

BSM/EW – Plan for Impact Studies

Full Luminosity & Energy Scope

Juliette Mammei, Zuhail Seyma Demiroglu

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ePIC and EIC Physics Readiness Workshop



University
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Center for Frontiers
in Nuclear Science

BSM/EW physics opportunities at the EIC

The EIC offers strong potential for both direct BSM searches and precision electroweak measurements in DIS.

Direct searches

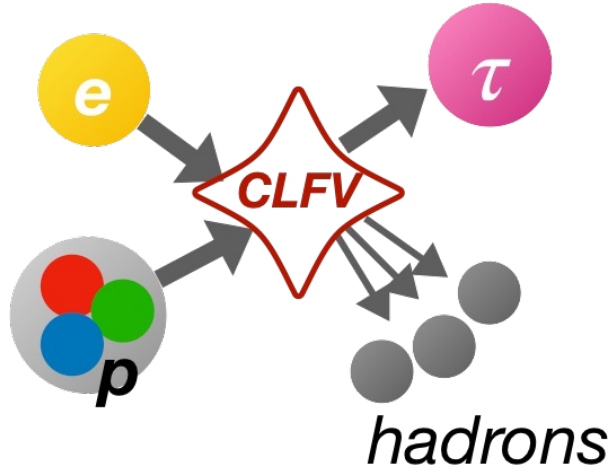
- Charged Lepton Flavor Violation (CLFV)
 - $e \rightarrow \tau$; τ via 3-prong or muonic decay
 - Probe different LQ chiralities
- Axion-like particles (ALPs)
 - Coherent $e+\text{Pb} \rightarrow e+a$
 - $a \rightarrow \gamma\gamma$ or $a \rightarrow \tau^- e^+$ (LFV)
- Dark photons & Hidden vectors
 - $e p \rightarrow e A'$; displaced decay vertex for low-background ID
- Heavy neutral leptons (HNLs)
 - Majorana ($e^+ 3j$, $e^+ \mu j + \text{MET}$) & Dirac ($\ell^+ \ell^- j + \text{MET}$); prompt + displaced modes

Precision measurements

- Weak mixing angle
 - $\sin^2 \theta_W \leftrightarrow M_W$ correlation: deviation in Q^2 running signals dark Z , Z' , or SUSY
- Parity violating DIS & EW couplings
 - Provides sensitivity to anomalous quark EW couplings and radiative corrections beyond LEP precision
- Electroweak Couplings via SMEFT
 - Model-independent BSM reach via four-fermion operators
 - Breaks LHC Drell-Yan flat directions in Wilson coefficient space: EIC+HL-LHC synergy

Goal of the BSM/EW impact study

- Full-scale EIC opens new territory beyond NAS science pillars.
 - Establish a framework to evaluate the BSM discovery potential and electroweak precision reach of the EIC.
- Develop benchmark studies for key channels
 - Charged Lepton Flavor Violation
 - $e \rightarrow \tau$ via leptoquarks
 - $e \rightarrow \mu$ decay channel
 - HNLs
 - Tau tagging performance relevant for BSM channels
 - ALPs
- Provide detector-level performance inputs
 - τ -jet tagging efficiency vs fake rate, μ/π separation metrics, basic inclusive electron tagging performance, displaced vertex capability.
- Show where EIC improves on existing constraints.



- $e + p \rightarrow \tau + X$; τ decays
 - Hadronic: $\tau \rightarrow 3\pi\nu$, $\tau \rightarrow K + X$
 - Leptonic: $\tau \rightarrow \mu\nu\nu$
- Signal generators:
 - LQGENEP: leptoquarks
 - SMEFT based CLFV generator
 - [SMEFT](#) and [leptoquark](#) model calculations suggest that EIC could provide competitive sensitivity to $e \rightarrow \tau$

