Top and EW Physics at the LHeC

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On behalf of

Outline

1) Introduction

2) Top physics at the LHeC

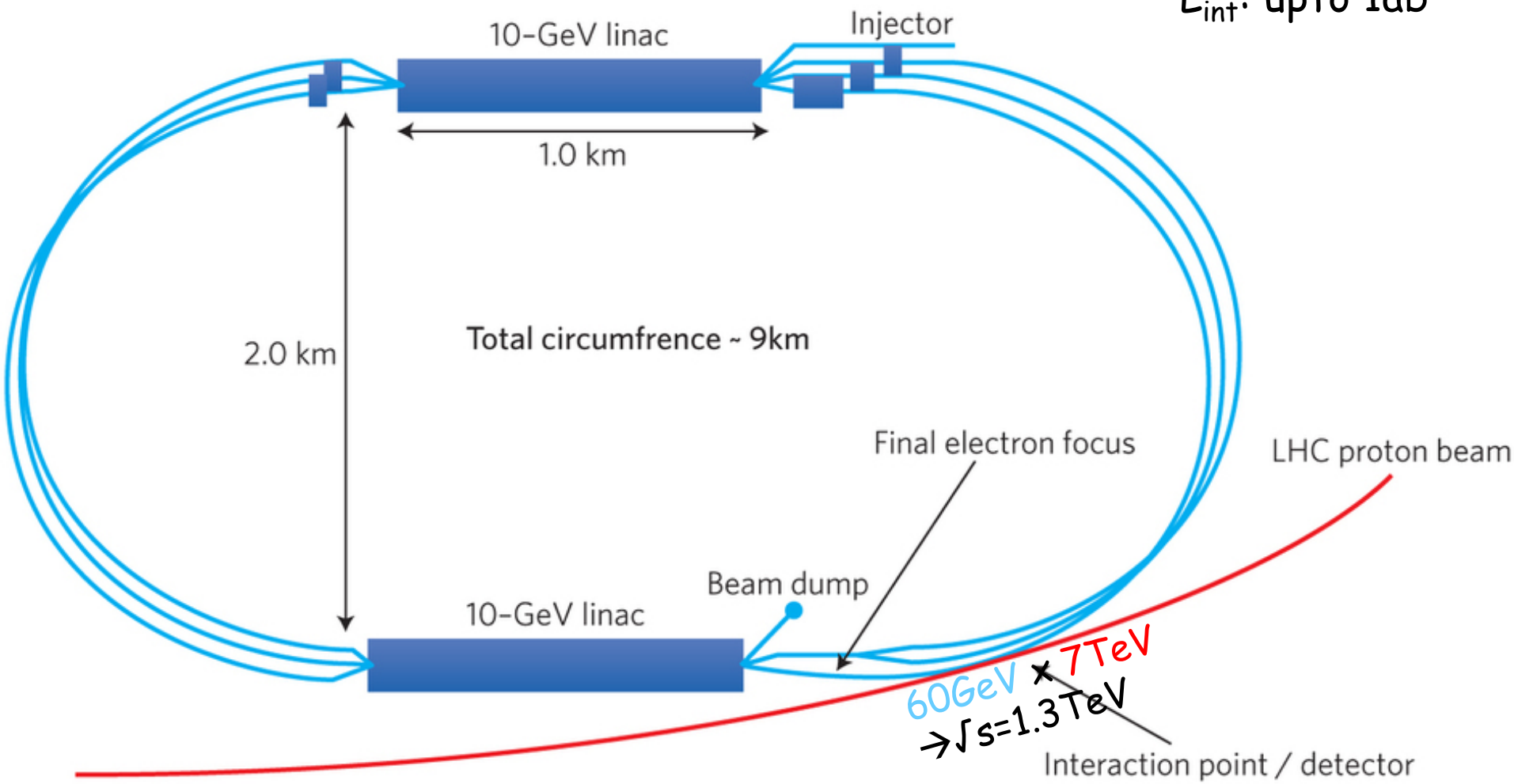
3) Examples of precision EW measurements

