Beyond Standard Model Physics at the EIC

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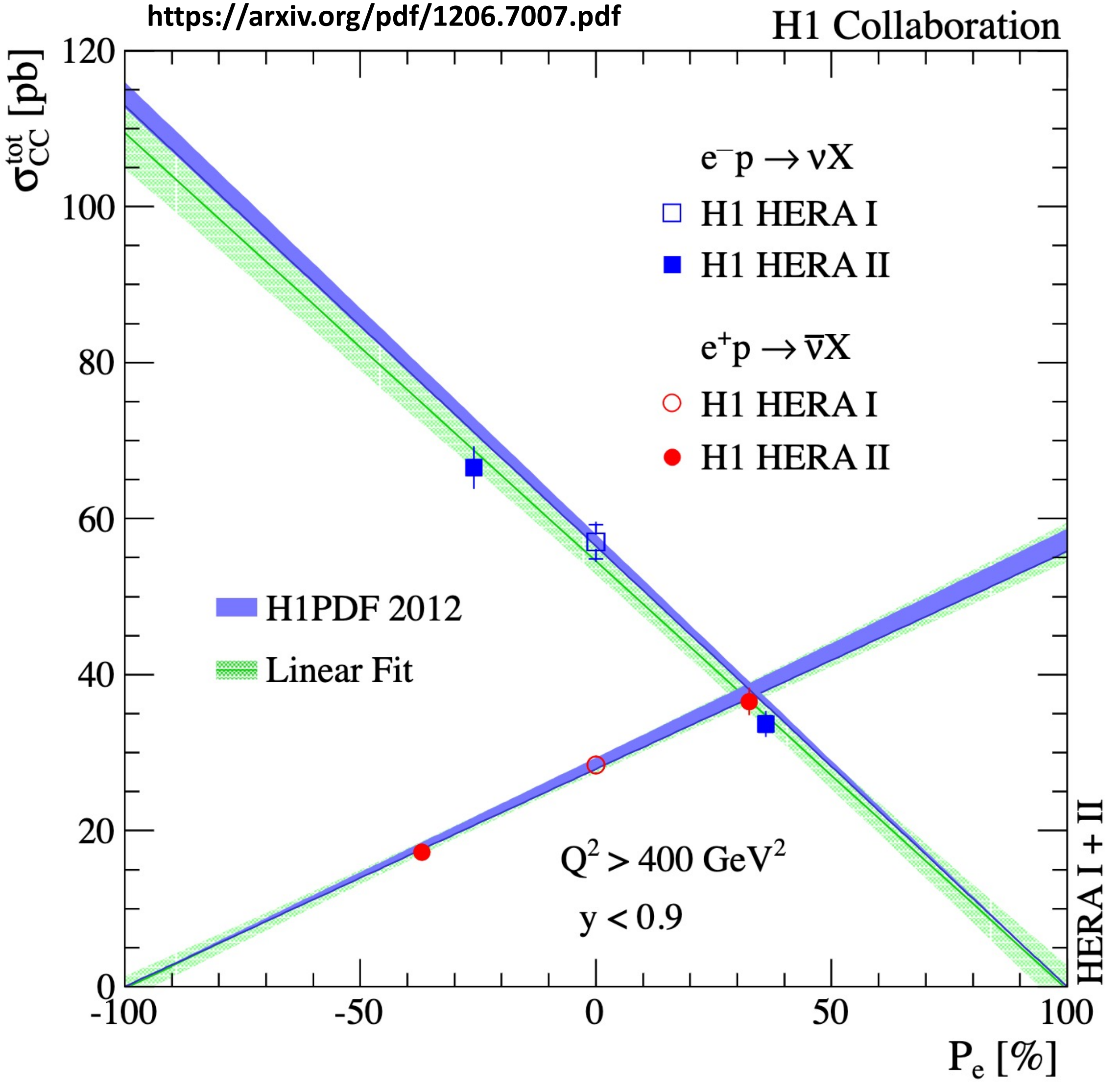
"There are unknown unknowns"

At first glance preparing to discover unknown unknowns seems like a fool's errand. Luckily for me there are know unknowns which give us some place to start by looking at what HERA accomplished.

Charged current cross section

- Perhaps one of the most accessible BSM searches at the EIC is the polarization dependence of the charged current cross section
    - The extrapolated (linear) fits at $P_e = +1$ for electrons are compared to the SM prediction
- The combined HERA fits exclude the existence of charged currents involving right-handed fermions mediated by bosons below 214 GeV

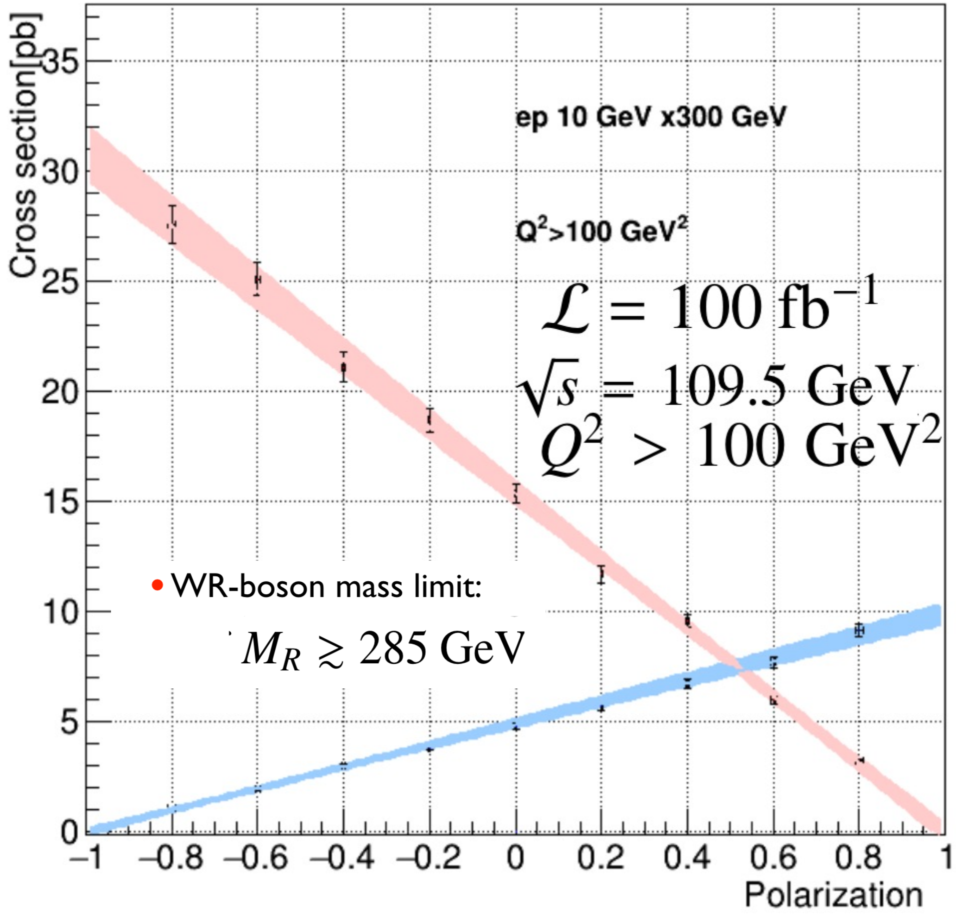
JHEP 09 (2012) 061
https://arxiv.org/pdf/1206.7007.pdf



