Right-Handed W-Boson

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				$SU(3)$	$SU(2)_L$	$U(1)_Y$
$Q_L^i =$	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} c_L \\ s_L \end{pmatrix}$	$\begin{pmatrix} t_L \\ b_L \end{pmatrix}$	3	2	$\frac{1}{6}$
$(u^c)_L^i =$	$(u^c)_L$	$(c^c)_L$	$(t^c)_L$	$\bar{3}$	1	$-\frac{2}{3}$
$(d^c)_L^i =$	$(d^c)_L$	$(s^c)_L$	$(b^c)_L$	$\bar{3}$	1	$\frac{1}{3}$
$L_L^i =$	$\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$	$\begin{pmatrix} \nu_{\mu L} \\ \mu_L \end{pmatrix}$	$\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$	1	2	$-\frac{1}{2}$
$(e^c)_L^i =$	$(e^c)_L$	$(\mu^c)_L$	$(\tau^c)_L$	1	1	1

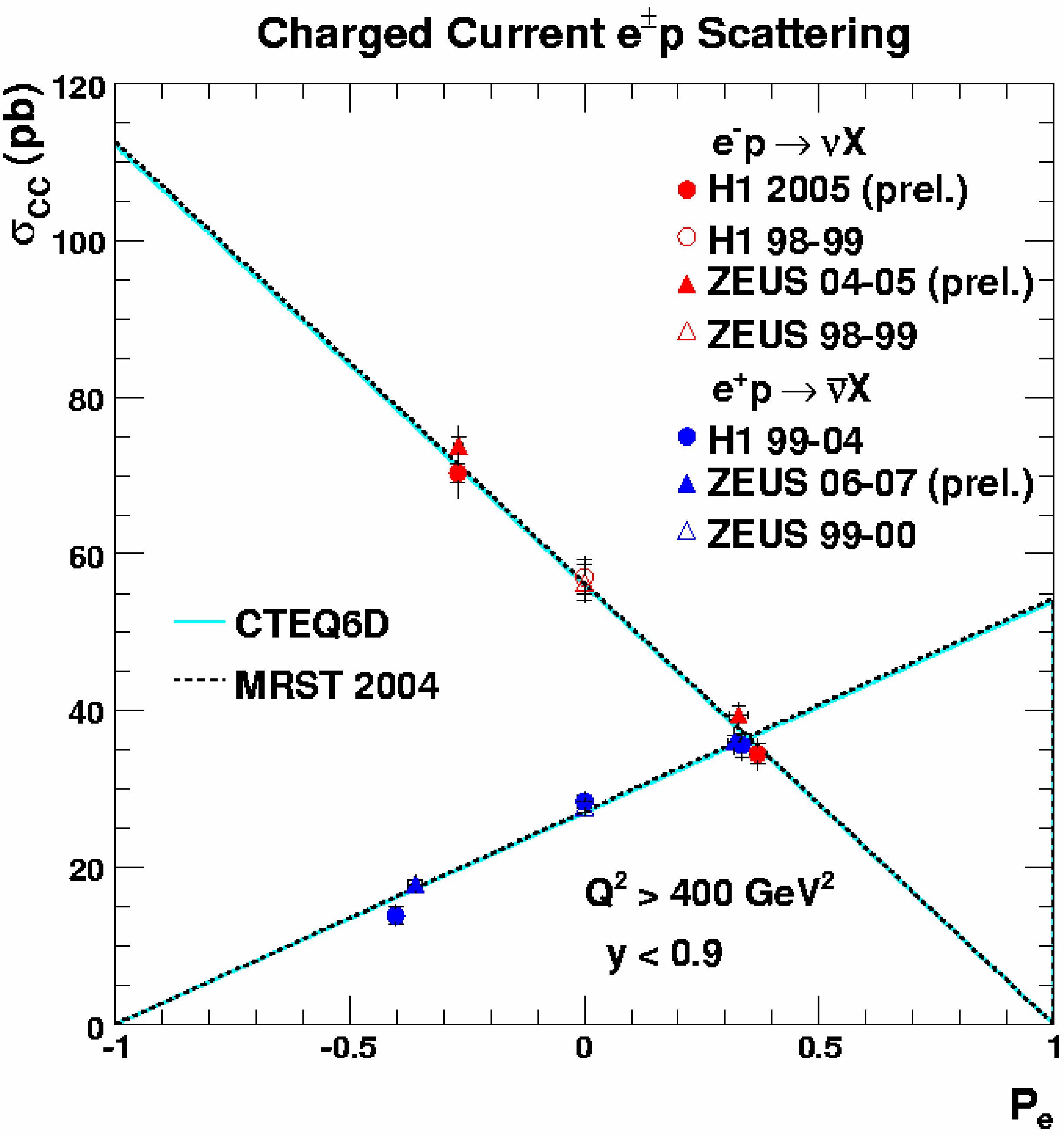
- Electroweak interactions in the Standard model violates parity maximally.
- The W-boson has interactions only with the left-handed quarks and leptons.
- Right-handed neutrinos, as evidenced by neutrino oscillations, require physics beyond the Standard Model

