Weak Mixing Angle at Electron-Ion Collider

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Outline

• Introduction

• Prospects of measuring weak mixing angle at EIC

• Conclusion
EW symmetry breaking: still a big puzzle!

- So many models:
  - Fundamental Higgs: SUSY, Extra Dim., RS...
  - Higgsless: Technicolor
  - Composite Higgs: Georgi-Kaplan model, Little Higgs, Gauge-Higgs Unification

Hungary for Experimental Data!
To ping down the EW symmetry breaking

• Direct search at high energy collider
  ➢ SM Higgs; ➢ SUSY particles; ➢ KK modes; ➢ other exotics;

  Major motivation for LHC!

• Indirect searchs via precision electroweak
  ➢ Play important role in the establishment of SM;
  ➢ Vital role in the establishment of the next model;

What can EIC do on this?
The hunt for $\sin^2 \theta_W$

- **Prediction within SM**

\[
\sin^2 \theta_W (M_Z)_{ms} = \frac{4\pi\alpha}{\sqrt{2}G_\mu M_Z^2 [1 - \Delta r(M_H)]}
\]

- **Z-pole measurements:**

  - **SLAC**: $\sin^2 \theta_W (M_Z)_{ms} = 0.23070(26)$
  - **CERN**: $\sin^2 \theta_W (M_Z)_{ms} = 0.23193(29)$

  - **World Average**: $\sin^2 \theta_W (M_Z)_{ms} = 0.23125(16)$

  3 sigma difference!

Correct?
The implications of $\sin^2 \theta_W$

- **World average**: $\sin^2 \theta_W (M_Z)_{ms} = 0.23125(16)$

  - $M_H = 85^{+39}_{-28}$ GeV;
  - $S = -0.13(10)$

  - Consistent with LEP bound (MH>114 GeV)
  - Suggestive for SUSY (MH<135 GeV)
  - Rule out most technicolor models

Satisfied and happy?
The implications of $\sin^2 \theta_W$

- **SLAC result:**
  \[ \sin^2 \theta_W (M_Z)_{ms} = 0.23070(26) + m_W=80.398(25) \text{ GeV} \]
  \[ M_H = 30^{+33}_{-18} \text{ GeV}; \quad S \approx -0.12 \]
  - Ruled out by LEP bound (MH>114 GeV)
  - Suggestive for SUSY

- **CERN result:**
  \[ \sin^2 \theta_W (M_Z)_{ms} = 0.23193(29) + m_W=80.398(25) \text{ GeV} \]
  \[ M_H = 450^{+300}_{-190} \text{ GeV}; \quad S \approx 0.45 \]
  - Consistent with LEP bound (MH>114 GeV)
  - Suggestive for technicolor models

Very different implication! We failed to nail weak mixing angle!
Past and currently planned experiments:

Where does EIC stand?
Weak mixing at EIC

• The good:
  - Both beam polarized;
  - High energy:
    higher asymmetry, wide coverage of $Q$.

• The bad:
  - Low luminosity ($10^{33,34,35}$ cm$^{-2}$ sec$^{-1}$) compared to fixed target experiments;

• The ugly:
  - Large uncertainty (5%) with the hadron beam polarization;
  - Large uncertainty with the polarized PDFs;
Weak mixing at EIC

• What are the good asymmetries?

• How to control the systematic error?

• What is the statistical error with reasonable luminosity?
Single-spin asym. with polarized electron

For ep-DIS:

\[
A_{ep}^e \equiv \frac{d\bar{\sigma}(P_e, P_p = 0) - d\bar{\sigma}(-P_e, P_p = 0)}{d\bar{\sigma}(P_e, P_p = 0) + d\bar{\sigma}(-P_e, P_p = 0)} = P_e \frac{\sum_i f_i(x) [(d\sigma_{RR}^i - d\sigma_{LL}^i) + (d\sigma_{RL}^i - d\sigma_{LR}^i)]}{\sum_i f_i(x) [(d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i)]}
\]

Simplified for ed-DIS: PDF drops out for isosinglet

\[
A_{ed}^e|_{x>0.2} \equiv \frac{d\bar{\sigma}(P_e, P_d = 0) - d\bar{\sigma}(-P_e, P_d = 0)}{d\bar{\sigma}(P_e, P_d = 0) + d\bar{\sigma}(-P_e, P_d = 0)} = P_e \frac{\sum_i [(d\sigma_{RR}^i - d\sigma_{LL}^i) + (d\sigma_{RL}^i - d\sigma_{LR}^i)]}{\sum_i [(d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i)]}
\]
Single-spin asym. with polarized hadron

For ep-DIS:

\[ A_{ep}^p \equiv \frac{d\bar{\sigma}(P_e = 0, P_p) - d\bar{\sigma}(P_e = 0, -P_p)}{d\bar{\sigma}(P_e = 0, P_p) + d\bar{\sigma}(P_e = 0, -P_p)} = \frac{\Sigma_i \Delta f_i(x) \left[ (d\sigma_{RR}^i - d\sigma_{LL}^i) - (d\sigma_{RL}^i - d\sigma_{LR}^i) \right]}{\Sigma_i f_i(x) \left[ (d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i) \right]} \]

