Signal and background in FLArE

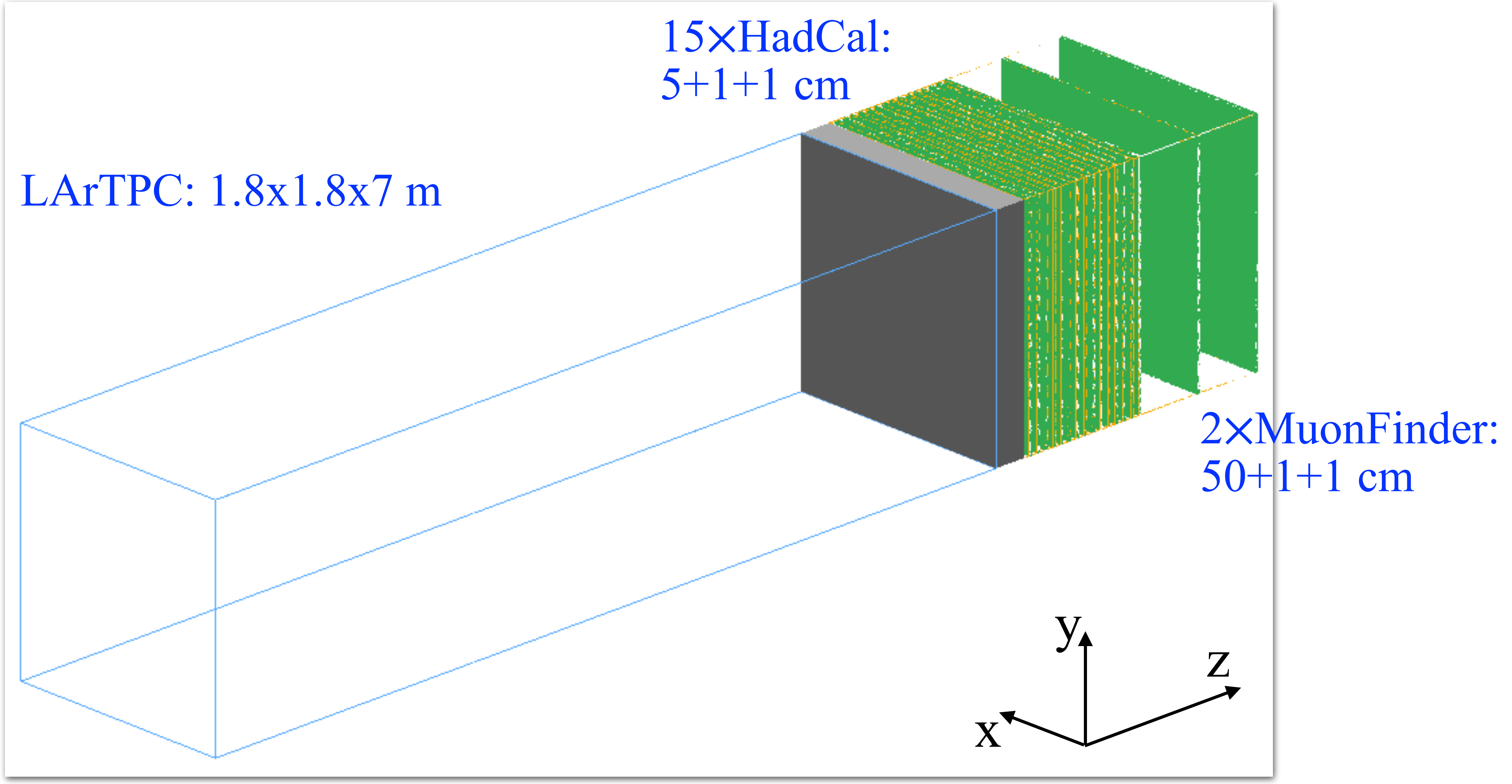
Jianming Bian, Wenjie Wu

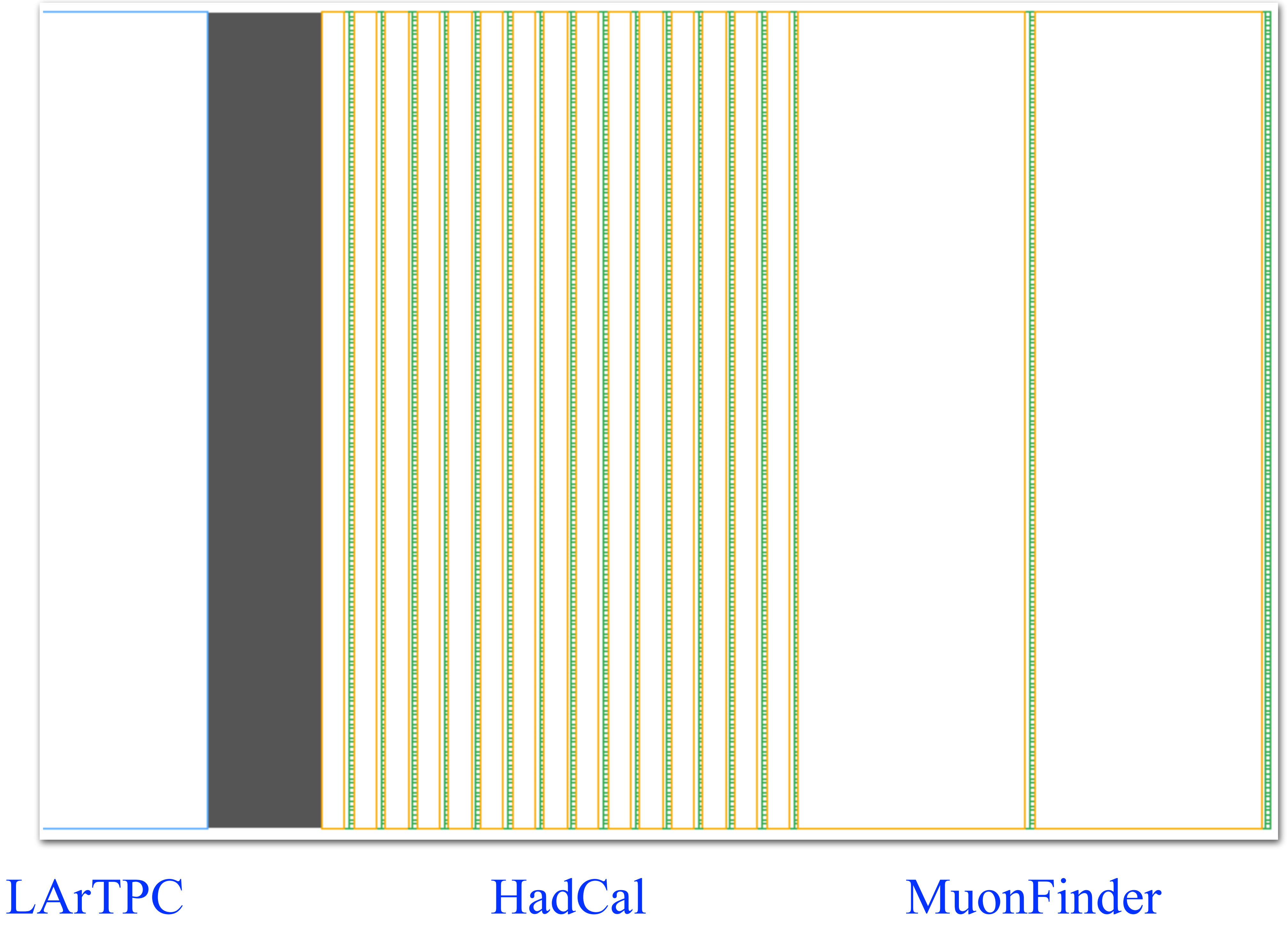
University of California, Irvine

July 7, 2022

Detector configuration in Geant4

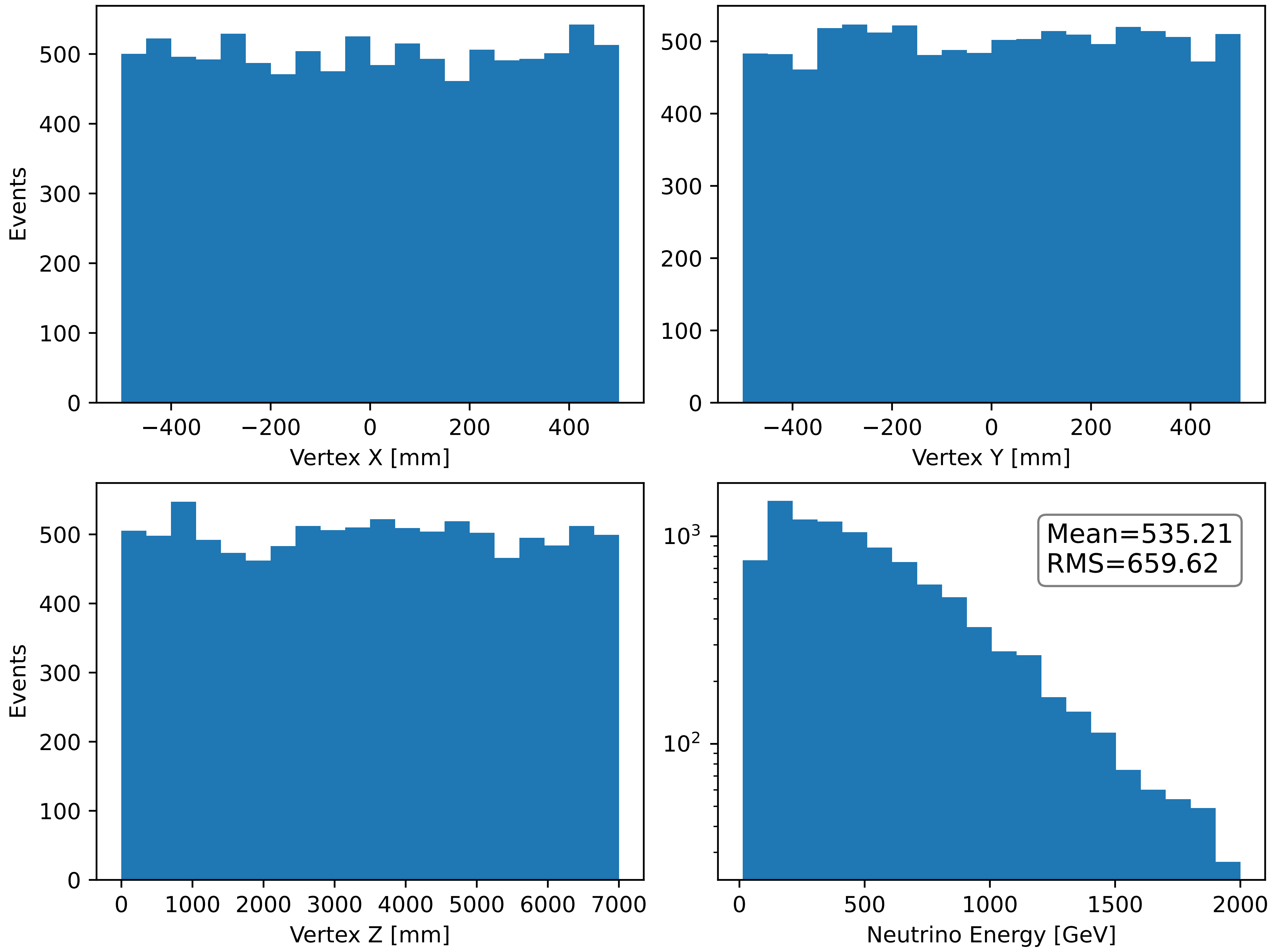
	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 9340





Simulation setup

- The vertices of neutrino interactions are uniformly distributed in the FV region (1x1x7 m)
- No angular smearing for the neutrino beam, all pointed at +z direction
- Same amount of neutrino interactions were simulated for ν_e, ν_μ, and ν_τ
  - flux ratio is ~100:400:1



Signal and background

- Only consider beam neutrino background for now
- Decay modes of the tau lepton
  - τ_e: taus decay to electrons
  - τ_μ: taus decay to muons
  - τ_{had}: taus decay to hadrons
- Major background of τ_μ signal: ν_μCC events
- Major background of τ_e signal: ν_eCC events
- Major background of τ_{had} signal: NC scattering events from all neutrinos

TABLE I. Dominant decay modes of τ^-. All decays involving kaons, as well as other subdominant decays, are in the "Other" category.

Decay mode	Branching ratio
Leptonic	35.2%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic	64.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\pi^0\nu_\tau$	9.3%
$\pi^-\pi^-\pi^+\nu_\tau$	9.0%
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.5%
Other	5.7%

