BSM/EW Conveners Report and Plans

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January 21, 2026

ePIC Collaboration Meeting

University of Manitoba
Stony Brook University
Center for Frontiers in Nuclear Science

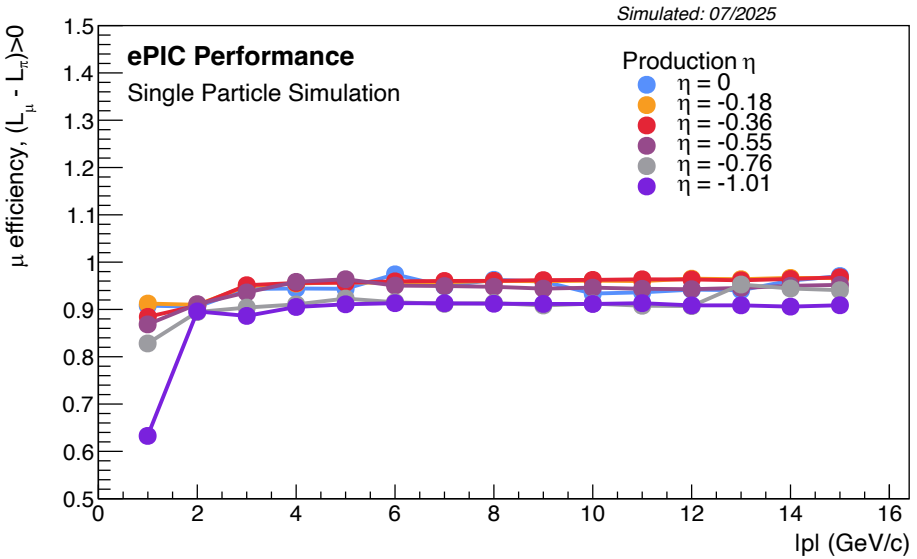
Overview of BSM/EW Efforts

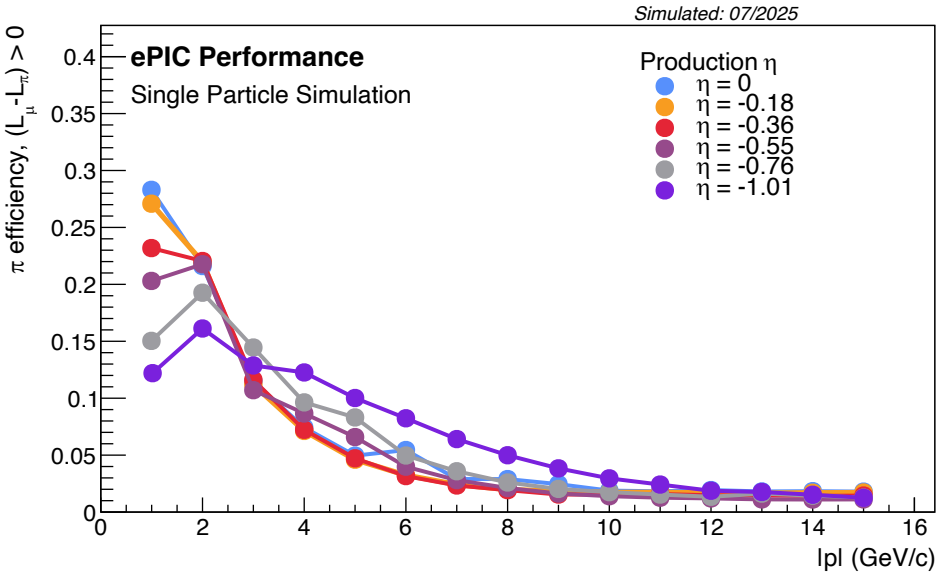
- Muon Identification Performance at ePIC (Andrew Hurley)
- CLFV via Leptoquarks (Bardh Quni)
- Future BSM/EW studies from BNL and LANL Teams

Muon Identification Performance at ePIC

Andrew Hurley (UMass Amherst)

- Reliable muon identification significantly enhances BSM sensitivity and improves background control in multiple channels.
  - Muon ID based on a likelihood approach, using:
    - Track momentum
    - Calorimetric variables (E/p and shower radius).
    - Discriminator defined as log-likelihood difference Lμ−Lπ
- Based on single-particle simulations;
  - Muon efficiency remains high and uniform, typically 90–98% for |p| > 3 GeV.
  - Pion mis-identification rate remains low, below ~10% in the central region.
- Impact
  - Demonstrates that muon ID in ePIC is robust in the central barrel.
  - Directly supports CLFV searches, sterile-neutrino studies, and EW/BSM measurements requiring clean muon final states.

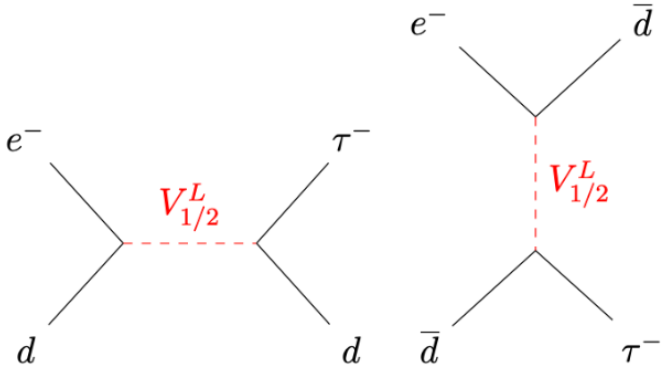


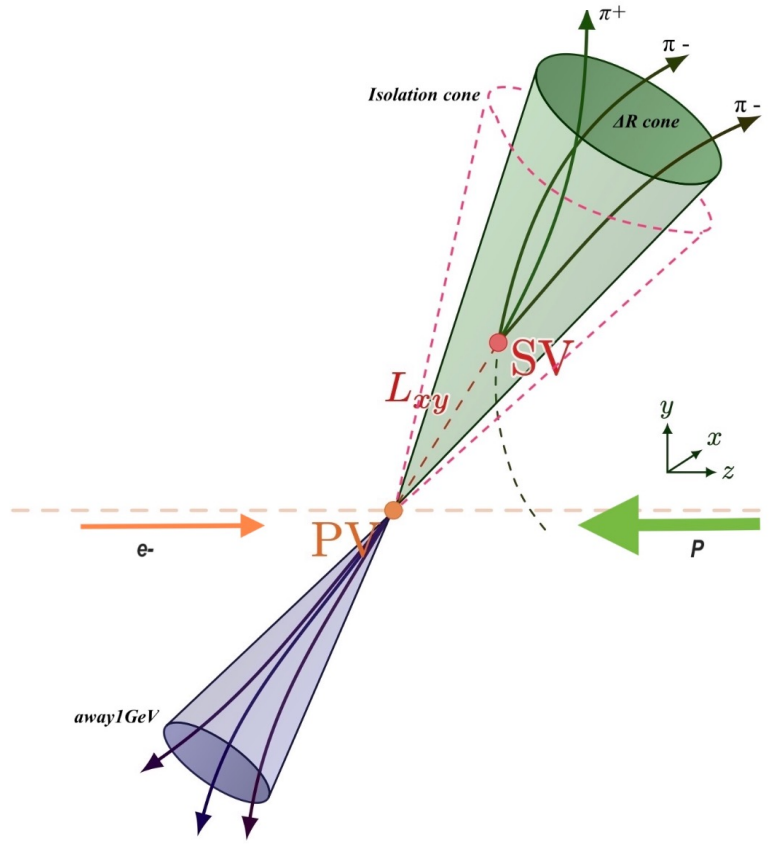


Charged Lepton Flavor Violation

Bardh Quni (University of Manitoba)

- Leptoquark mediated-CLFV: $e + p \rightarrow \tau + X$
  - Studying CLFV in DIS-like events at $\sqrt{s} = 141\ GeV$ (18×275)
  - Focus on 3-prong τ decays: $\tau \rightarrow \pi^-\pi^+\pi^-\nu_\tau$
  - Signal model: vector LQ5 $V^L_{1/2}$ (s- and u- channel)
  - Developed vertex based 3-prong τ identification
  - Applied selection on NC/CC/SIDIS backgrounds:
    - Surviving events dominated by NC DIS + CC DIS
    - Reconstructed decay length distributions show MC and detector level agreement.
  - Performed scaling to 100 fb^{-1}, produced expected yields and bin error estimates.

