Top and EW Physics at the LHeC

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On behalf of

Outline

1) Introduction
2) Top physics at the LHeC
3) Examples of precision EW measurements
4) Summary
Introduction

Energy-Recovery Linac (ERL)

L: $>10^{33}$ cm$^{-2}$s$^{-1}$

$L_{int}$: upto 1 ab$^{-1}$
Introduction

Largely extending HERA kinematic region into an unexplored territory

It has a very rich physics program

The focus of this talk is on top & EW physics
Top Physics at the LHeC

- Single (anti)top production in Charged Current (CC) processes
  * Sensitive to PDFs of the proton
  * Direct measurement of $|V_{tb}|$ (0.5%)
  * Top quark polarization
  * $W$ boson helicity
  * Search for anomalous $Wtb$ couplings
  * Study $ttH$ in $tH$ production?

- Top production in Neutral Current (NC) processes
  * Search for anomalous $ttγ(Z)$ couplings
  * FCNC (single top in $γp$ process)
**Single Top Production at LHeC**

CC single (anti)top production: the dominant process at LHeC

LHeC (60GeV x 7TeV): has a clean environment for top physics studies

LHC 14TeV: has larger cross section ~250pb ($m_t=173$GeV, t-channel), but large background and low selection efficiency

http://arxiv.org/abs/1307.1688

Dutta, Goya, Kumar, Mellado
Anomalous $Wtb$ Couplings

$$\mathcal{L}_{Wtb} = \frac{g}{\sqrt{2}} \left[ W_\mu \bar{t} \gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2m_W} W_\mu \bar{t} \sigma^{\mu \nu} (f_2^L P_L + f_2^R P_R) b \right] + h.c.$$ 

- **SM V-A, Left-handed Vector coupling**
  $$f_1^L = 1 + \Delta f_1^L$$
- **BSM, R-handed Vector coupling**
- **BSM, L,R-handed Tensor couplings**

**SM:** $f_1^L = 1$, $\Delta f_1^L = f_1^R = f_2^L = f_2^R = 0$


LHeC expected to have the largest sensitivity to $\Delta f_1^L$
Expected Precision vs. Other Determinations

Dutta, Goya, Kumar, Mellado
http://arxiv.org/abs/1307.1688

One example from hadronic decays → Important to control syst. error.

Similar constraints available for other couplings from both hadronic and leptonic decay modes

| Upper limits at 95%CL | $|\Delta f_1^L|$ | $|f_1^R|$ | $|f_2^L|$ | $|f_2^R|$ |
|----------------------|----------------|------------|------------|------------|
| LHeC (100fb⁻¹, had, syst: 0.01-0.1) | 0.005-0.03 | 0.01-0.1 | 0.01-0.1 | 0.01-0.1 |
| D0 (5.4fb⁻¹, W-helicity, single top) arXiv:1204.2332 | | 0.548 | 0.324 | 0.347 |
| LHC (Wt, γp, 100fb⁻¹) arXiv:1210.3235 | 0.03-0.06 | 0.22-0.34 | 0.06-0.08 | 0.06-0.08 |
| B decays (indirect) arXiv:0802.1412 | [-0.13, 0.03] | [-0.0007, 0.0025] | [-0.0013, 0.0004] | [-0.15, 0.57] |
Examples for precision EW measurements at the LHeC based on inclusive DIS interactions
Inclusive Neutral/Charged Current Processes

- Dominant hard processes at LHeC
- Event kinematics:
  - $Q^2 = -q^2$: Boson virtuality
  - $x$: momentum fraction of struck parton
  - $y = Q^2/sx$: inelasticity

  can be precisely determined (for NC in particular using different methods)
Cross Sections, Quark Couplings & PDFs

\[
\frac{d^2\sigma_{\text{NC}}^\pm}{dx dQ^2} \sim Y_+ \tilde{F}_2 + Y_- \tilde{F}_3 - y^2 \tilde{F}_L \quad \text{with} \quad Y_\pm = 1 \pm (1 - y)^2
\]

\[
\begin{align*}
\tilde{F}_2 &= F_2 - (v_e - P_e a_e) \kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 - 2 P_e v_e a_e) \kappa_Z^2 F_2^Z \\
\tilde{F}_3 &= F_3 - (a_e - P_e v_e) \kappa_Z x F_3^{\gamma Z} + [2v_e a_e - P_e (v_e^2 + a_e^2)] \kappa_Z^2 x F_3^Z
\end{align*}
\]

\[
\begin{align*}
\left[ F_2, F_2^{\gamma Z}, F_2^Z \right] &= x \sum_q \left[ e_q^2, 2e_q v_q, v_q^2 + a_q^2 \right] \{ q + \bar{q} \} \\
x F_3^{\gamma Z}, x F_3^Z \right] &= 2x \sum_q \left[ e_q a_q, v_q a_q \right] \{ q - \bar{q} \}
\end{align*}
\]

Structure function formulae given for e^-p scattering, for e^+p, P_e \rightarrow -P_e

\[
\kappa^{-1}_Z = \frac{2\sqrt{2\pi\alpha} Q^2 + M_Z^2}{G_F M_Z^2} \frac{Q^2}{Q^2}
\]

CC cross sections have similar but different structure functions and PDF combinations

F_L=0 in LO parton model, F_L \sim g at NLO
Simultaneous fit of quark couplings & PDFs to simulated LHeC & HERA NC, CC data


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B has smaller acceptance than C
A Comparison with Other Determinations

LHeC has great potential to determine quark couplings with unprecedented precision.

Note: LHeC corresponds to scenario C, HERA determination is being updated, some improvement expected.
Relative Contribution of $\gamma Z$ & $Z$

$$\tilde{F}_2 \simeq F_2 + P a_e \kappa Z F_2^{\gamma Z} + a_e^2 \kappa_Z^2 F_2^Z$$

The relative contribution of $\gamma Z$ interference & $Z$ exchange becomes increasingly important toward high $x$ and $Q^2$
\[ A^\pm = \frac{\sigma_{NC}^\pm(P_R) - \sigma_{NC}^\pm(P_L)}{\sigma_{NC}^\pm(P_R) + \sigma_{NC}^\pm(P_L)} \approx \pm \frac{\kappa_Z a_e(P_L - P_R)}{2} \frac{F_Z^\gamma}{F_2} \]

\[ \kappa_Z^{-1} = 4 \sin^2 \theta \cos^2 \theta \frac{Q^2 + M_Z^2}{Q^2} \]

NC/CC cross section ratio also sensitive to $\sin^2 \theta$ provided PDFs dependence is under control

Expected LHeC determination is precise and covers a large energy scale range
CC Total Cross Section vs $M_W$

**CC:**

W propagator mass

$\nu$ propagator mass

$e^+ \rightarrow \nu_e$

$W^-$

$q' \rightarrow q$

$p \rightarrow x_p$

Spectacular demonstration of finite/massive $M_W$

Other measurements exist for better $M_W$ determination & constraining right-handed CC

H1 Collab.


LHeC

HERA
Summary

- LHeC if realized will greatly enlarge the physics program, discovery potential of the LHC in a complementary manner

- Top and EW physics based on previous studies are two good examples

- Larger potential expected with more studies from both theory and experimental communities
H. Spiesberger: LHeC 5th workshop, Jan. 20, 2014