Charged current cross section

- The study assumed 1% polarization uncertainty and 3% experimental systematic and were performed at old sqrt(s) configurations
- The analysis from Yulia and Sonny needs some updating
  - Early indications are that we could start covering new phase space once we reach 30-50 fb^{-1}
- Due to the type of collisions involved the EIC limits would access different combinations of chiral and flavor structures making this study complementary to limits from the LHC (which are already in the TeV ranges)

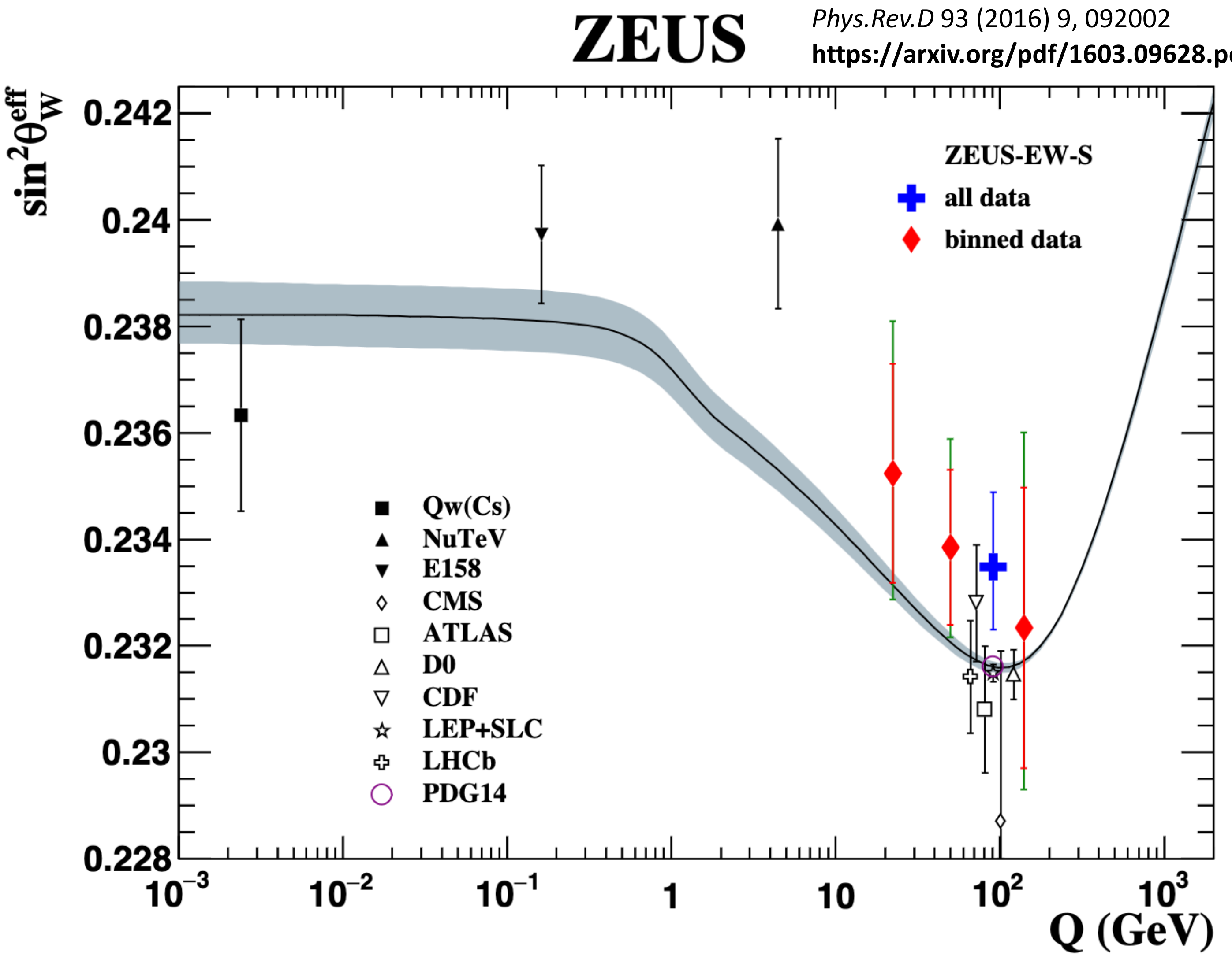
Yulia Furletova, Sonny Mantry
AIP Conf.Proc. 1970 (2018) 1, 030005



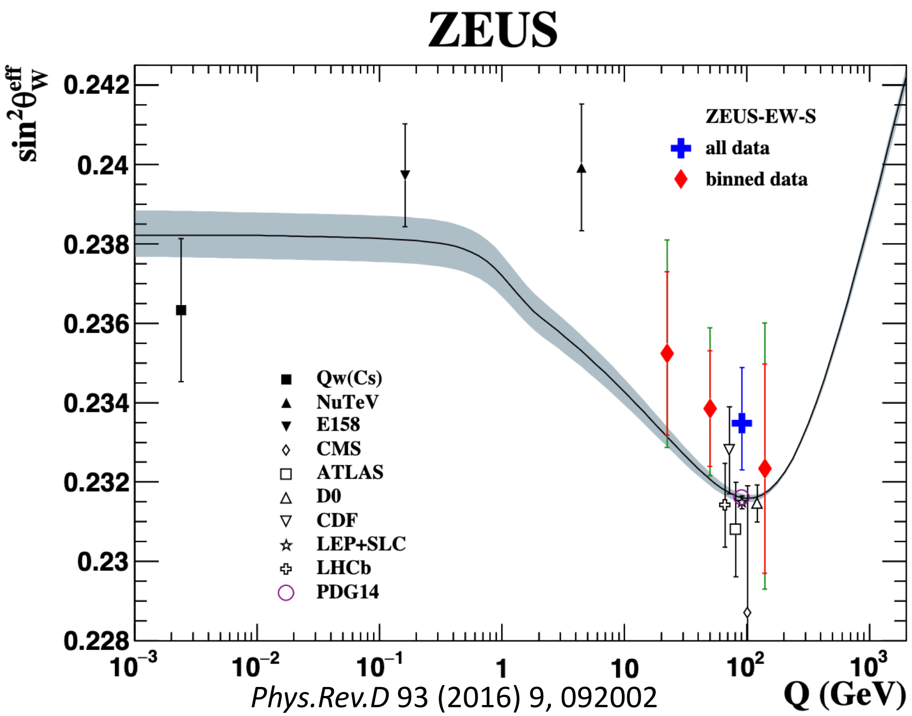
Weak mixing angle extraction

- As one of the parameters of the SM determinations the weak mixing angle are especially sensitive to BSM physics
- The most precise measurements are at the Z-pole and we will get new low Q^2 determinations in the next decade

