# Electroweak and SM Physics at EIC

(Rolf Ent – EIC2004 03/15/04)

I am clearly not the expert on this subject. This presentation simply aims to investigate Electroweak/SM research directions with high luminosity electron-ion colliders. I will especially benefit from a series of recent ZEUS/H1 publications.

Two methods for Electroweak and SM Physics:

1) High $Q^2$ Electron and Positron Scattering.

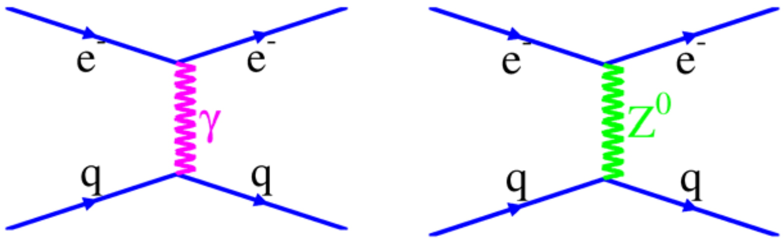
    Here the luminosity assumed for positrons is $10^{33}$ due to limitations in positron sources.

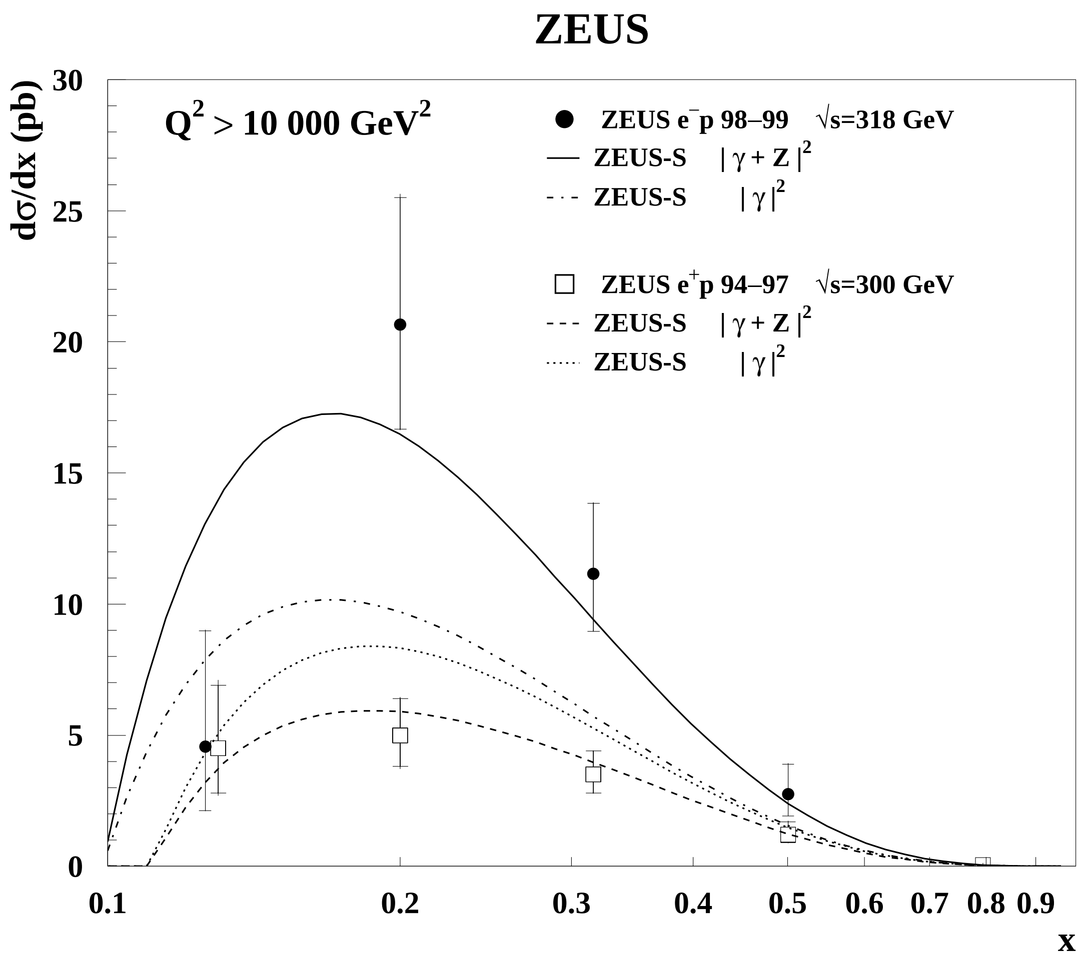
    This would be easiest accomplished in the Ring-Ring eRHIC scenario, but may also work for the ELIC Linac-Ring scenario.

2) Parity-Violating Electron Scattering

    This is only possible in the Linac-Ring Scenario. Here the luminosity assumed is $10^{35}$, relevant for the ELIC scenario.

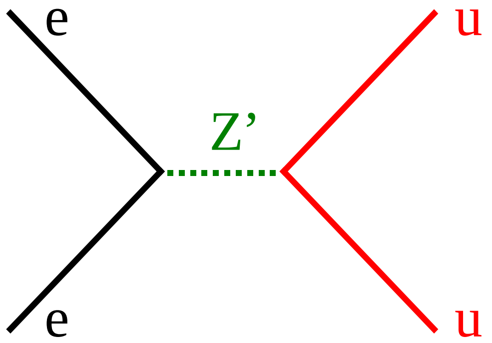
High $Q^2$ $e^-p$ and $e^+p$ scattering:
Direct $Z^0$ term
Parity-Violating $e^-p$ scattering:
Interference