- Left-Right Symmetric Models restore the symmetry between and left and right-handed quarks and leptons at high energies beyond the electroweak scale:

$$\mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{U}(1)_{B-L} \longrightarrow \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$$

- Left-Right symmetric models predict the existence of new degrees of freedom, including a heavy right-handed W-boson and heavy right-handed neutrinos.

Right-Handed W-Boson



- The Standard Model W-boson only couples to left-handed electrons and right-handed positrons.

- Thus, the Standard Model predicts a linear dependence of the charged current (CC) cross-section on the lepton beam polarization.

- Polarized electron and positron beams can test this Standard Model paradigm.

HERA limits on the right-handed W mass:

e^+p: > 208 GeV [A.Aktas et.al (H1)]
e^-p: > 186 GeV

(assuming equal couplings for left and right handed Ws)

Right-Handed W-Boson at EIC

- The lower center of mass energy (compared to HERA) at the EIC will lead to smaller charged current cross sections.

- However, the higher luminosity and degree of lepton beam polarization at the EIC can lead to higher precision on the charged current cross section measurements.

- Higher precision could lead to stronger mass bounds.

SM Polarization Dependence of Charged Current Cross Section

- The Standard Model W-boson only couples to left-handed electrons and right-handed positrons:

$$\sigma_{\mathrm{SM}}^{e^{\pm}p}(P_e) = (1 \pm P_e)\sigma_{\mathrm{SM}}^{e^{\pm}p}(P_e = 0)\ , \qquad P_e = \frac{N_R - N_L}{N_R + N_L}$$

- Electron and positron beams act as independent probes of the polarization dependence charged current cross section due to the difference in initial state PDFs that contribute:

$$\frac{\sigma_{\mathrm{SM}}^{e^{+}p}(P_e)}{dx\,dQ^2} = (1 + P_e)\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2\left[\bar{u}(x, Q^2) + \bar{c}(x, Q^2) + (1 - y)^2\Big(d(x, Q^2) + s(x, Q^2)\Big)\right]$$

$$\frac{\sigma_{\mathrm{SM}}^{e^{-}p}(P_e)}{dx\,dQ^2} = (1 - P_e)\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2\left[u(x, Q^2) + c(x, Q^2) + (1 - y)^2\Big(\bar{d}(x, Q^2) + \bar{s}(x, Q^2)\Big)\right]$$

BSM Polarization Dependence of Charged Current Cross Section

- SM polarization dependence:

$$\sigma_{\rm SM}^{e^\pm p}(P_e) = (1 \pm P_e)\sigma_{\rm SM}^{e^\pm p}(P_e = 0) \longrightarrow \boxed{\sigma_{\rm SM}^{e^\pm p}(P_e = \mp 1) = 0}$$

- Polarization dependence in the presence of a right-handed W boson (with SM coupling strength):

$$\sigma^{e^\pm p}(P_e) = (1 \pm P_e)\,\sigma_{\rm SM}^{e^\pm p}(P_e = 0) + (1 \mp P_e)\,\sigma_{\rm SM}^{e^\pm p}(P_e = 0, M_W \to M_R)$$

$$\downarrow$$

$$\boxed{\sigma^{e^\pm p}(P_e = \mp 1) = 2\,\sigma_{\rm SM}^{e^\pm p}(P_e = 0, M_W \to M_R) \neq 0}$$

$$\sigma^{e^\pm p}(P_e = \mp 1) = 2\, \sigma_{\rm SM}^{e^\pm p}(P_e = 0, M_W \to M_R)$$