Phys.Rev.D 93 (2016) 9, 092002
https://arxiv.org/pdf/1603.09628.pdf

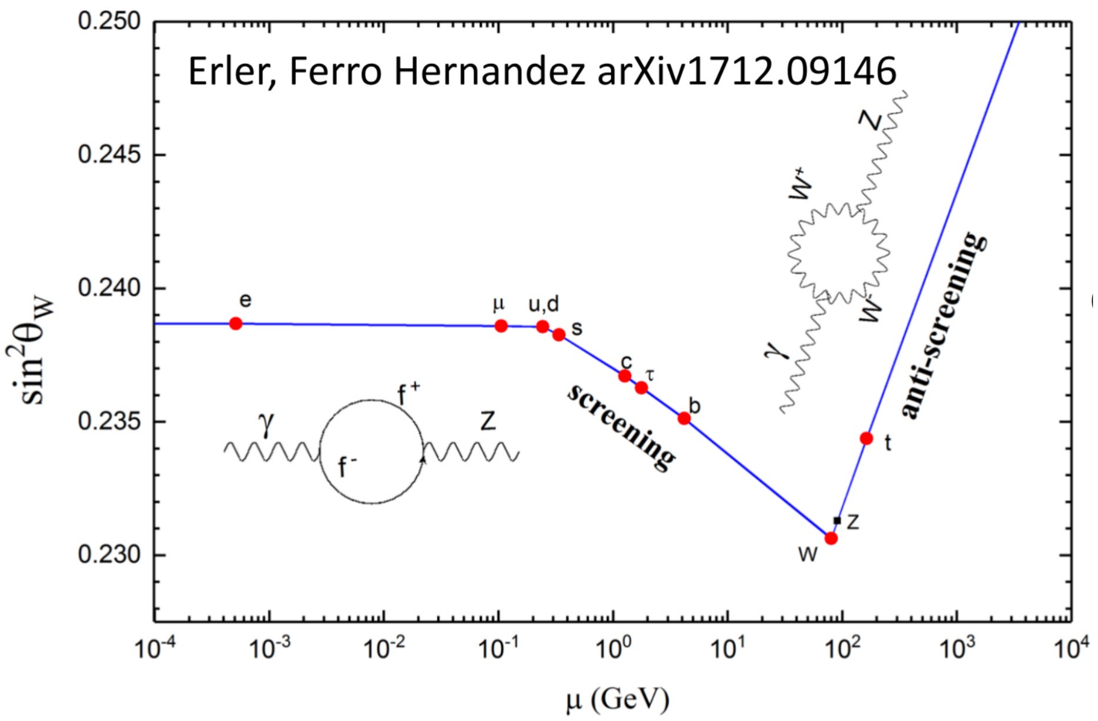


Theoretical improvements



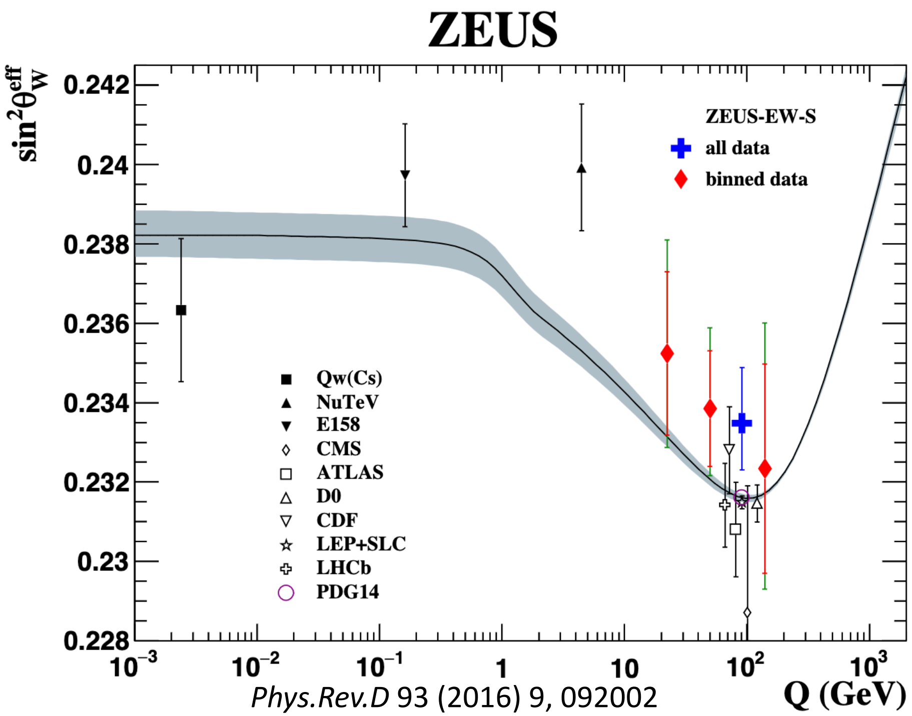
Phys.Rev.D 93 (2016) 9, 092002

https://arxiv.org/pdf/1603.09628.pdf



- Significant improvements in measurements and theoretical calculations have reduced the uncertainty on the weak mixing angle running
  - The uncertainty of the SM prediction is on the level of the thickness of the curve in the plot on the right

New phase-space



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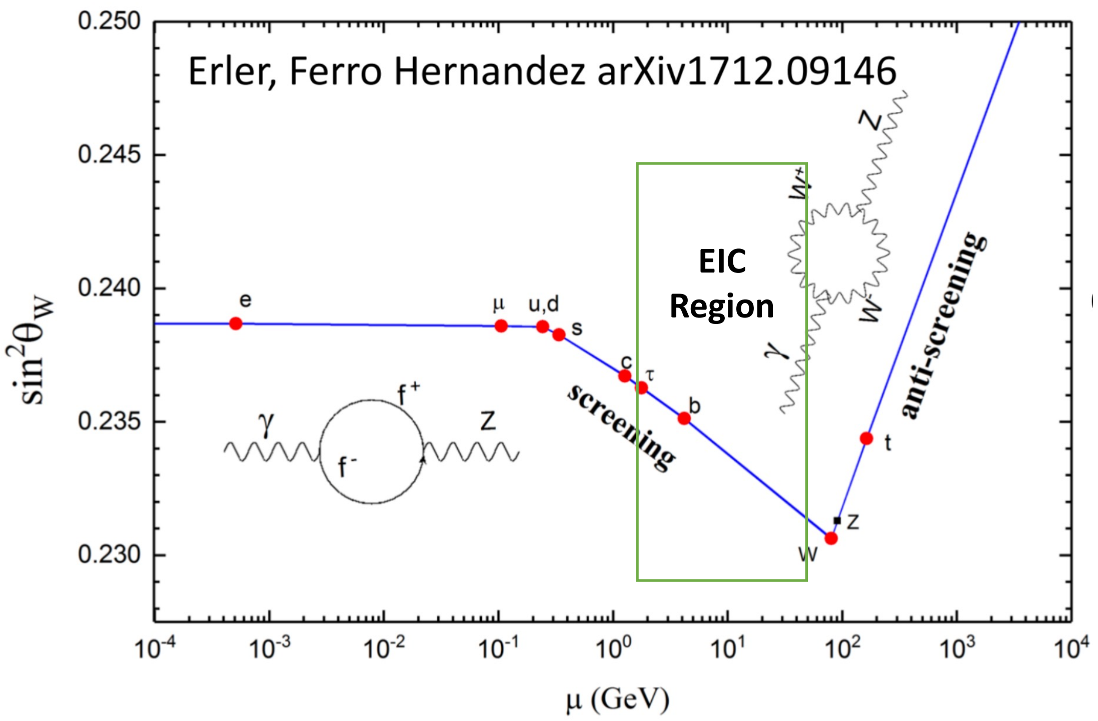
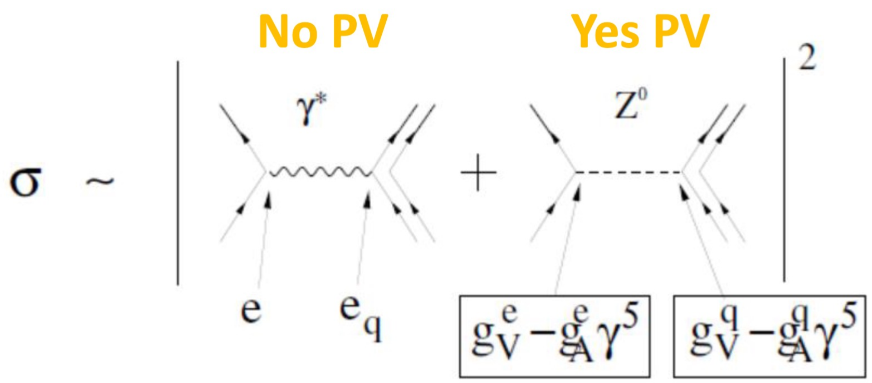