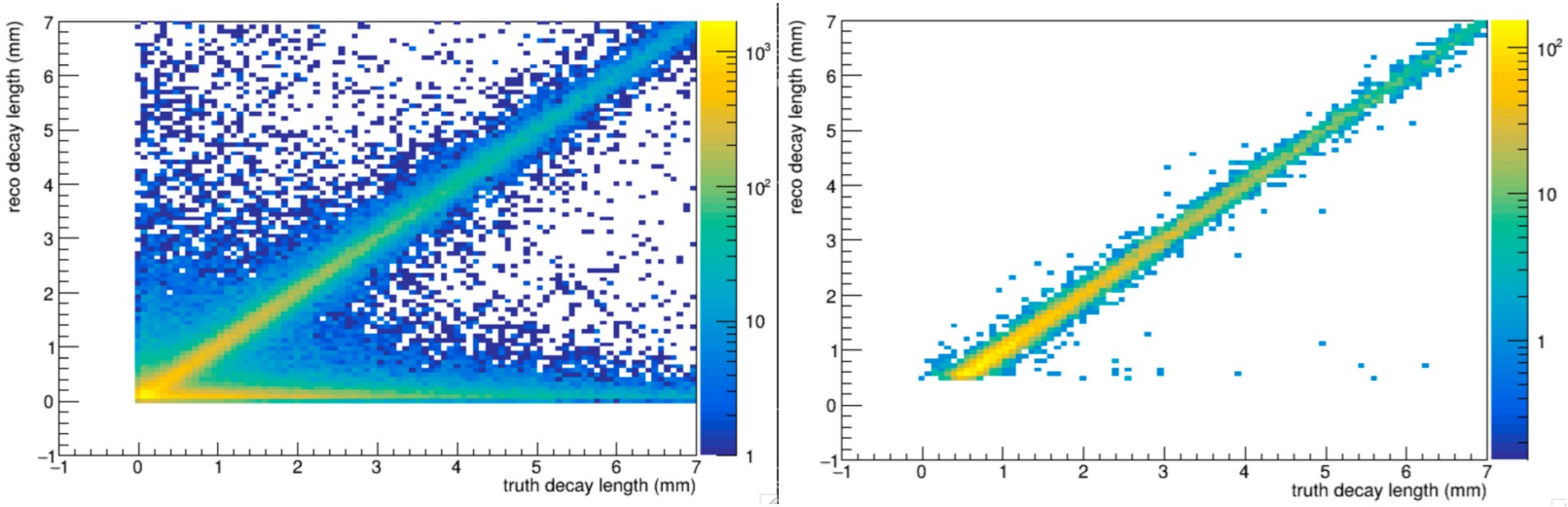




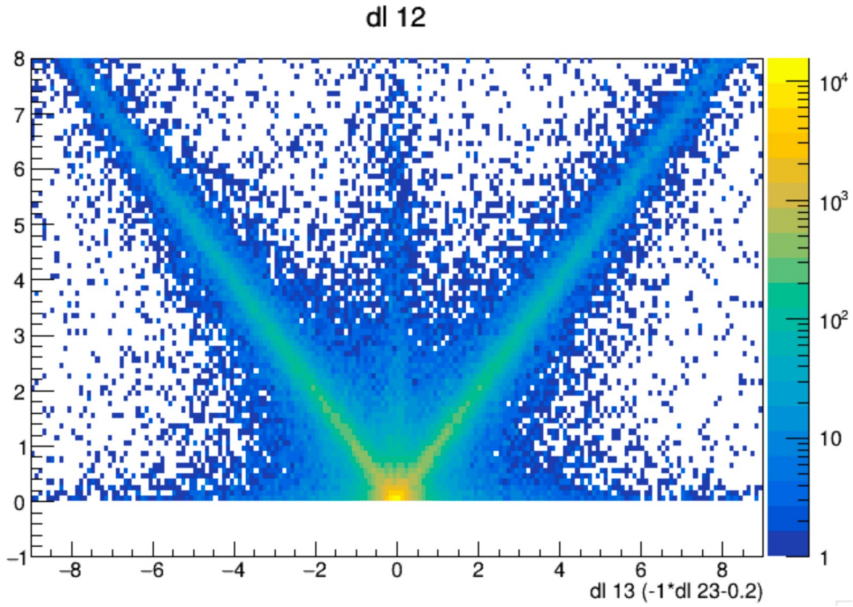
Vertex Identification

Bardh Quni (University of Manitoba)

- From the simulation of the 3-prong decay mode of the τ lepton, we reconstruct three "intermediate" vertices.
- Coincidence between two out of three vertices (left or right) is usually enough to indicate a "3-prong" secondary vertex.



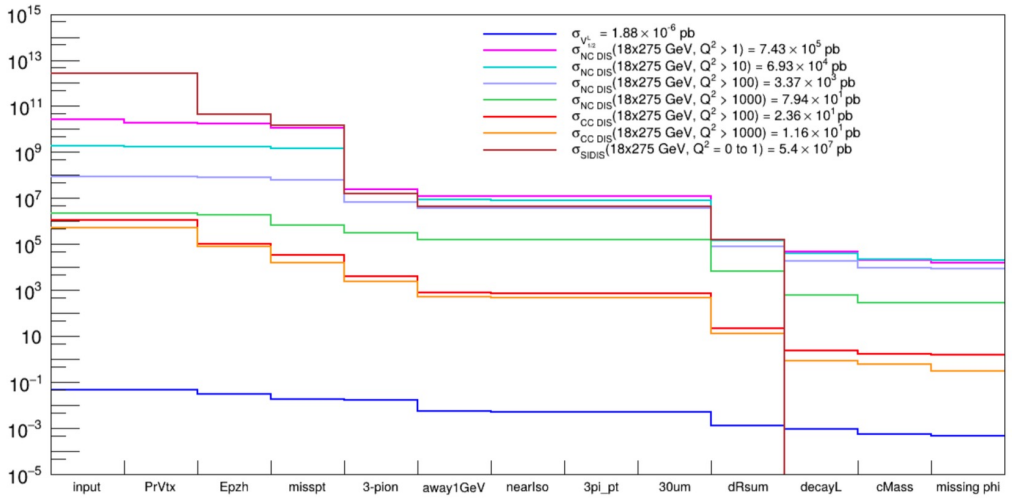
The final reconstructed decay length (right), after the last cut has been applied, is presented as a comparison between the true (MC) and reconstructed (RC) decay lengths at the ePIC detector level.

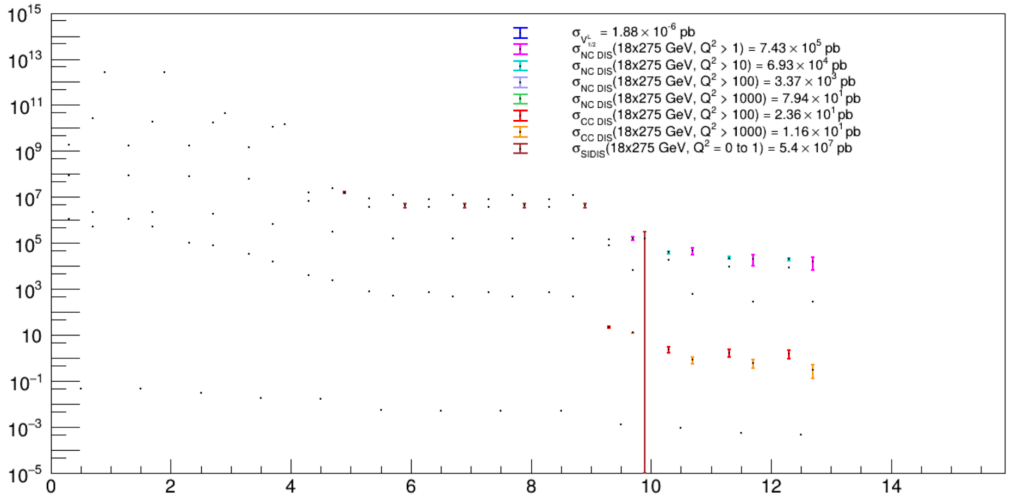


2D histogram of distances between track pairs (dl12 vs dl13) from the 3-prong τ decay.

Consecutive cuts on $V_{1/2}^{L}$, NC, CC, SIDIS events

Bardh Quni (University of Manitoba)





A full cut-flow study shows the progressive suppression of SIDIS and other DIS background processes. After all selection criteria, only NC and CC DIS remain relevant, establishing a clean environment for LQ-mediated CLFV searches.

Statistical uncertainties are evaluated for each process after all cuts using 100 fb^{-1} projections. These per-bin error estimates will inform optimization studies and future significance calculations.

- **Future Plans**
  - Check the sensitivity for other 13 LQs based on the selection criteria.
  - Apply more advanced techniques (like machine learning/Boost Decision Trees (BDT)) to determine optimized regions of phase space where the LQ type signal is maximally distinct from the background.
  - Compute statistical measures of significance (e.g., S/B, where S is signal and B is background yield) across the selection criteria to demonstrate where the signal could be most detectable.