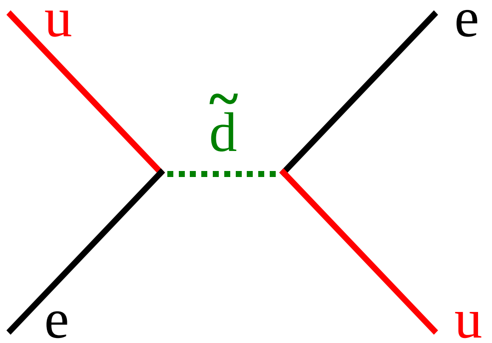



# Examples of Possible Standard Model Extensions

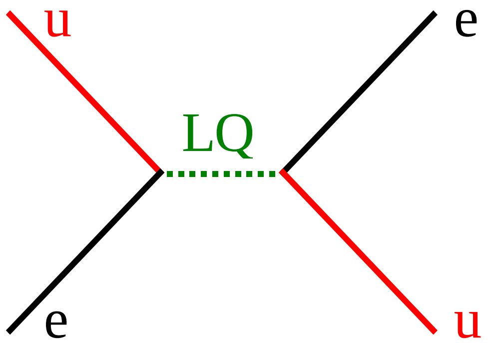
## $E_6$ Z' Based Extensions




## RPV SUSY Extensions




## Leptoquarks



# Parity-Violating $g_5$ Structure Function

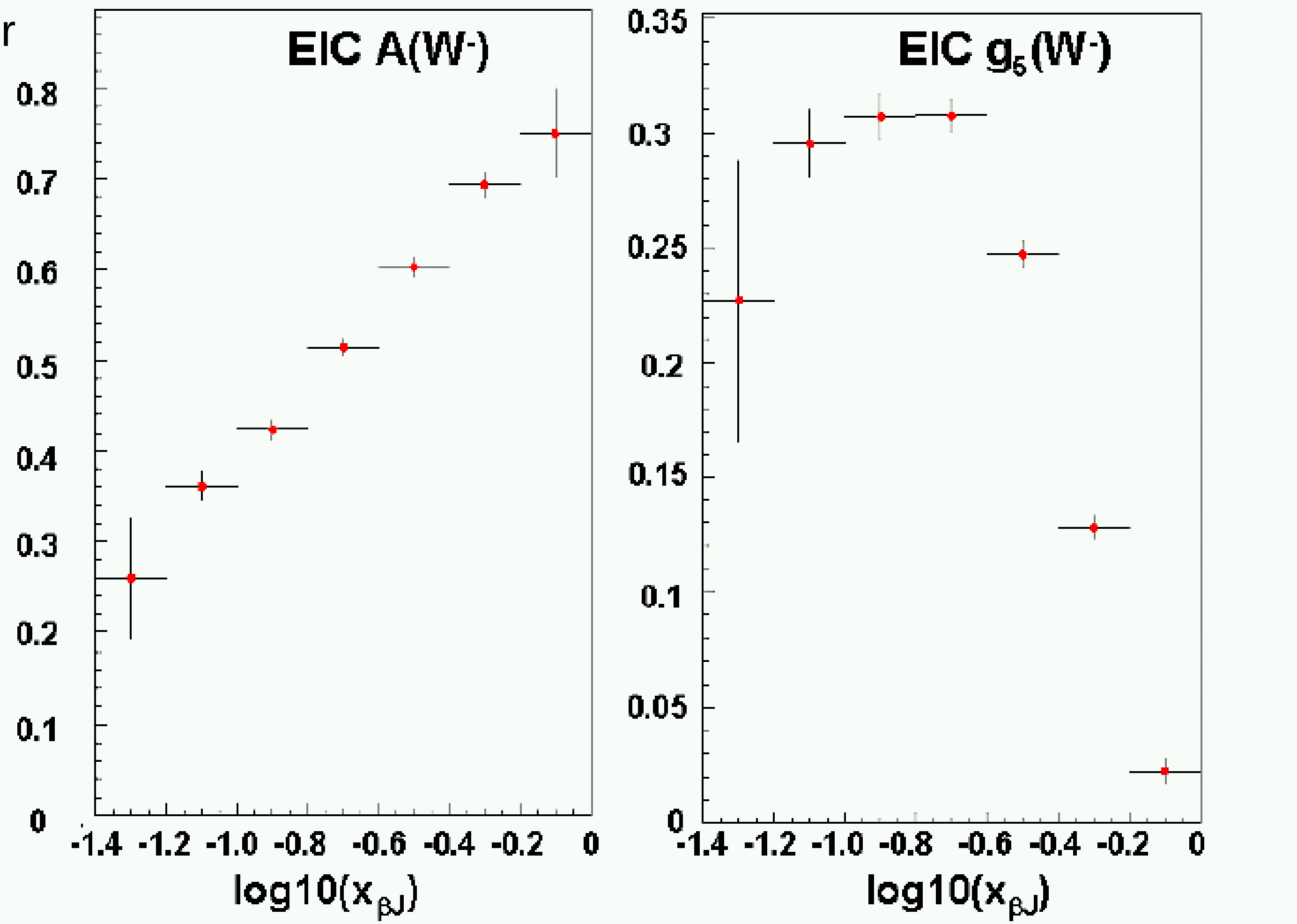
$$A^W = \frac{d\sigma^W_{\uparrow\downarrow} - d\sigma^W_{\uparrow\uparrow}}{d\sigma^W_{\uparrow\downarrow} + d\sigma^W_{\uparrow\uparrow}} = \frac{(+/-)bg_1^W + ag_5^W}{aF_1^W (+/-)bF_3^W} \approx \frac{g_5^W}{F_1^W}$$

$$g_5^{W+} = \Delta d + \Delta s - \Delta\bar{u} - \Delta\bar{c}$$
$$g_5^{W-} = \Delta u + \Delta c - \Delta\bar{d} - \Delta\bar{s}$$

To date unmeasured due to lack of high $Q^2$ polarized e-p possibility.

Projected $A(W^-)$ Assuming $xF_3$ will be known

From EIC White Paper (Contreras et al).
Assumptions:
1) $Q^2 > 225$ $GeV^2$
2) One month at luminosity of $10^{33}$



# Example: ELIC@JLab - Kinematics

(Highest luminosity relevant for this program, but will also show results for eRHIC option)

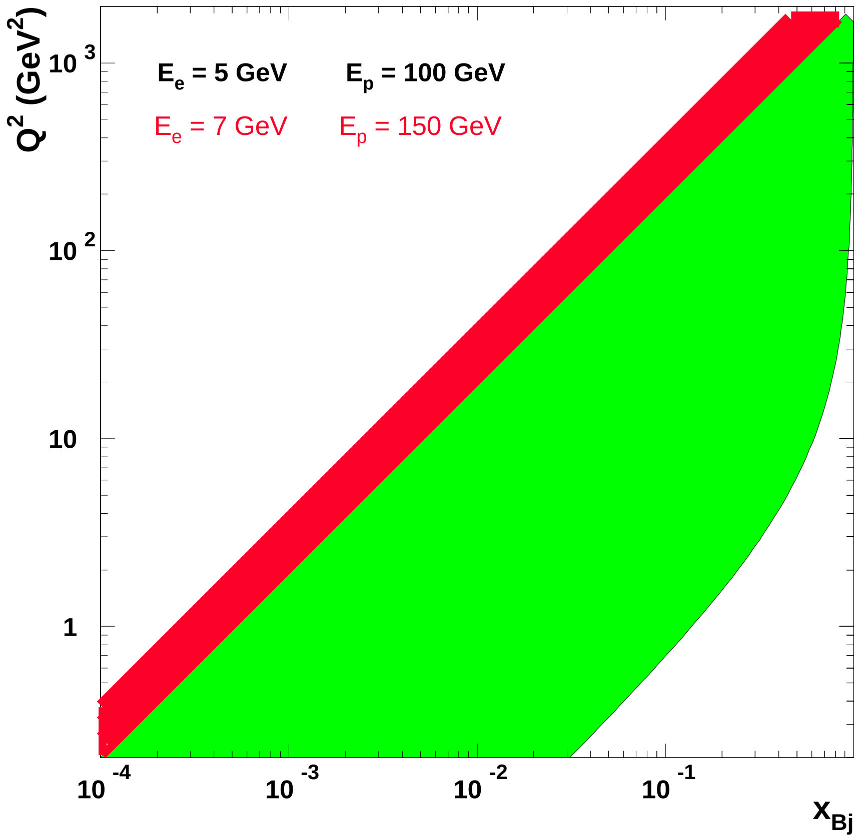
- Luminosity of up to $10^{35}$ $cm^{-2}$ $sec^{-1}$
  - One day → 5,000 events/pb
  - Supports precision experiments