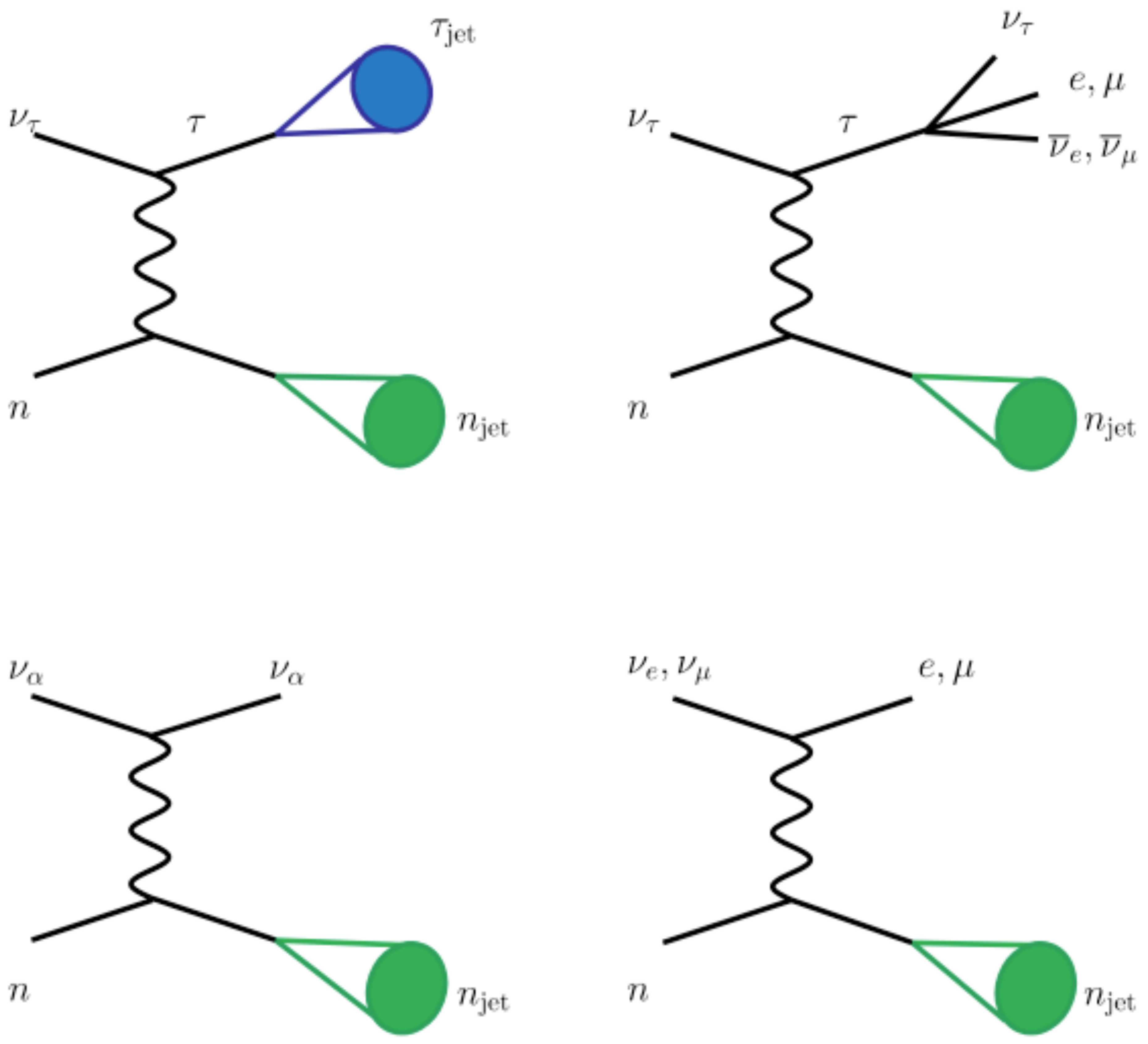


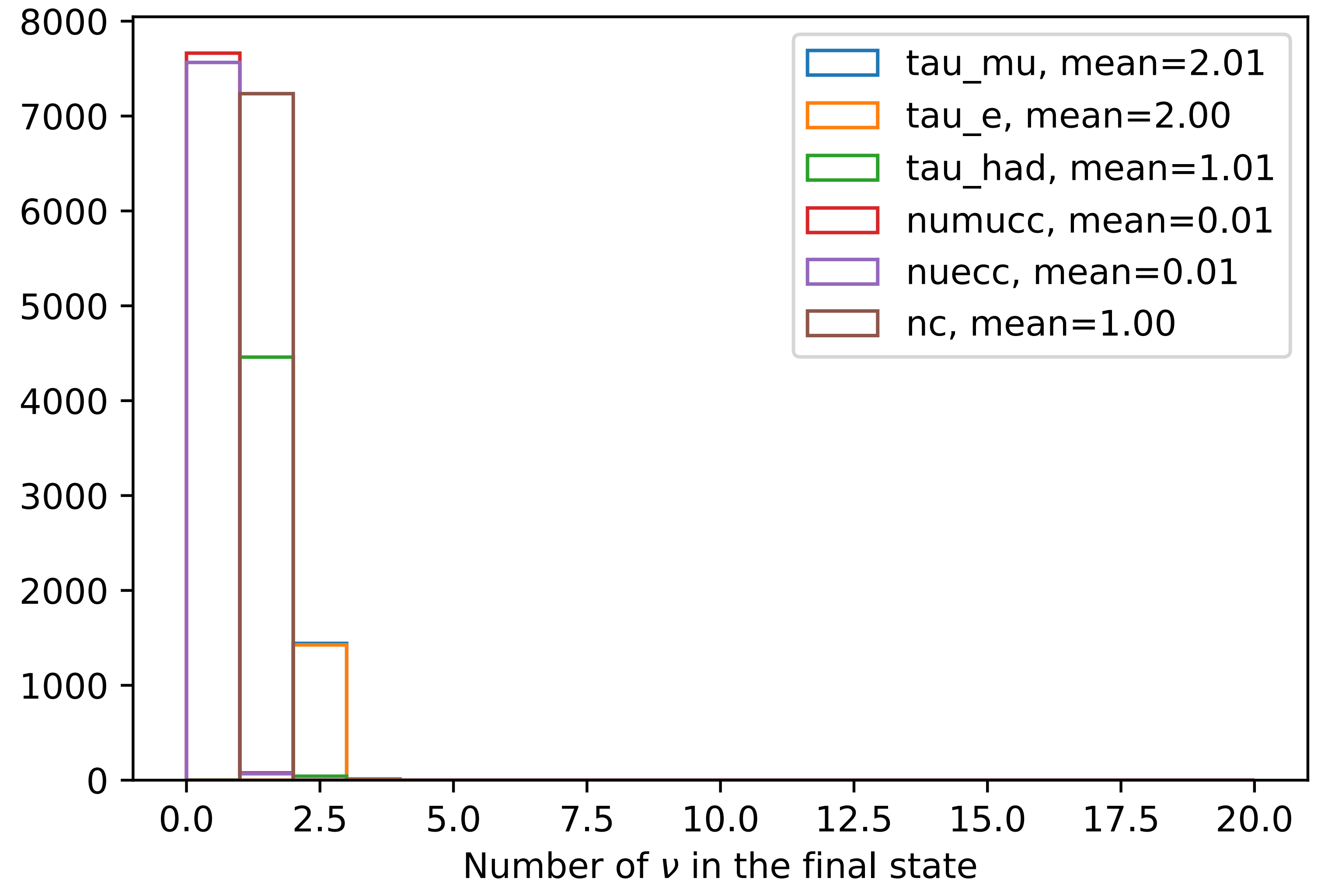
FIG. 2. Pictorial representation of hadronic tau (upper left) and leptonic tau (upper right) signals, and their corresponding backgrounds (lower).

