

EW AND BSM PHYSICS BETWEEN THE LHEC AND THE EIC

STEFANO FORTE
UNIVERSITÀ DI MILANO & INFN



UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

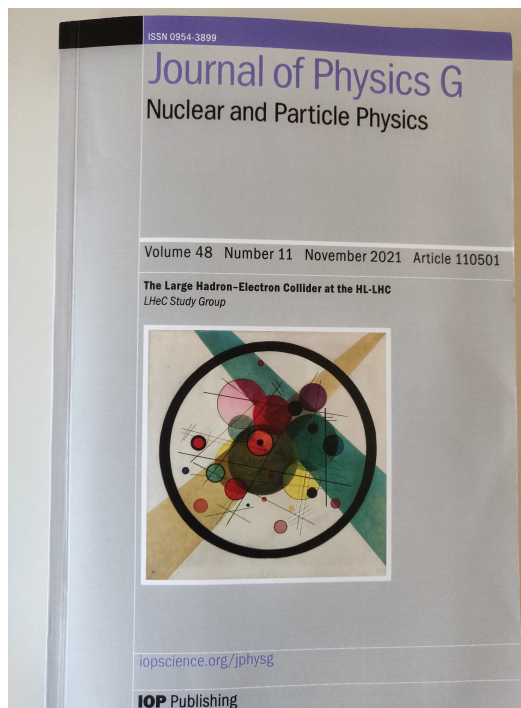


Istituto Nazionale di Fisica Nucleare

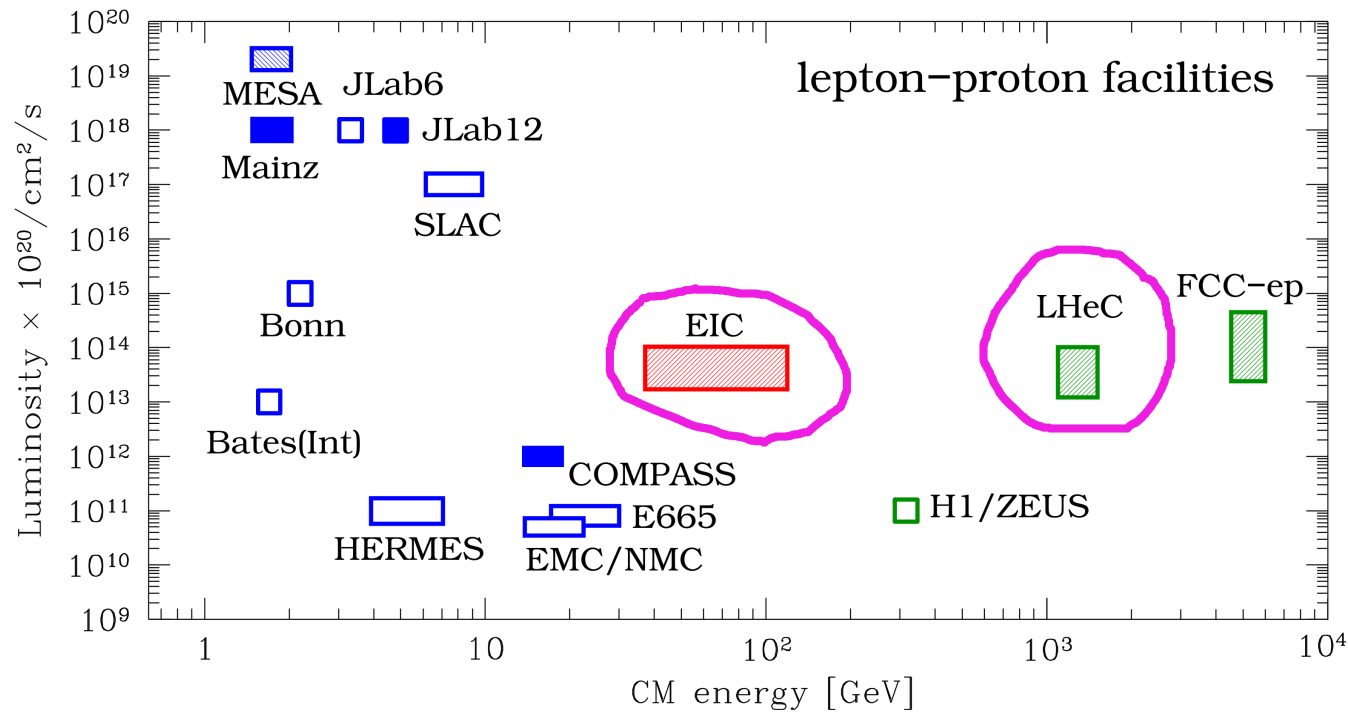
EIC-LHC synergy meeting

CERN, 21 June 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 740006



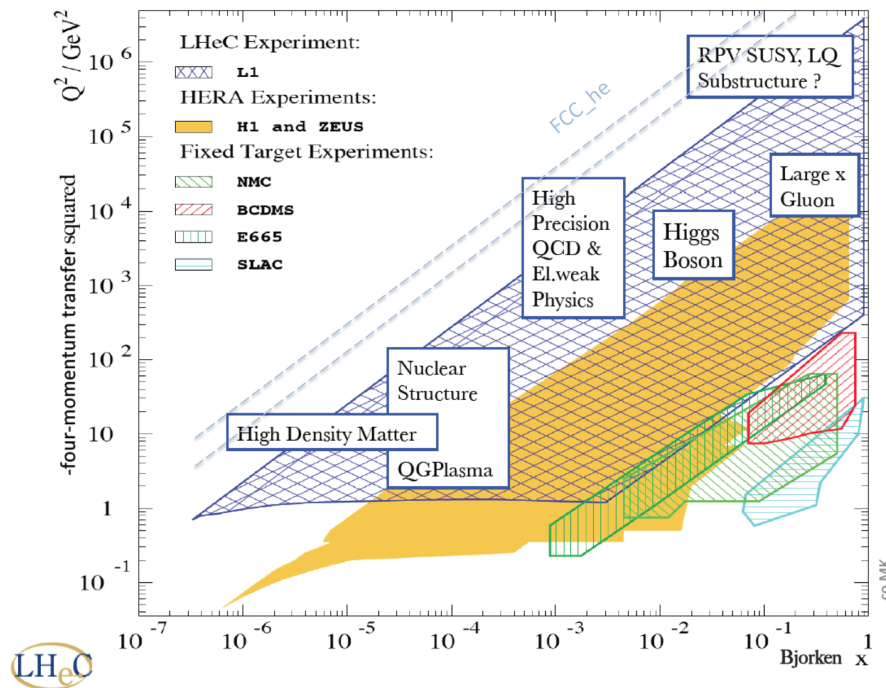
PAST AND FUTURE; REAL AND VIRTUAL



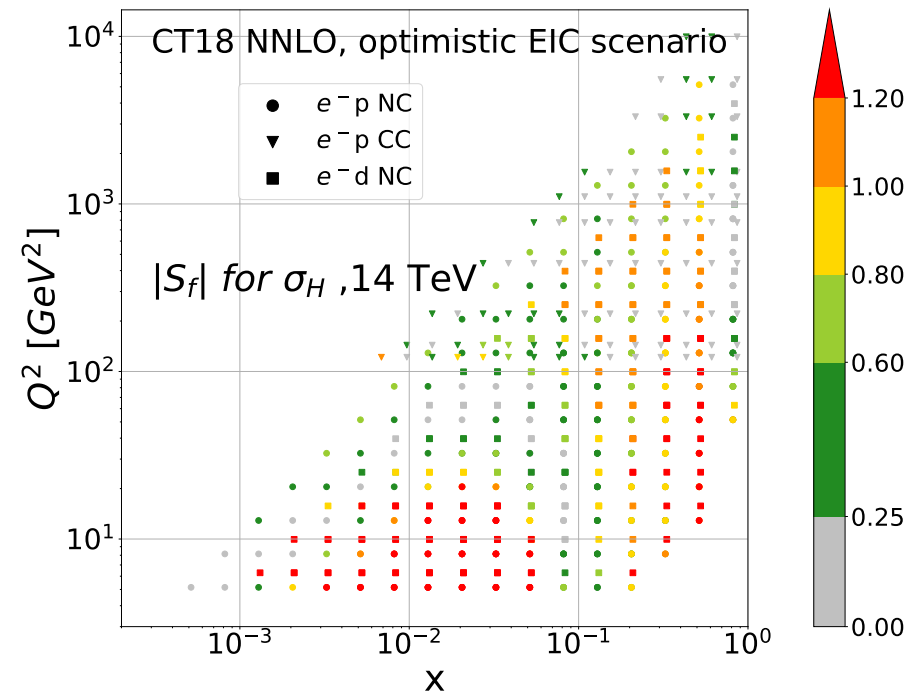
- POSITRON OPTION: BOTH
- LIGHT NUCLEAR TARGET (d , ^3He) MOSTLY EIC
- PROTON POLARIZATION: EIC ONLY