4) Summary

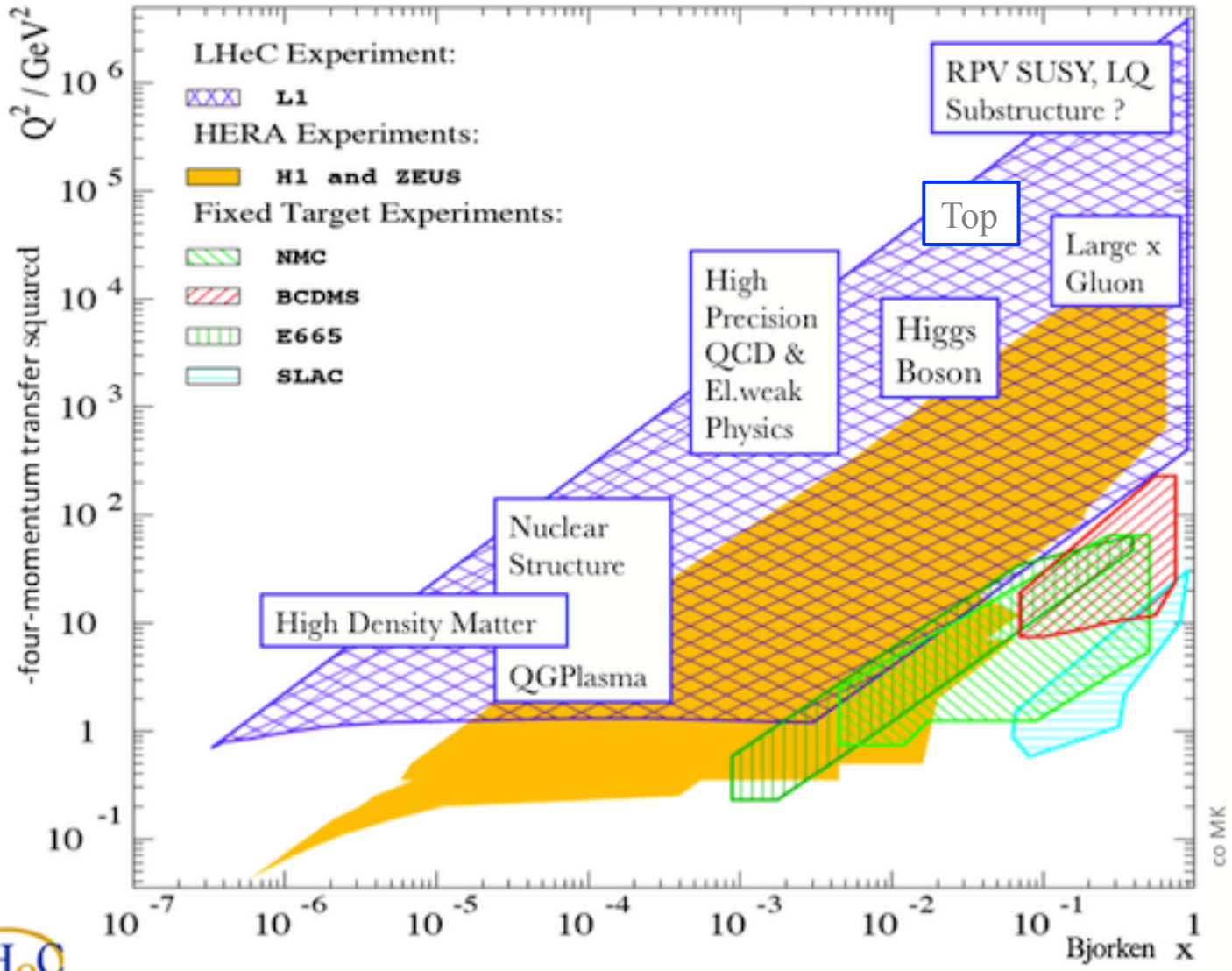
Introduction

Energy-Recovery Linac (ERL)

L: >10^{33} $cm^{-2}s^{-1}$
L_{int}: upto $1ab^{-1}$



Introduction



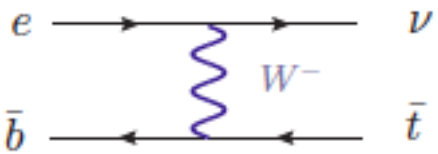
Largely extending HERA kinematic region into an unexplored territory

It has a very rich physics program

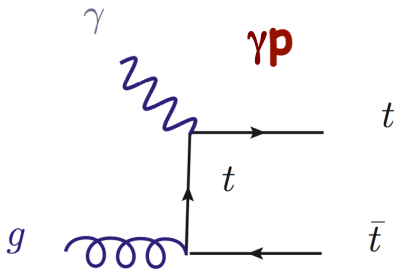
The focus of this talk is on top & EW physics

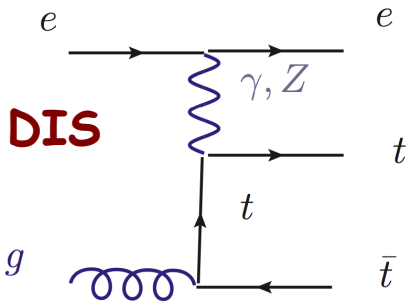
Top Physics at the LHeC

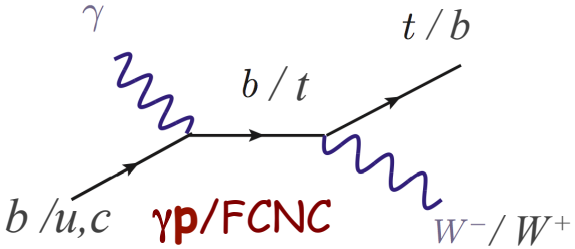
- **Single (anti)top production in Charged Current (CC) processes**
  - * Sensitive to PDFs of the proton
  - * Direct measurement of $|V_{tb}|$ (0.5%)
  - * Top quark polarization
  - * W boson helicity
  - * Search for anomalous Wtb couplings
  - * Study ttH in tH production?