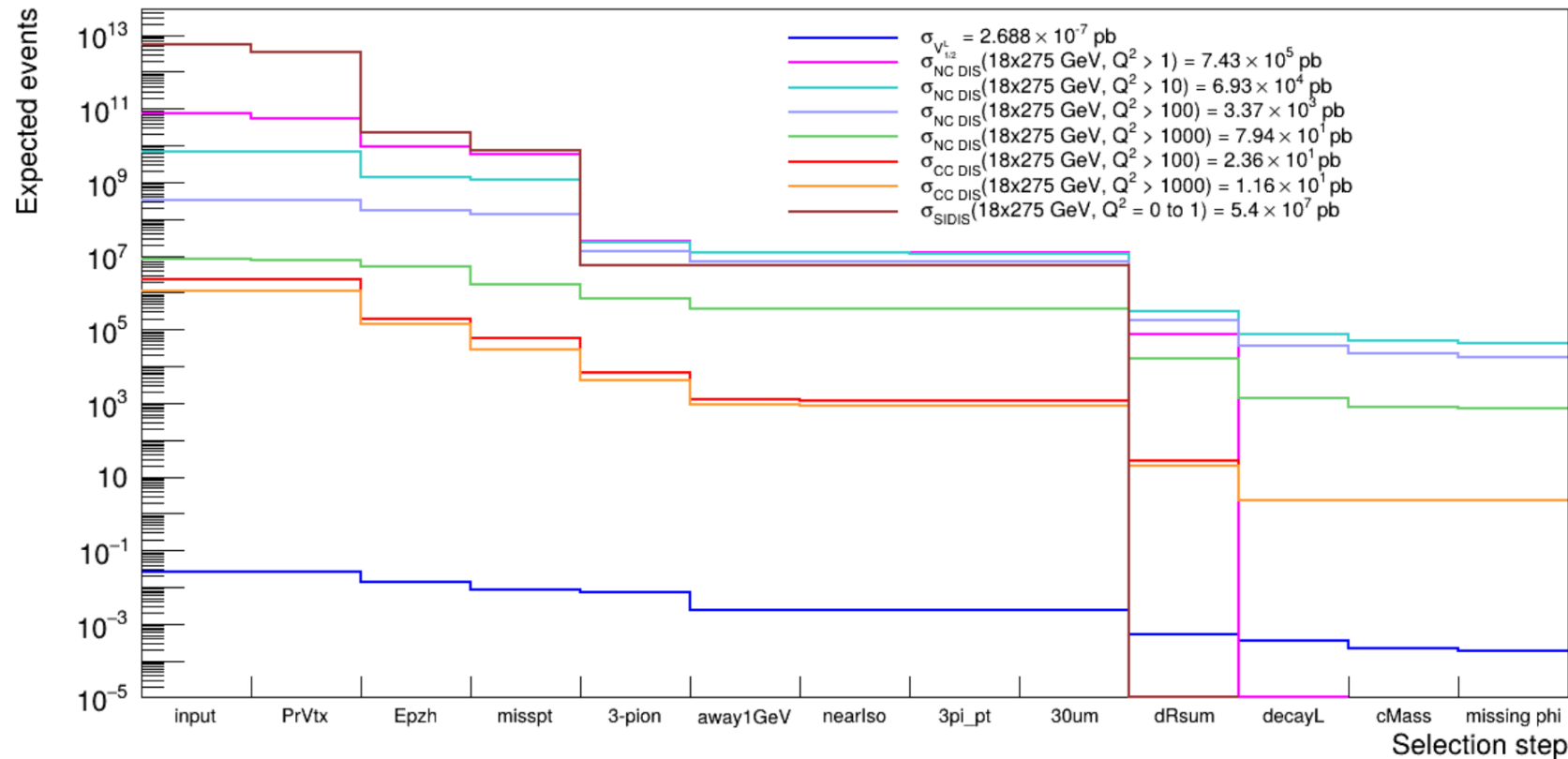
- Aim:
 - Full ePIC simulation/reconstruction
 - Develop sensitivity projections and compare to existing constraints (e.g. HERA); clarify EIC reach
- Current work:
 - Bardh: baseline CLFV analysis with LQGENEP. Working through 14 LQ types across quark generations.
 - Andrew: $\tau \rightarrow \mu$ channel + possible SMEFT comparison
 - Backgrounds: DIS with fake τ , heavy-flavor decays, etc.
- Timeline:
 - harmonize Bardh and Andrew analysis frameworks, agree on final state selections.
 - preliminary sensitivity studies for at least one benchmark scenario are targeted by mid-summer.