KINEMATIC COVERAGE

LHeC



EIC



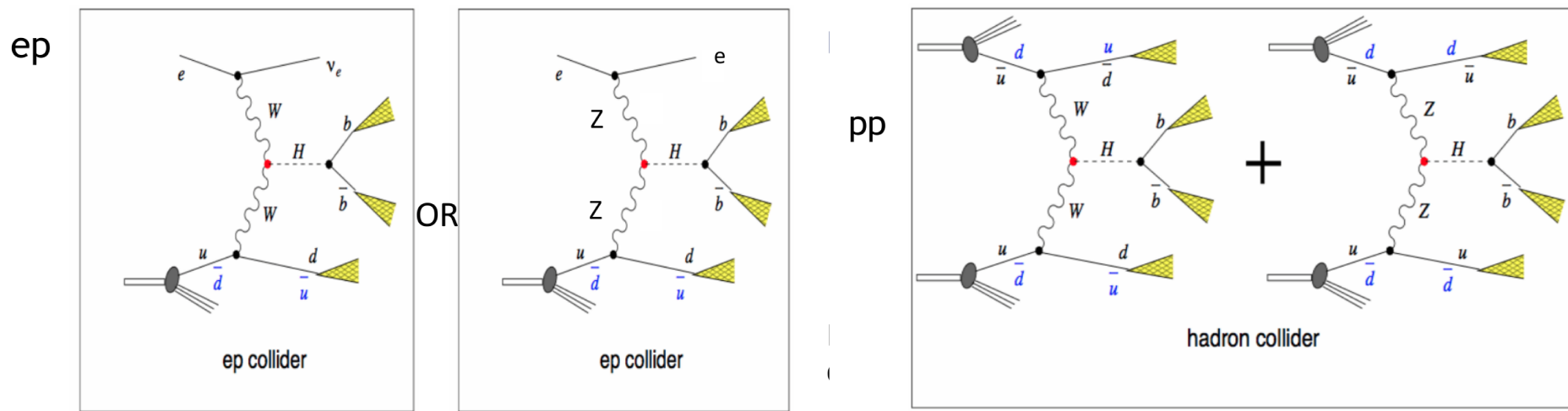
OUTLINE

- WHAT CANNOT BE DONE AT THE EIC: HIGGS AND TOP
- PRECISION EW: THE WEINBERG ANGLE AND GLOBAL FITS
- BSM: FROM SMEFT FITS TO LFV, ALPS, DARK PHOTONS AND MORE

WHAT CANNOT BE DONE AT THE EIC

HIGGS PRODUCTION

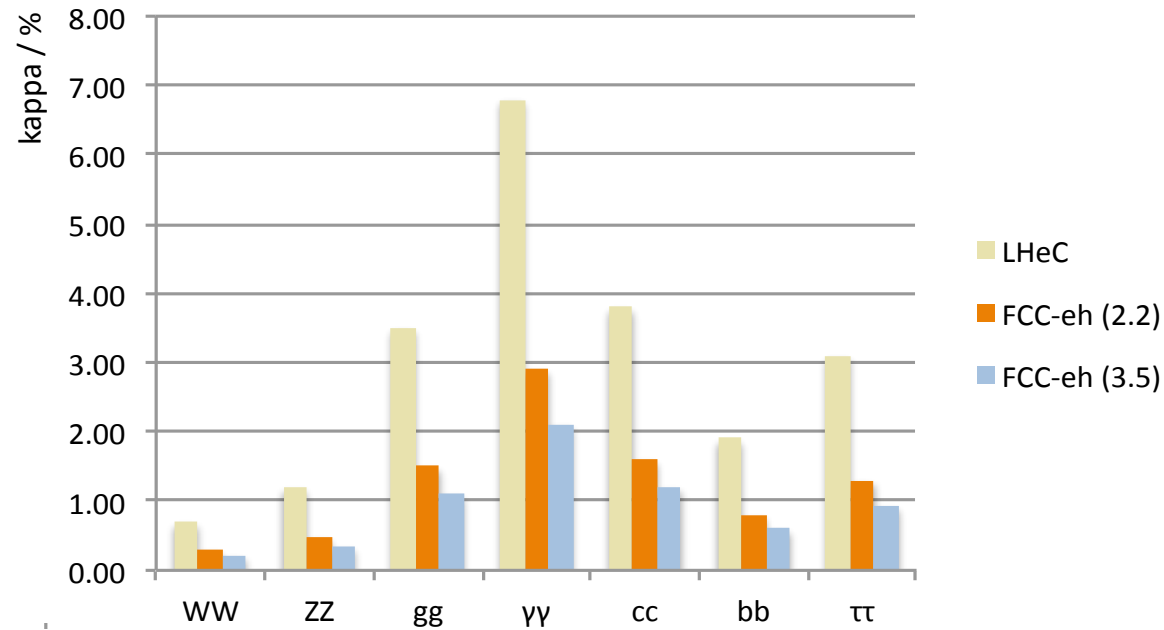
EP VS. PP



- HIGGS PRODUCED IN CC OR NC INTERACTIONS
- CLEAN SIGNAL AND ZZH vs. WWH SEPARATION $\Rightarrow$ PROBE OF HWW VERTEX $\rightarrow$ HIGGS CP PROPERTIES
- DIRECTION OF FS QUARK WELL DEFINED $\rightarrow$ ACCURATE $b\bar{b}$ DECAY MEASUREMENT