BNL Team Involvement

Alessandro Tricoli (BNL)

BNL-funded LDRD-A project on "Electroweak and Beyond-The-Standard-Model Physics at the EIC":

- Consortium of experimentalists and theorists in HEP and NP to study precision of EW measurements and BSM reach with the ePIC detector and 2nd Detector at the EIC
  - A. Tricoli (HEP-Exp), S. Dawson (HEP-Th), H. Davoudiasl (HEP-Th), R. Szafron (HEP-Th), Y. Hatta (NP-Th), P. Steinberg (NP-Exp), Z. Tu (NP-Exp), Hongkai Liu (HEP-Th), A. Jentsch (NP-exp) etc.
  - **3 Post Docs:** Zhite Yu (Th), Jae D. Nam (Exp.), Ganesh Parida (Exp)
  - **Student:** Alyssa Wheeler (SURP/SULI)
  - **Collaborations** with SBU, MSU (Keping Xie)

Brookhaven National Laboratory

- Bring HEP and NP communities closer together ➔ Study overlaps and complementarity between LHC and EIC
- Expand interests and prospects for studies at EIC ➔ Increase effort on experimental studies in EW/BSM
- Expand reach and precision of ePIC detector ➔ improve reconstruction software and study possible upgrades (e.g. far-backward, parasitic ones etc.)
- Study ultimate reach of ePIC and complementary prospects for the 2nd Detector

BSM/EW Program at BNL

Alessandro Tricoli (BNL)

- Initial benchmark studies based on simplified models of a new scalar and vector particle, either stable or decaying into muons, including Axion-Like Particles (e.g. arXiv:2601.00068v1) and other light BSM scenarios
  - Implementation of coherent e–A scattering and BSM processes in MadGraph, interfaced with LHAPDF (Keping Xie and Hongkai Liu)
  - Particle-level and fast-simulation (DELPHES) kinematic studies to define signal characteristics
  - Transition to full simulation and reconstruction with ePIC software, including:
    - Central detector
    - Far-forward and far-backward detector systems
- Near-term goals:
  - Development of event selection and reconstruction strategies
  - Quantification of background rejection performance
  - Evaluation of signal-to-background ratios and projected sensitivities
  - Identification of a small set of key benchmark searches for early ePIC physics deliverables

LANL Team Involvement

Ming Xiong Liu (LANL)

- **LANL LDRD: a joint theory + experiment R&D, FY25 - 27**

  "Discovering non-standard interactions of sterile neutrinos"

  - BSM model development, EIC BSM physics and more
  - Experimental feasibility study

- **People:**
  - Ming Liu, Yasser Corrales Morales, Jakub Kvapil, John Kang et al (Experiment) + external collaborators
  - Emanuele Mereghetti, Kaori Fuyuto, Stefan Sandner et al (Theory)

Overall role in the ePIC BSM effort

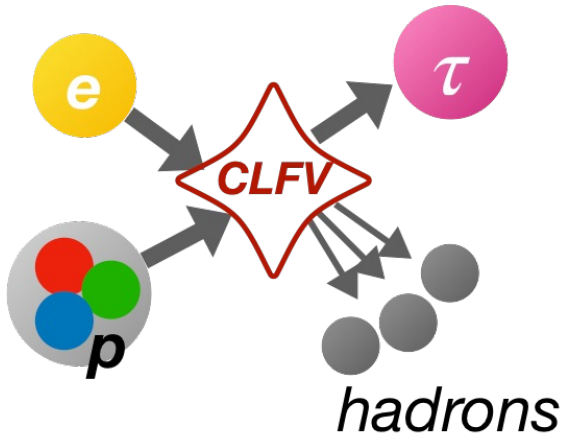
- Provide CLFV/sterile neutrinos studies tied to realistic detector performance.
- Supply tau-tagging and ML frameworks needed by multiple BSM channels.
- Deliver BSM models and simulation tools necessary for event-level reconstruction in ePIC.

Searching for BSM physics at EIC

Ming Xiong Liu (LANL)

- Develop a new BSM search program at the EIC targeting heavy sterile neutrinos and charged-lepton-flavor violation processes.
- Study feasibility of detecting τ final states via displaced vertices and multi-prong decays.
  - Heavy lepton tagging at EIC – tau
    - Displaced vertex in Tau-jet in ePIC
    - Benchmark using sPHENIX p+p data

$$e^- + p \rightarrow \tau^- + X$$

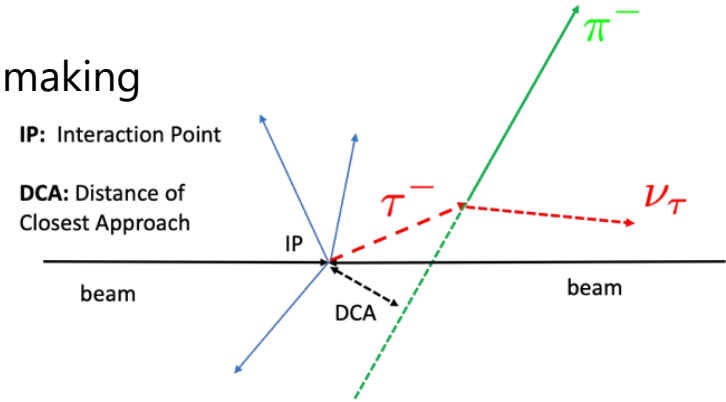


$$p + p \rightarrow \Upsilon + X$$

$$\Upsilon \rightarrow \tau^+ + \tau^-$$

$$\tau^- \rightarrow \pi^- + \pi^- + \pi^+ + \nu_\tau$$

- **Plans:**
  - Build BSM sterile-neutrino models and generate signal/background samples for $e^- p \rightarrow l^{\pm} + 3j$
  - Compare predicted CLFV rates with low-energy constraints.
  - Begin implementing new BSM physics models in Pythia8 for integration into ePIC simulation
  - Use sPHENIX $\mathrm{p} + p \rightarrow \Upsilon \rightarrow \tau^+\tau^-$ samples as a benchmark to validate τ –tagging and vertex reconstruction performance
  - Demonstrate that sPENIX/ePIC share similar silicon MAPS tracking ~5um hit resolution, making the benchmark relevant.
  - Develop ML-based τ –tagging using LSTM networks and event-level features.
  - Study τ – jet substructure with anti-kT jet algorithms and prong multiplicity.



Summary

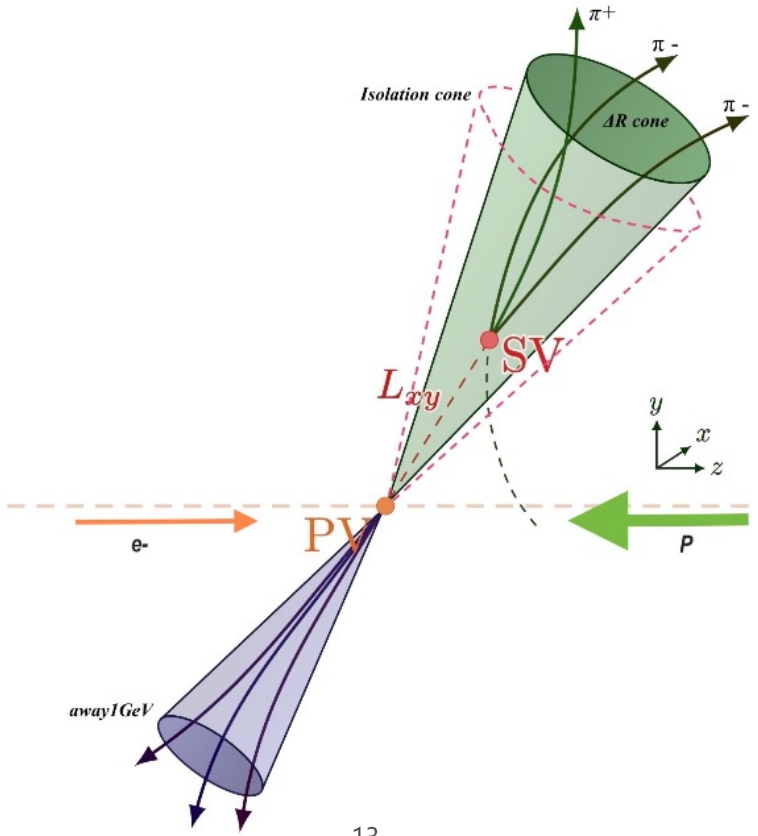
- The EIC provides realistic and complementary opportunities for BSM physics, especially in channels involving τ and μ final states.
  - Current BSM/EW activity focuses on enabling key detector capabilities (τ-tagging, μ-ID) and developing benchmark analyses such as CLFV.
  - New efforts from the BNL and LANL teams have recently started, bringing theory input and simulation work that will support future BSM/EW studies.
- Further progress will relyon:
  - More realistic simulations, expanded benchmark models, ML-based event selections
  - More contributors joining targeted studies
- **This program is still growing, there is substantial space for new analyses, new observables, and student projects.**
- **Biweekly joint meeting with the Inclusive PWG**
  - Tuesdays at 12PM ET.
  - Mailing list: eic-projdet-bsmew-l@lists.bnl.gov
  - To subscribe, visit: https://lists.bnl.gov/mailman/listinfo/eic-projdet-bsmew-l
  - Mattermost: https://chat.epic-eic.org/main/channels/ew-bsm

Backup

Optimizing Signal-to-Background for e→ τ Transitions via Leptoquarks

Bardh Quni (University of Manitoba)

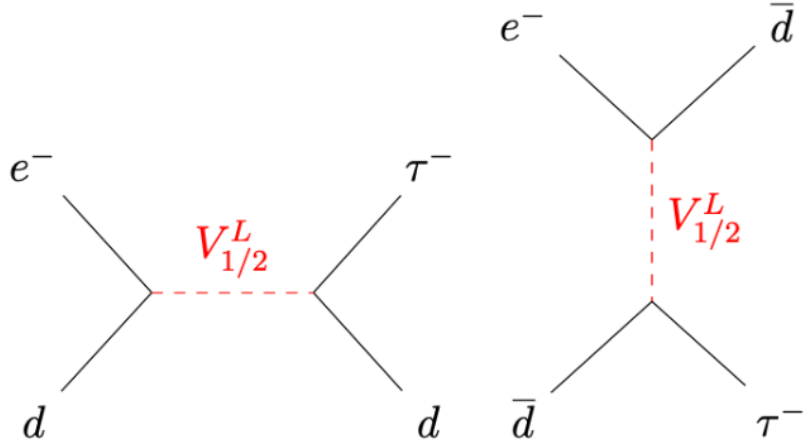
- Analysis carried for CLFV in DIS-like events mediated by LQs : $e + p \rightarrow \tau + X$ using the highest available center-of-mass energy configuration of $\sqrt{s} = 141\ \mathrm{GeV}$, corresponding to 18 GeV electron and 275 GeV proton beams.
- Current focus into 3-prong τ decays : $\tau \rightarrow \pi^-\pi^+\pi^-\nu_\tau$



LQ5= $V_{1/2}^{L}$ Signal and DIS Background

Bardh Quni (University of Manitoba)

- Presented results regarding the signal are based on s and u channel contributions mediated by the Leptoquark(LQ) $V_{1/2}^{L}$.