CLFV ($e \rightarrow \tau$): Cutflow, $V_{1/2}^L$ signal vs DIS Background

Bardh Quni, University of Manitoba

- Number of events surviving each selection cut for $V_{1/2}^L$ signal, generated using LQGENEP, and DIS background samples from simulation campaign (ePIC 25.10.0 ep (18x275) GeV) scaled to an integrated luminosity of $\mathcal{L} = 100 \text{ fb}^{-1}$, with focus into 3-prong $\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$

Cutflow scaled to 100 fb^{-1}



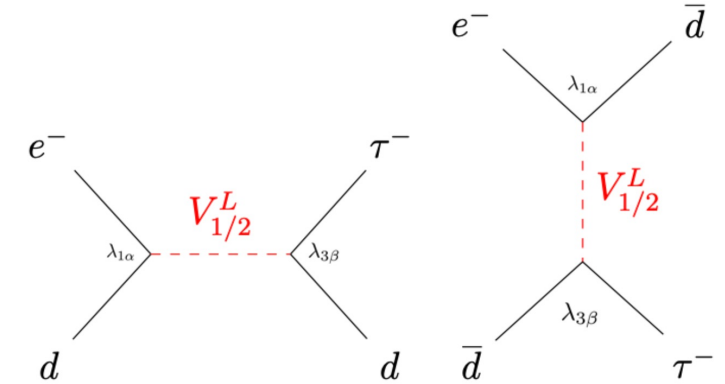
CLFV ($e \rightarrow \tau$): Sensitivity Projection, $V_{1/2}^L$ Leptoquark

Bardh Quni, University of Manitoba

- The exclusion boundary is defined where the theoretical cross section equals the exclusion limit

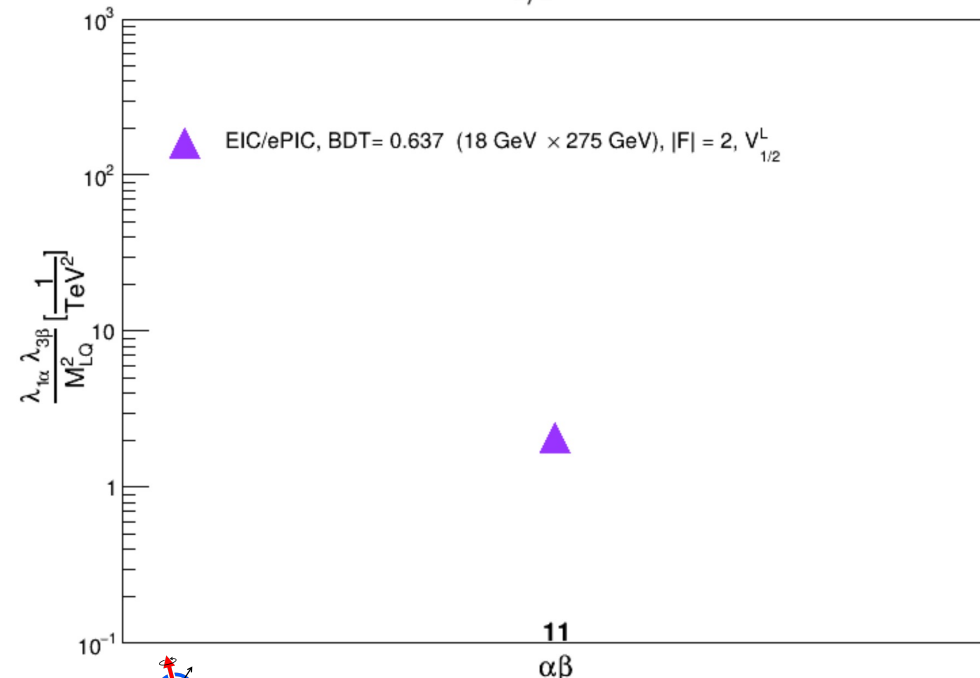
- $\sigma_{theory} = \sigma_{excl}$, $y_{excl} = y_{theory} \sqrt{\frac{\sigma_{excl}}{\sigma_{theory}}}$ where $y = \frac{\lambda_{1\alpha}\lambda_{3\beta}}{M_{LQ}^2}$
- The exclusion boundary is represented by a purple triangle at position ($\alpha\beta = 11, y = 2.06 \text{ TeV}^{-2}$)
- Any leptoquark model satisfying $\frac{\lambda_{11}\lambda_{31}}{M_{LQ}^2} > 2.06 \text{ TeV}^{-2}$ is excluded