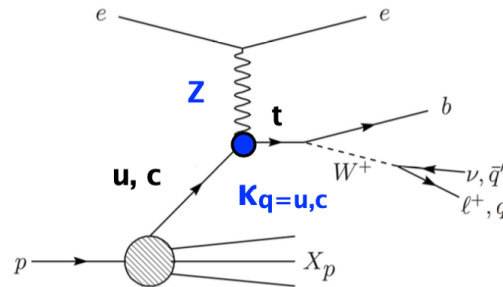
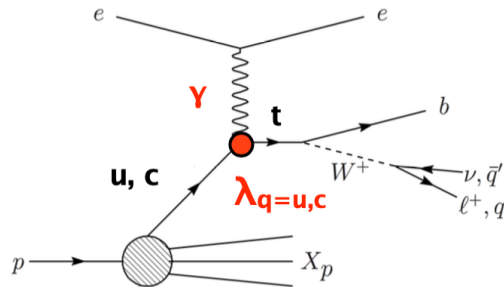
HIGGS PHYSICS AT THE LHeC (AND FCC-EH)

SUMMARY OF UNCERTAINTIES ON COUPLINGS

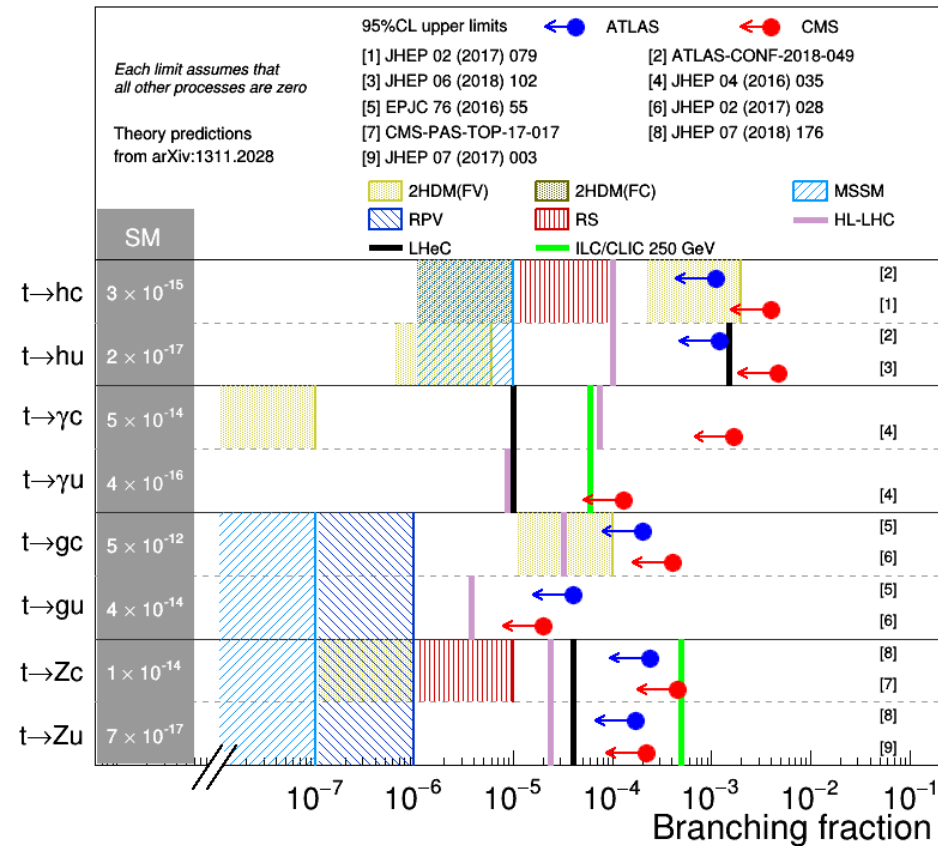


- GLUON FUSION AND W FUSION $\Rightarrow$ CURRENTLY MEASURED AT 10% - 20%
- $H\bar{b}b$ MEASURED TO PERCENTAGE PRECISION;
- $\tau\tau$ AND $\bar{c}c$ ALSO MEASURABLE

TOP PHYSICS AT THE LHeC: FCNC



- CLEAN DEEP-INELASTIC SINGLE TOP PRODUCTION
- TEST ANOMALOUS COUPLINGS
- COMPETITIVE WITH ILC FOR $tq\gamma$ & tuZ



PRECISION EW PHYSICS

DIS: EXPLOITING THE POTENTIAL

CROSS-SECTION AND COUPLINGS

$$\frac{d^2\sigma^i}{dxdy} = \frac{2\pi\alpha^2}{xyQ^2} \eta^i \left[Y_+ F_2^i \mp Y_- x F_3^i - y^2 F_L^i \right] \quad \eta_\gamma = 1 \ ; \ \eta_{\gamma Z} = \left(\frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha} \right) \left(\frac{Q^2}{Q^2 + M_Z^2} \right);$$

$$\eta_Z = \eta_{\gamma Z}^2 \ ; \ \eta_W = \frac{1}{2} \left(\frac{G_F M_W^2}{4\pi\alpha} \frac{Q^2}{Q^2 + M_W^2} \right)^2.$$

$$\pm \leftrightarrow e^\pm$$

CHARGED CURRENT STRUCTURE FUNCTIONS

$$\eta^{\text{CC}} = (1 \pm \lambda)^2 \eta_W \quad F_2^{W^-} = 2x(u + \bar{d} + \bar{s} + c \dots) \ ,$$

$$F_3^{W^-} = 2(u - \bar{d} - \bar{s} + c \dots) \ ,$$

$$\lambda \Rightarrow \text{pol.}$$

NEUTRAL CURRENT STRUCTURE FUNCTIONS

$$F_2^{\text{NC}} = F_2^\gamma - (g_V^e \pm \lambda g_A^e) \eta_{\gamma Z} F_2^{\gamma Z} + (g_V^{e2} + g_A^{e2} \pm 2\lambda g_V^e g_A^e) \eta_Z F_2^Z$$

$$xF_3^{\text{NC}} = -(g_A^e \pm \lambda g_V^e) \eta_{\gamma Z} x F_3^{\gamma Z} + [2g_V^e g_A^e \pm \lambda(g_V^{e2} + g_A^{e2})] \eta_Z x F_3^Z$$

$$g_V^e = -\frac{1}{2} + 2 \sin^2 \theta_W, \quad g_A^e = -\frac{1}{2}$$

- CAN DISENTANGLE M_w , $\sin^2 \theta_w$
- MINIMIZE PDF DEPENDENCE

EXTRACTING THE COUPLINGS

COMBINATIONS & ASYMMETRIES

EXAMPLE: THE PASCHOS-WOLFENSTEIN RATIO:

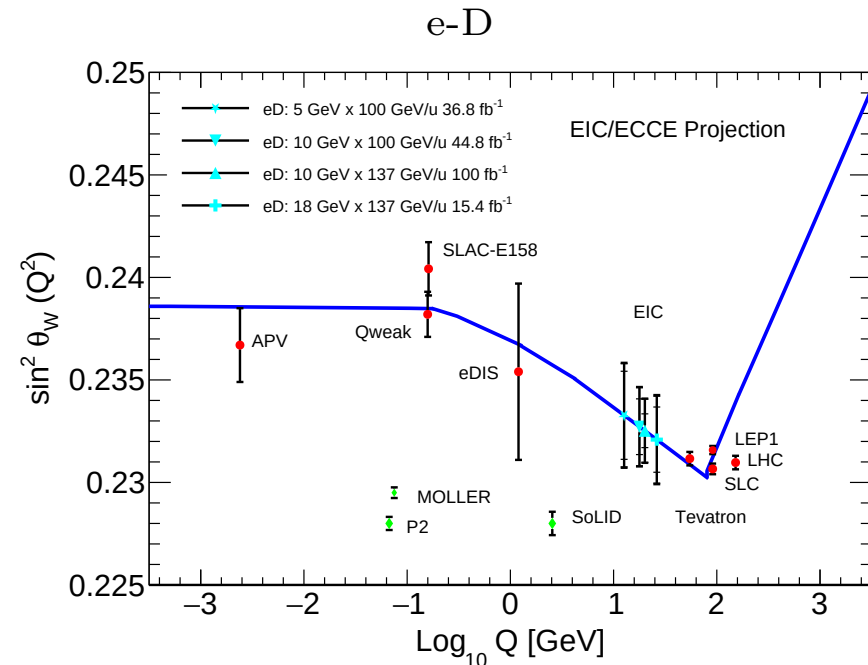
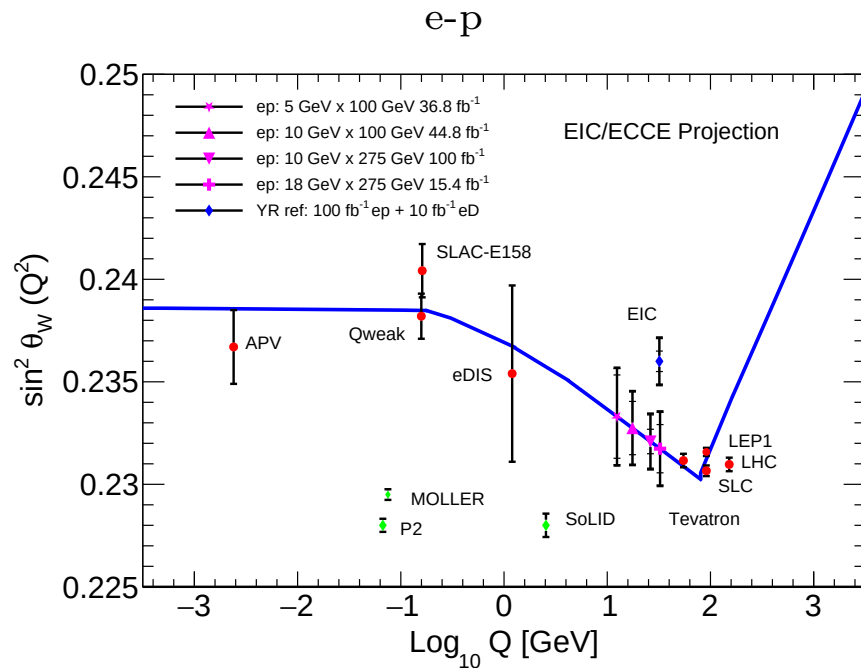
$$R^- = \frac{\sigma_{NC}(\nu_\mu) - \sigma_{NC}(\bar{\nu}_\mu)}{\sigma_{CC}(\nu_\mu) - \sigma_{CC}(\bar{\nu}_\mu)} = \frac{1}{2} - \sin^2 \theta_W$$

- $g_V - g_A$ SEPARATION $\Leftrightarrow$ POSITRONS
- ISOTRIplet-ISOSINGLET $\Leftrightarrow$ DEUTERON
- $W - Z$ $\Leftrightarrow$ CC vs. NC

ALL INFORMATION COMBINED IN A GLOBAL PDF-EW FIT

ELECTROWEAK MIXING ANGLE: EIC

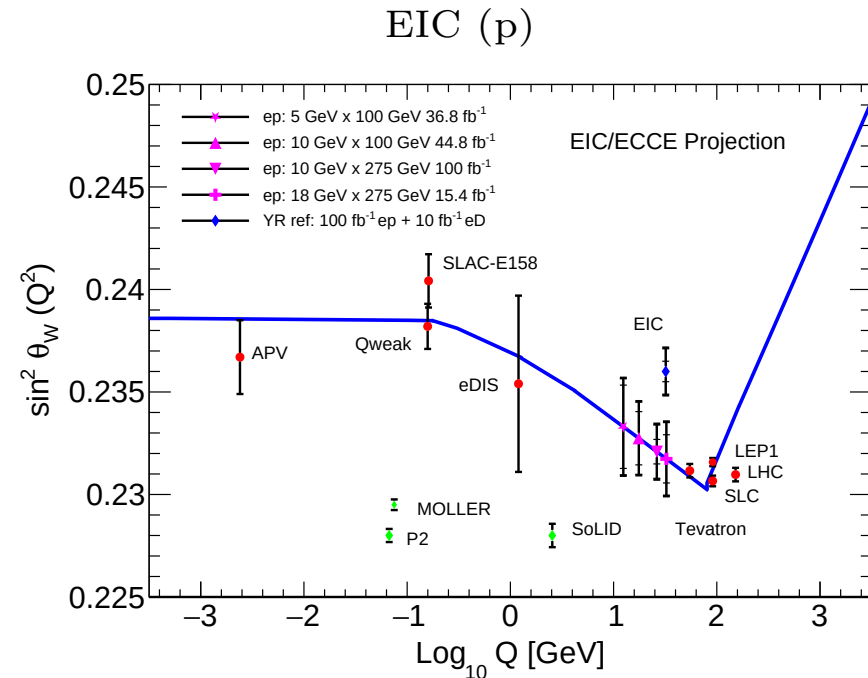
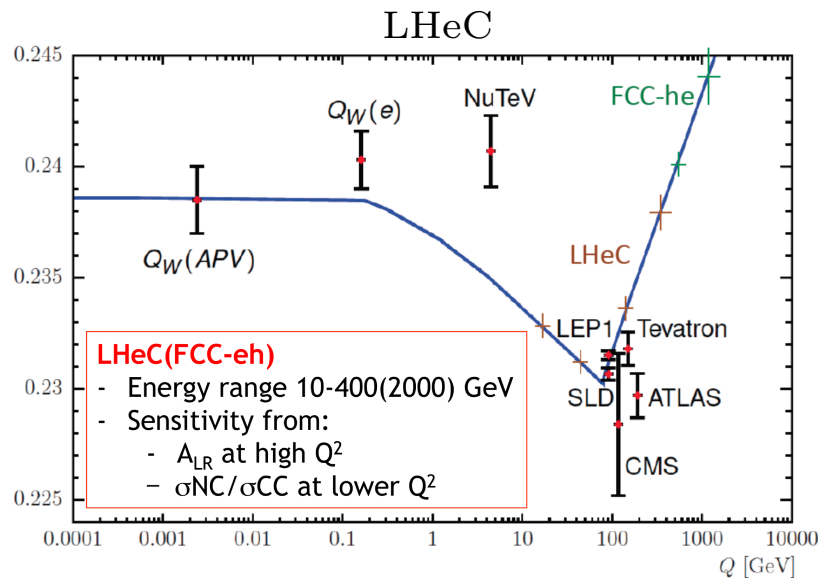
- $\sin^2 \theta_W$ FROM NC POLARIZATION ASYMMETRY
- SEVERAL Q^2 VALUES $\Rightarrow$ TEST OF SCALE DEPENDENCE