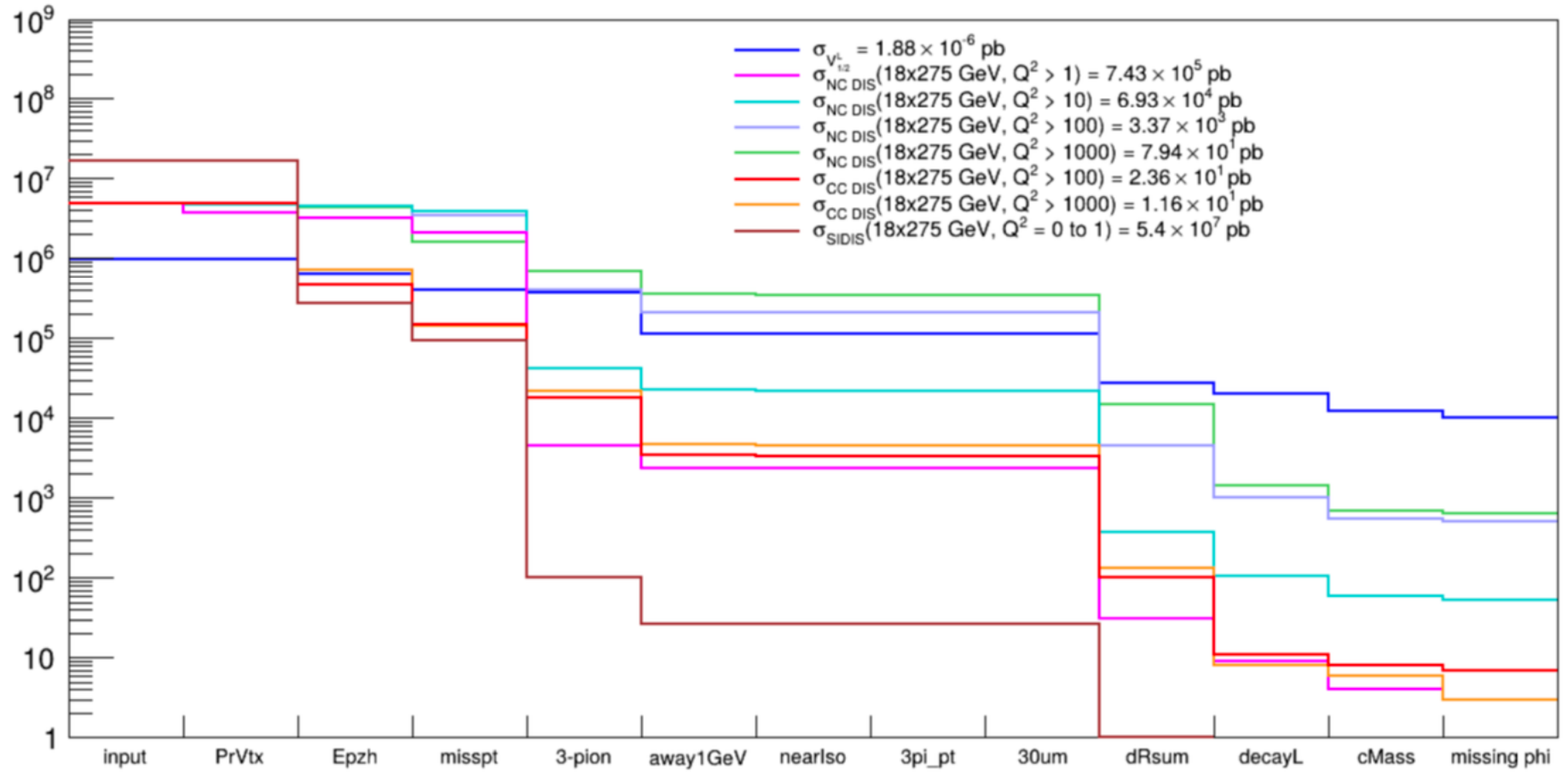
There are more leptoquarks to look into ...

- **Scalar Leptoquarks:**
  - S_0^L, S_0^R, $\tilde{S}_0^R$, S_1^L
  - $S_{1/2}^L$, $S_{1/2}^R$, $\tilde{S}_{1/2}^L$
- **Vector Leptoquarks:**
  - V_0^L, V_0^R, $\tilde{V}_0^R$, V_1^L
  - $V_{1/2}^L$, $V_{1/2}^R$, $\tilde{V}_{1/2}^L$

Consecutive cuts on $V_{1/2}^{L}$, NC, CC, SIDIS events

Bardh Quni (University of Manitoba)

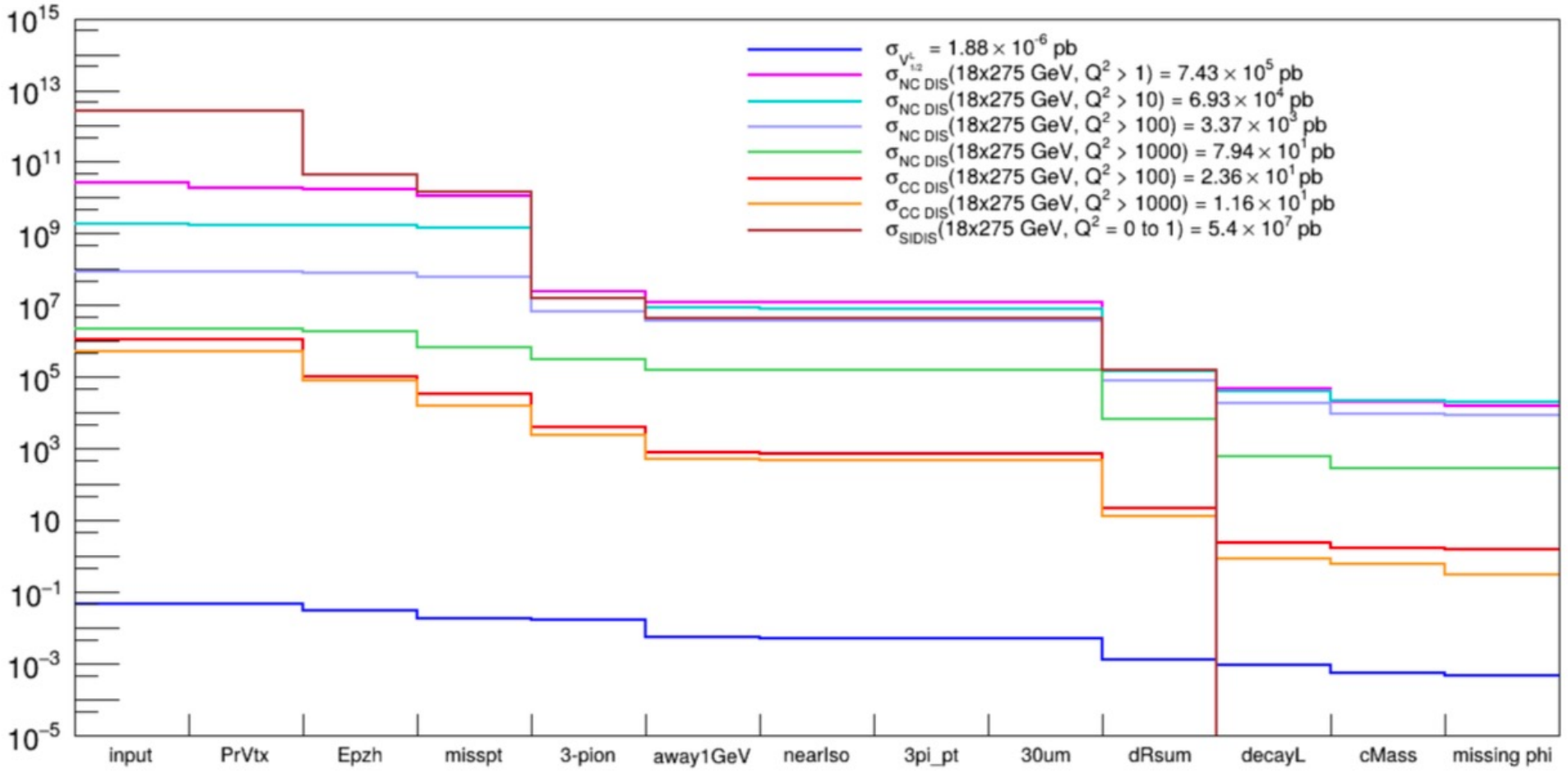
- Using $V_{1/2}^{L}$ as the signal and the DIS background event samples (see Figure below) from *root://dtn-eic.jlab.org//volatile/eic/EPIC/RECO/25.10.0*, we see that only NC DIS and CC DIS events meet all the selection criteria.



