_{LL})\propto P_{eff}$

$P_{eff}=(P_e-P_p)/(1-P_eP_p)$ opposite signs

like relativistic velocities addition≤1

eg $P_e=0.8\pm0.008$, $P_p=-0.7\pm0.03 \rightarrow P_{eff}=0.962\pm0.004$

small uncertainty

How to best utilize P_{eff}?

Measure: $\sigma_{RR},\sigma_{LL},\sigma_{RL},\sigma_{LR}$ Fit → Polarization Dist.

Example: Polarized Protons or Deuterons

(Unpolarized Electrons)

$C_{1q} \Leftrightarrow C_{2q} \propto (1\text{-}4\sin^2\theta_W)$

Use to measure $\sin^2\theta_W$?

Poster for Electroweak Physics at eRHIC

based of Y. Li calculation

Polarized ep or eD at $(s)^{1/2} \approx 140$GeV

Running of $\sin^2\theta_W(Q)$ & eRHIC [Y. Li]