95% confidence interval of measurement leads to upper bound

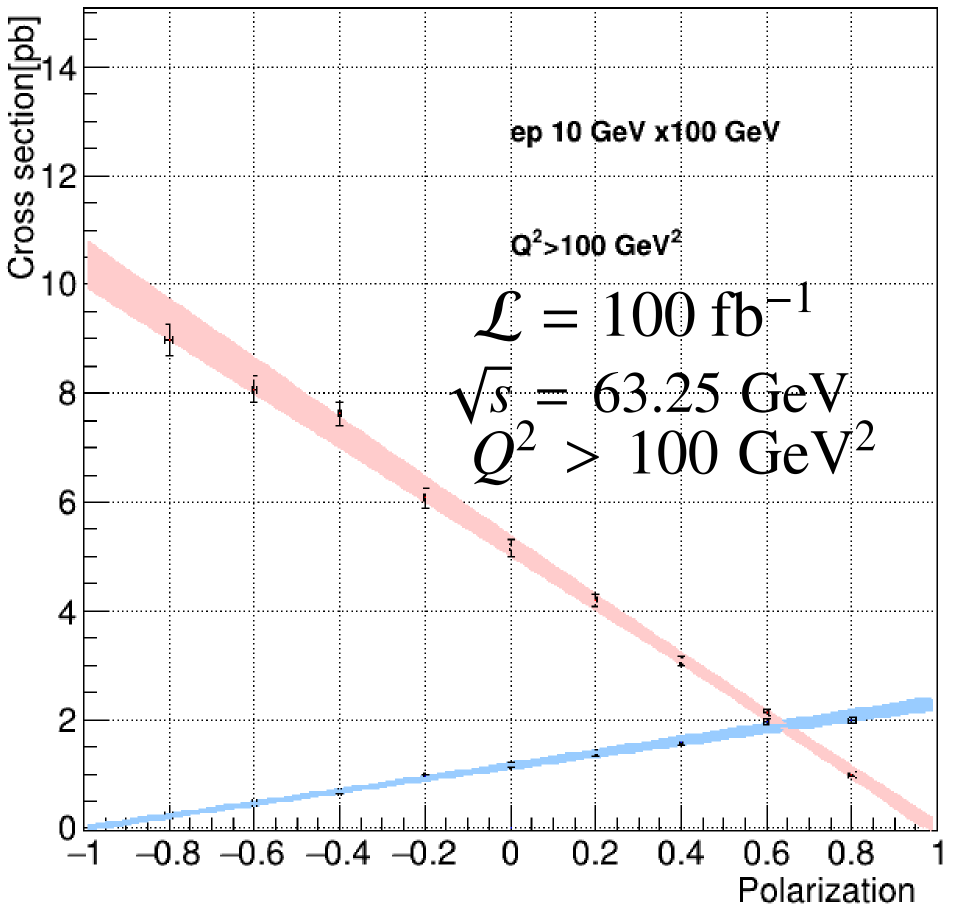
$$\sigma_{\rm SM}^{e^\pm p}(P_e = 0, M_W \to M_R) < \frac{\sigma_{\text{upper bound}}^{e^\pm p}(P_e = \mp 1)}{2}$$

$$\sigma_{\rm SM}^{e^- p}(P_e = 0, M_W \to M_{W_R}) \;=\; \int_{Q^2_{\rm min}}^{s} dQ^2 \int_{\frac{Q^2}{s}}^{1} dx\, \frac{G_R^2}{2\pi}\left(\frac{M_R^2}{M_R^2 + Q^2}\right)^2 \left[u + c + (1-y)^2(\bar{d} + \bar{s})\right]$$

MR dependence leads to a mass limit

Preliminary Simulation Results

[Y. Furletova, S. Mantry]