- COMPETITIVE WITH EXISTING DETERMINATIONS
- COULD IMPROVE WITH GLOBAL EW-PDF FIT

ELECTROWEAK MIXING ANGLE: EIC vs. LHeC

- $\sin^2 \theta_W$ FROM NC POLARIZATION ASYMMETRY
- LHeC: **HIGHER** ENERGY, **COMPARABLE** UNCERTAINTY

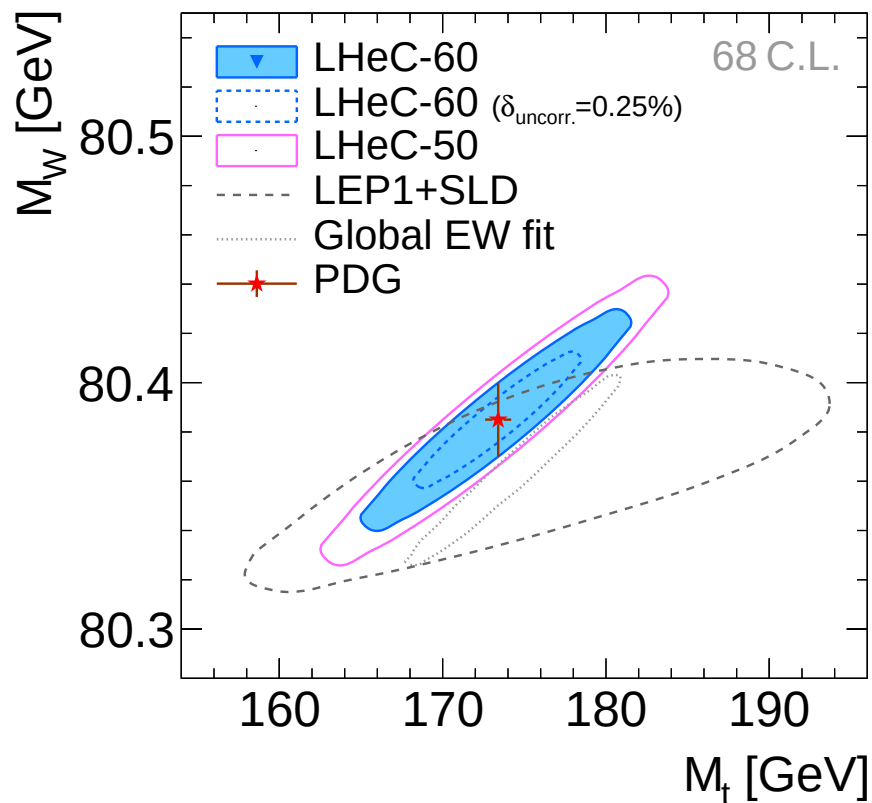


- **COMPETITIVE** WITH EXISTING DETERMINATIONS
- COULD **IMPROVE** WITH GLOBAL EW-PDF FIT

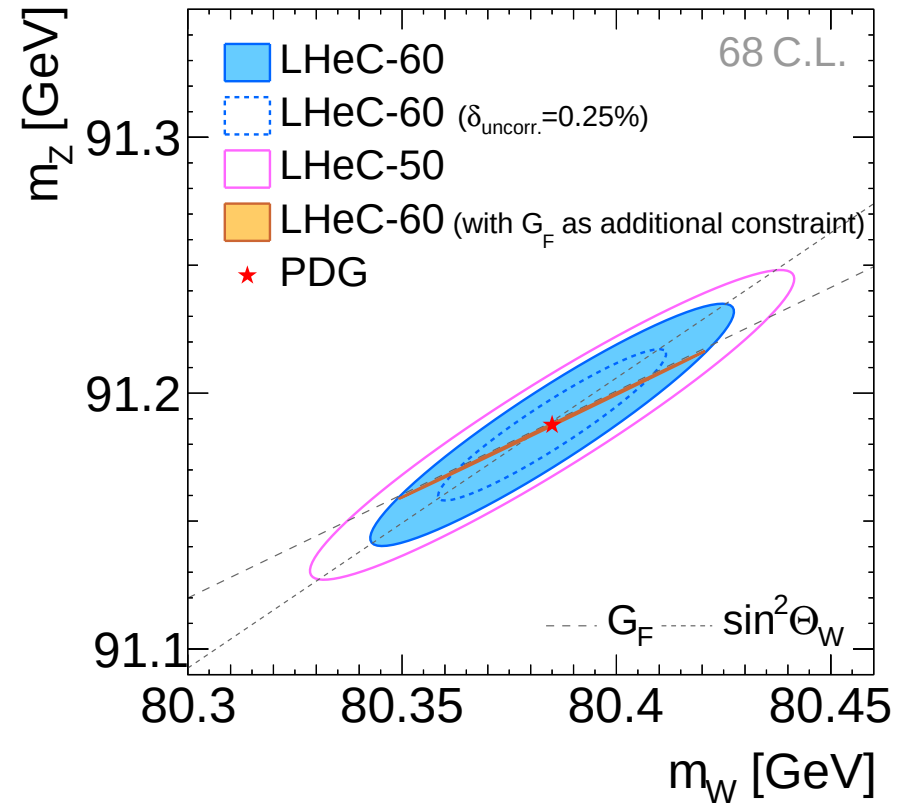
LHeC: GLOBAL EW+QCD FIT

- CANNOT USE EXTERNAL PDF SET WHEN MEASURING SM PARAMETERS
- SIMULTANEOUS FIT $\Rightarrow$ RELIABLE UNCERTAINTIES
- ALL INFORMATION INCLUDED $\Rightarrow$ UNCERTAINTIES MINIMIZED

