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

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

- Z-pole measurements:

$$\text{SLAC}: \quad \sin^2\theta_W(M_Z)_{\overline{ms}} = 0.23070(26)$$

$$\text{CERN}: \quad \sin^2\theta_W(M_Z)_{\overline{ms}} = 0.23193(29)$$

3 sigma difference!

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

Correct?

The implications of $\sin^2\theta_W$

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

$M_H = 85^{+39}_{-28}$ 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: $\sin^2\theta_W(M_Z)_{\overline{ms}} = 0.23070(26)$ + m_W=80.398(25) GeV

$M_H = 30^{+33}_{-18}$ GeV; → Ruled out by LEP bound (MH>114 GeV)

$S \approx -0.12$ → Suggestive for SUSY

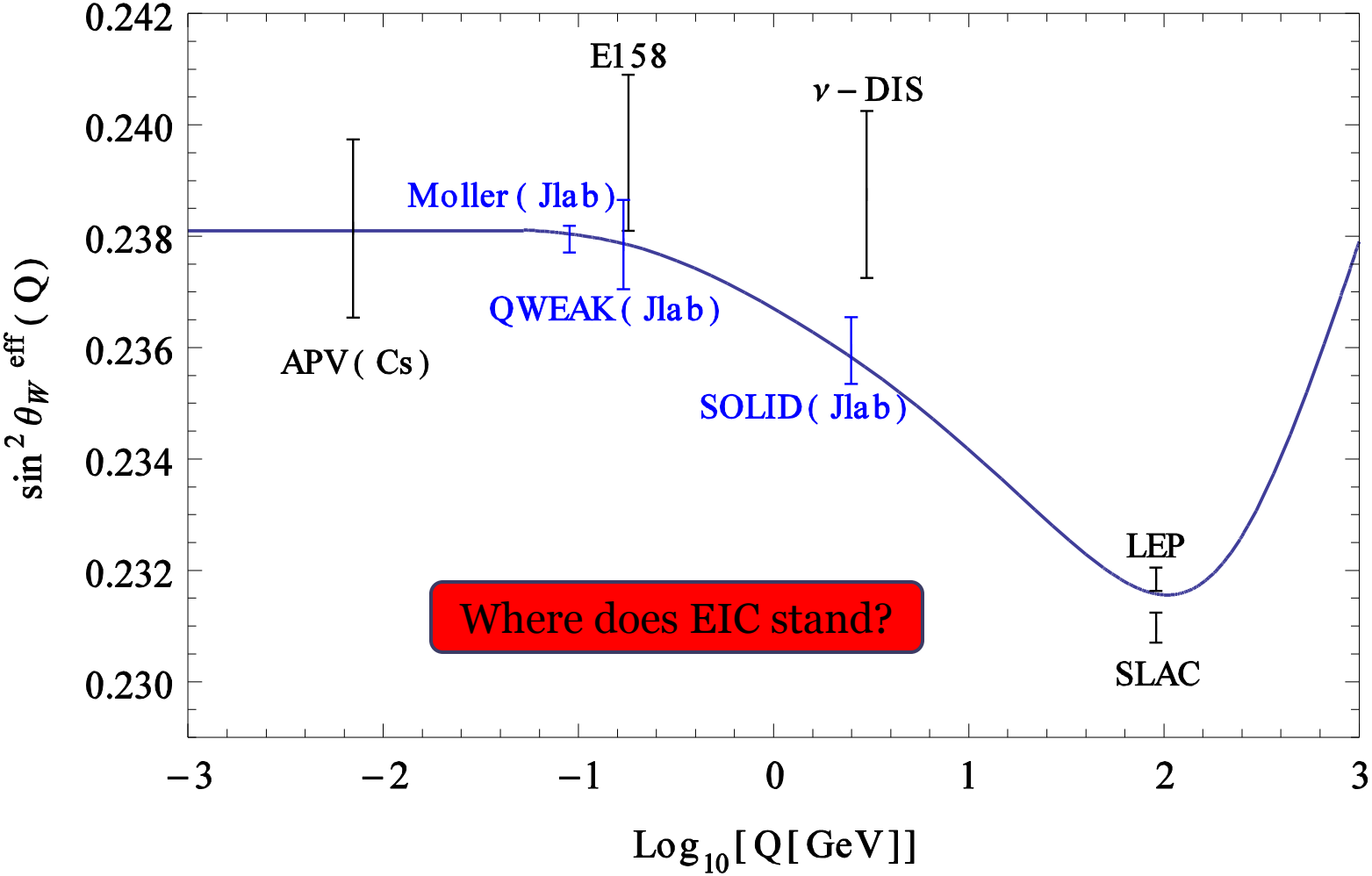
- CERN result: $\sin^2\theta_W(M_Z)_{\overline{ms}} = 0.23193(29)$ + m_W=80.398(25) GeV