For ed-DIS:

\[ A_{ed}^d|_{x > 0.2} \equiv \frac{d\bar{\sigma}(P_e = 0, P_d) - d\bar{\sigma}(P_e = 0, -P_d)}{d\bar{\sigma}(P_e = 0, P_d) + d\bar{\sigma}(P_e = 0, -P_d)} = \frac{\tilde{f}_D P_d \Sigma_i \left[ (d\sigma_{RR}^i - d\sigma_{LL}^i) - (d\sigma_{RL}^i - d\sigma_{LR}^i) \right]}{\Sigma_i \left[ (d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i) \right]} \]

Large uncertainty with hadron polarization and polarized PDF
Effective polarization:
the trick learned from Moller scattering

- Take advantage of effective polarization:

\[ P_{\text{eff.}} = \frac{P_e + \tilde{f}(x)P_d}{1 + \tilde{f}(x)P_eP_d} \]

\[ p_e = 0.8(1 \pm 0.5\%), \quad p_d = 0.7(1 \pm 5\%), \quad \tilde{f}^D = 0.5(1 \pm 5\%) \]

\[ \tilde{f}^Dp_d = 0.35(1 \pm 7\%) \]

\[ p_{\text{eff.}} = 0.9(1 \pm 0.64\%) \]
Double-spin asymmetry:

\[ A_{ep,ed}^{\pm} \equiv \frac{d\tilde{\sigma}(P_e, P_{p,d}) - d\tilde{\sigma}(-P_e, -P_{p,d})}{d\tilde{\sigma}(P_e, P_{p,d}) + d\tilde{\sigma}(-P_e, -P_{p,d})} \]

\[ = \frac{\Sigma_i f_i(x) \left\{ (P_e + \tilde{f}_i(x) P_{p,d})(d\sigma_{RR}^i - d\sigma_{LL}^i) + (P_e - \tilde{f}_i(x) P_{p,d})(d\sigma_{RL}^i - d\sigma_{LR}^i) \right\}}{\Sigma_i f_i(x) \left\{ (1 + \tilde{f}_i(x) P_e P_{p,d})(d\sigma_{RR}^i + d\sigma_{LL}^i) + (1 - \tilde{f}_i(x) P_e P_{p,d})(d\sigma_{RL}^i + d\sigma_{LR}^i) \right\}} \]

Simplified for e-d at kinematic region with \( y \rightarrow 1 \):

\[ A_{ed}^{ed}|_{y \rightarrow 1, x > 0.2} \approx P_{\text{eff}} \cdot \frac{\Sigma_i (d\sigma_{RR}^i - d\sigma_{LL}^i)}{\Sigma_i (d\sigma_{RR}^i + d\sigma_{LL}^i)} \]
Good asymmetries

- **e-p collider:**

\[ A_{ep}^e(x) = p_e \frac{\Sigma_i f_i(x) [(d\sigma_{RR}^i - d\sigma_{LL}^i) + (d\sigma_{RL}^i - d\sigma_{LR}^i)]}{\Sigma_i f_i(x) [(d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i)]} \]

- **e-d collider:**

\[ A_{ed}^e(x) = p_e \frac{\Sigma_i [(d\sigma_{RR}^i - d\sigma_{LL}^i) + (d\sigma_{RL}^i - d\sigma_{LR}^i)]}{\Sigma_i [(d\sigma_{RR}^i + d\sigma_{LL}^i) + (d\sigma_{RL}^i + d\sigma_{LR}^i)]} \]

\[ A_{ed}^{ed}|_{y\rightarrow1,x>0.2} \approx P_{\text{eff}} \frac{\Sigma_i (d\sigma_{RR}^i - d\sigma_{LL}^i)}{\Sigma_i (d\sigma_{RR}^i + d\sigma_{LL}^i)} \]
Monte Carlo simulation: asymmetries

- single-spin asymmetry in ed-DIS:
Monte Carlo simulation: Figure of merit

- Figure of merit for ed-DIS:
Monte Carlo simulation: statistical error

- Statistical error for ed-DIS:

\[ \Delta A_{e}^{d}/A_{e}^{d} \]

\(\text{ed-DIS, } \sqrt{s} = 140 \text{ GeV, } P_{e} = 0.8, x > 0.2, L = 200 \text{ fb}^{-1}\)
Past, currently planed, and EIC experiments:

- Weak mixing probed at wide range of $Q$ at EIC:
Summary

• Precision tests are very important probe of BSM complementary to LHC.

• It is highly desirable to have another experiment on weak mixing angle given the 3 sigma difference in two Z-pole experiments.

• EIC has good chance to measure $\sin^2 \theta_W$ over a wide range of Q with statistical error similar to Z-pole experiments.

Thank you !!!