top and W mass



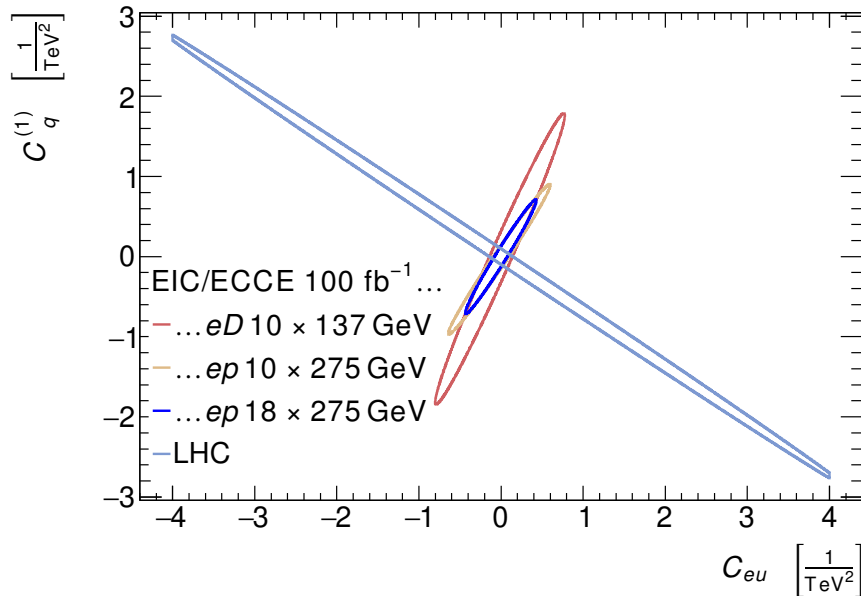
W and Z mass



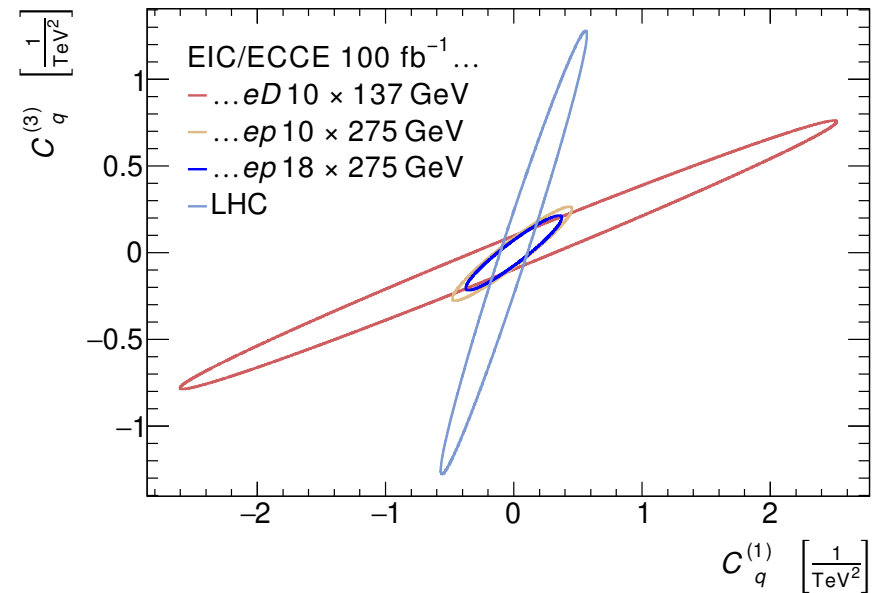
(SOME) BSM SEARCHES

SMEFT FITS

$$(\bar{\ell}_L \gamma^\mu \ell_L)(\bar{q}_L \gamma^\mu q_L) \text{ vs. } (\bar{e}_R \gamma^\mu e)(R\bar{u}_R \gamma^\mu q_R)$$



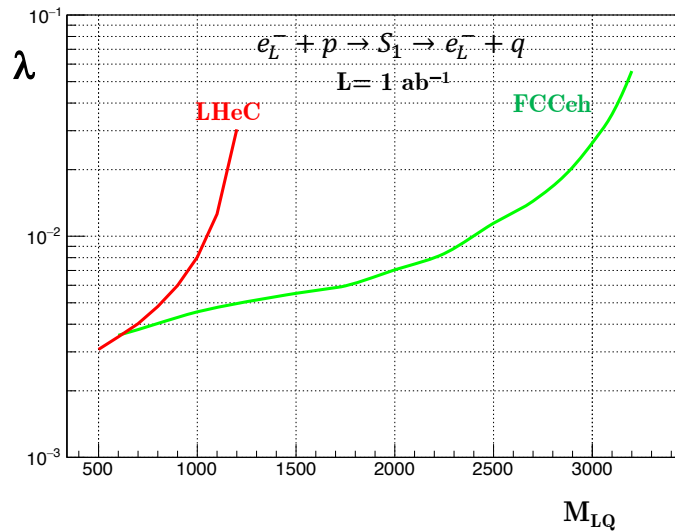
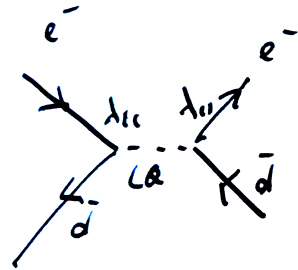
$$(\bar{\ell}_L \gamma^\mu \tau^I \ell_L)(\bar{q}_L \gamma^\mu \tau^I q_L) \text{ vs. } (\bar{e}_R \gamma^\mu e_R)(\bar{u}_R \gamma^\mu q_R)$$



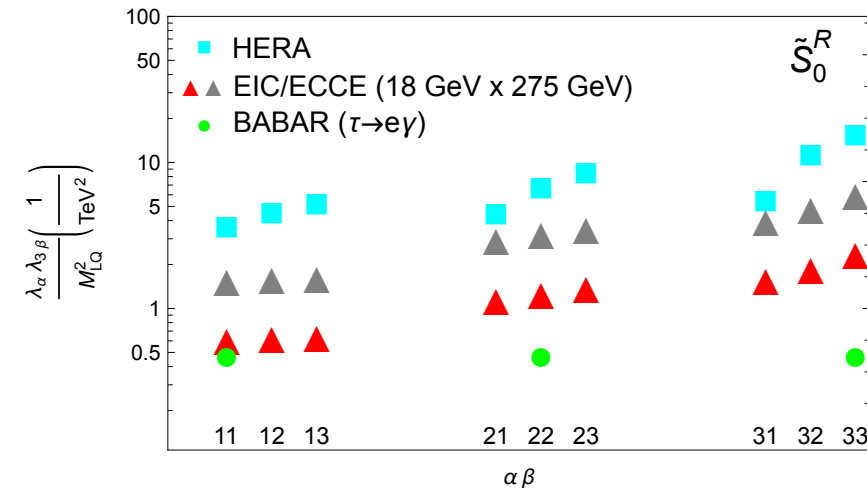
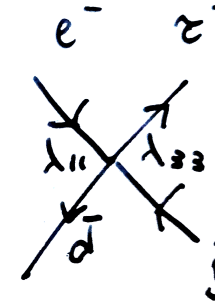
- FIT OF DIMENSION 6 OPERATORS
- COMBINATION OF HADRONIC (DY) & DIS (PVA) OBSERVABLES
- FLAT DIRECTIONS REMOVED
- GLOBAL SMEFT+ PDF FIT (SMEFiT, PBSB)