Maximum $Q^2$ ~ 2,000 $GeV^2$

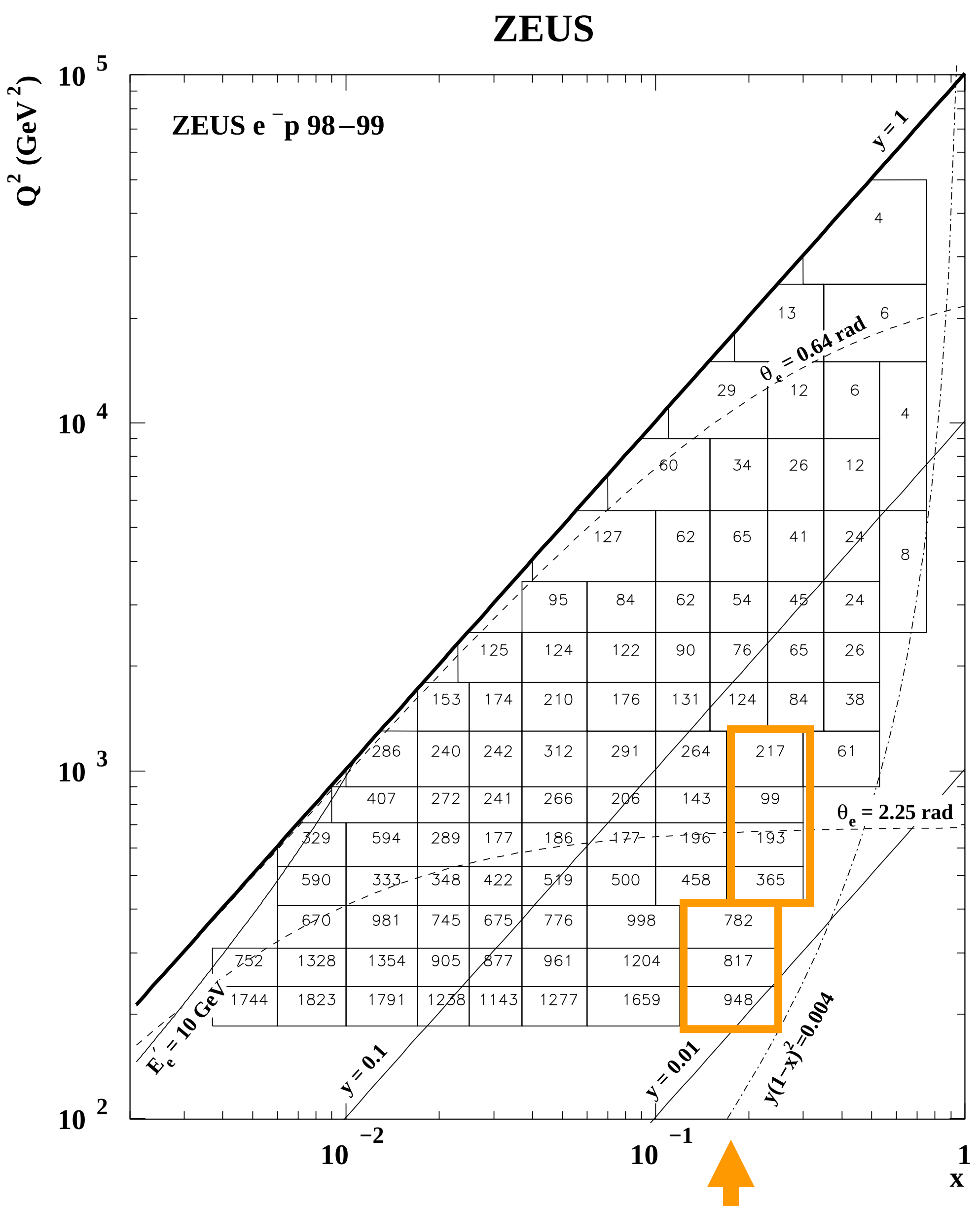
If $Q^2$ > 200 $GeV^2$, typical cut required for Electroweak Processes, can reach x down to 4 times $10^{-2}$ (down to 1.5 times $10^{-2}$ for eRHIC)

($E_{cm}$ = 100 GeV)

ELIC kinematics at $E_{cm}$ = 45 GeV ($E_{cm}$ = 65 GeV), and beyond the resonance region.



## Integrated Luminosity: 16 pB$^{-1}$




Assume: 10 weeks running at a luminosity of $10^{35}$ → 600,000 pB$^{-1}$

**For x bin indicated in orange**

*(If Simply on Luminosity: Times 37K)*

maximum $Q^2 \sim xs$ → factor of 10-20 lower than ZEUS/H1

EIC (ELIC) MC Simulation:

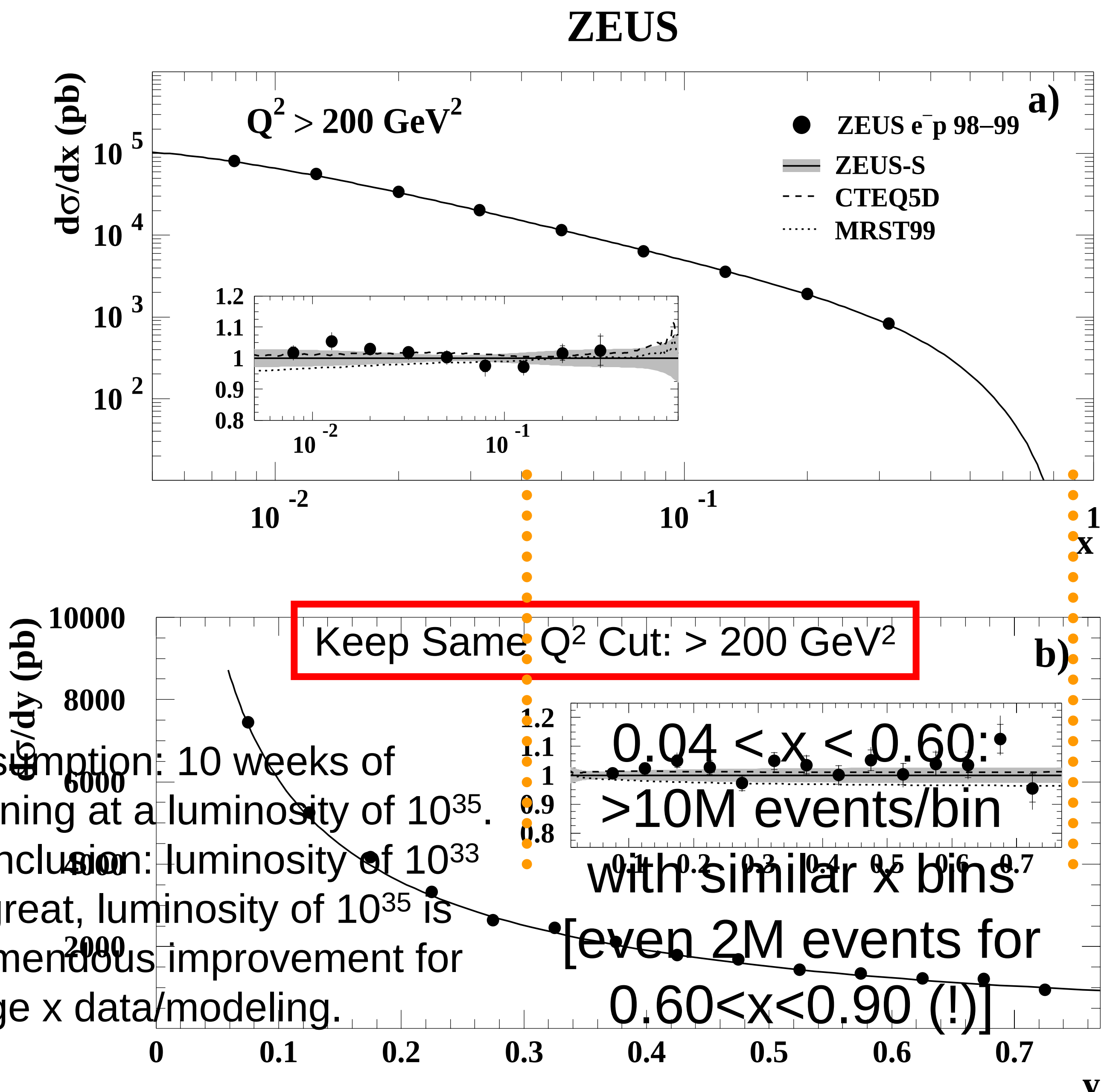
- 217 → 0.6M
- 99 → 1.8M
- 193 → 8.6M
- 365 → 5.6M
- 782 → 11.2M
- 817 → 24.0M
- 948 → 17.4M

(99, 193, 365: } $Q^2 \sim 500$)

*(Empirical Scale Factor: ~ Times 20K)*

# Does it Help?

# Simple First Exercise: The Large x Region




Keep Same $Q^2$ Cut: > 200 GeV$^2$

0.04 < x < 0.60: >10M events/bin with similar x bins [even 2M events for 0.60<x<0.90 (!)]

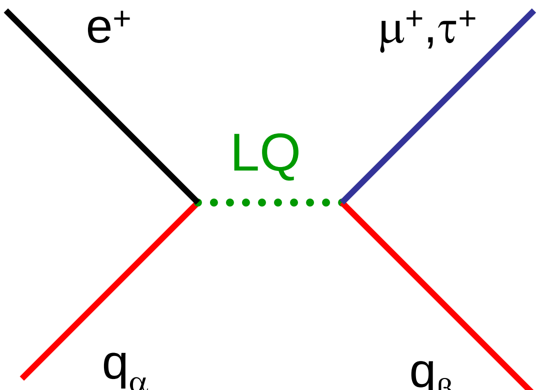
Assumption: 10 weeks of running at a luminosity of $10^{35}$. Conclusion: luminosity of $10^{33}$ is great, luminosity of $10^{35}$ is tremendous improvement for large x data/modeling.

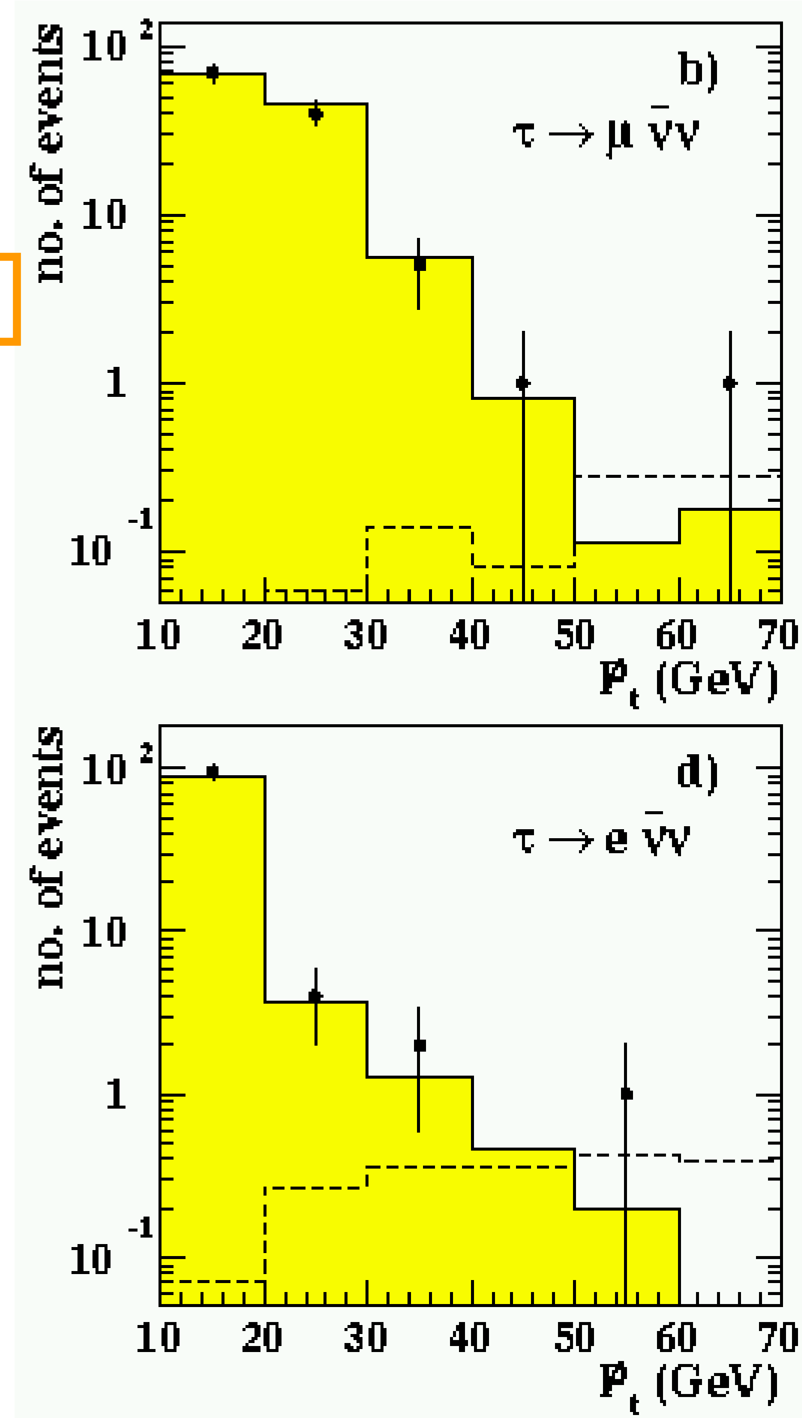
# Search for lepton-flavor violation in $e^+p$ collisions at HERA