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



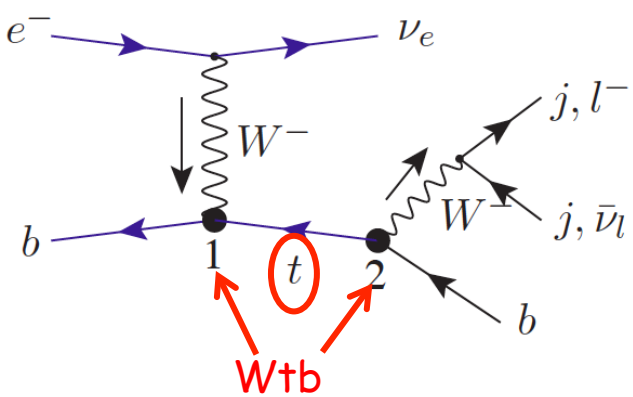


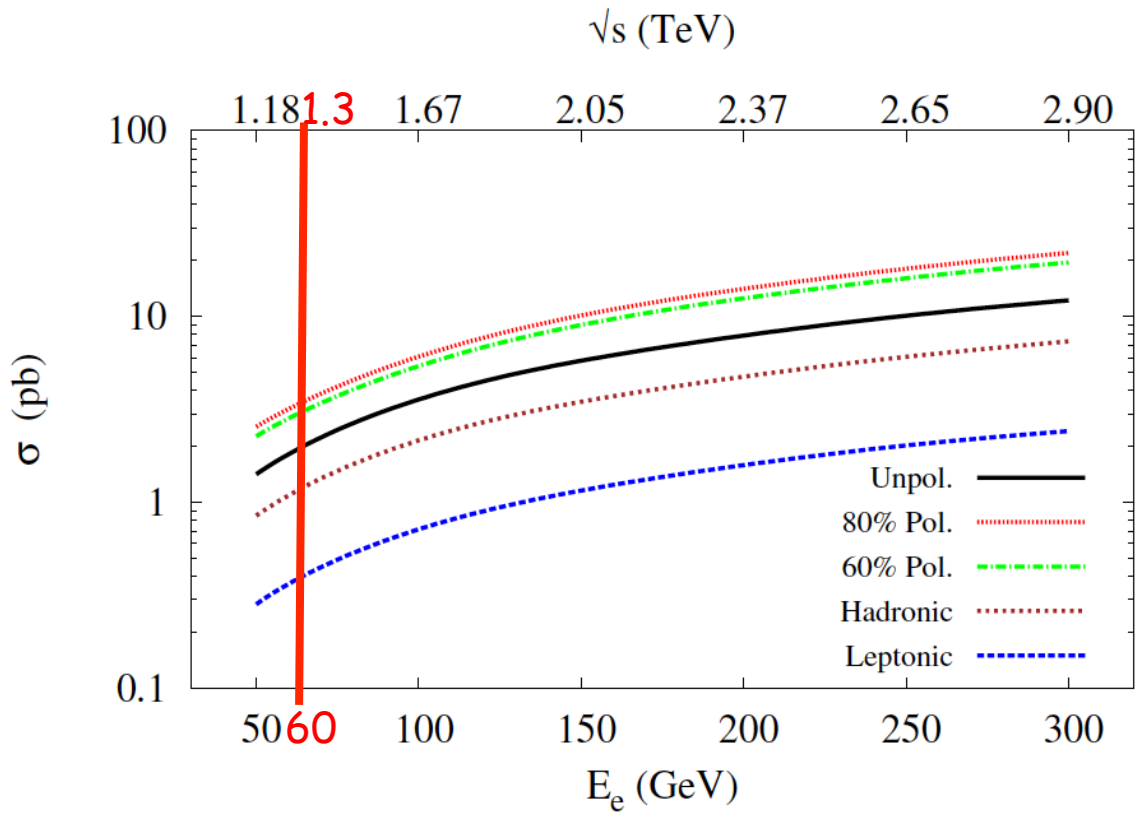


Single Top Production at LHeC

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

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=173GeV, t-channel), but large background and low selection efficiency

Anomalous Wtb Couplings

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

SM V-A, Left-handed Vector coupling

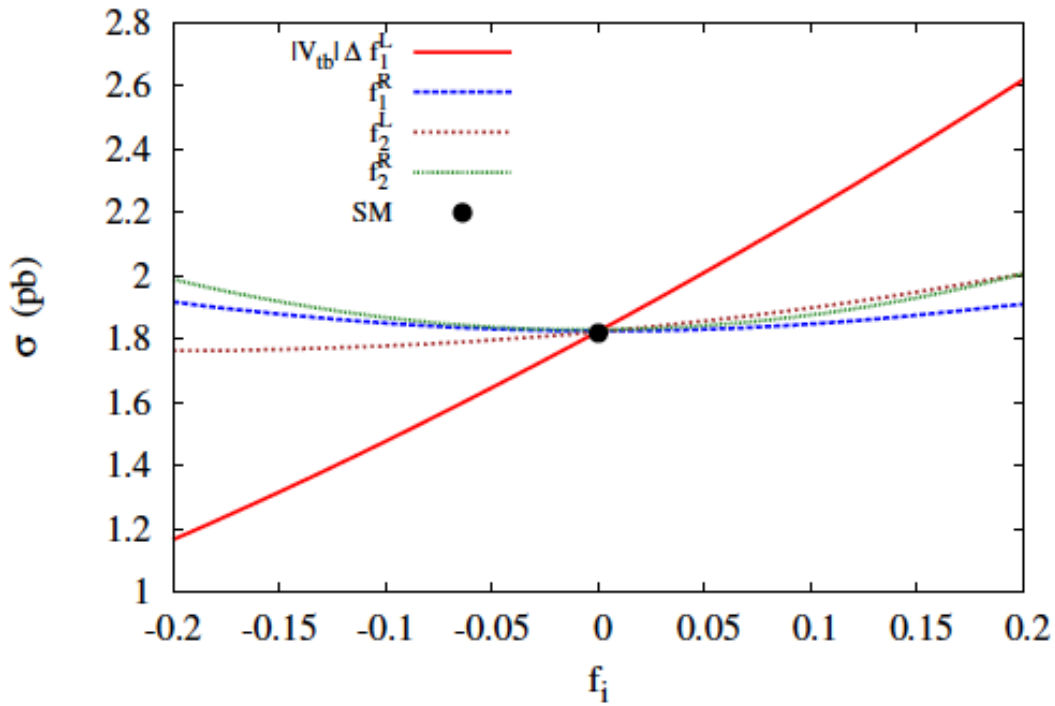
BSM, R-handed Vector coupling

BSM, L,R-handed Tensor couplings

$f_1^L = 1 + \Delta f_1^L$

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

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



LHeC expected to have the largest sensitivity to Δf_1^L

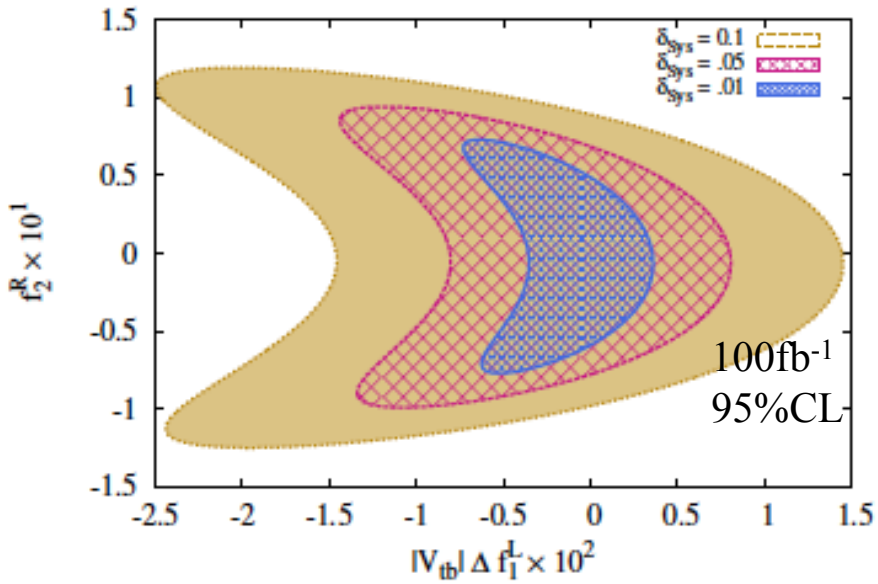
Expected Precision vs. Other Determinations