- The EIC will probe a region that has not investigated since HERA and with sufficient luminosity could verify the running
  - Although most of the precise data will be closer to the Z-pole

Parity violation at the EIC

Phys.Rev.D 106 (2022) 1, 016006
https://arxiv.org/pdf/2204.07557.pdf



$$\mathrm{d}\sigma = \mathrm{d}\sigma_0 + P_e\,\mathrm{d}\sigma_e + P_H\,\mathrm{d}\sigma_H + P_eP_H\,\mathrm{d}\sigma_{eH}$$

$$N^{++} = a_{\mathrm{det}}L^{++}\left(\mathrm{d}\sigma_0 + |P_e^{++}|\,\mathrm{d}\sigma_e + |P_H^{++}|\,\mathrm{d}\sigma_H + |P_e^{++}||P_H^{++}|\,\mathrm{d}\sigma_{eH}\right)$$
$$N^{+-} = a_{\mathrm{det}}L^{+-}\left(\mathrm{d}\sigma_0 + |P_e^{+-}|\,\mathrm{d}\sigma_e - |P_H^{+-}|\,\mathrm{d}\sigma_H - |P_e^{+-}||P_H^{+-}|\,\mathrm{d}\sigma_{eH}\right)$$
$$N^{-+} = a_{\mathrm{det}}L^{-+}\left(\mathrm{d}\sigma_0 - |P_e^{-+}|\,\mathrm{d}\sigma_e + |P_H^{-+}|\,\mathrm{d}\sigma_H - |P_e^{-+}||P_H^{-+}|\,\mathrm{d}\sigma_{eH}\right)$$
$$N^{--} = a_{\mathrm{det}}L^{--}\left(\mathrm{d}\sigma_0 - |P_e^{--}|\,\mathrm{d}\sigma_e - |P_H^{--}|\,\mathrm{d}\sigma_H + |P_e^{--}||P_H^{--}|\,\mathrm{d}\sigma_{eH}\right)$$

$$Y^{ij} \equiv N^{ij}/L^{ij}$$

- The EIC can measure two parity violating asymmetries which gives access to different structure functions
- The sensitivity to the weak mixing angle is best when looking at the electron asymmetry

$$A_{\mathrm{PV}}^{(e)} \equiv \frac{\mathrm{d}\sigma_e}{\mathrm{d}\sigma_0} = \frac{1}{|P_e|}\frac{Y^{++}+Y^{+-}-Y^{-+}-Y^{--}}{Y^{++}+Y^{+-}+Y^{-+}+Y^{--}}$$

$$A_{\mathrm{PV}}^{(H)} \equiv \frac{\mathrm{d}\sigma_H}{\mathrm{d}\sigma_0} = \frac{1}{|P_H|}\frac{Y^{++}-Y^{+-}+Y^{-+}-Y^{--}}{Y^{++}+Y^{+-}+Y^{-+}+Y^{--}}$$