$M_H = 450^{+300}_{-190}$ GeV; → Consistent with LEP bound (MH>114 GeV)

$S \approx 0.45$ → Suggestive for technicolor models

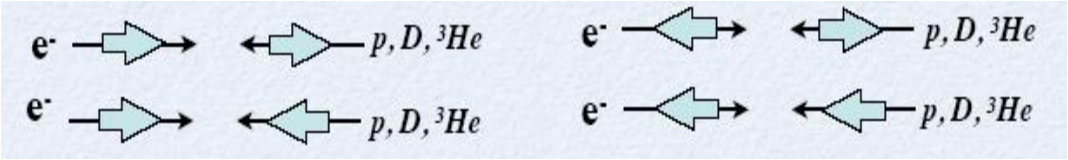
Very different implication! We failed to nail weak mixing angle!

Past and currently planed experiments:



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 asy. with polarized electron

- For ep-DIS:

$$A^e_{ep} \equiv \frac{d\bar{\sigma}(P_e, P_p = 0) - d\bar{\sigma}(-P_e, P_p = 0)}{d\bar{\sigma}(P_e, P_p = 0) + d\bar{\sigma}(-P_e, P_p = 0)}$$
$$= P_e \frac{\Sigma_i f_i(x) \left[(d\sigma^i_{RR} - d\sigma^i_{LL}) + (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i f_i(x) \left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

- Simplified for ed-DIS:

PDF drops out for isosinglet

$$A^e_{ed}|_{x>0.2} \equiv \frac{d\bar{\sigma}(P_e, P_d = 0) - d\bar{\sigma}(-P_e, P_d = 0)}{d\bar{\sigma}(P_e, P_d = 0) + d\bar{\sigma}(-P_e, P_d = 0)}$$
$$= P_e \frac{\Sigma_i \left[(d\sigma^i_{RR} - d\sigma^i_{LL}) + (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i \left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

Single-spin asy. with polarized hadron

- For ep-DIS:

$$A^p_{ep} \equiv \frac{d\bar{\sigma}(P_e=0,P_p) - d\bar{\sigma}(P_e=0,-P_p)}{d\bar{\sigma}(P_e=0,P_p) + d\bar{\sigma}(P_e=0,-P_p)}$$
$$= P_p \frac{\Sigma_i \Delta f_i(x) \left[(d\sigma^i_{RR} - d\sigma^i_{LL}) - (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i f_i(x) \left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

- For ed-DIS:

$$A^d_{ed}|_{x>0.2} \equiv \frac{d\bar{\sigma}(P_e=0,P_d) - d\bar{\sigma}(P_e=0,-P_d)}{d\bar{\sigma}(P_e=0,P_d) + d\bar{\sigma}(P_e=0,-P_d)}$$
$$= \tilde{f}^D P_d \frac{\Sigma_i \left[(d\sigma^i_{RR} - d\sigma^i_{LL}) - (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i \left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

Large uncertainty with hadron polarization and polarized PDF

Effective polarization: the trick learned from Moller scattering

- Take advantage of effective polarization:

$$P_{\text{eff.}} \equiv \frac{P_e + \tilde{f}(x) P_d}{1 + \tilde{f}(x) P_e P_d}$$

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

$$\tilde{f}^D p_d = 0.35(1 \pm 7\%)$$

$$p_{eff.} = 0.9(1 \pm 0.64\%)$$

Double-spin asymmetry

- Double-spin asymmetry:

$$A_{ep,ed}^{ep,ed} \equiv \frac{d\bar{\sigma}(P_e, P_{p,d}) - d\bar{\sigma}(-P_e, -P_{p,d})}{d\bar{\sigma}(P_e, P_{p,d}) + d\bar{\sigma}(-P_e, -P_{p,d})}$$