Dutta, Goya, Kumar, Mellado

http://arxiv.org/abs/1307.1688

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

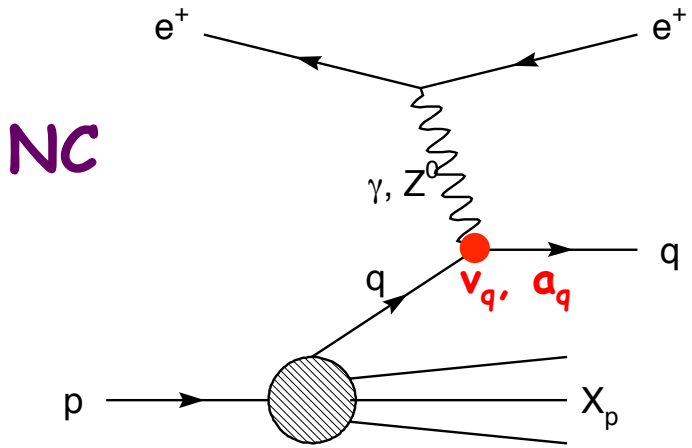
Similar constraints available for other couplings from both hadronic and leptonic decay modes

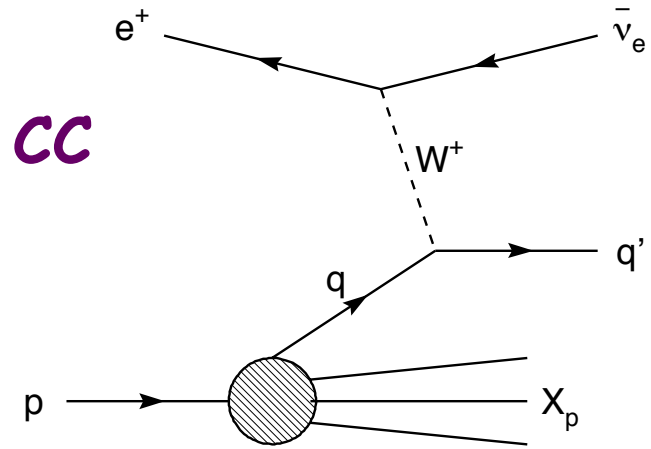


Upper limits at 95%CL	$\lvert\Delta f_1^L\rvert$	$\lvert f_1^R\rvert$	$\lvert f_2^L\rvert$	$\lvert f_2^R\rvert$
LHeC (100fb^{-1}, had, syst: 0.01-0.1)	0.005-0.03	0.01-0.1	0.01-0.1	0.01-0.1
D0 (5.4fb^{-1},W-helicity, single top) arXiv:1204.2332		0.548	0.324	0.347
LHC (Wt, γp, 100fb^{-1}) arXiv:1210.3235	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

$$\frac{d^2\sigma^{\pm}_{\rm NC}}{dxdQ^2} \sim Y_+\tilde{F}_2 \mp Y_-\tilde{F}_3 - y^2\tilde{F}_L \qquad \text{with} \quad Y_\pm = 1 \pm (1-y)^2$$

γ exchange γZ interference Z exchange

$$\tilde{F}_2 = F_2 - (\cancel{v_e} - P_e a_e)\kappa_Z F_2^{\gamma Z} + (\cancel{v_e^2} + a_e^2 - \cancel{2P_e v_e a_e})\kappa_Z^2 F_2^Z$$

v_e~0, ➔ some of the terms are negligible

$$x\tilde{F}_3 = -(a_e - \cancel{P_e v_e})\kappa_Z x F_3^{\gamma Z} + \left[\cancel{2v_e a_e} - P_e(\cancel{v_e^2} + a_e^2)\right]\kappa_Z^2 x F_3^Z$$

$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right]\{q + \bar{q}\}$$

$$\kappa_Z^{-1} = \frac{2\sqrt{2}\pi\alpha}{G_F M_Z^2}\frac{Q^2 + M_Z^2}{Q^2}$$

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_a a_q\right]\{q - \bar{q}\}$$

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

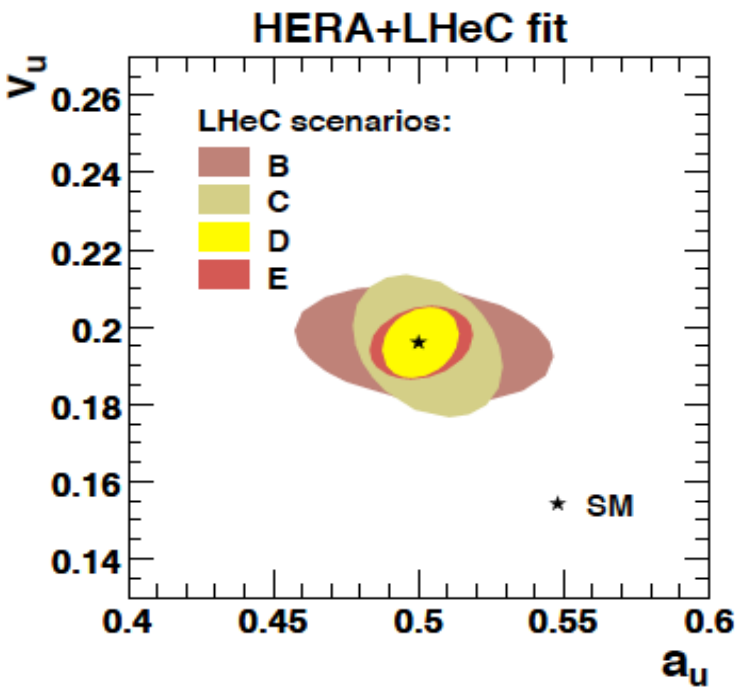
CC cross sections have similar but different structure functions and PDF combinations