LEPTOQUARKS

LHeC: s -CHANNEL RESONANCE



LHeC: EFFECTIVE LFV INTERACTION

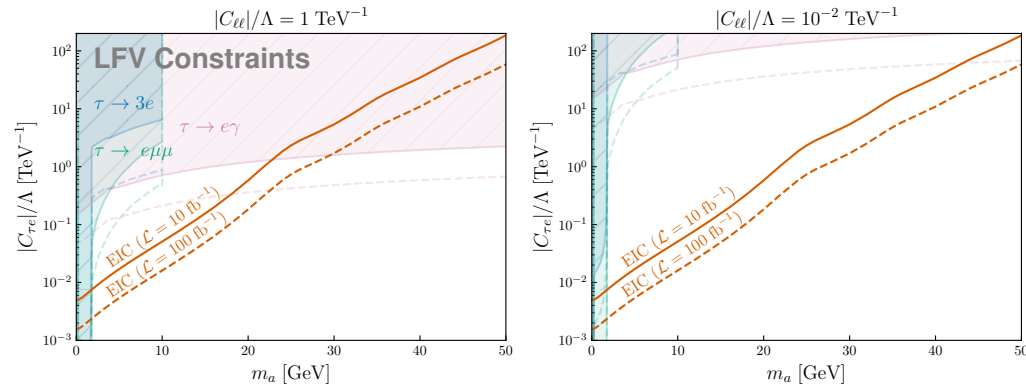
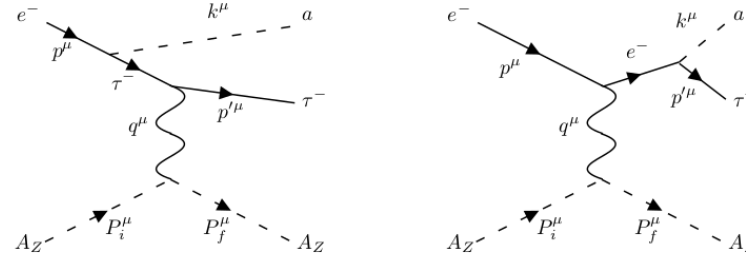
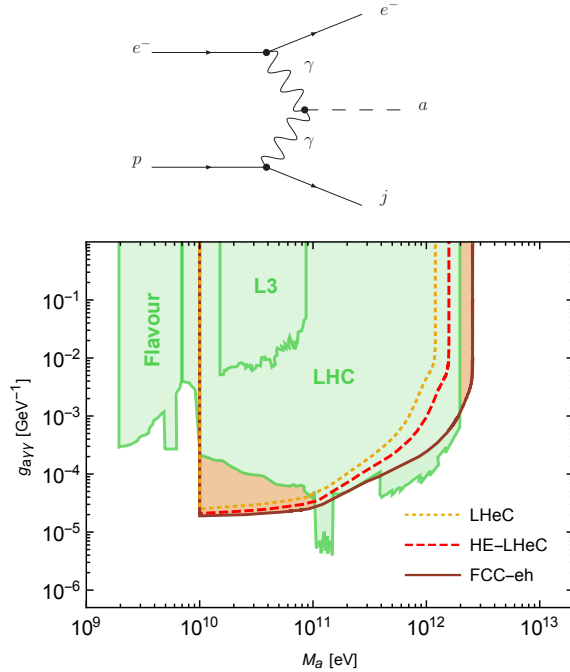


- **LHeC** vs **EIC**: **RESONANCE** vs. **LFV INTERACTION**
- **EIC**: **ORDER ONE COUPLING** PROBED FOR **TeV-SCALE**

AXION-LIKE PARTICLES

EIC: LFV RADIATION

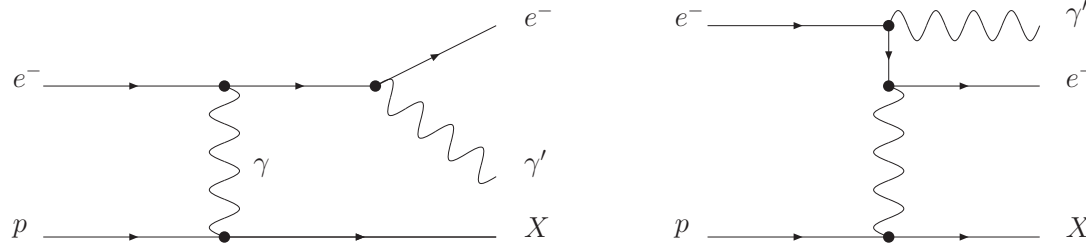
LHeC: s -CHANNEL RESONANCE



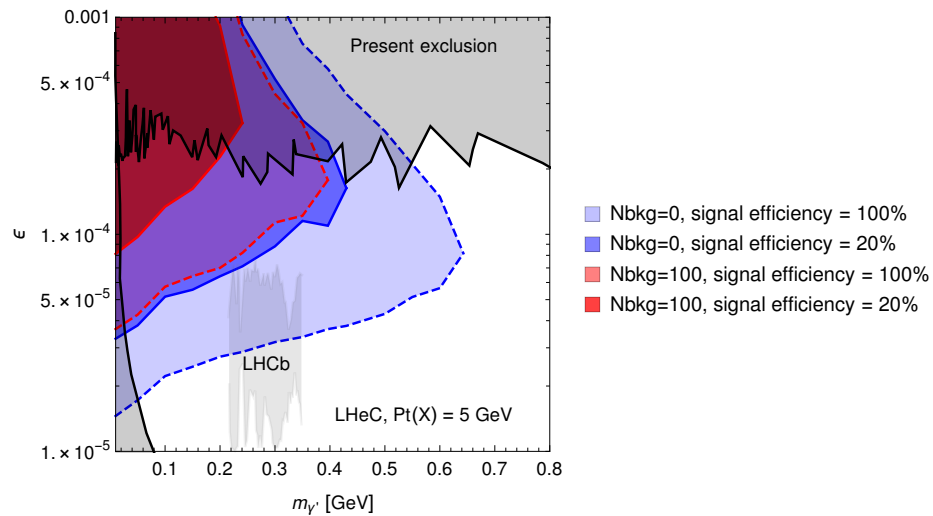
- **LHeC**: s -CHANNEL RESONANT PRODUCTION (LFC)
- **EIC**: **LFV RADIATION** PROPORTIONAL TO $m_{\ell_1}^2 - m_{\ell_2}^2 \Rightarrow$ MAXIMIZED FOR e - τ
- RATE PROPORTIONAL TO $Z \Rightarrow$ MAXIMAL FOR HEAVY IONS (GOLD)
- LHeC vs EIC: SIMILAR COUPLINGS, VERY DIFFERENT m_a RANGES