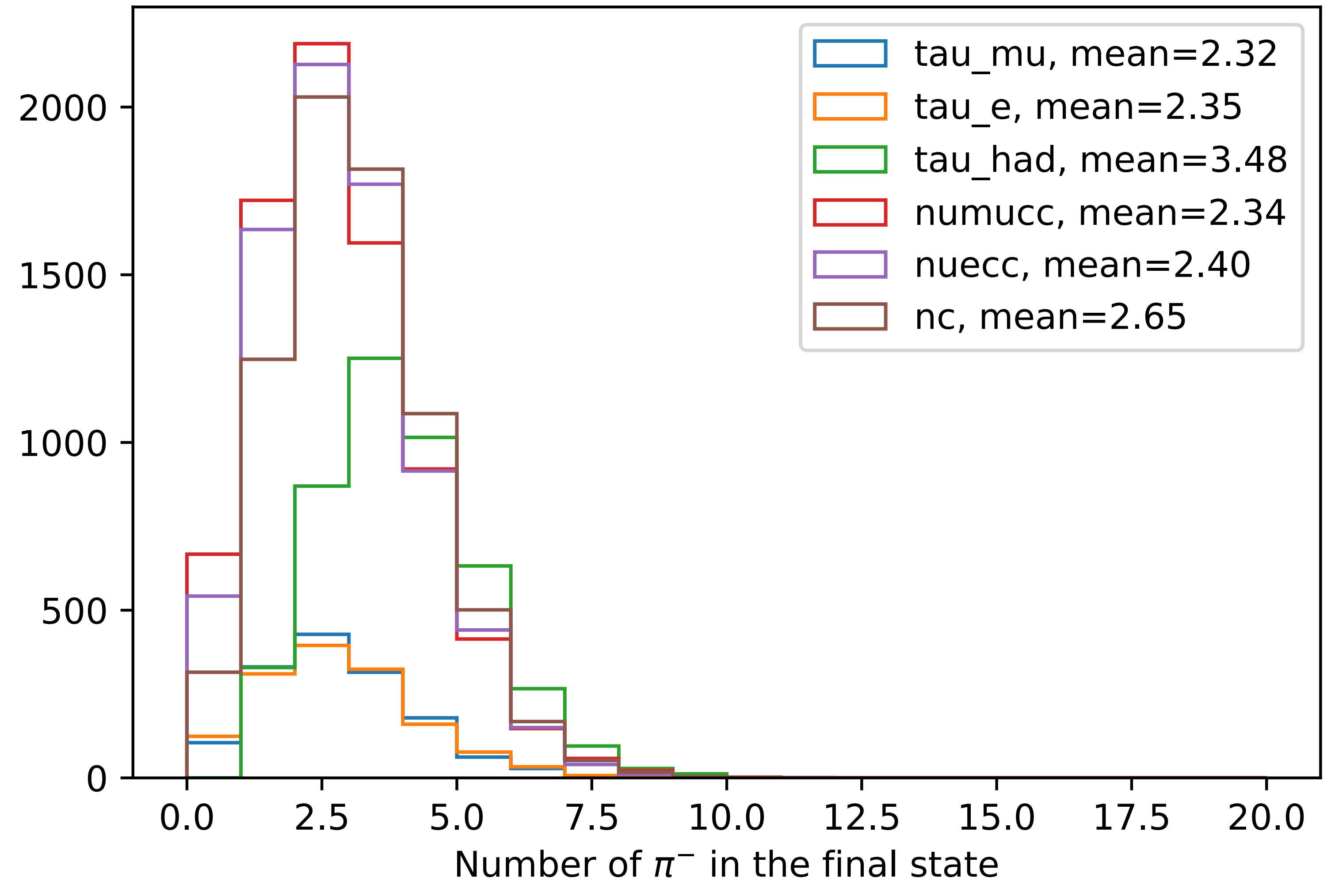
10.1103/PhysRevD.102.053010

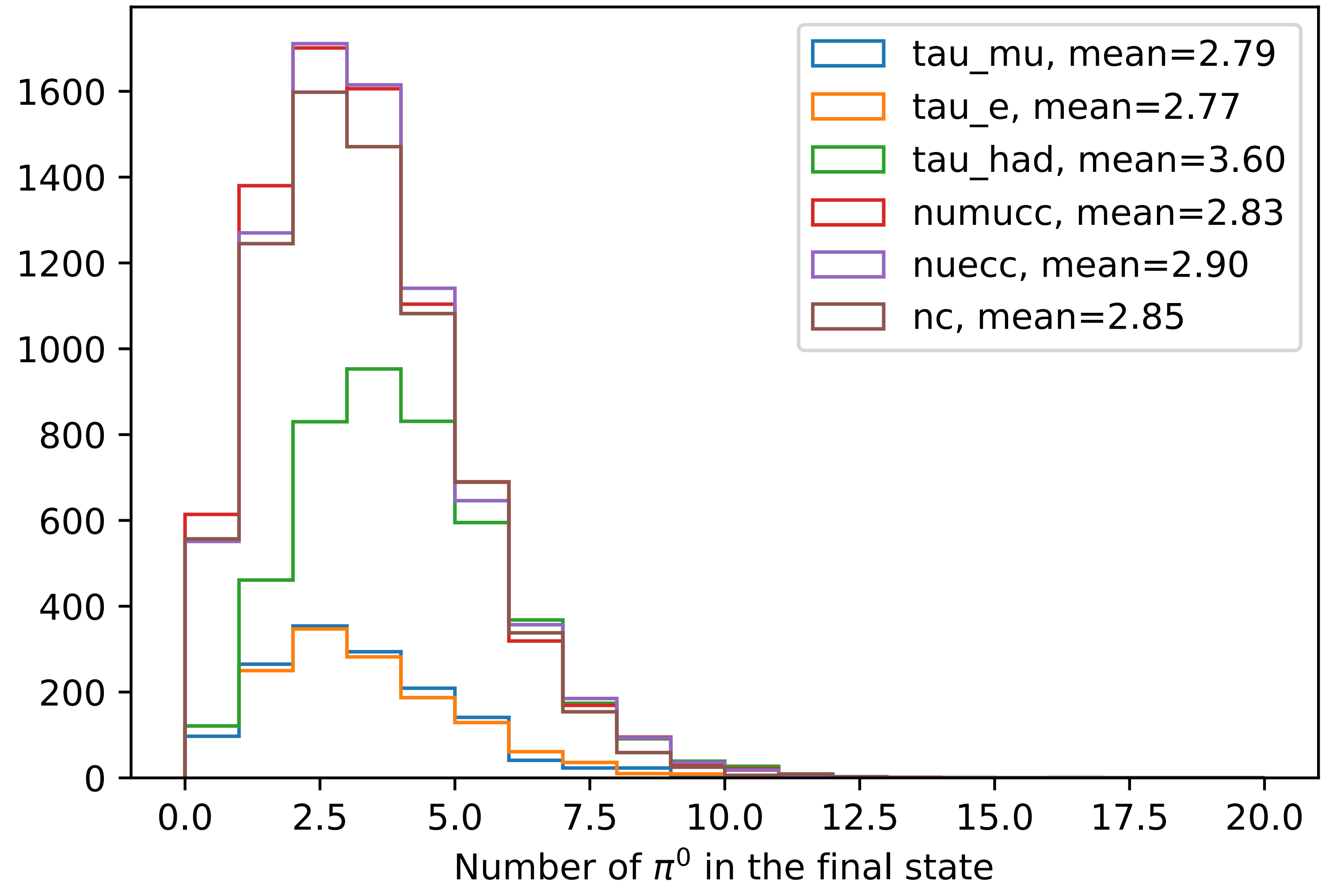
UCIRVINE

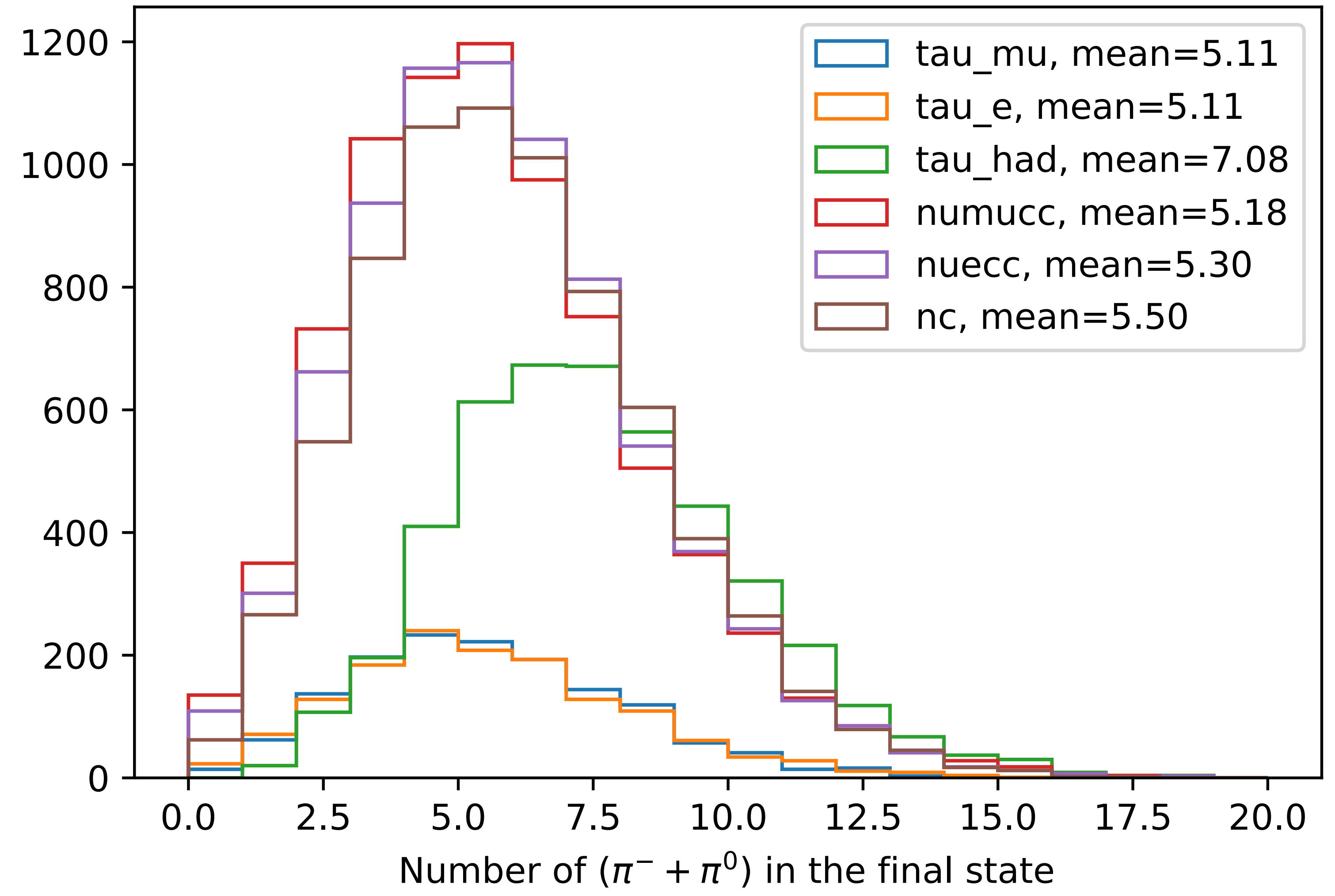
Signatures of the final state particles

- Stable particles in the final state, including particles from tau decay
- τ_{had} have at least $1\pi^-$ in the final state
  - τ_{had} have more (π^-, π^0) in the final state
- Neutrinos in the final state are invisible to the detector, contributing to the missing energy
  - Almost all ν_μCC, ν_eCC have zero neutrino in the final state
  - NC events and τ_{had} have 1 neutrino, τ_μ and τ_e have 2 neutrinos