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

- Simplified for e-d at kinematic region with y->1:

$$A_{ed}^{ed}|_{y\to 1, x>0.2} \approx P_{\text{eff.}} \frac{\Sigma_i(d\sigma_{RR}^i - d\sigma_{LL}^i)}{\Sigma_i(d\sigma_{RR}^i + d\sigma_{LL}^i)}$$

Good asymmetries

- e-p collider:

$$A^e_{ep}(x) = p_e \frac{\Sigma_i f_i(x)\left[(d\sigma^i_{RR} - d\sigma^i_{LL}) + (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i f_i(x)\left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

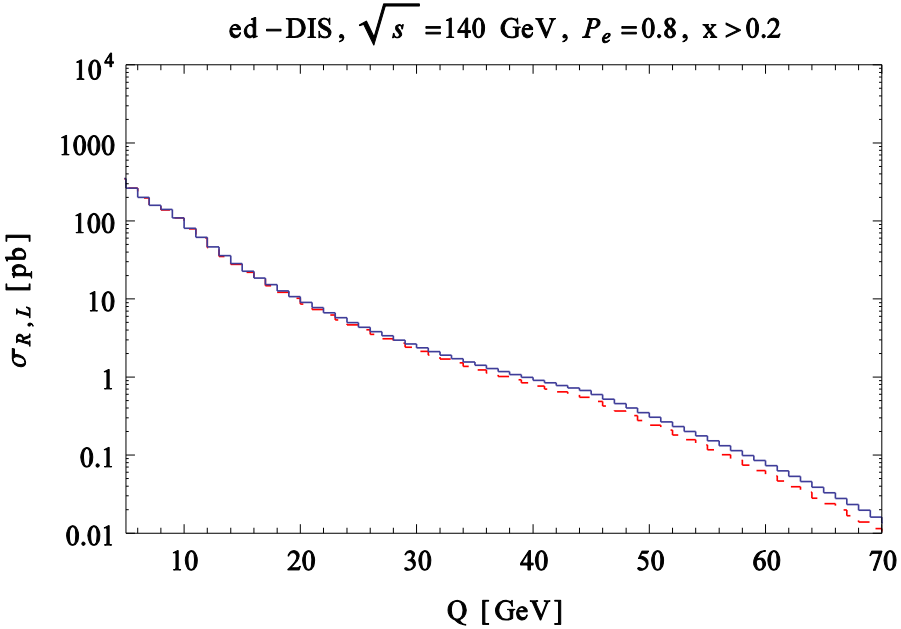
- e-d collider:

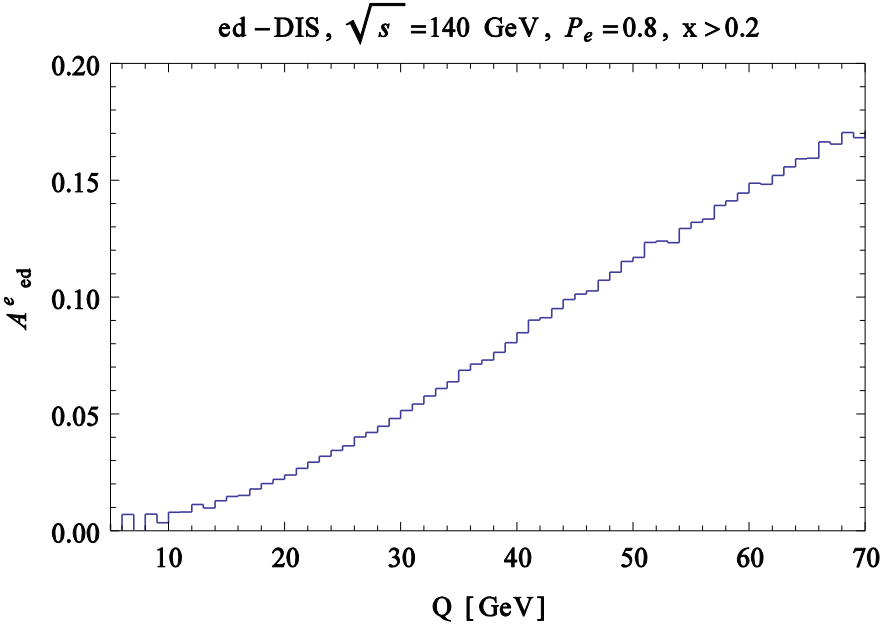
$$A^e_{ed}(x) = p_e \frac{\Sigma_i \left[(d\sigma^i_{RR} - d\sigma^i_{LL}) + (d\sigma^i_{RL} - d\sigma^i_{LR})\right]}{\Sigma_i \left[(d\sigma^i_{RR} + d\sigma^i_{LL}) + (d\sigma^i_{RL} + d\sigma^i_{LR})\right]}$$