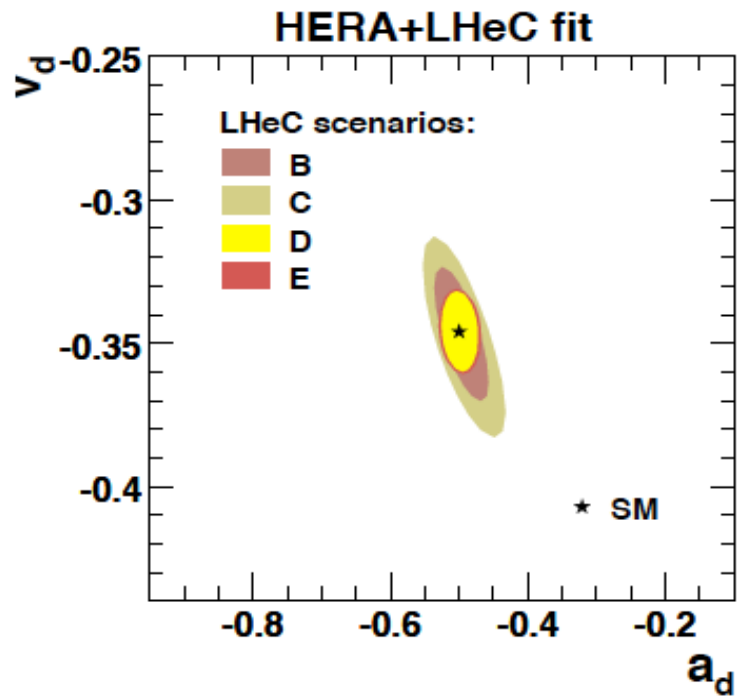
F_L=0 in LO parton model, F_L~g at NLO

Quark Couplings to the Z Boson

Simultaneous fit of quark couplings & PDFs to simulated LHeC & HERA NC, CC data

LHeC CDR http://arxiv.org/abs/1206.2913



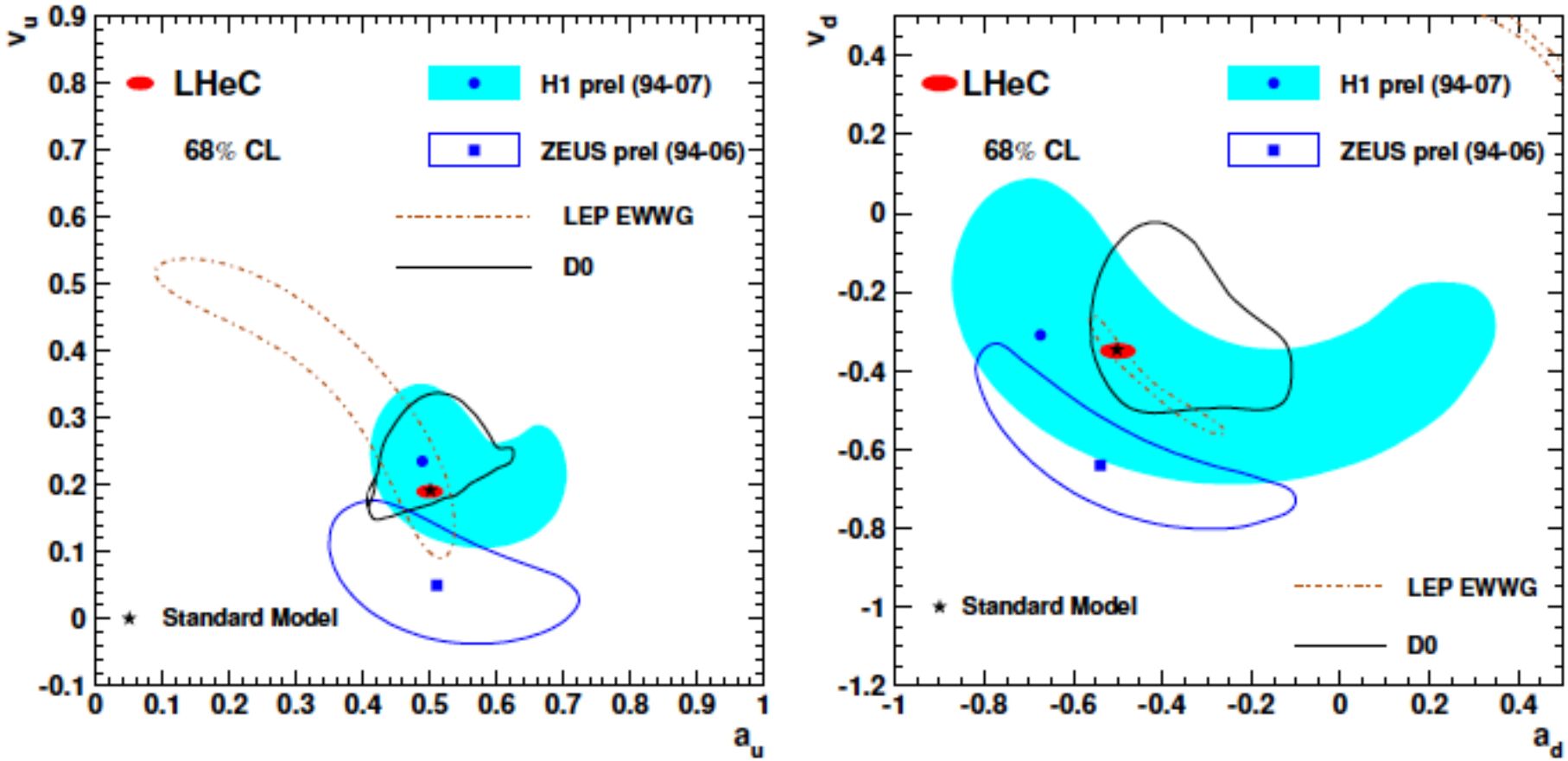


Set	E_e/GeV	E_N/TeV	N	L^+/fb^{-1}	L^-/fb^{-1}	Pol
B	50	7	7	50	50	0.4
C	50	7	7	1	1	0.4
D	100	7	7	5	10	0.9
E	150	7	7	3	6	0.9