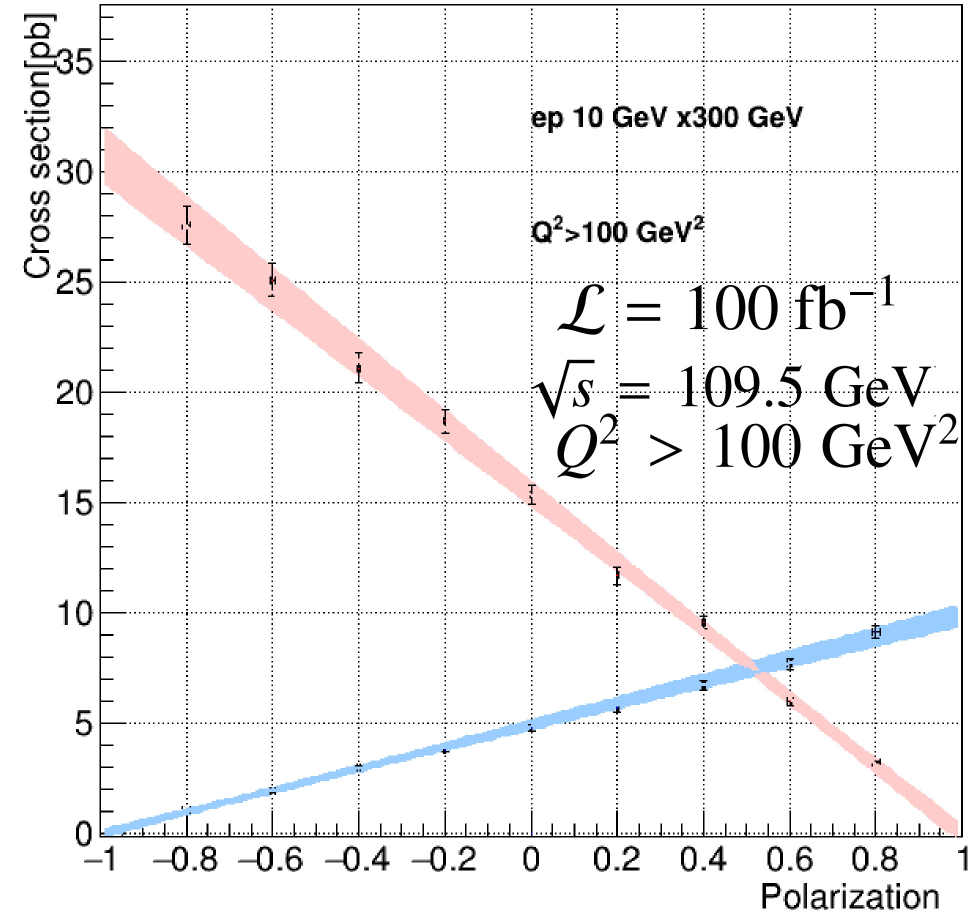


Assumed polarization uncertainty:

$$\Delta P_e / P_e \sim 1\%$$

Assumed systematic uncertainty:

$$\sim 3\%$$



- Center of mass energy:

$$\sqrt{s} = 63.25\ \mathrm{GeV}$$

- 95% CL upper bound:

$$\sigma^{e^+ p}(P_e = -1) < 0.0207\mathrm{pb}$$

- WR-boson mass limit:

$$M_R \gtrsim 270\ \mathrm{GeV}$$

- Center of mass energy:

$$\sqrt{s} = 109.5\ \mathrm{GeV}$$

- 95% CL upper bound:

$$\sigma^{e^+ p}(P_e = -1) < 0.0776\mathrm{pb}$$

- WR-boson mass limit:

$$M_R \gtrsim 285\ \mathrm{GeV}$$

Procedure for CC W_R Analysis

1. Get $\sigma(P_e=0)$ by running DJANGOH:
   - 18×275 GeV configuration
   - $Q^2 > 100$ GeV^2

   $\Rightarrow \sigma(P_e=0) = 24.1$ pb

2. Cross-section at all other values of P_e:

$$\sigma(P_e) = (1-P_e)\,\sigma(P_e=0)$$

3. Cross-section uncertainty:
   - Statistical: $\frac{\delta\sigma^{stat.}}{\sigma} = \frac{1}{\sqrt{N}} \Rightarrow \delta\sigma^{stat.} = \frac{\sigma}{\sqrt{N}}$

$$\Rightarrow \delta\sigma^{stat}(P_e) = \frac{(1-P_e)\,\sigma(P_e=0)}{\sqrt{(1-P_e)\,N}}$$

$$N = \mathcal{L}\,\sigma(P_e=0)$$

$$\therefore \delta\sigma^{stat}(P_e) = \frac{(1-P_e)\,\sigma(P_e=0)}{\sqrt{(1-P_e)\,\mathcal{L}\,\sigma(P_e=0)}}$$

$$\therefore \delta\sigma^{stat}(P_e) = \sqrt{\frac{(1-P_e)\,\sigma(P_e=0)}{\mathcal{L}}}$$