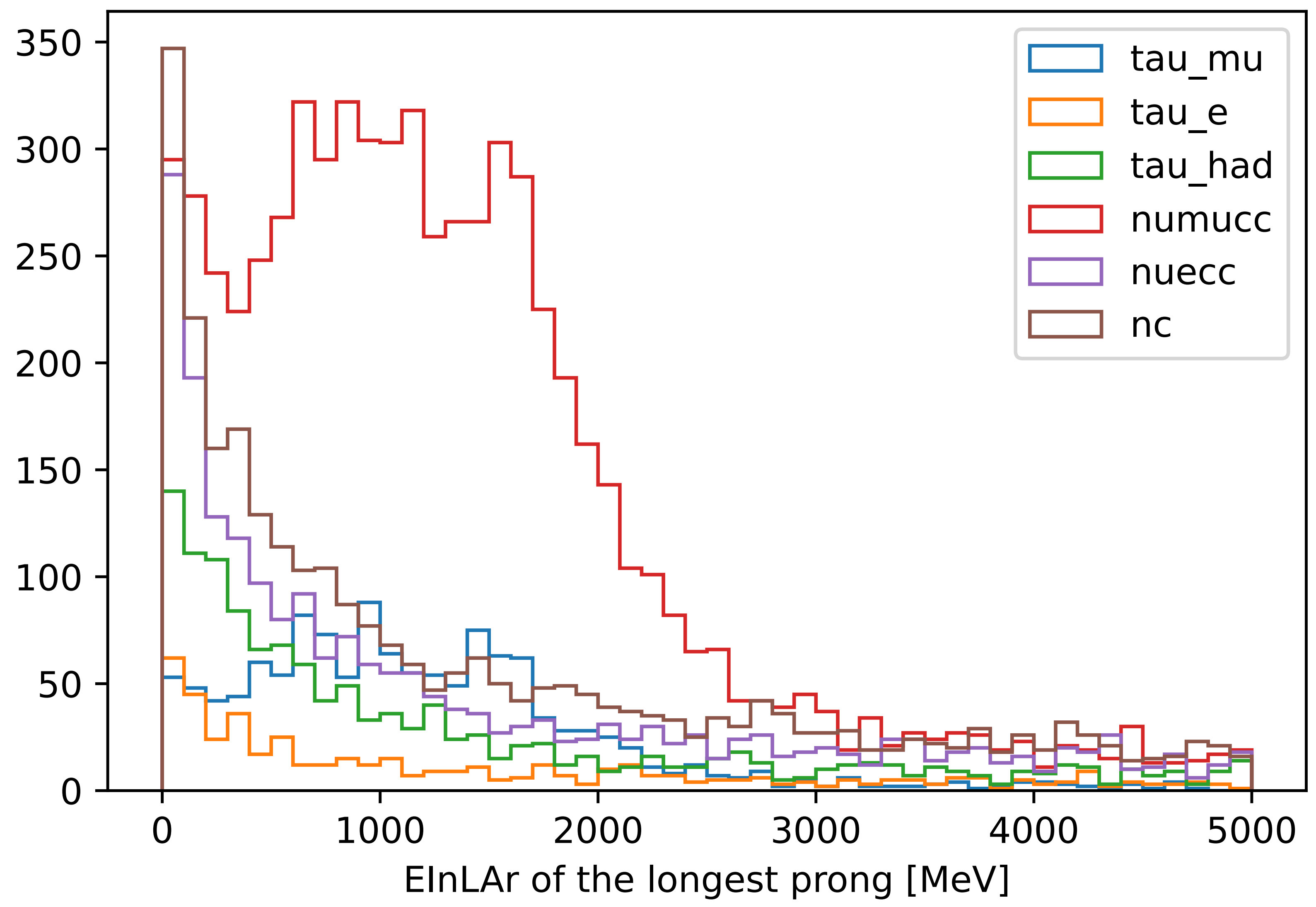


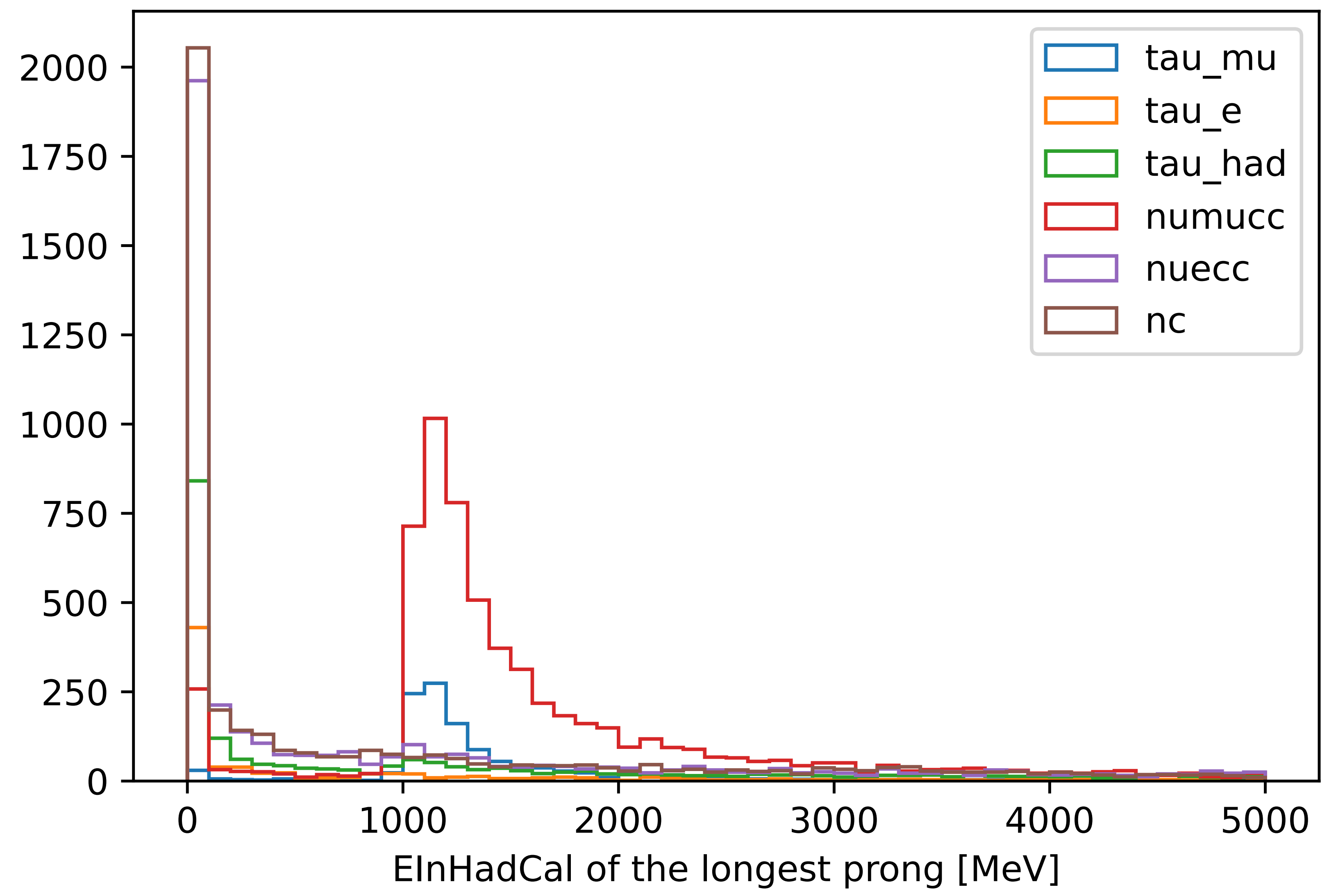


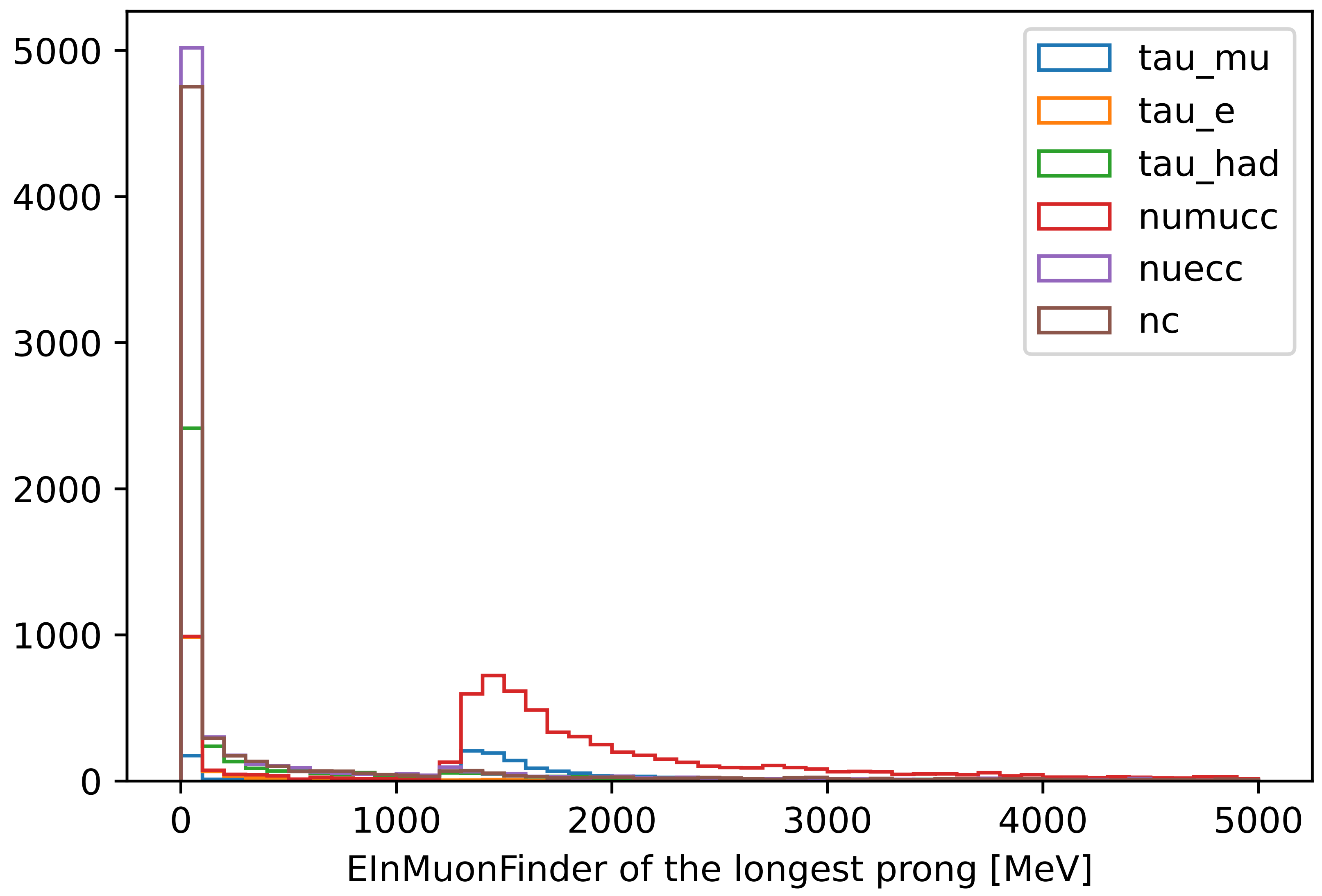


Deposited energy of the longest prong