B has smaller acceptance than C

A Comparison with Other Determinations

LHeC CDR http://arxiv.org/abs/1206.2913



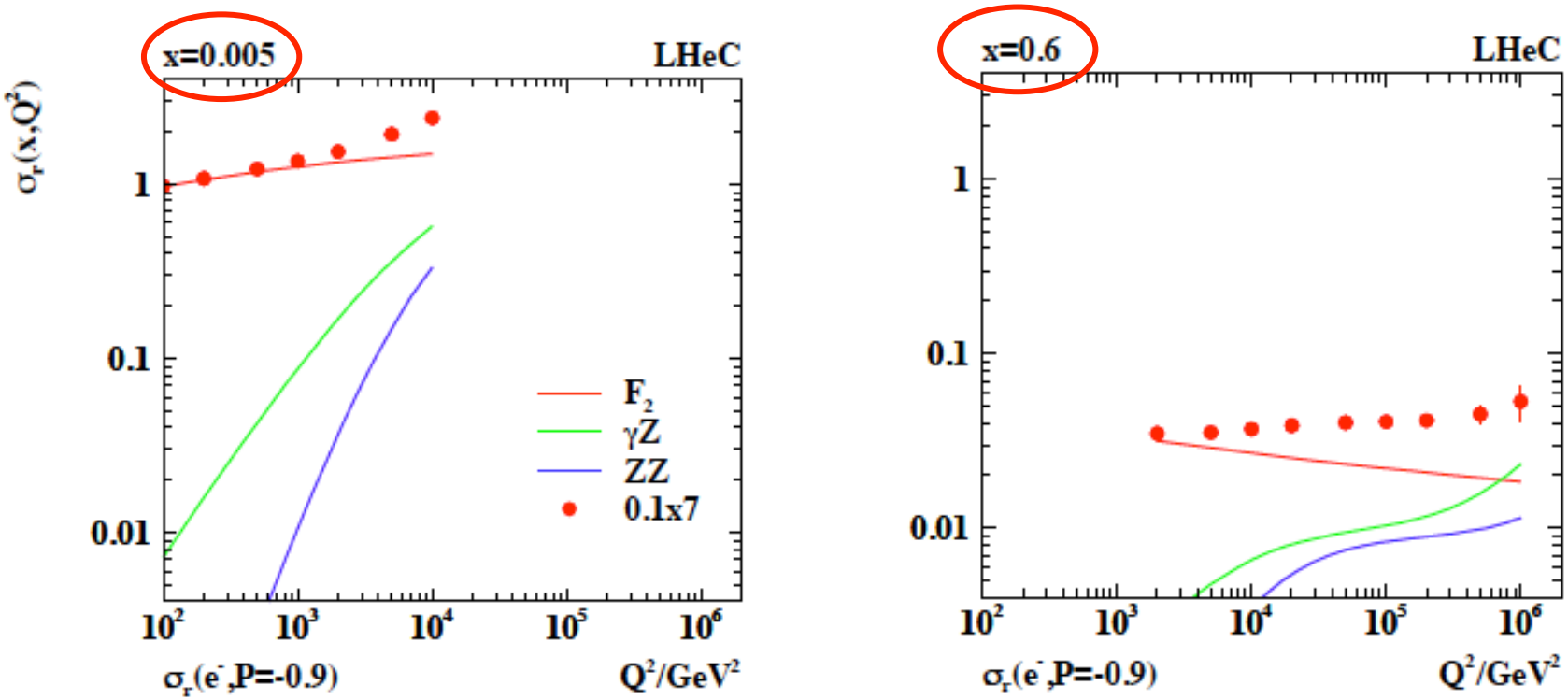
LHeC has great potential to determine quark couplings with unprecedented precision

Note: LHeC corresponds to scenario C,
HERA determination is being updated, some improvement expected