Scaling for LQ5= $V_{1/2}^{L}$, NCDIS, CCDIS, and SIDIS

Bardh Quni (University of Manitoba)

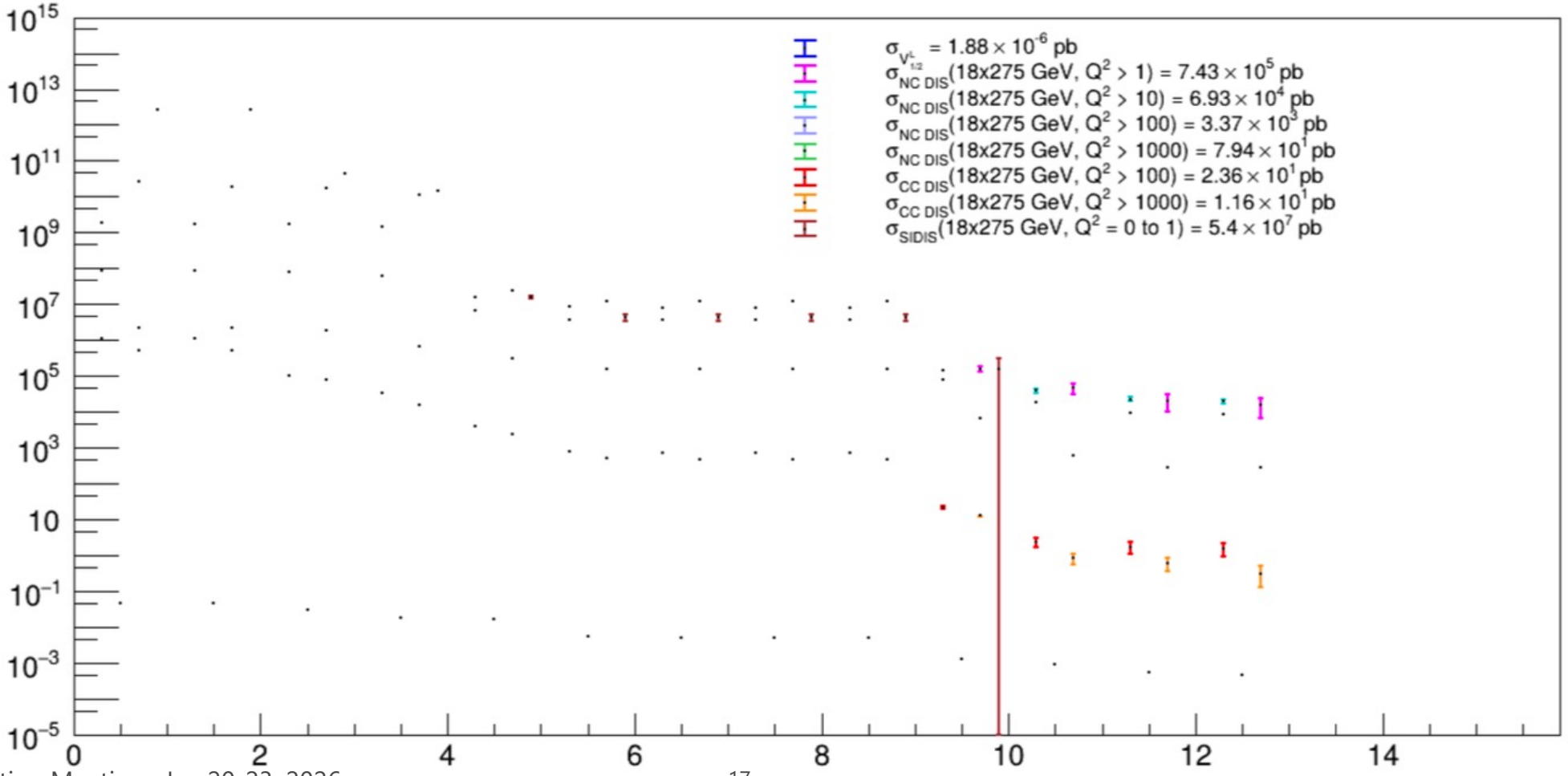
- Number of events that survived each selection cut, for an integrated luminosity of $\mathcal{L} = 100\ \mathrm{fb}^{-1}$.



Error bars for LQ5= $V_{1/2}^{L}$, NCDIS, CCDIS, and SIDIS

Bardh Quni (University of Manitoba)

- $\text{Bin Error}_{\mathcal{S}} = \sqrt{\mathcal{N}} \times \frac{\sigma}{\mathcal{N}_{\text{total}}} \times \mathcal{L}$, for the expected number of events per $\mathcal{L} = 100 fb^{-1}$.



Searching for BSM physics at EIC

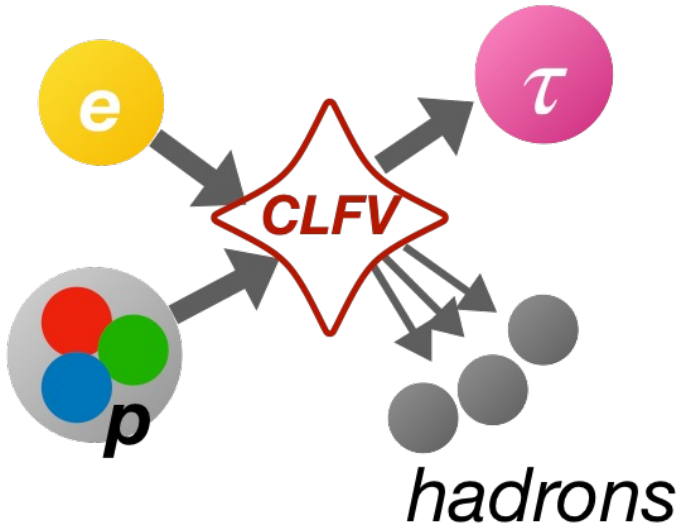
Ming Xiong Liu (LANL)

LANL LDRD: a joint theory + experiment R&D, FY25 - 27

"Discovering non-standard interactions of sterile neutrinos"

- BSM model development, EIC BSM physics and more
- Experimental feasibility study

$$e^- + p \to \tau^- + X$$



- Heavy mass sterile neutrino at EIC, possible CLFV signals
  - Heavy lepton tagging at EIC – tau
    - Displaced vertex in Tau-jet in ePIC
    - Benchmark using sPHENIX p+p data