HEAVY OR “DARK” PHOTONS

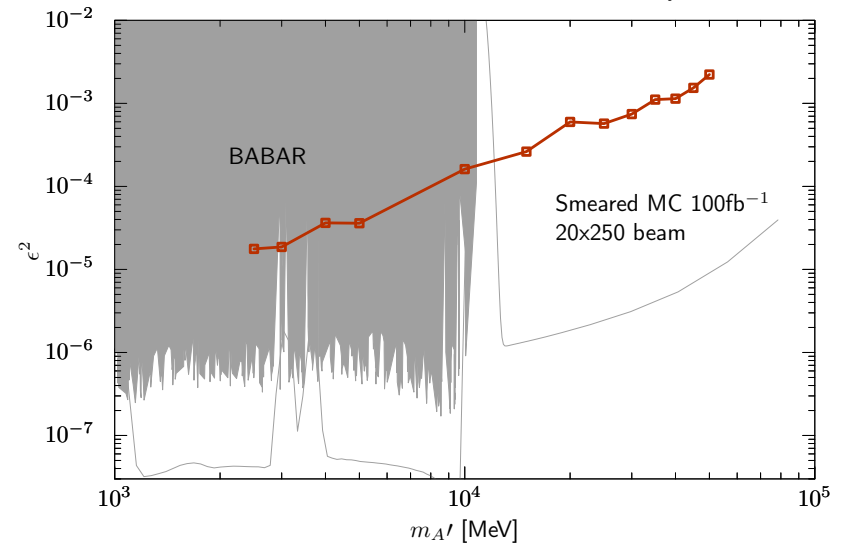
DIS RADIATION



LHeC



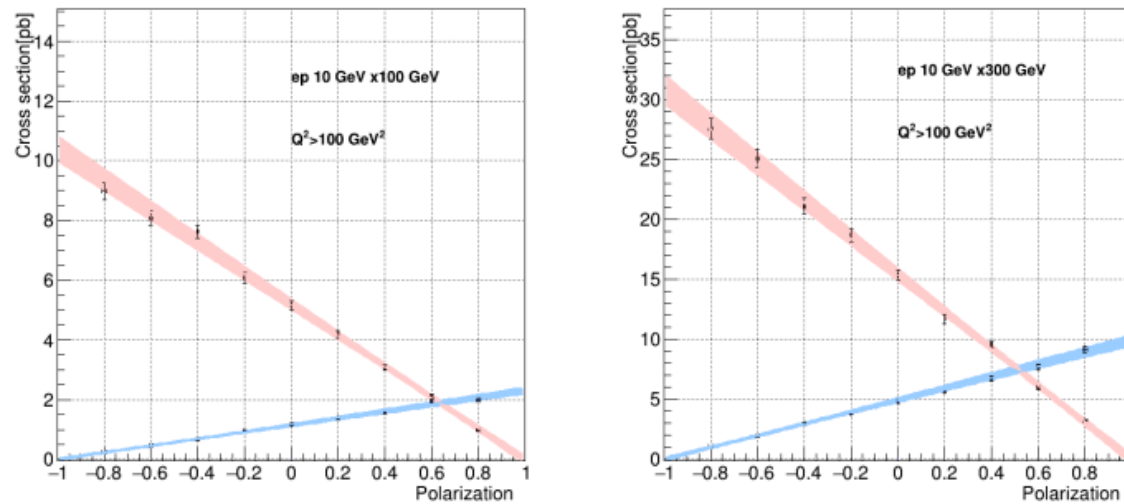
Dark Photon Exclusions from Visible Decay



- RESONANT PEAK IN DILEPTON SPECTRUM
- COLLIDER SIGNAL CLEARER THAN FIXED-TARGET DUE TO BOOST
- DIFFRACTIVE PRODUCTION $\Rightarrow$ EIC VS LHeC QUALITATIVELY SIMILAR

TESTS OF CHIRAL STRUCTURE AT THE EIC

- CC $e^\pm$ DIS:
- $\sigma_{\text{SM}}^{e^\pm p}(P_e) = (1 \pm P_e)\sigma_{\text{SM}}^{e^\pm p}(P_e = 0)$ FOR POLARIZATION P_e
- DEVIATIONS FROM $\sigma_{\text{SM}}^{e^\pm p}(P_e = \mp 1) = 0 \Rightarrow$ **NONSTANDARD CHIRAL** STRUCTURE
- **DIFFERENT POLARIZATION** $\Rightarrow$ **TESTED** THROUGH LINEAR FIT



EXCLUDE $M_R \lesssim 270 \text{ GeV}$ AT 95% C.L. **RIGHT-HANDED** W

MORE BSM SEARCHES AT THE LHeC

- EXTENDED HIGGS SECTORS
 - MODIFIED TOP-HIGGS INTERACTIONS
 - CHARGED SCALARS
 - NEUTRAL SCALARS
 - MODIFIED HIGGS SELF-COUPPLINGS
 - EXOTIC HIGGS DECAYS
- SUSY SEARCHES
 - SUSY EW SECTOR: PROMPT SIGNATURES
 - SUSY EW SECTOR: LONG-LIVED PARTICLES
 - R - PARITY VIOLATION
- FEEBLY INTERACTING PARTICLES
 - HEAVY NEUTRINOS
 - FERMION TRIPLETS IN TYPE-II SEESAW
- ANOMALOUS GAUGE COUPLINGS
- VECTOR-LIKE QUARKS
- EXCITED FERMIONS
 - COLOR OCTET LEPTONS
 - QUARK SUBSTRUCTURE AND CONTACT INTERACTIONS
- ANOMALOUS GAUGE COUPLINGS
- VECTOR-LIKE QUARKS
- KALUZA-KLEIN GRAVITONS

SUMMARY

“Nature does not distinguish ‘Nuclear’ vs. ‘High Energy’ physics”

(Abhay Deshpande)

- RICH SET OF OPPORTUNITIES FOR EW AND BSM STUDIES AT EIC
UNRELATED TO PDFs/NUCLEON STRUCTURE
- CURRENT EIC STUDIES ONLY SCRATCHED THE SURFACE OF FUTURE OPPORTUNITIES
- EXPLOIT KNOW-HOW ACCUMULATED OVER 15 YEARS OF LHeC STUDIES