*(ZEUS Collaboration, Phys. Rev. D65:092004 (2002))*

$eq_i \rightarrow lq_f$, $l = \mu, \tau$ with high transverse momentum

In ep collisions lepton flavor can be violated by, e.g., leptoquarks and R-parity violating squarks



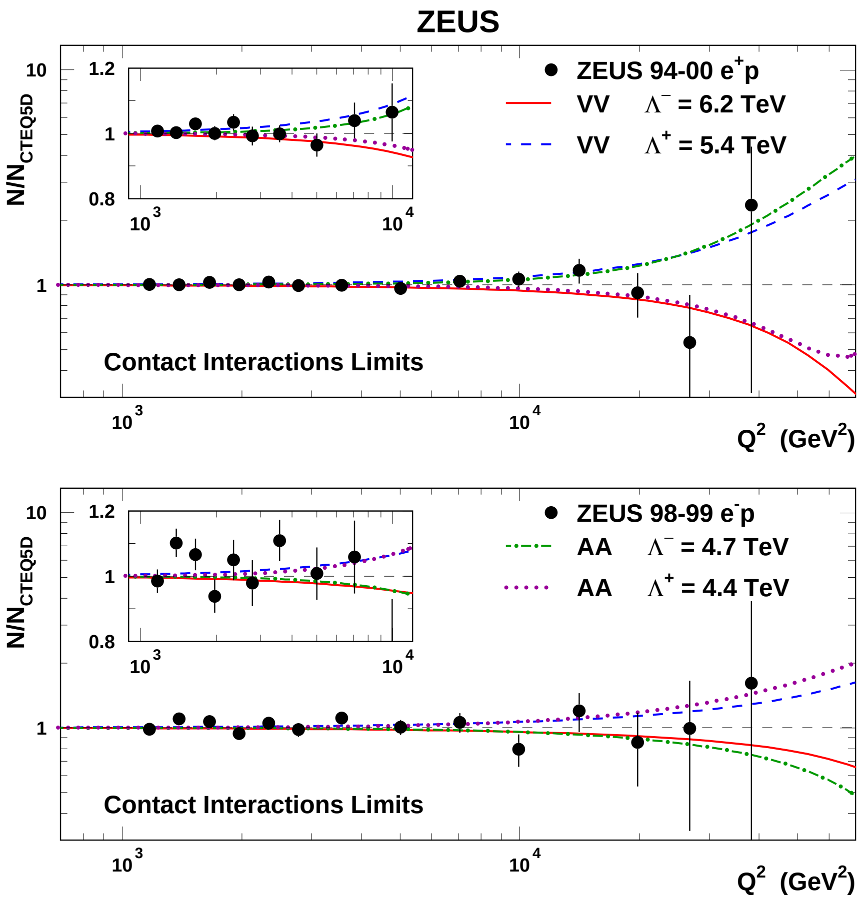



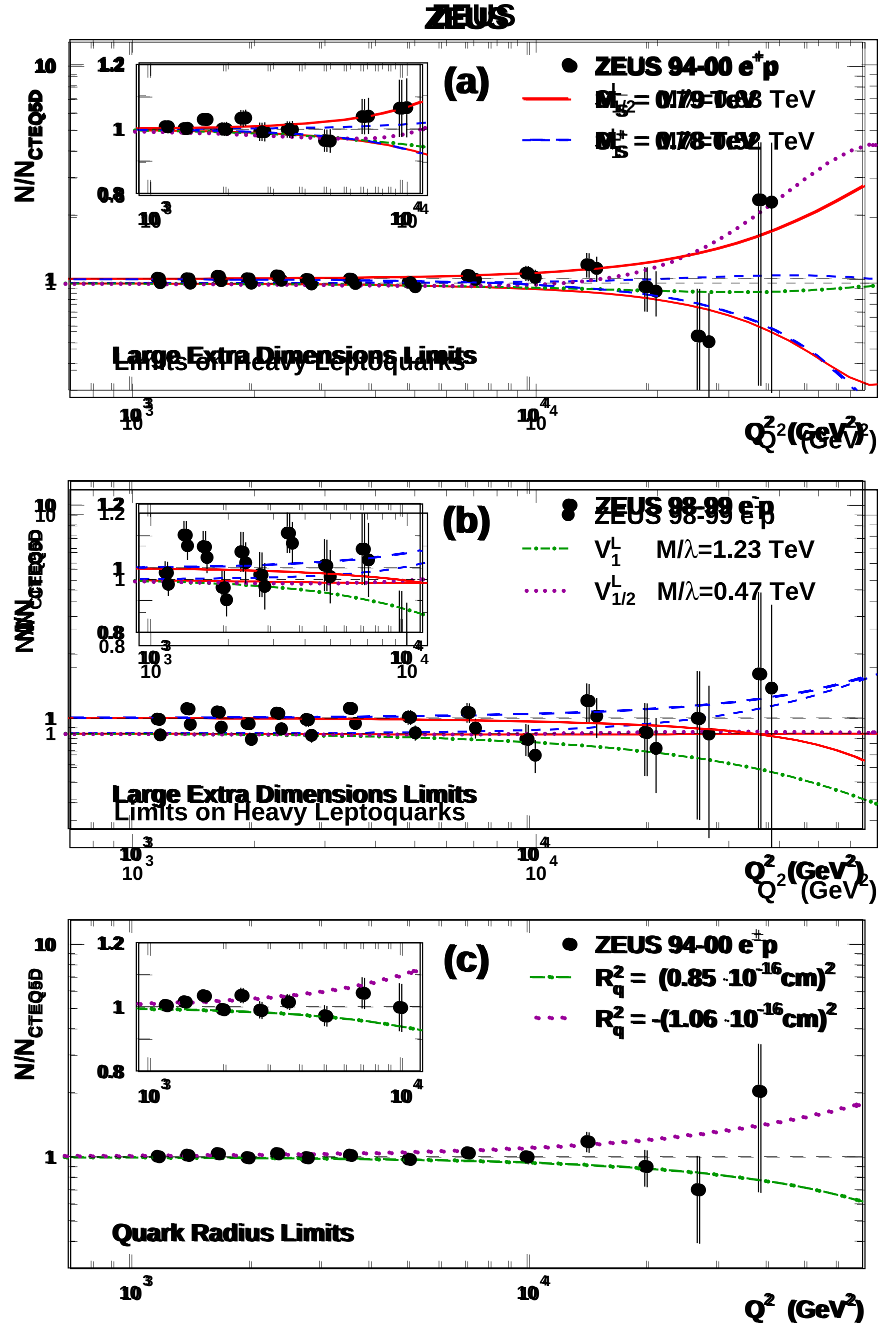

EIC Simulation:

Acceptance up to $\not{P}_t$ = 50 (60) GeV for ELIC (eRHIC) Conditions

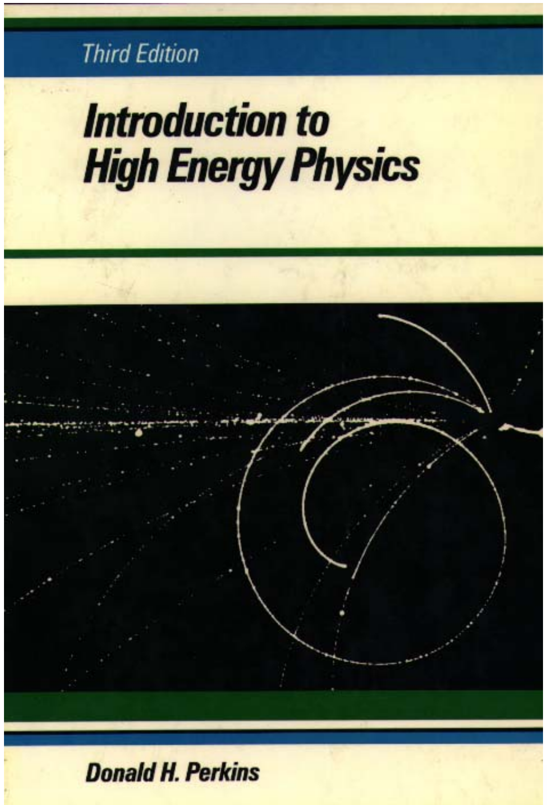
Count Rate Estimates in Progress

Search for contact interactions, large extra dimensions and finite quark radius in ep collisions at HERA (ZEUS, hep-ex/0401009)




In general, difficult to improve upon $e^+$-p for $Q^2 < 2000$ GeV$^2$. Can improve upon $e^-$-p.



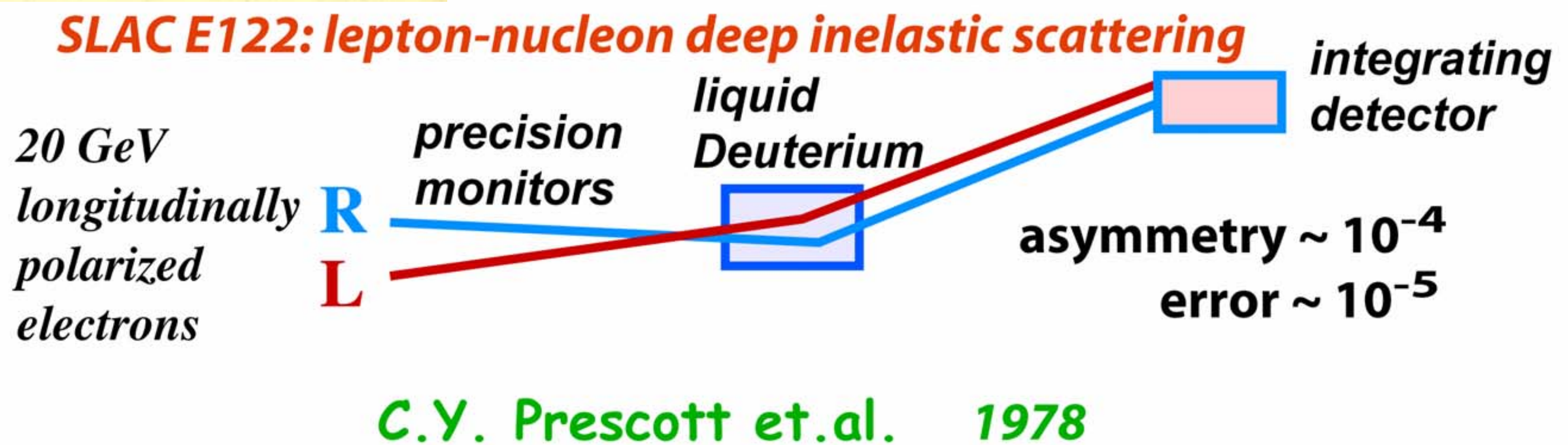

# Textbook Physics: Polarized e⁻ d scattering



**9.7.4. Asymmetries in the Scattering of Polarized Electrons by Deuterons**

Finally we discuss a very delicate experiment to detect tiny parity-violation effects (asymmetries) due to the interference between $Z^0$ and $\gamma$-exchange in inelastic scattering of polarized electrons by deuterons. The experiment was carried out with beams of electrons of 16–22-GeV/$c$ momentum at SLAC, the reaction being

$$e^-_{L,R} + d_{\text{unpolarized}} \to e^- + X,$$



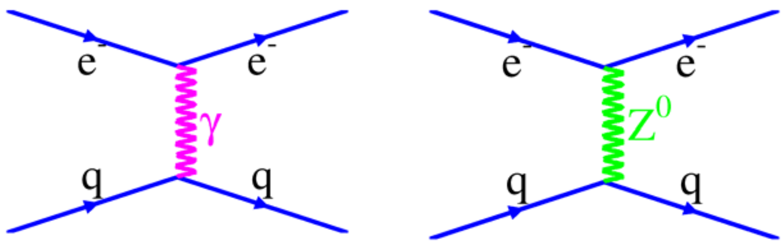

EIC: polarized electron-unpolarized deuteron collisions. Reverse electron helicity in electron source of LINAC

# DIS-Parity: Polarized $e^-$

$$A_d = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \approx 10^{-4} Q^2$$

Longitudinally polarized electrons on unpolarized isoscaler (deuterium) target.

$$= -\left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right) \frac{2C_{1u} - C_{1d}\left[1 + R_s(x)\right] + Y\left(2C_{2u} - C_{2d}\right) R_v(x)}{5 + R_s(x)}$$




$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \approx -0.19$$
$$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \approx 0.35$$
$$C_{2u} = -\frac{1}{2} + 2\sin^2(\theta_W) \approx -0.04$$
$$C_{2d} = \frac{1}{2} - 2\sin^2(\theta_W) \approx 0.04.$$