$$p + p \to \Upsilon + X$$

$$\Upsilon \to \tau^+ + \tau^-$$

$$\tau^- \to \pi^- + \pi^- + \pi^+ + \nu_\tau$$

- **People:**
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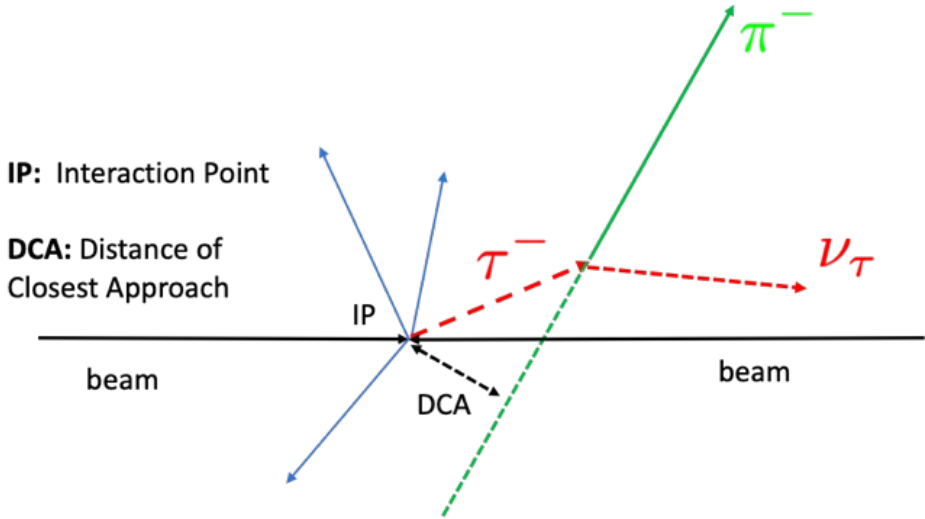
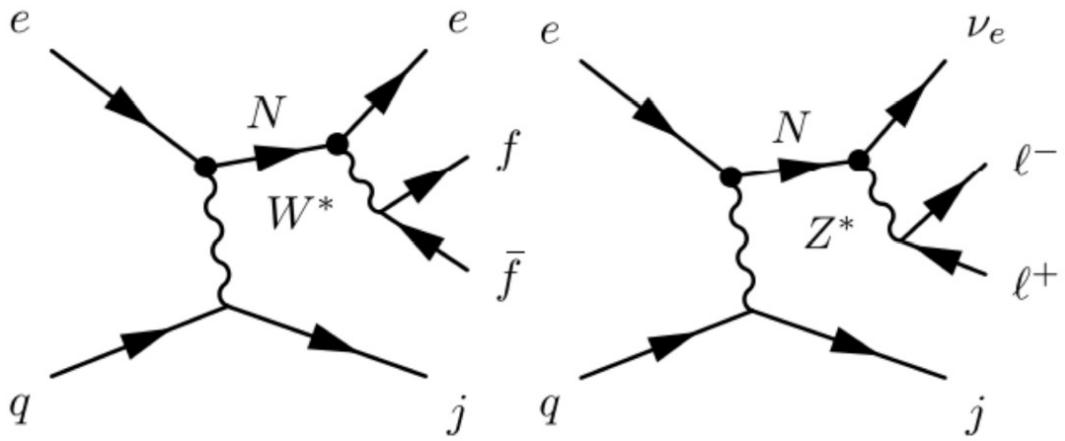
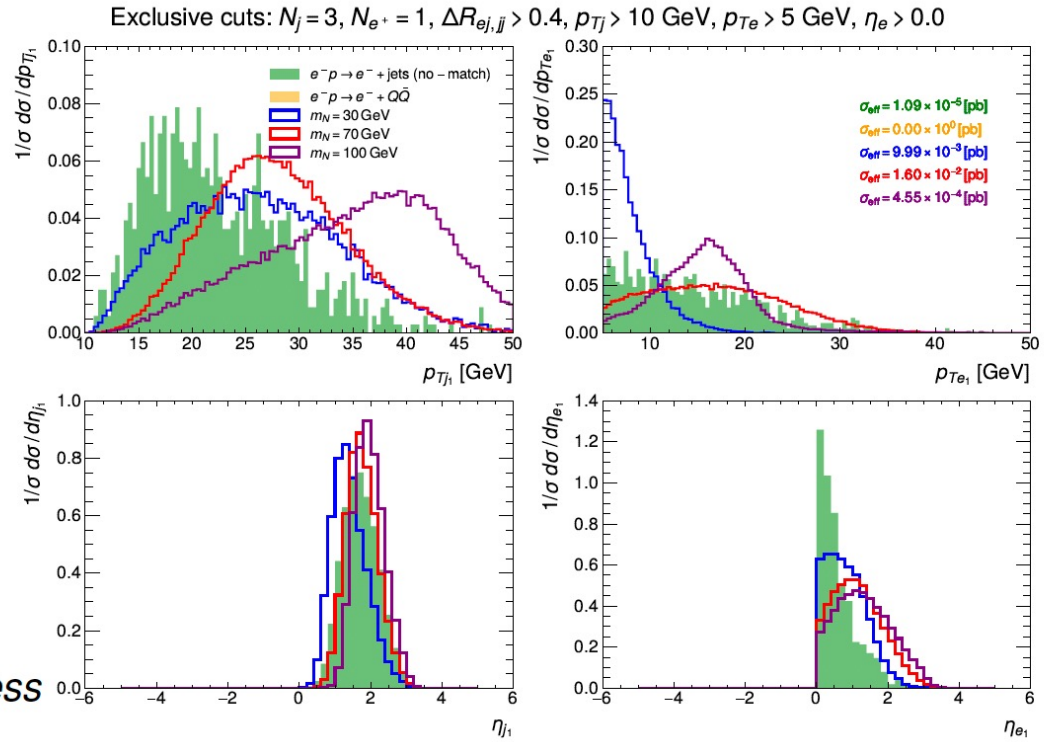


Sterile Neutrino Production at the EIC

Ming Xiong Liu (LANL)

CLFV: $e + p \to \tau(\mu) + X$





S. Urrutia Quiroga, V. Cirigliano, W. Dekens, K. Fuyuto, EM, *in progress*

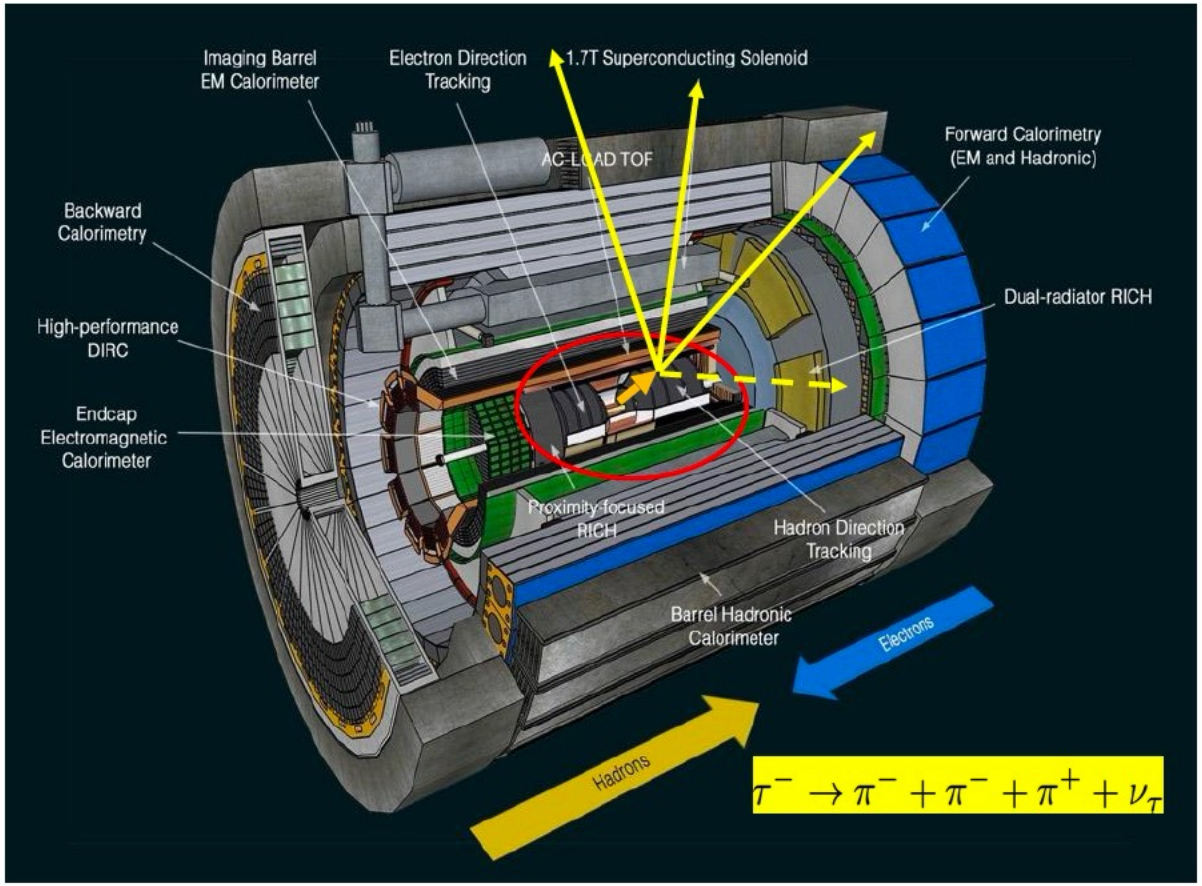
- We are starting from minimal case, with generic lepton flavor
- Generated signal and backgrounds for $e^-p \to l^\pm + 3j$ **Possible charged-lepton flavor violation**
- Working to devise the optical cuts and compare to low energy observables

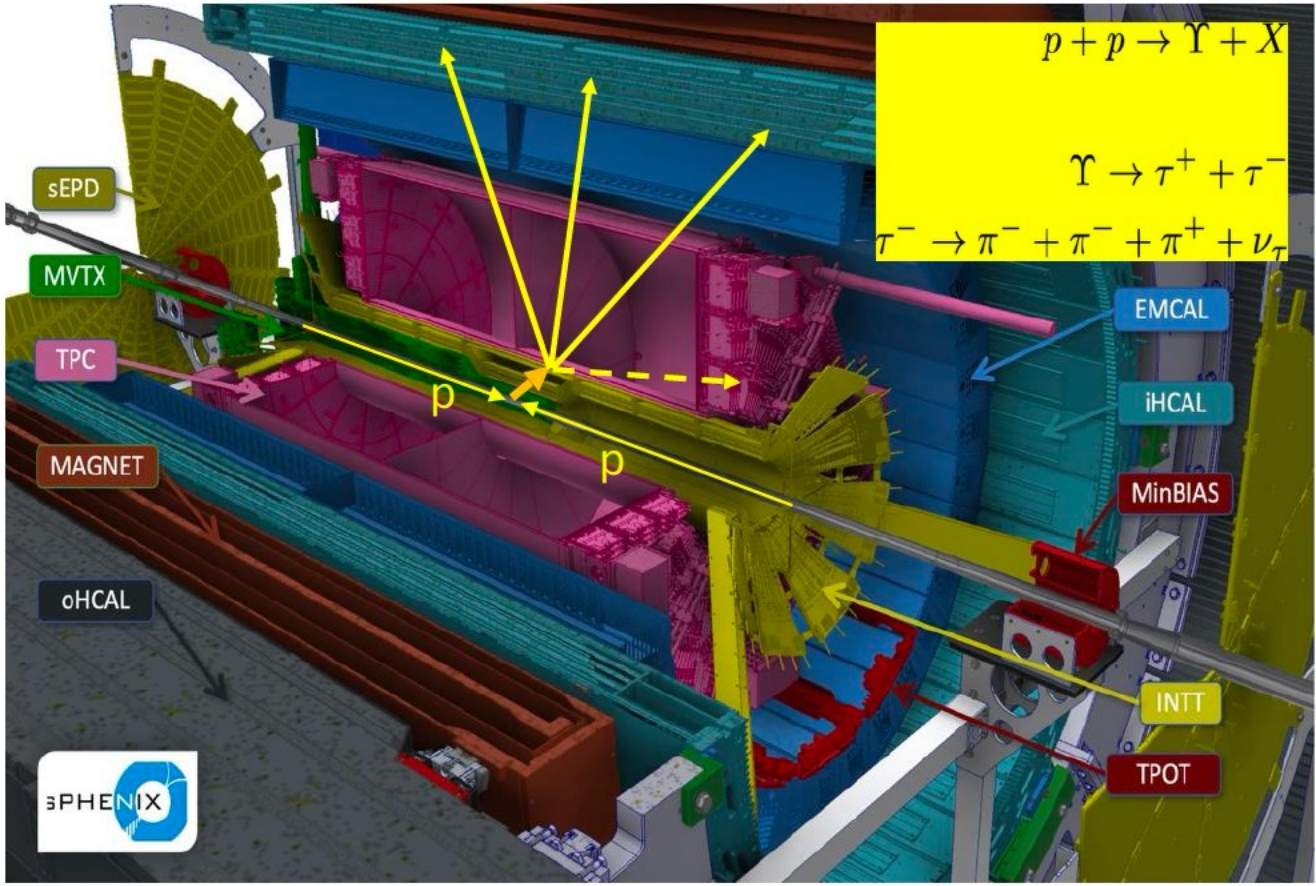
Feasibility Study: ePIC and sPHENIX

Ming Xiong Liu (LANL)