- τ_μ and ν_μCC are distinctive from other channels

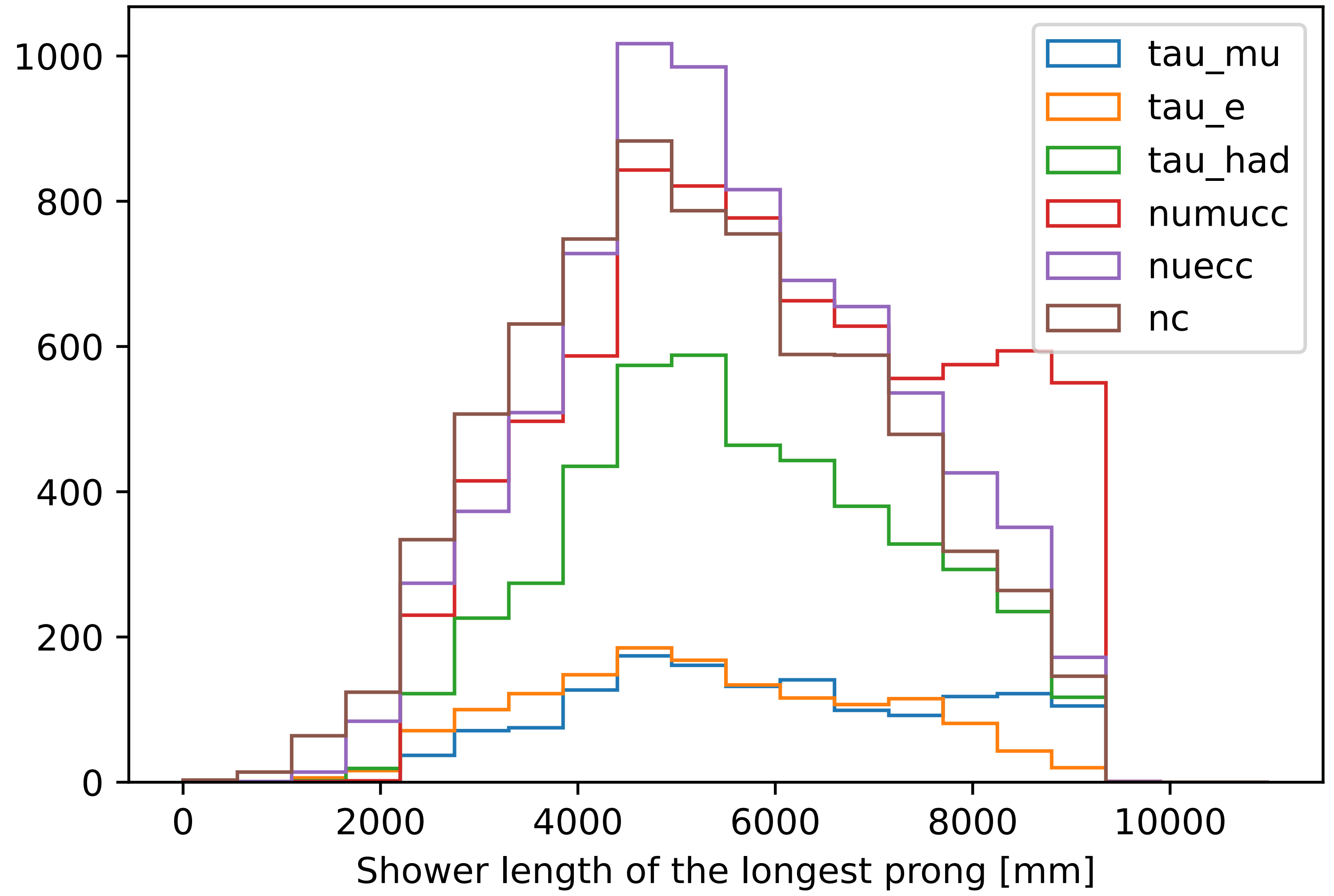


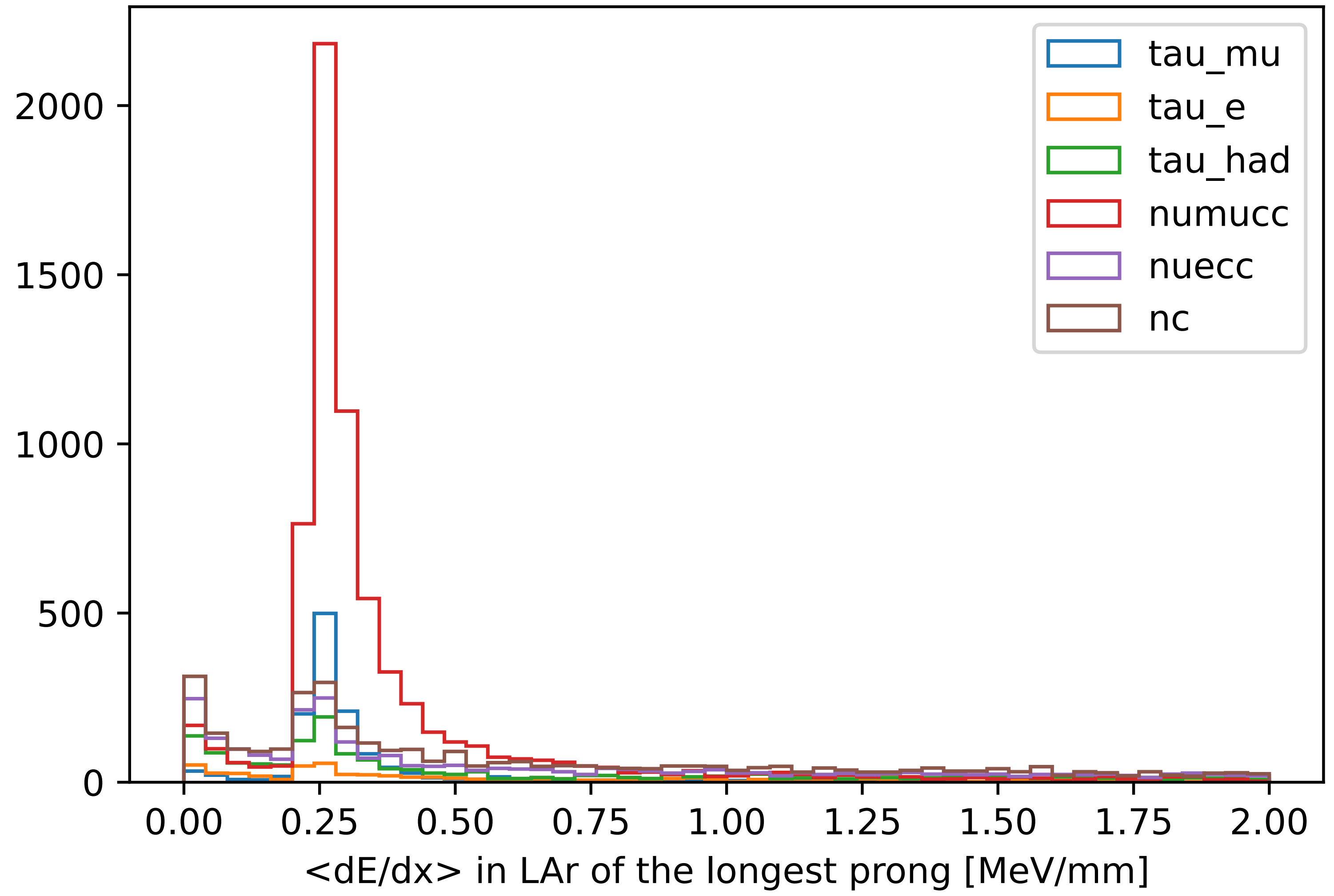