– Systematic uncertainty (3%):

$$\frac{\delta\sigma^{sys.}}{\sigma} = 0.03$$

$$\therefore \delta\sigma^{sys.} = 0.03\,\sigma$$

$$\therefore \delta\sigma^{sys}(P_e) = 0.03(1-P_e)\,\sigma(P_e=0)$$

– Polarization uncertainty (1%)

$$\delta P_e = 0.01\,P_e$$

$$\sigma(P_e) = (1-P_e)\,\sigma(P_e=0)$$

$$\therefore \delta\sigma^{pol}(P_e) = -\delta P_e\,\sigma(P_e=0)$$

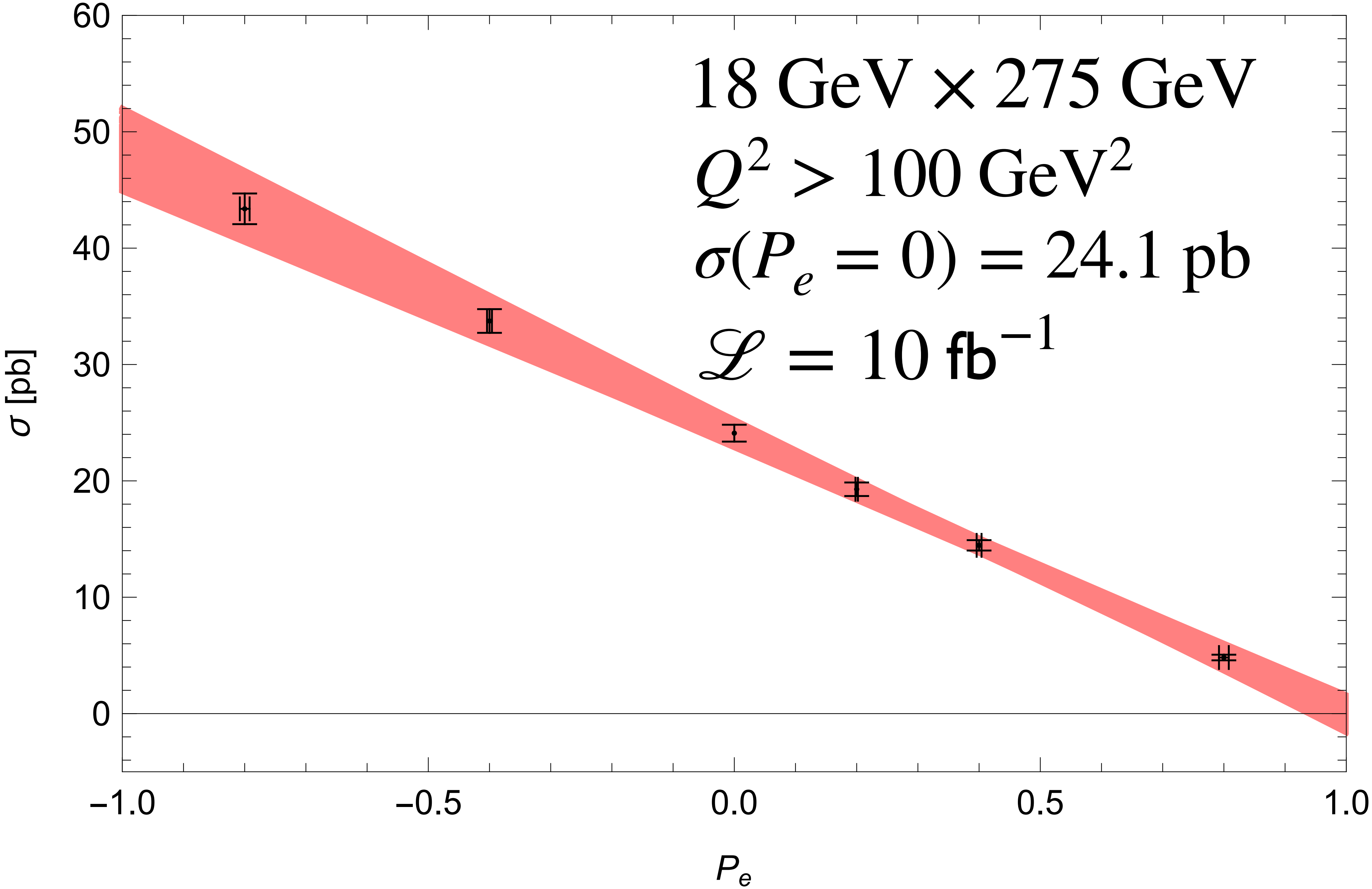
$$\therefore \delta\sigma^{pol}(P_e) = -0.01\,P_e\,\sigma(P_e=0)$$

Thus, adding in quadrature, the total uncertainty:

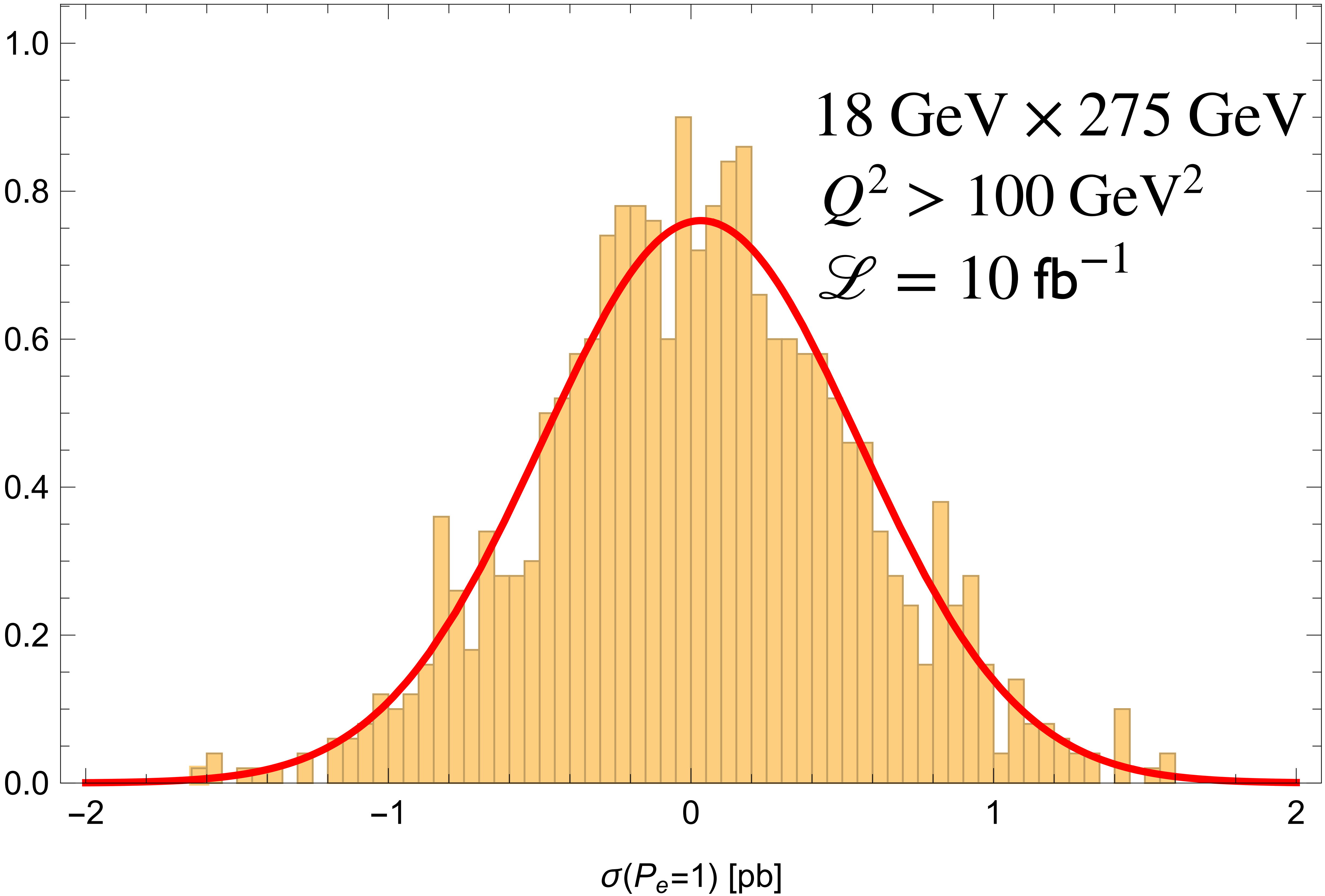
$$\delta\sigma^{tot} = \sqrt{(\delta\sigma^{stat})^2 + (\delta\sigma^{sys})^2 + (\delta\sigma^{pol})^2}$$

$$\therefore \delta\sigma^{tot} = \sqrt{\frac{(1-P_e)\sigma(P_e=0)}{\mathcal{L}} + \left[0.03(1-P_e)\sigma(P_e=0)\right]^2 + \left[0.01\,P_e\,\sigma(P_e=0)\right]^2}$$

Cross Section as Function of Beam Polarization



Preliminary Simulation Results



Next Steps

- Write C++ code to get CC cross section as a function of M_R .

- Use this code to determine lowest allowed value of M_R to saturates allowed cross section bound.

- Include PDF error? Can generate total charge current cross section using different PDF sets to extract PDF error and include it in the analysis.