Relative Contribution of γZ & Z

LHeC CDR http://arxiv.org/abs/1206.2913

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

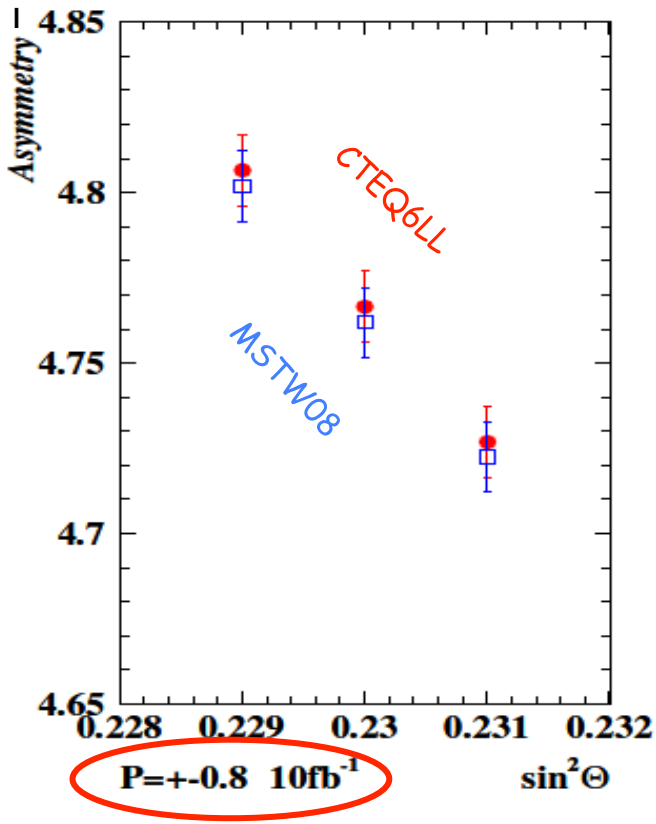


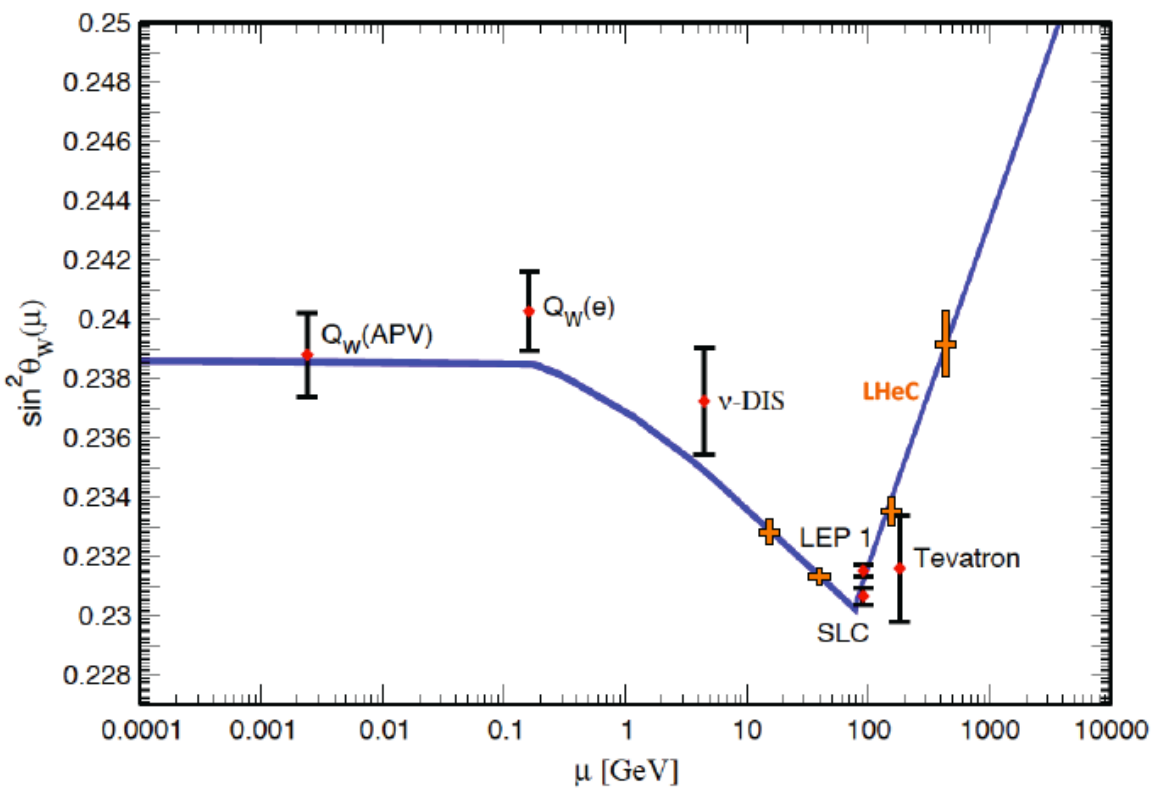
The relative contribution of γZ interference & Z exchange becomes increasingly important toward high x and Q^2

Pol. Asymmetry & Weak Mixing Angle

LHeC CDR http://arxiv.org/abs/1206.2913

$$A^{\pm} = \frac{\sigma^{\pm}_{\rm NC}(P_R) - \sigma^{\pm}_{\rm NC}(P_L)}{\sigma^{\pm}_{\rm NC}(P_R) + \sigma^{\pm}_{\rm NC}(P_L)} \simeq \mp \frac{\kappa_Z a_e (P_L - P_R)}{2} \frac{F_2^{\gamma Z}}{F_2} \qquad \kappa_Z^{-1} = 4\sin^2\theta\cos^2\theta \frac{Q^2 + M_Z^2}{Q^2}$$



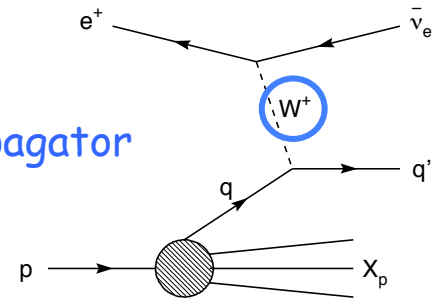


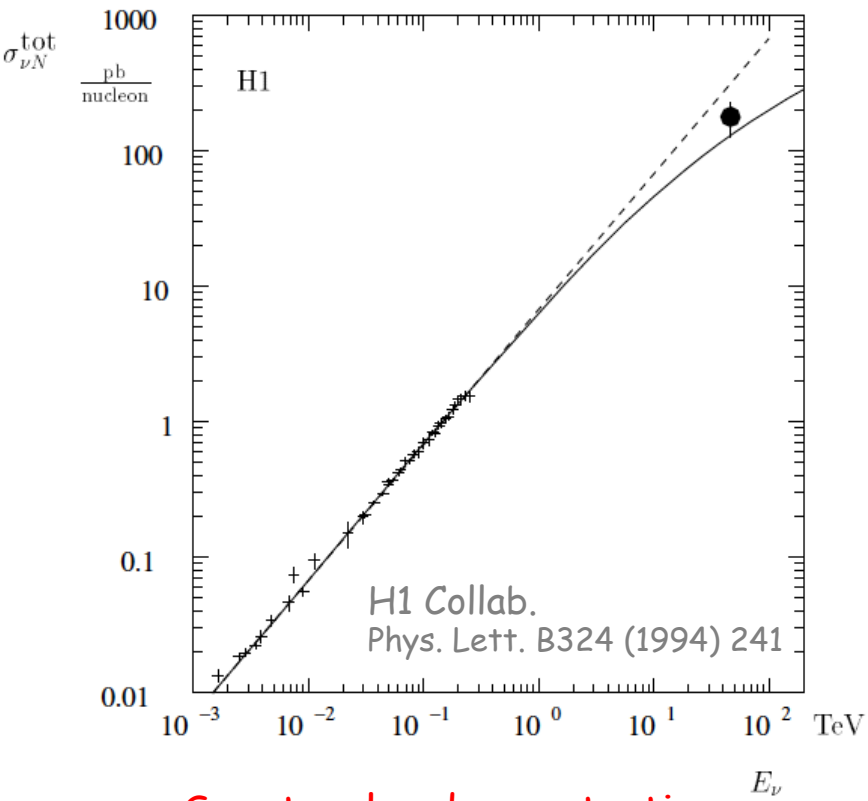
NC/CC cross section ratio also sensitive to $\sin^2\theta$ provided PDFs dependence is under control