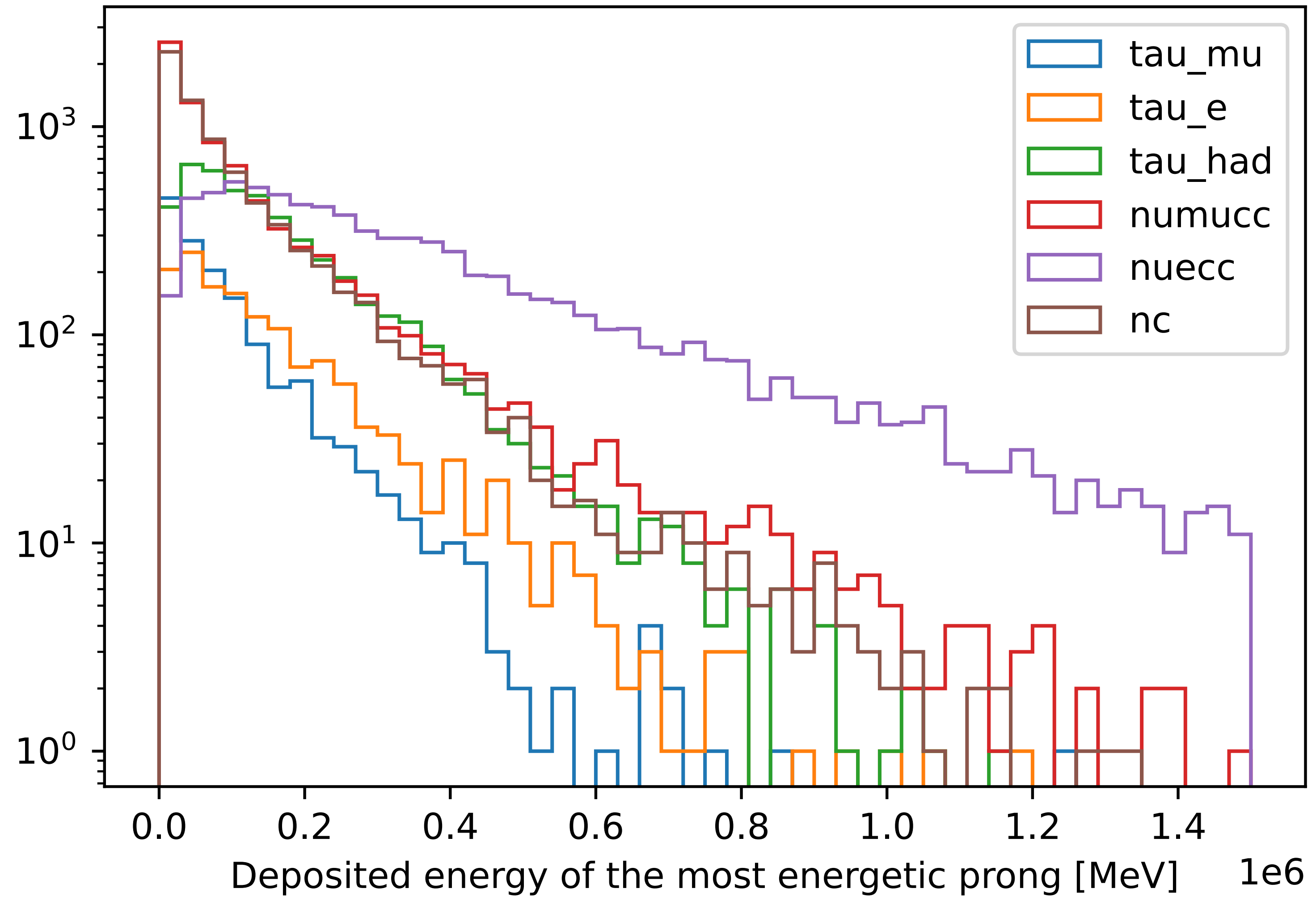


Some other features

- τ_μ and ν_μCC have relatively longer shower length
- Averaged <dE/dx> can also be used to select τ_μ and ν_μCC