Share similar tracking technology - Silicon pixel tracking detectors (MAPS) for vertexing

- Track hit spatial resolution: ~5um



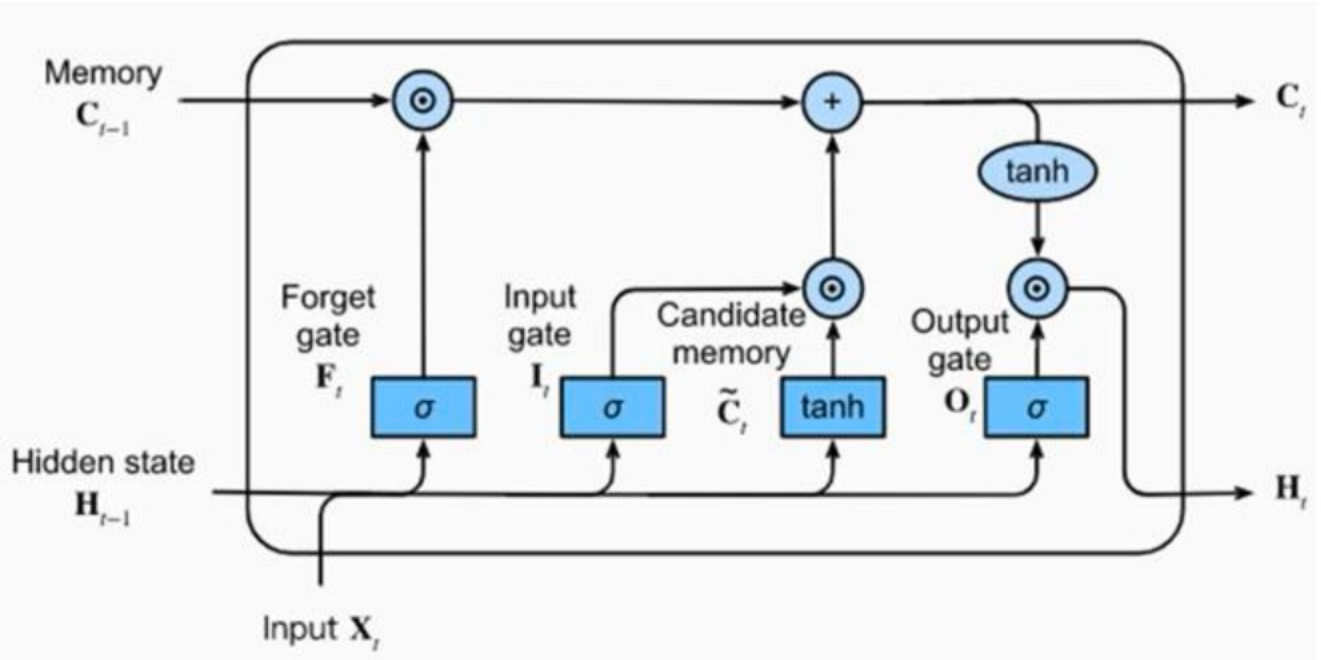


Tau Event Tagging w/ ML in sPHENIX setup

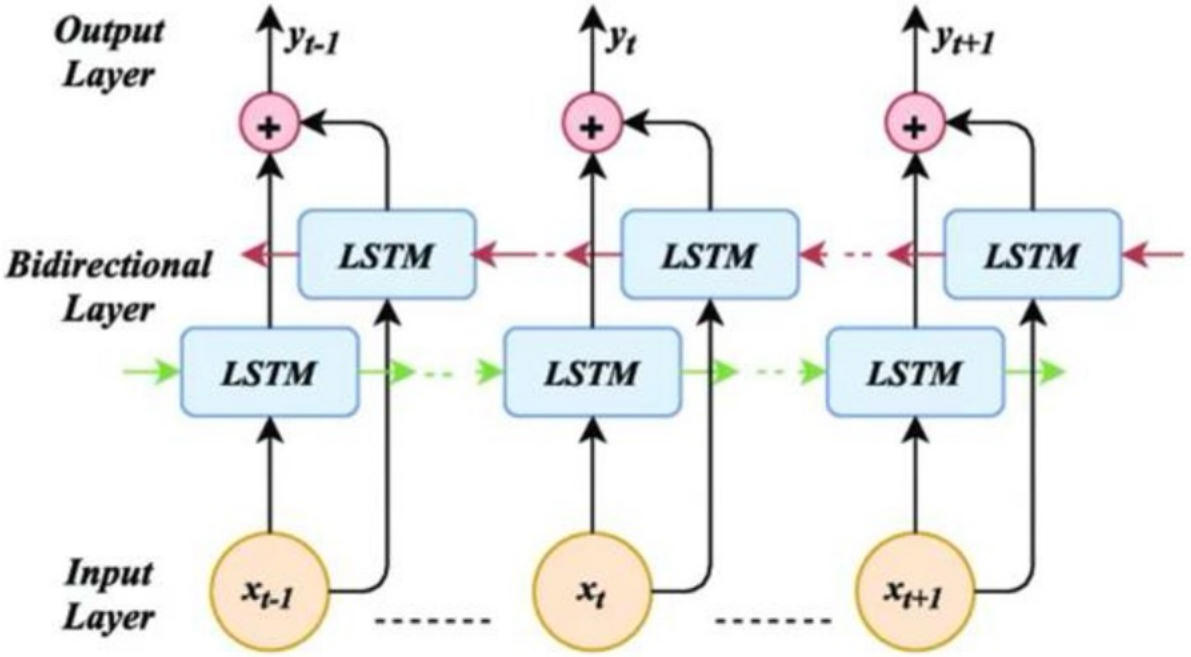
Ming Xiong Liu (LANL)