ECCE studies

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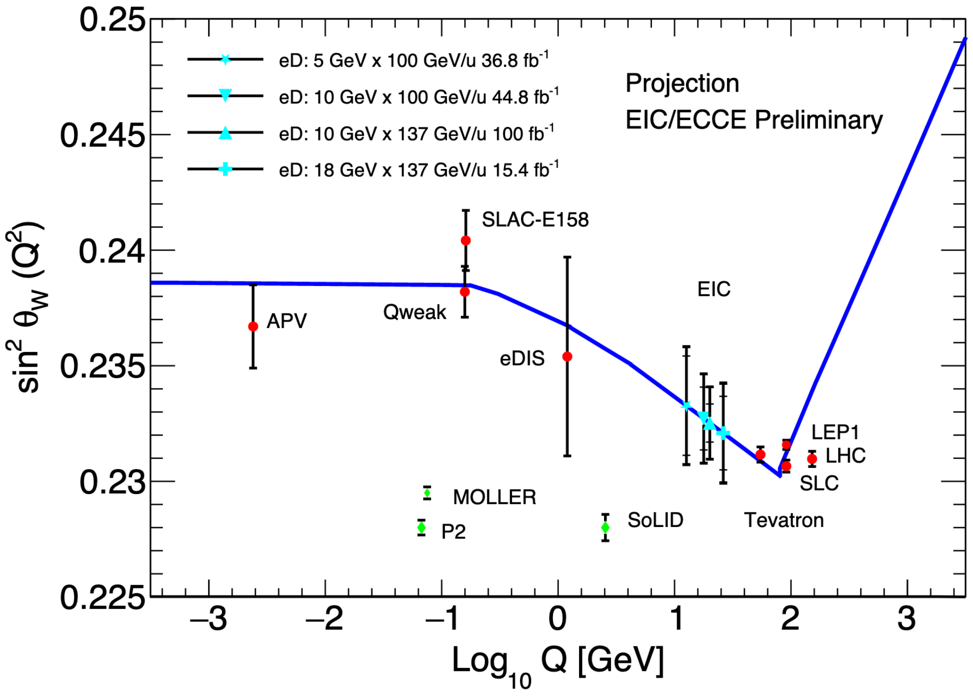
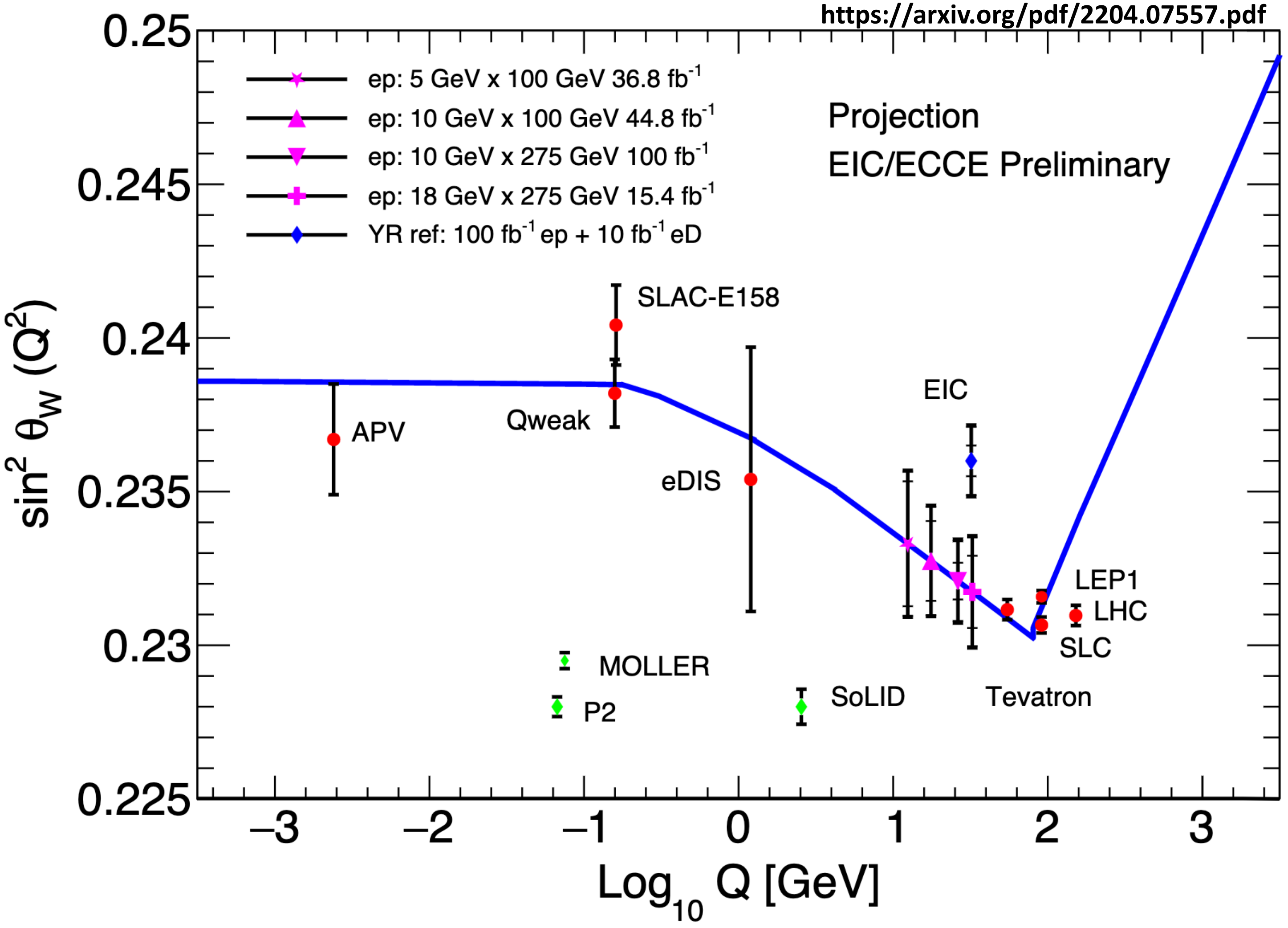


- The iso-singlet nature of deuterium made it an ideal candidate for precision measurements (PDF dependence cancels)



- Several recent analyses have shown that the PDF uncertainties have a small impact on the weak mixing angle extraction in ep

ECCE studies

- The studies performed by the ECCE EW&BSM group averaged all the statistics in each sqrt(s) configuration into one point
- The assumption of 1% background contamination was assumed to be subtractable by determining the parity violating asymmetry can be measured separately

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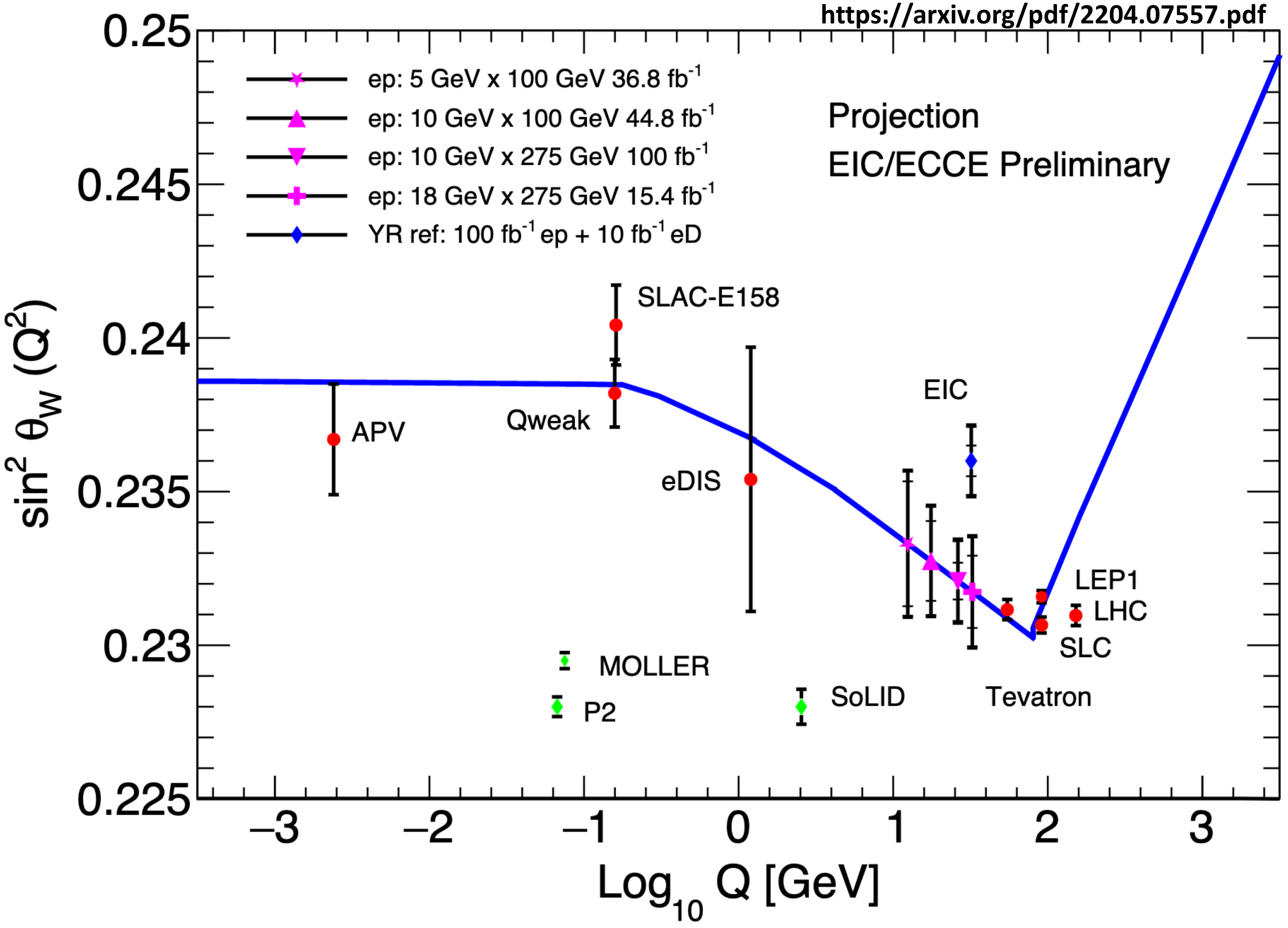
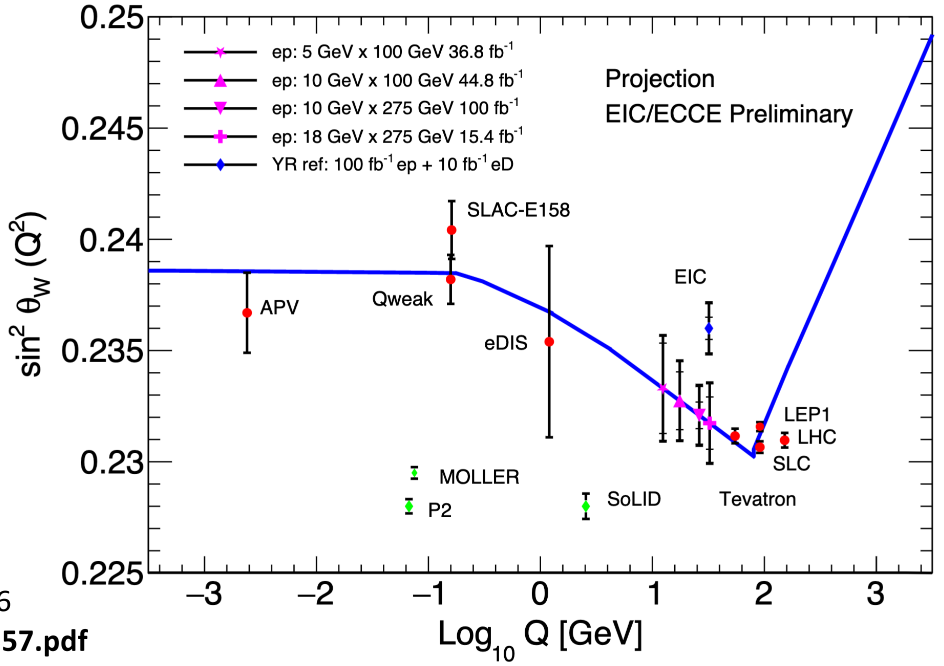