Expected LHeC determination is precise and covers a large energy scale range

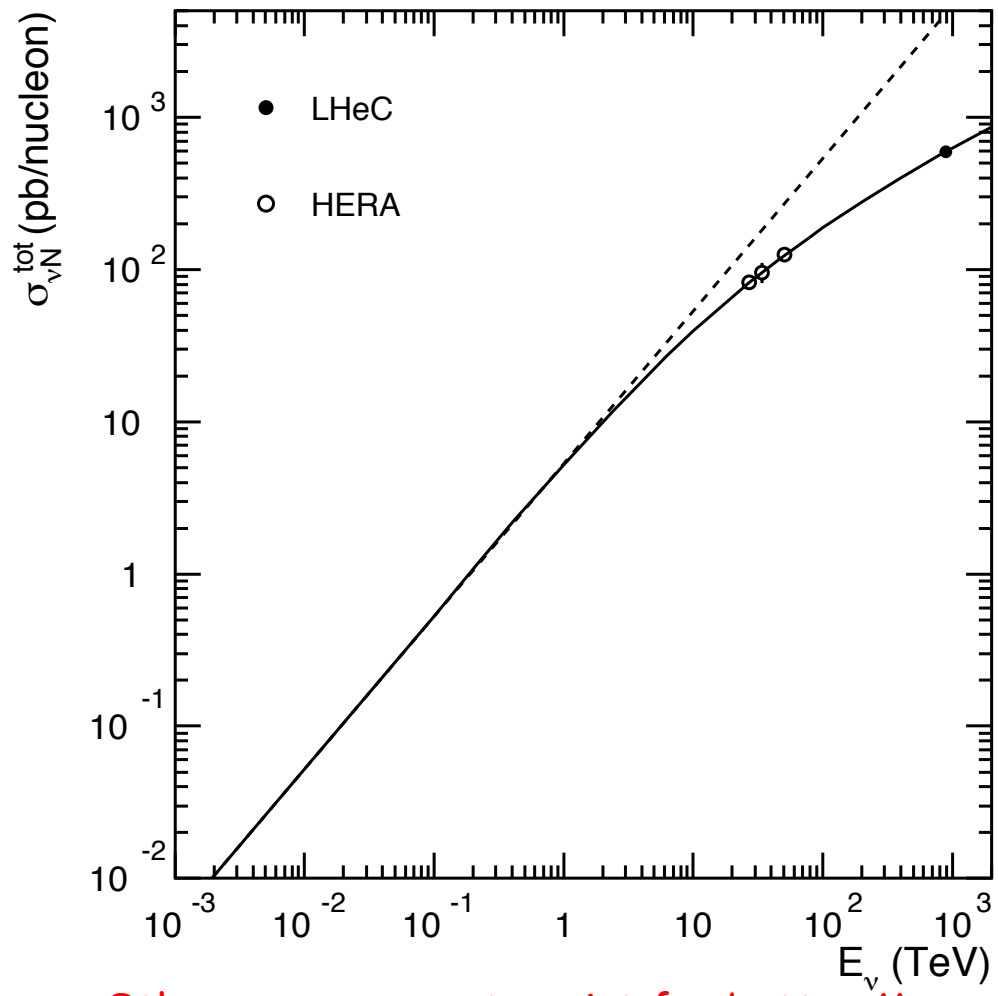
CC Total Cross Section vs M_W

CC:
W propagator mass





Spectacular demonstration of finite/massive M_W



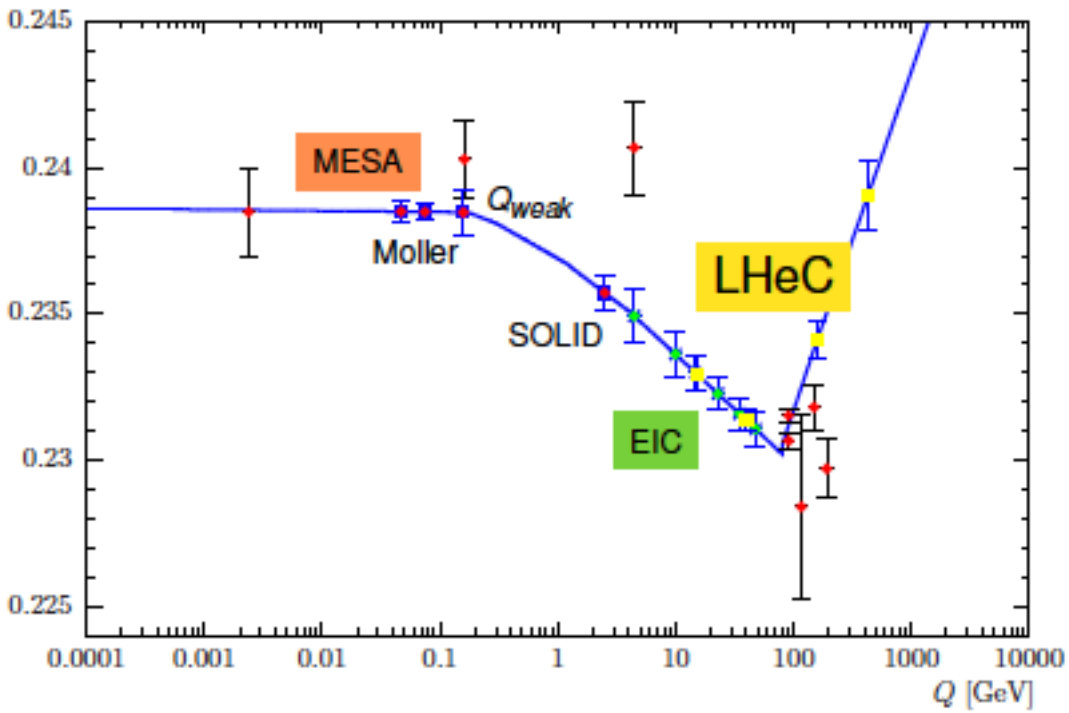
Other measurements exist for better M_W determination & constraining right-handed CC

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

Backup: Weak Mixing Angle

H. Spiesberger: LHeC 5th workshop, Jan. 20, 2014



Future of $\sin^2 \hat{\theta}_W(Q)$

- Low energy
  MESA, Moller, Q_{weak}
- Medium energy
  SOLID, EIC
- High energy
  LHC, LHeC