$$p + p \rightarrow \Upsilon \rightarrow \tau^{+} + \tau^{-}$$

An LSTM unit

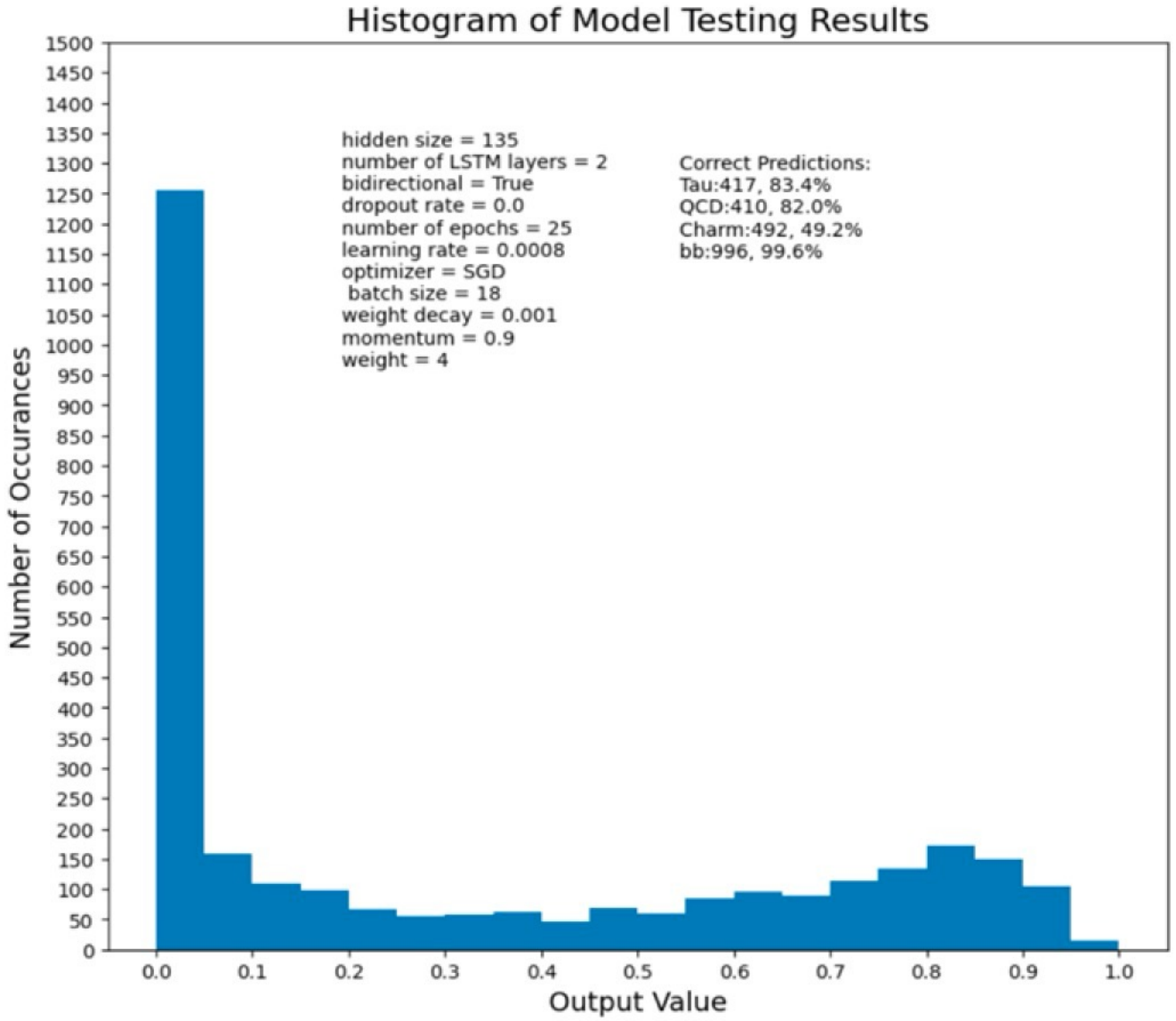


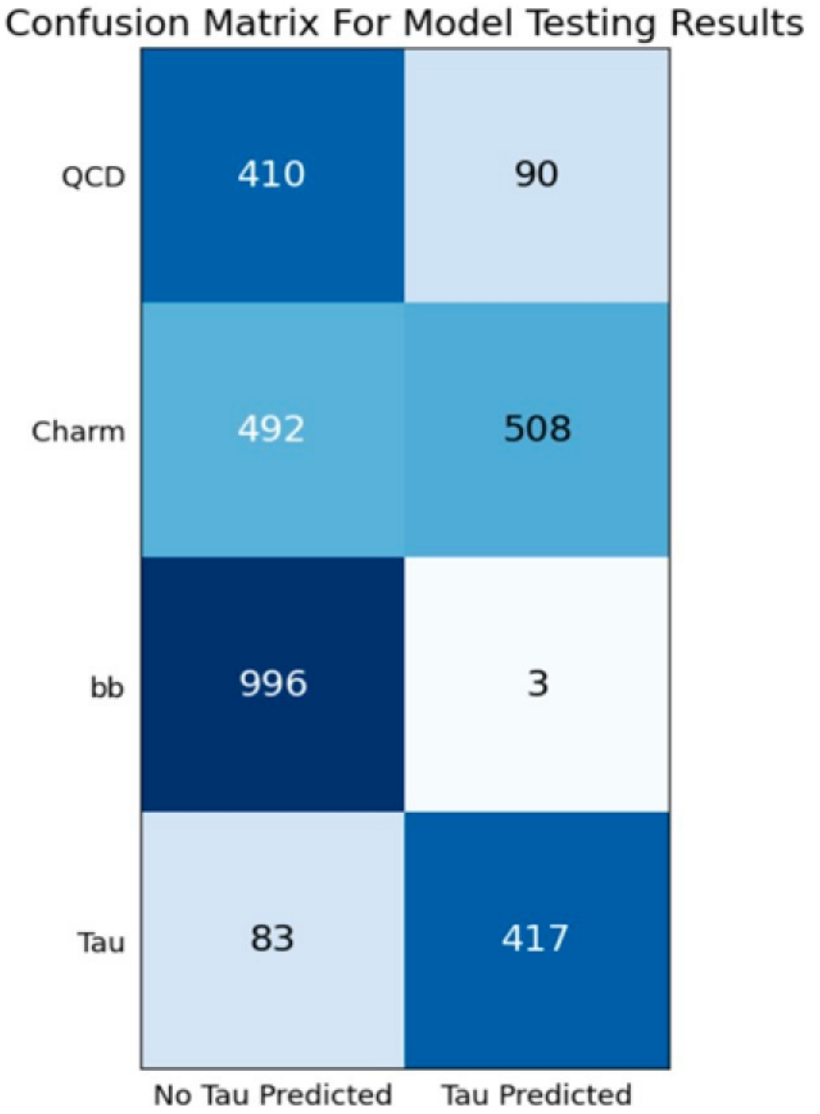
Bidirectional LSTM Structure



Event Level Tau Tagging LSTM Testing Results

Ming Xiong Liu (LANL)

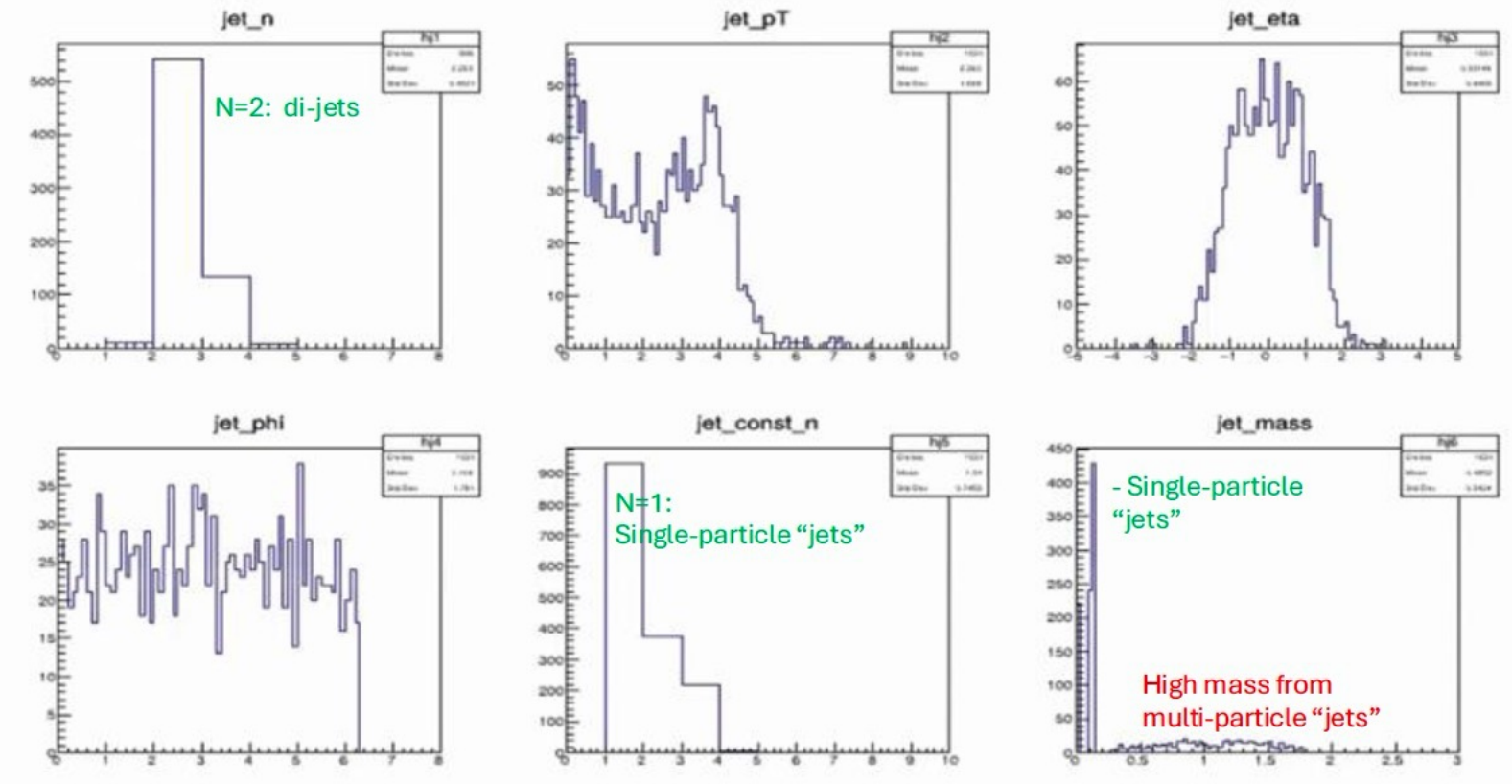




"Tau-Jet" Tagging: $p + p \rightarrow \Upsilon \rightarrow \tau^+ + \tau^-$

Ming Xiong Liu (LANL)

- Used true MC (p,E) for daughter particles;
- Full sPHENIX detector resolution, next step



Fast-Jet algorithm:
- anti-kT
- R =1.0

Single prong jets:
- Mu, e, ~35%
- pi^+/-, ~50%

3-prong jets:
- Hadrons, ~15%

Summary and To-Do's

Ming Xiong Liu (LANL)

- **Preliminary study of Tau tagging in p+p-> Upsilon in sPHENIX simulations**
  - Tau event tagging
  - Tau-jet tagging
- **Next: Tau tagging in ePIC setup**
  - ePIC full detector simulation
  - Generate e+p -> Upsilon -> tau+tau events
- **Implement new BSM physics in ePIC**
  - New BSM models implemented in pythia8