$$A^{ed}_{ed}|_{y\to 1, x>0.2} \approx P_{\text{eff.}} \frac{\Sigma_i (d\sigma^i_{RR} - d\sigma^i_{LL})}{\Sigma_i (d\sigma^i_{RR} + d\sigma^i_{LL})}$$

Monte Carlo simulation: asymmetries

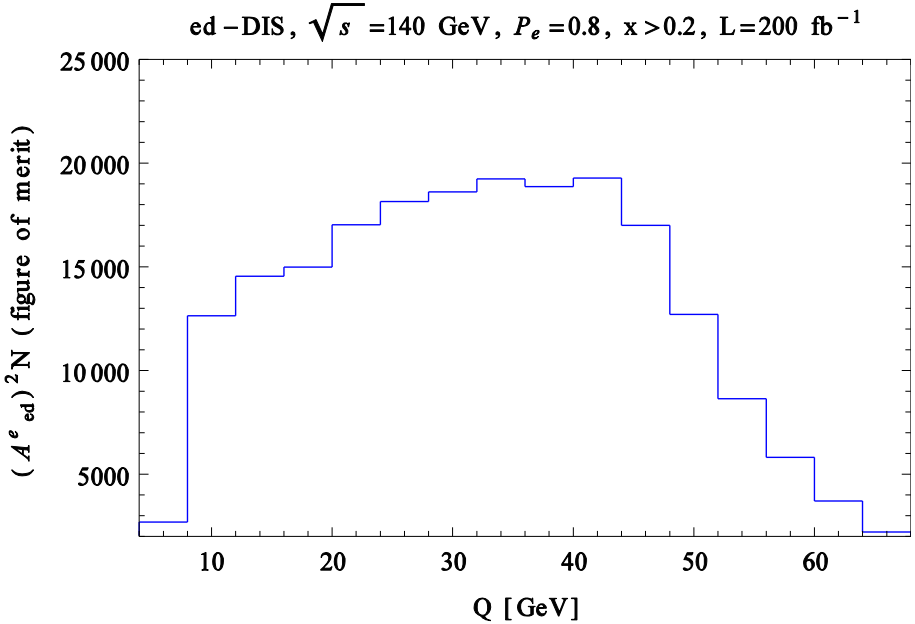
- single-spin asymmetry in ed-DIS:

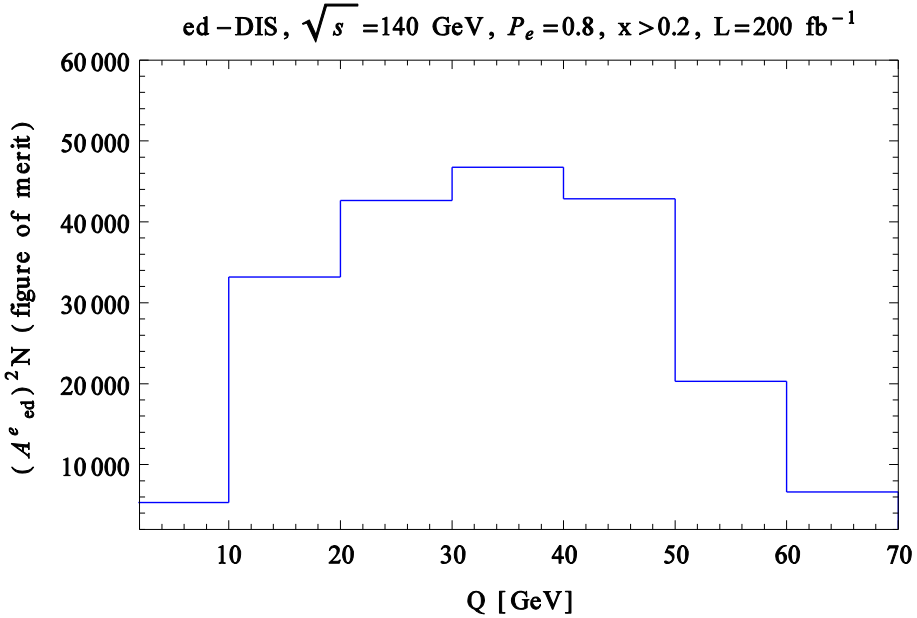




Monte Carlo simulation: Figure of merit

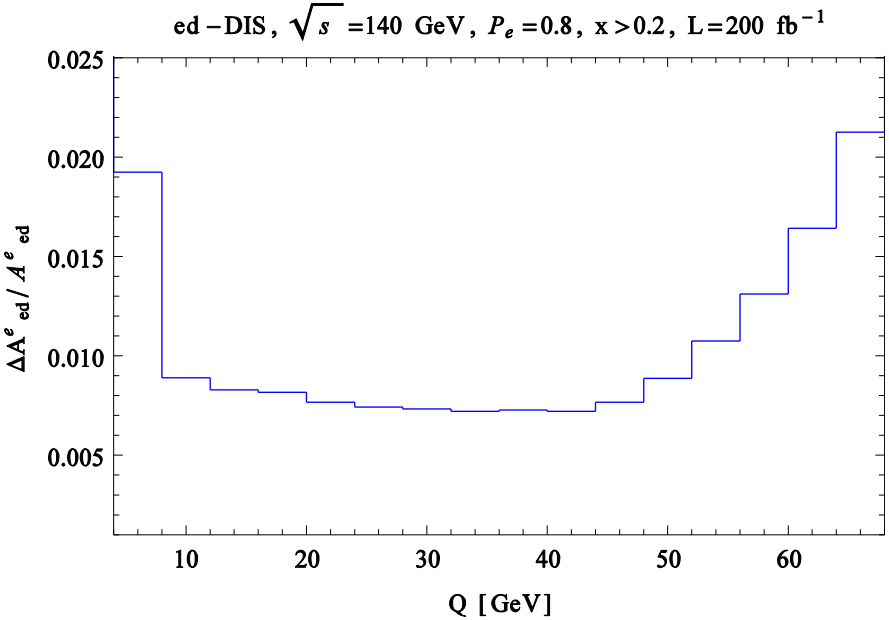
- Figure of merit for ed-DIS:

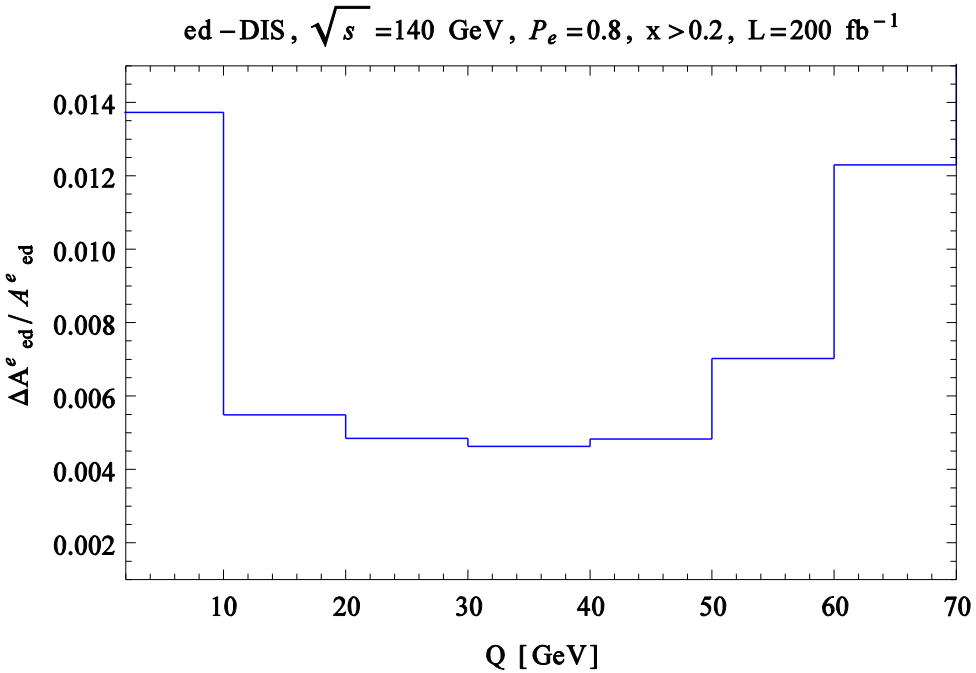




Monte Carlo simulation: statistical error

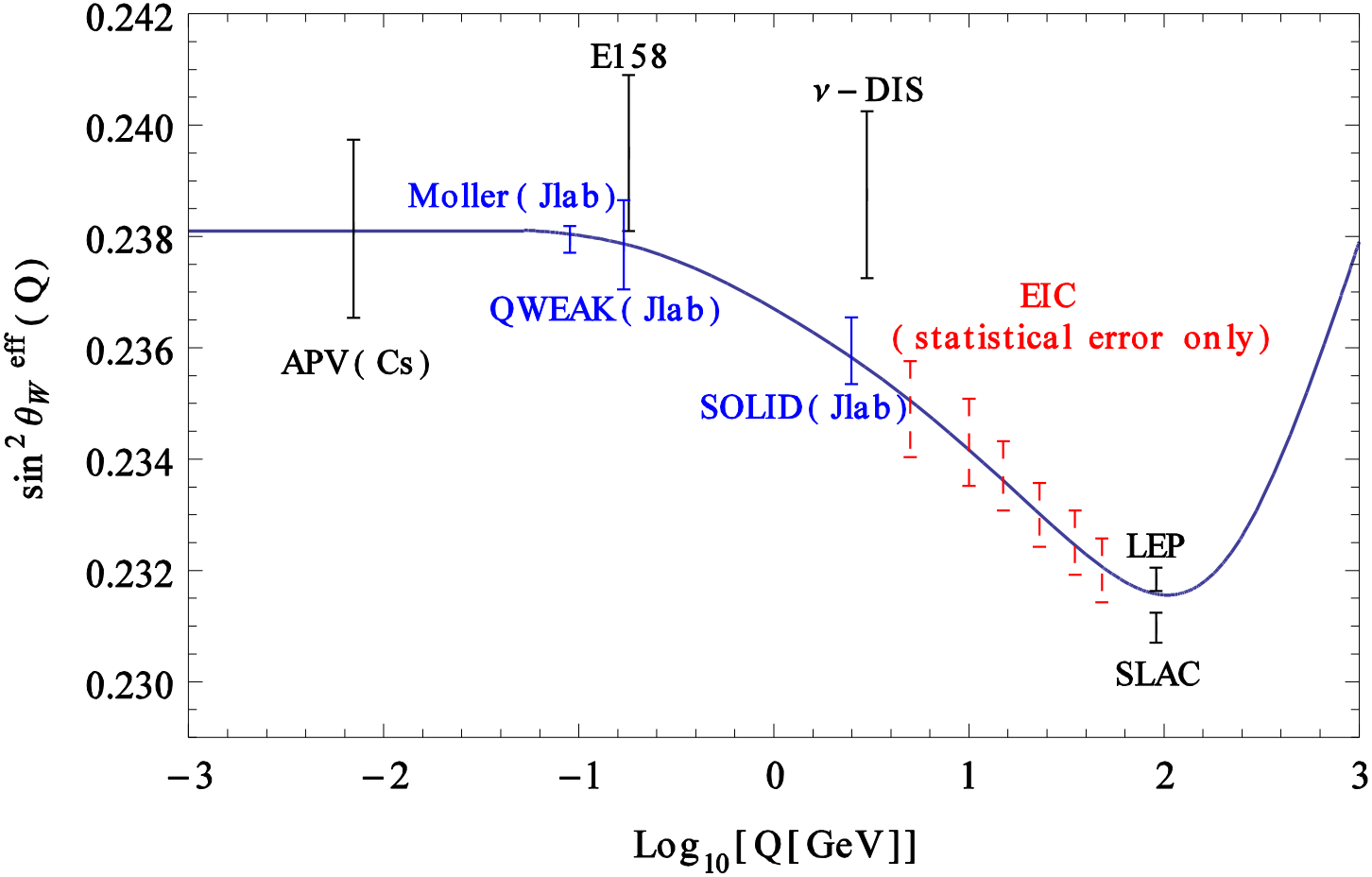
- Statistical error for ed-DIS:





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 !!!