1% polarization uncertainty
1% background contamination

ECCE studies

- For the 2 highest sqrt(s) bins the polarization uncertainty is the dominant uncertainty on the parity violating asymmetry
- The PDF uncertainties were analyzed by looking at the impact of different replicas on the weak mixing angle extraction
  - They add very little to the overall experimental uncertainty



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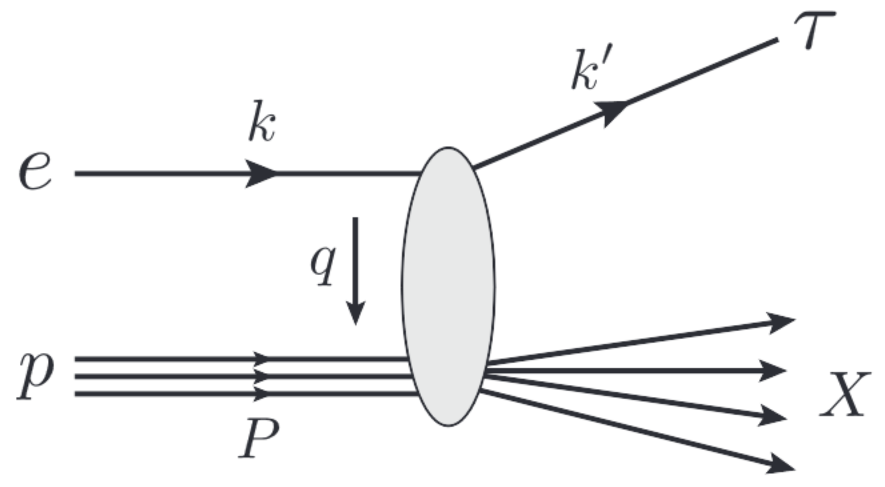
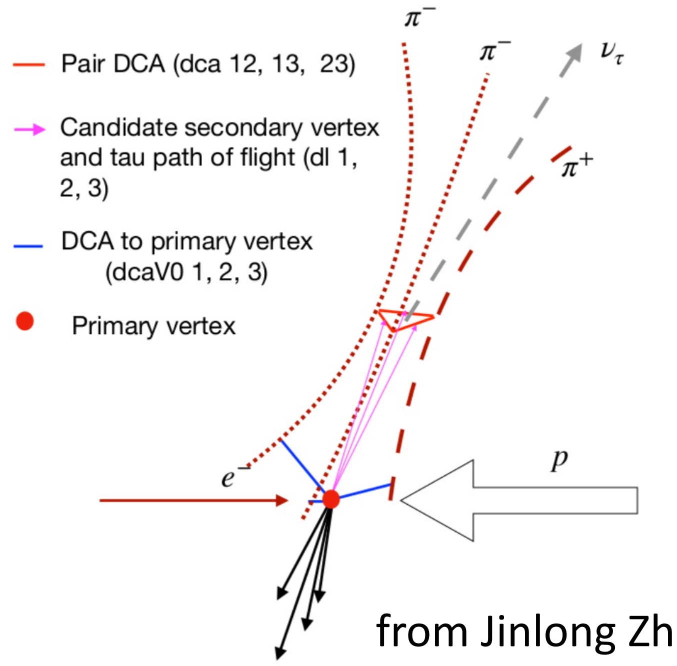
Beam type and energy Label	ep 5 × 100 P2	ep 10 × 100 P3	ep 10 × 275 P4	ep 18 × 275 P5	ep 18 × 275 P6
Luminosity (fb^{-1})	36.8	44.8	100	15.4	(100 YR ref)
$\langle Q^2 \rangle$ (GeV^2)	154.4	308.1	687.3	1055.1	1055.1
$\langle A_{PV} \rangle$ ($P_e = 0.8$)	−0.00854	−0.01617	−0.03254	−0.04594	−0.04594
$(dA/A)_{\text{stat}}$	1.54%	0.98%	0.40%	0.80%	(0.31%)
$(dA/A)_{\text{stat+syst(bg)}}$	1.55%	1.00%	0.43%	0.81%	(0.35%)
$(dA/A)_{1\%\text{pol}}$	1.0%	1.0%	1.0%	1.0%	(1.0%)
$(dA/A)_{\text{tot}}$	1.84%	1.42%	1.09%	1.29%	(1.06%)
Experimental					
$d(\sin^2\theta_W)_{\text{stat+syst(bg)}}$	0.002032	0.001299	0.000597	0.001176	0.000516
$d(\sin^2\theta_W)_{\text{stat+syst+pol}}$	0.002342	0.001759	0.001297	0.001769	0.001244
with PDF					
$d(\sin^2\theta_W)_{\text{tot,CT18NLO}}$	0.002388	0.001807	0.001363	0.001823	0.001320
$d(\sin^2\theta_W)_{\text{tot,MMHT2014}}$	0.002353	0.001771	0.001319	0.001781	0.001270
$d(\sin^2\theta_W)_{\text{tot,NNPDF31}}$	0.002351	0.001789	0.001313	0.001801	0.001308