$$e^- + q_i \rightarrow V_{1/2}^L \rightarrow \tau^- + q_j$$



Training with Boost Decision Trees

The best significance is achieved with $\text{BDT_cut} = 0.637$



- Preliminary limits at 95% CL on $\frac{\lambda_{11}\lambda_{31}}{M_{LQ}^2}$ for $V_{1/2}^L$ leptoquark
- Extending to $\alpha\beta$ for all quark generations $\alpha, \beta \in \{1,2,3\}$, the leptoquark states to investigate will include $S_0^L, S_0^R, \tilde{S}_0^R, S_1^L, S_{1/2}^L, S_{1/2}^R, \tilde{S}_{1/2}^L, V_0^L, V_0^R, \tilde{V}_0^R, V_1^L, V_{1/2}^R,$ and $\tilde{V}_{1/2}^L$

- EIC with heavy ion beams could enhanced coherent production cross sections, boosting sensitivity to LFV ALPs
 - Complementary to other experiments
- Aim:
 - Three channels under study: fermion coupled ALP, lepton flavor violating ALP, U(1) gauge extensions
 - Run full ePIC detector simulation and reconstruction
 - Compare signal vs background distributions
 - Develop initial detector level sensitivity estimates
- Current work:
 - $e + Pb \rightarrow e + a$
 - Simulation chain: MadGraph5 event generation + IP6 afterburner + ElCrecon detector sim
 - Electron beam: 5-18 GeV, Pb beam: 110 GeV/nucleon. ALP mass range: 0.1 – 20 GeV
 - First simulation results including ALP kinematics, acceptance, preliminary signal yields
- Timeline:
 - Initial sensitivity projections expected by mid-summer.

See J. Nam's talk for latest results

"Discovering non-standard interactions of sterile neutrinos"

- HNLs are well motivated as an explanation for neutrino mass generation.
 - EIC is particularly powerful for displaced decay vertex searches of long-lived HNLs, a regime poorly covered by the LHC.
- Aim:
 - Implement theory-driven models in the ePIC simulation chain
 - Develop tagging tools
 - Tau tagging via ML + displaced vertex in ePIC framework for $e + p \rightarrow \tau + X$
 - Use these to develop initial sensitivity projections to CLFV signatures
- Current work:
 - SM & SMEFT events (Pythia8+Delphes) integrated into ePIC
 - Tracking efficiency validated
 - Studies of τ reconstruction performance
- Timeline:
 - Request official production of LANL generated new model, validate simulation outputs, first tagging performance studies and initial sensitivity projections expected by mid-summer.

See Y. Corrales's talk for latest results

Summary

Channel	Status
CLFV	Baseline analysis ongoing; BDT trained; preliminary 95% CL limits
ALPs	First simulation results
CLFV + HNL	Generator + sim validation

- **Biweekly joint meeting with the Inclusive PWG**

- Tuesdays at 12PM ET.
- Mailing list, sign up if not already subscribed:
eic-projdet-bsmew-l@lists.bnl.gov
- To subscribe, visit: <https://lists.bnl.gov/mailman/listinfo/eic-projdet-bsmew-l>
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Backup