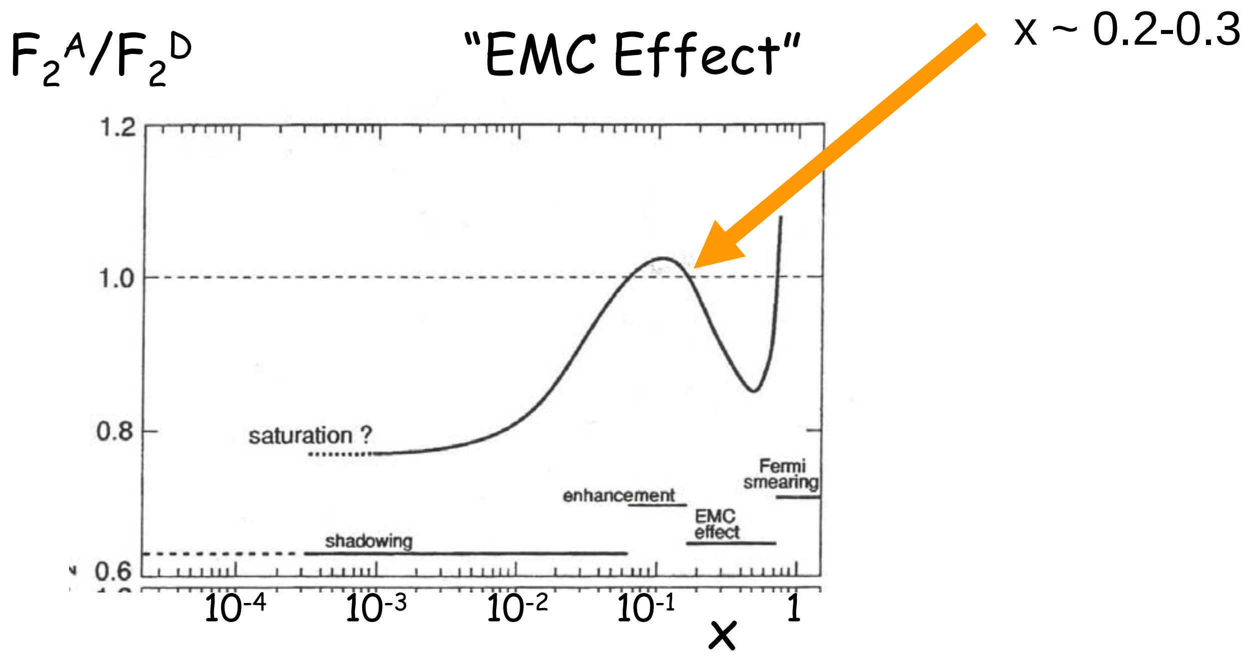
$C_{1q}$ ) NC vector coupling to *q*
x NC axial coupling to *e*

$C_{2q}$ ) NC axial coupling to *q*
x NC vector coupling to *e*

Note that each of the $C_{ia}$ are sensitive to *different* possible S.M. extensions.

# Choice of Kinematics for e-D scattering

Choice of x:
No "Nuclear Effects"



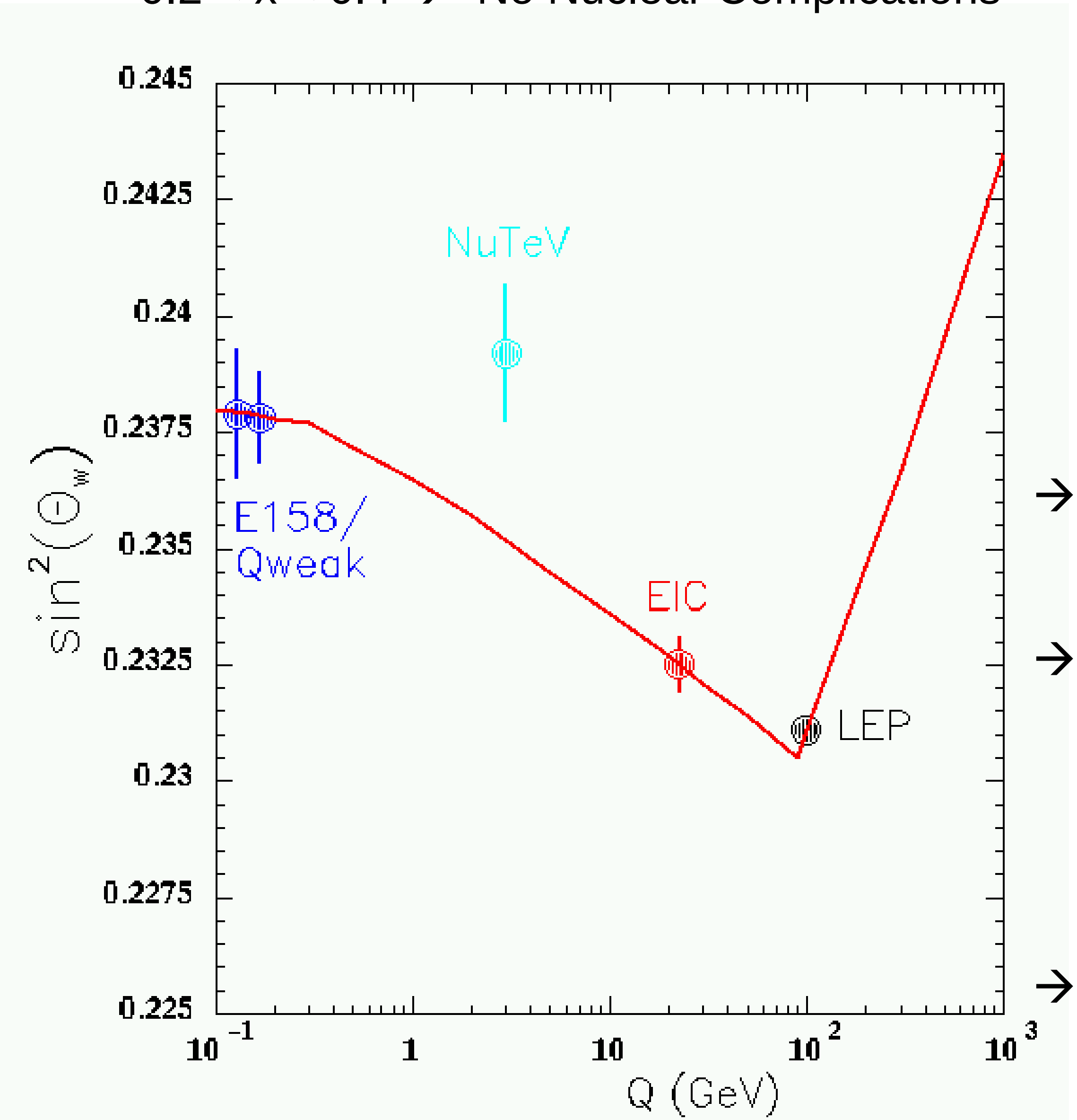

Due to finite Y

Choice of $Q^2$:
High is better!
~ 500 $GeV^2$

$$\left.\frac{\delta \sin^2\theta_W}{\sin^2\theta_W}\right|_{Y=0.40} \approx \frac{1}{2}\left(\frac{\delta A_d}{A_d}\right)$$

$A_d \approx 4.1 \times 10^{-2}$ LARGE!