Charged lepton flavor violation

- The e -> tau constraints currently still allow for the EIC to probe new phase space
- Initial interest in the e -> tau conversions was on the three-pion decay mode due to its topological signature
  - Studies done by Jinlong Zhang indicate that this channel alone could increase the limits set by HERA by a factor of 2 (at 100 fb^{-1})

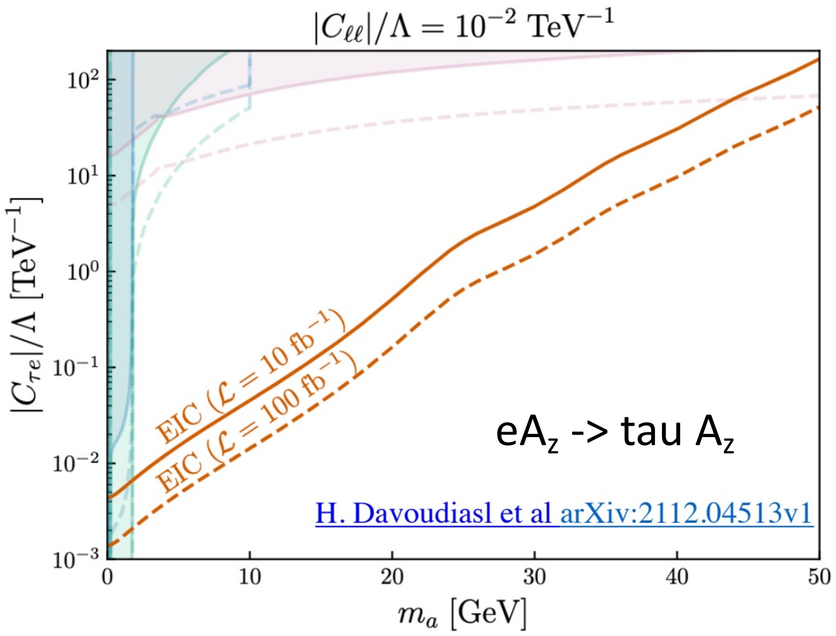


JHEP 03 (2021) 256
https://arxiv.org/pdf/2102.06176.pdf



from Jinlong Zhang

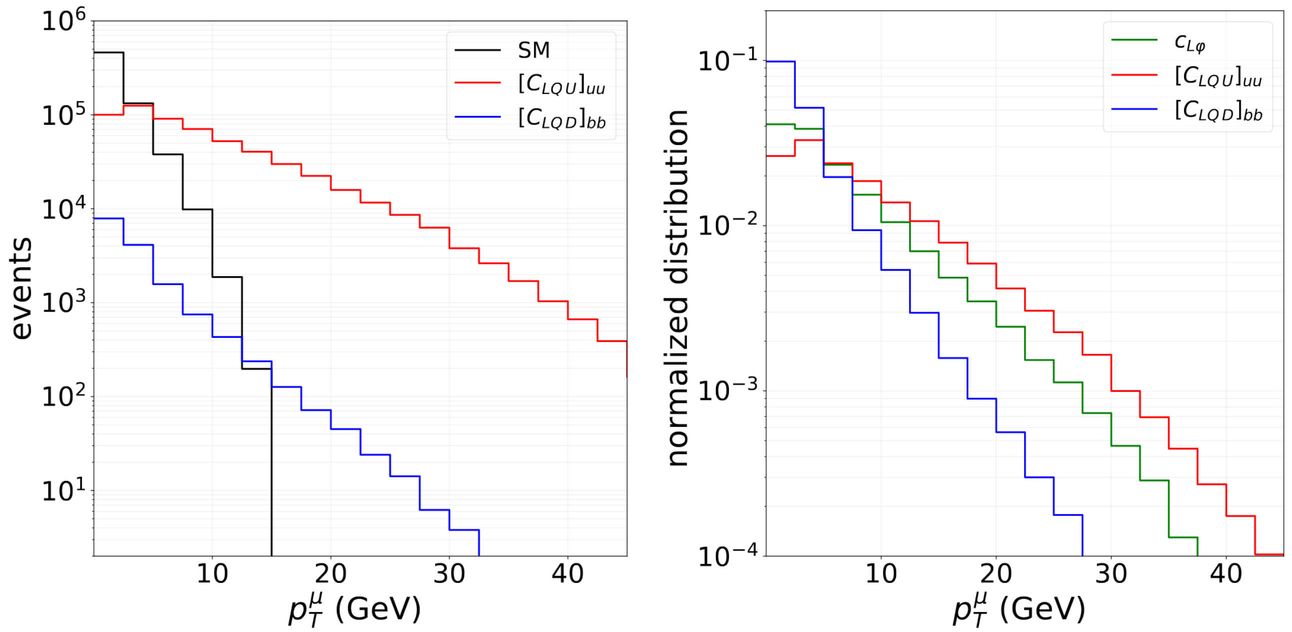
- Sensitivity to axion-like particles has been shown to be quite high for the EIC in eA collisions through similar measurements (where nucleus stays intact)



Charged lepton flavor violation

JHEP 03 (2021) 256
https://arxiv.org/pdf/2102.06176.pdf

- An analysis by Emanuele and collaborators shows that looking at the 1-prong muon decay of the tau allows for very efficient background suppression
- Analysis used ATHENA Delphes card and looked at SM processes and a leptoquark generator



$$ep \to \tau X \to \mu + \not{E} + X$$

from E. Mereghetti

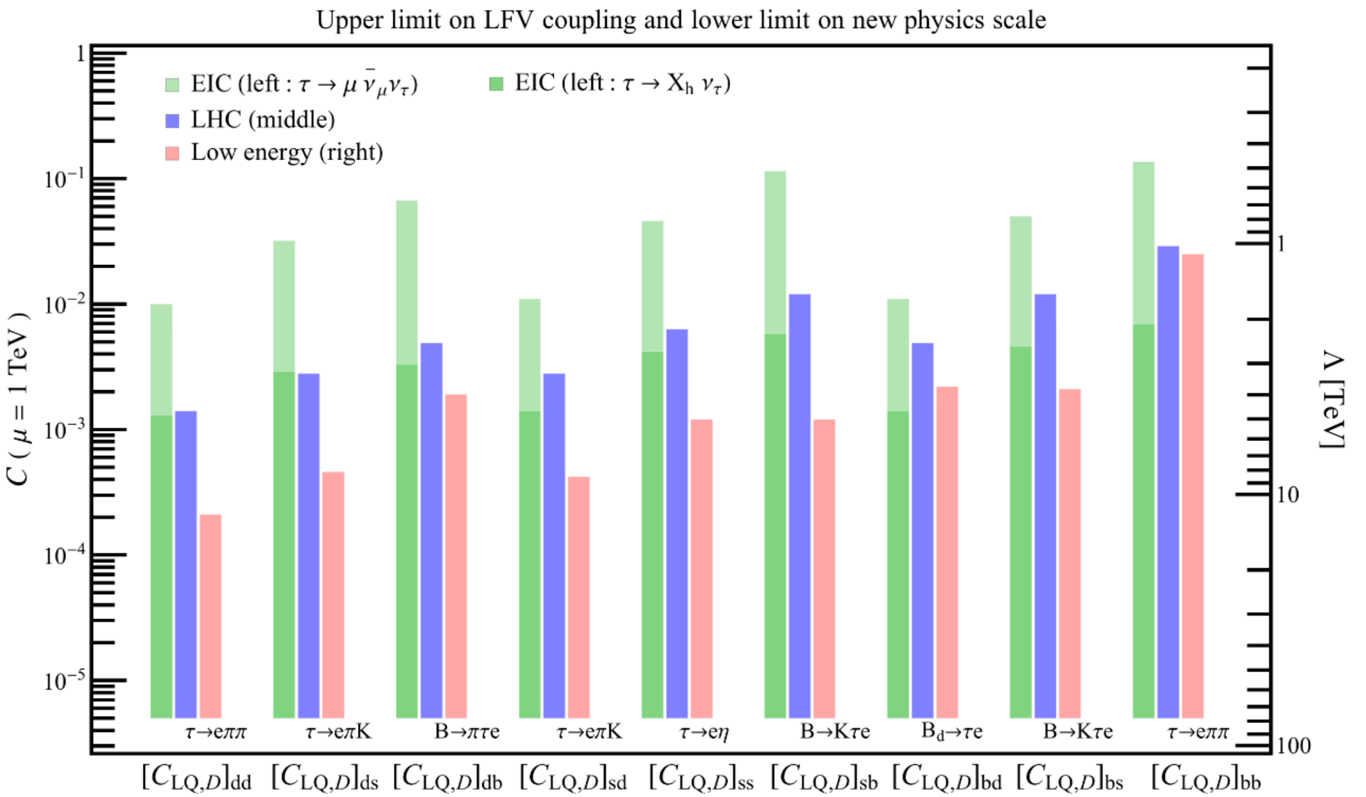
$$p_T^\mu > 10\,\text{GeV}, \quad \not{E}_T > 15\,\text{GeV}, \quad p_T^{j_1} > 20\,\text{GeV}$$

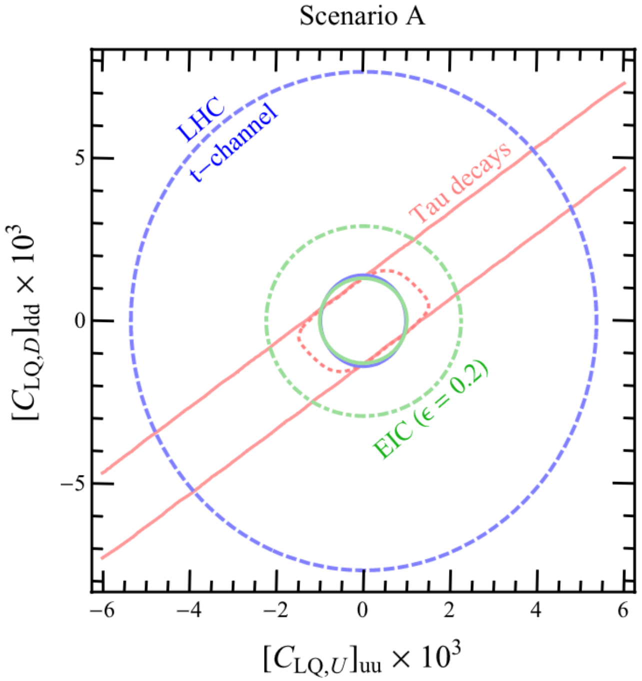
eliminates all SM background

Charged lepton flavor violation

JHEP 03 (2021) 256
https://arxiv.org/pdf/2102.06176.pdf

- Depending on the LQ model involved the EIC has varying degrees of constraining power
- When taken into a global context the EIC data can provide significant constraints on contact interaction terms together with low energy and LHC data

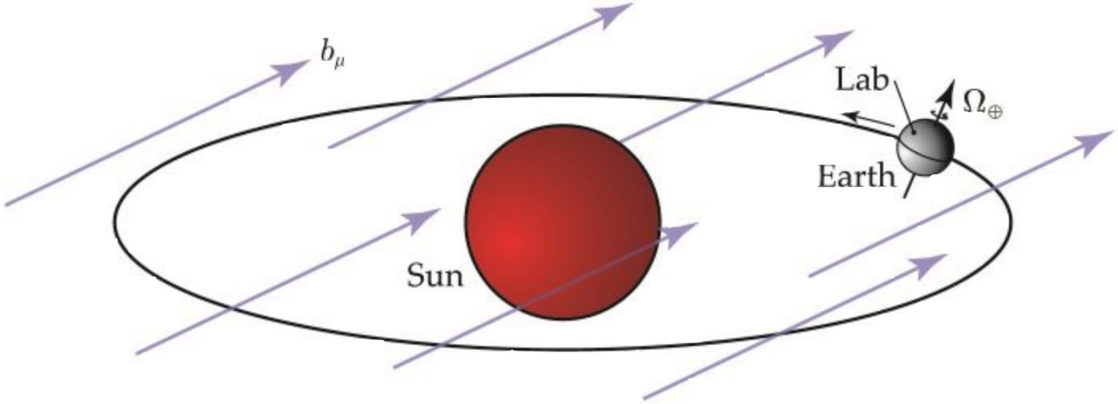




The additional inclusion of hadronic tau decays (dark green) increases the sensitivity by more than a factor of 10 in some cases bringing the EIC close to LHC limits

Other opportunities (arXiv 2203.13199)

- For the Snowmass process we managed to collate a couple more studies:
  - Heavy photons: the unique x, Q2 coverage of the EIC (at the high luminosities) would allow to probe new regions of the dark photon phase space (beyond the current limits set by BABAR)
  - Including the bread-and-butter polarized EIC measurements into global analysis frameworks such as the Standard Model Effective Field theory provides significant restrictions on the phase space of BSM theories in conjunction with LHC data
  - Precise measurements of quantities over extended periods of time can probe Lorentz and CPT-violating effects



Summary

- As was pointed out repeatedly in this workshop having one detector ”discovering” something requires a second measurement to shore up (improve upon?!) the result
  - This goes double for BSM searches that have had several 3-4 sigma measurements in the past
- Lepton identification is fundamental for any search (especially electrons, muons have been shown to significantly improve CLFV)
  - The studies that were done so far indicate that a 1% pion background would be manageable for the weak mixing angle extraction but improving this detector performance parameter would allow additional sensitivity
- While we have some particular channels we know would be interesting to investigate we (both ePIC and 2nd detector) should be open to unconventional signatures (i.e. “unknown unknowns”) and investigate all deviations from expectations
  - Doing this requires a very strong theoretical backing (MC models and studies will be crucial)