0.2 < x < 0.4 → "No Nuclear Complications"




This assumed a luminosity of $10^{35}$ and 10 weeks. Conclusion (?): seems to be only feasible at high luminosities

→ Would imply most precise measurement of $\sin^2(\Theta_W)$ below the Z-peak.

→ True value are constraints on effective 4-Fermi coefficients (contact interactions) to which Z-pole experiments are nearly blind

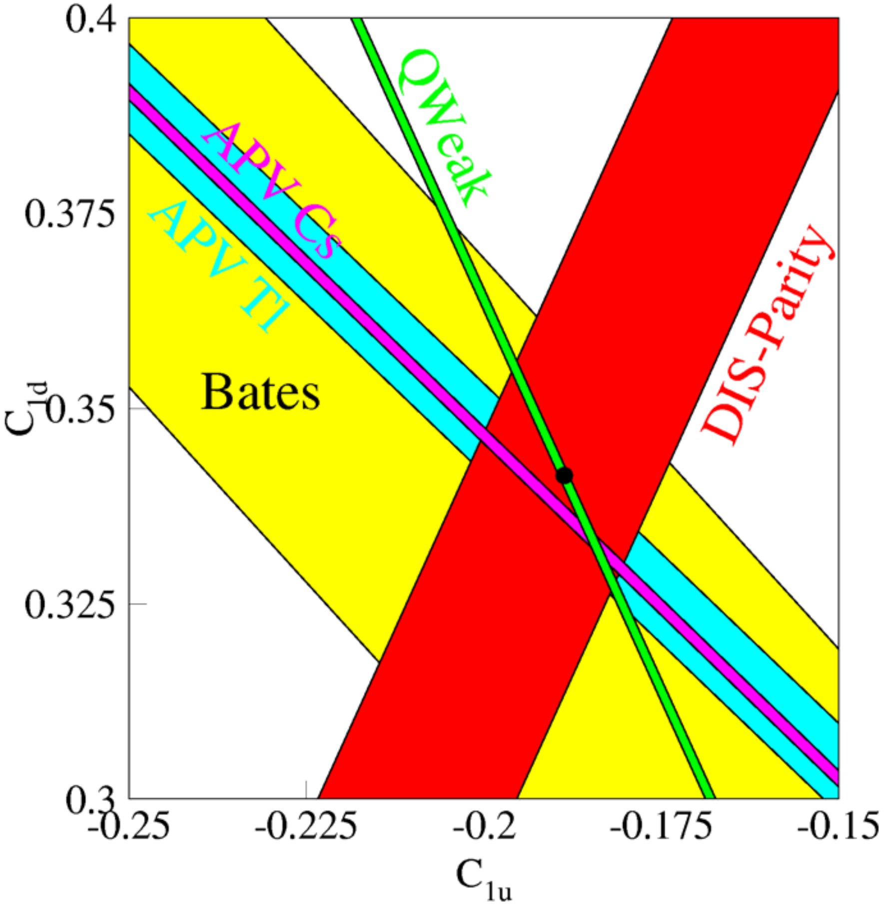
→ $a(2C_{1u} - C_{1d})$ and $bY(2C_{2u}-C_{2d})$

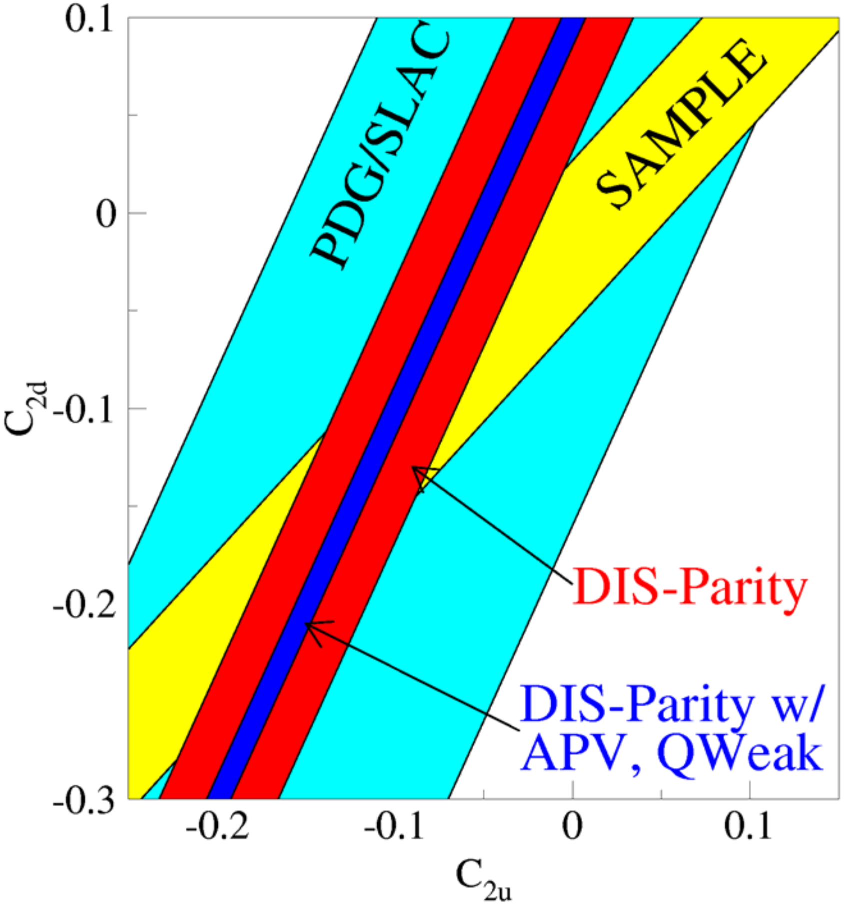
→ Especially $(2C_{2u}-C_{2d})$ not well constrained

Additional (x,Q) data will be simultaneously accumulated

# DIS-Parity determines $2C_{2u}$-$C_{2d}$

Illustrative example from a 12 GeV JLab Fixed Target projection how a DIS-Parity experiment will constrain $2C_{2u}$-$C_{2d}$. This projection is at Q ~ 2 and has an uncertainty close to the NuTeV result. A plot showing the (large) improvement possible with the EIC measurement is under construction (Jens Erler)



# (Preliminary) Conclusions

- There seem to be real possibilities for Electroweak Physics at a high energy EIC with sufficient luminosity
- Access to Electroweak Structure Functions (like $g_5$) likely only requires a luminosity of $10^{33}$
- Electron-proton and Positron-proton comparisons at similar luminosities will likely only be possible in the Ring-Ring option
- Access to Physics beyond the SM may only be possible for luminosities higher than $10^{33}$, and is on the edge of the precision and kinematics accessible with the EIC
- The Linac-Ring option may allow for Parity-violating experiments, thus enhancing sensitivity to SM tests at lower energies

- Someone with more familiarity than me with Electroweak and SM Physics may be needed to pursue this!