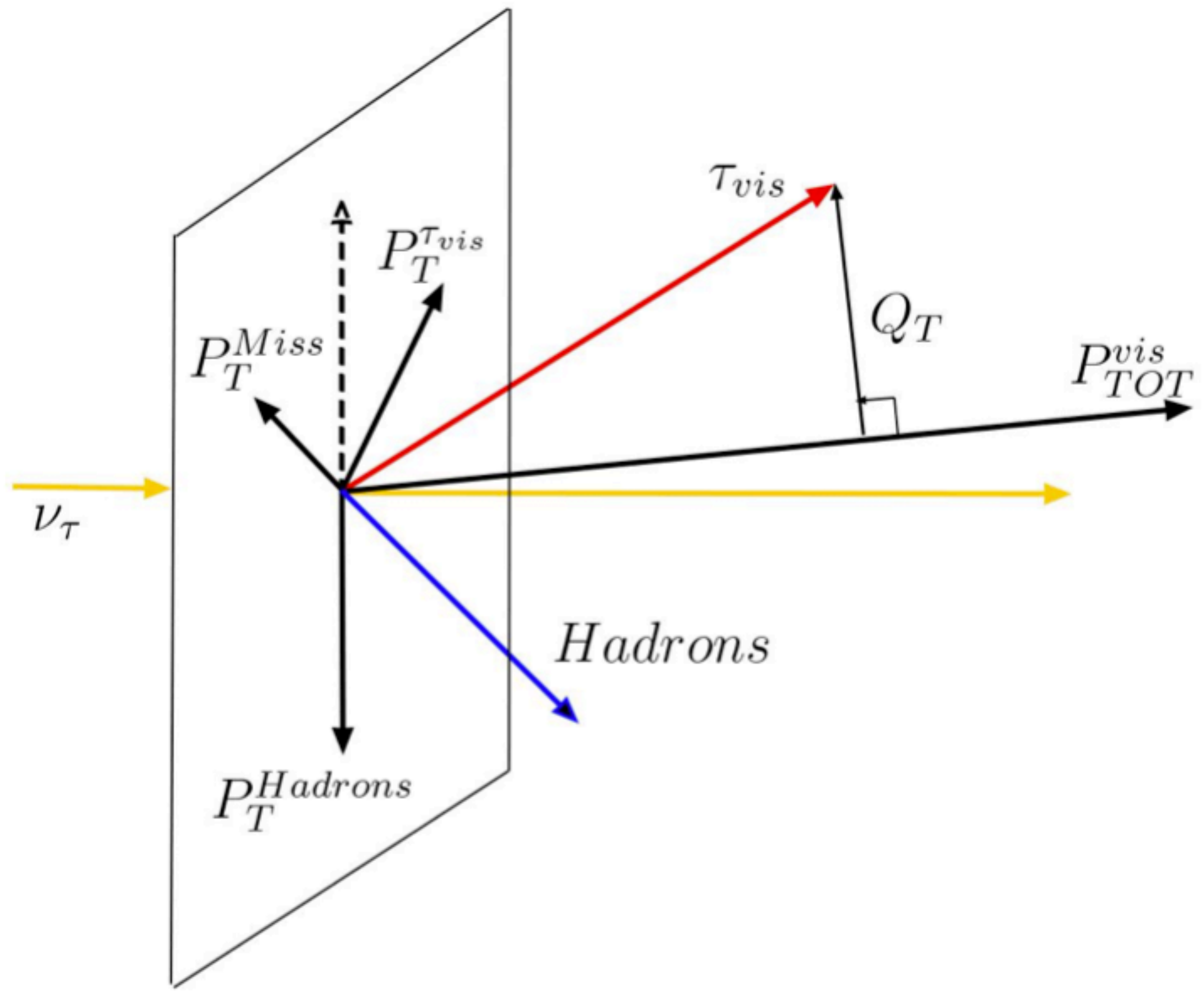


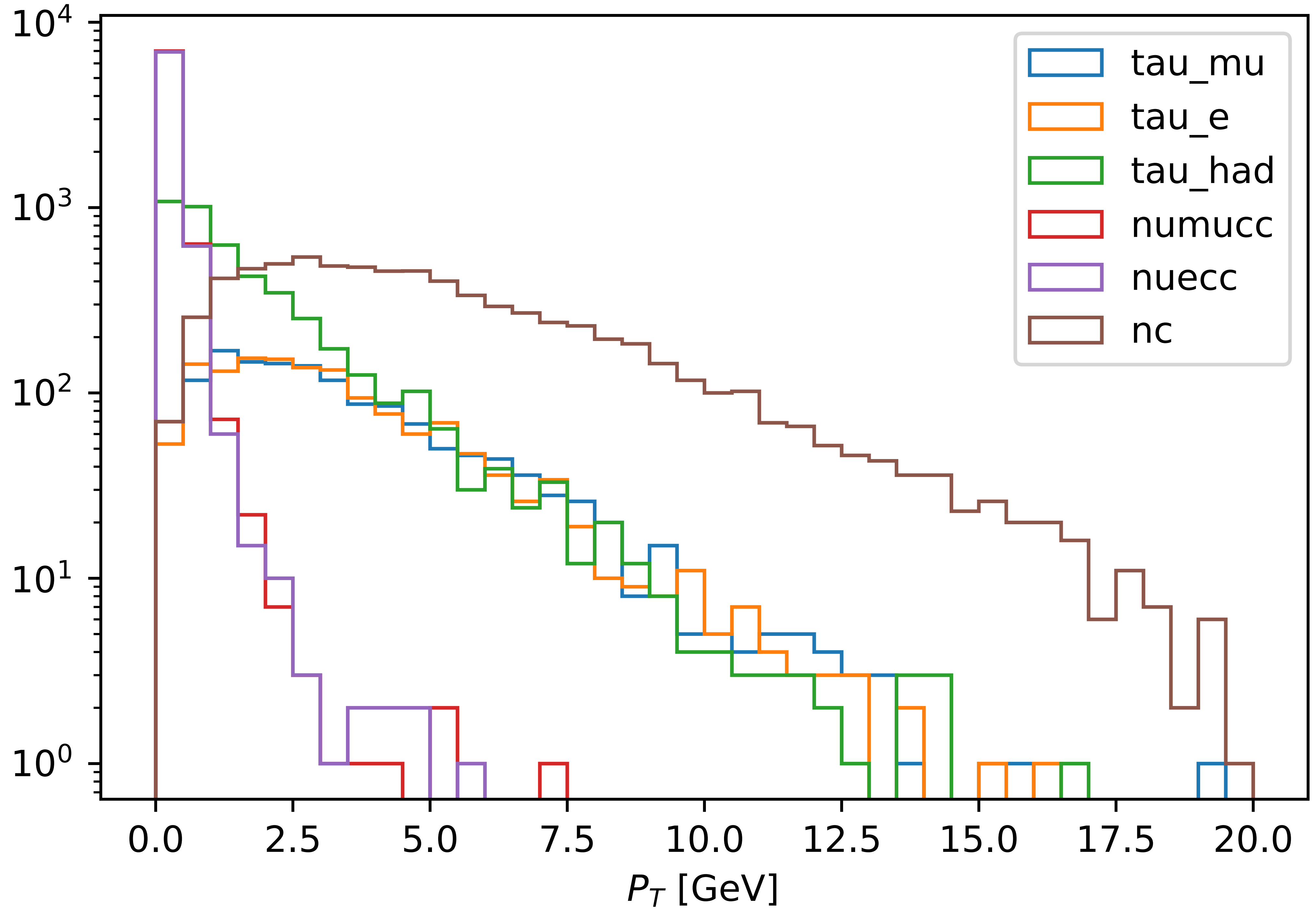


Jianming Bian, Wenjie Wu (UCI)

Missing transverse momentum

- τ_μ have more neutrinos in the final state than ν_μCC, thus more missing momentum in the transverse plane

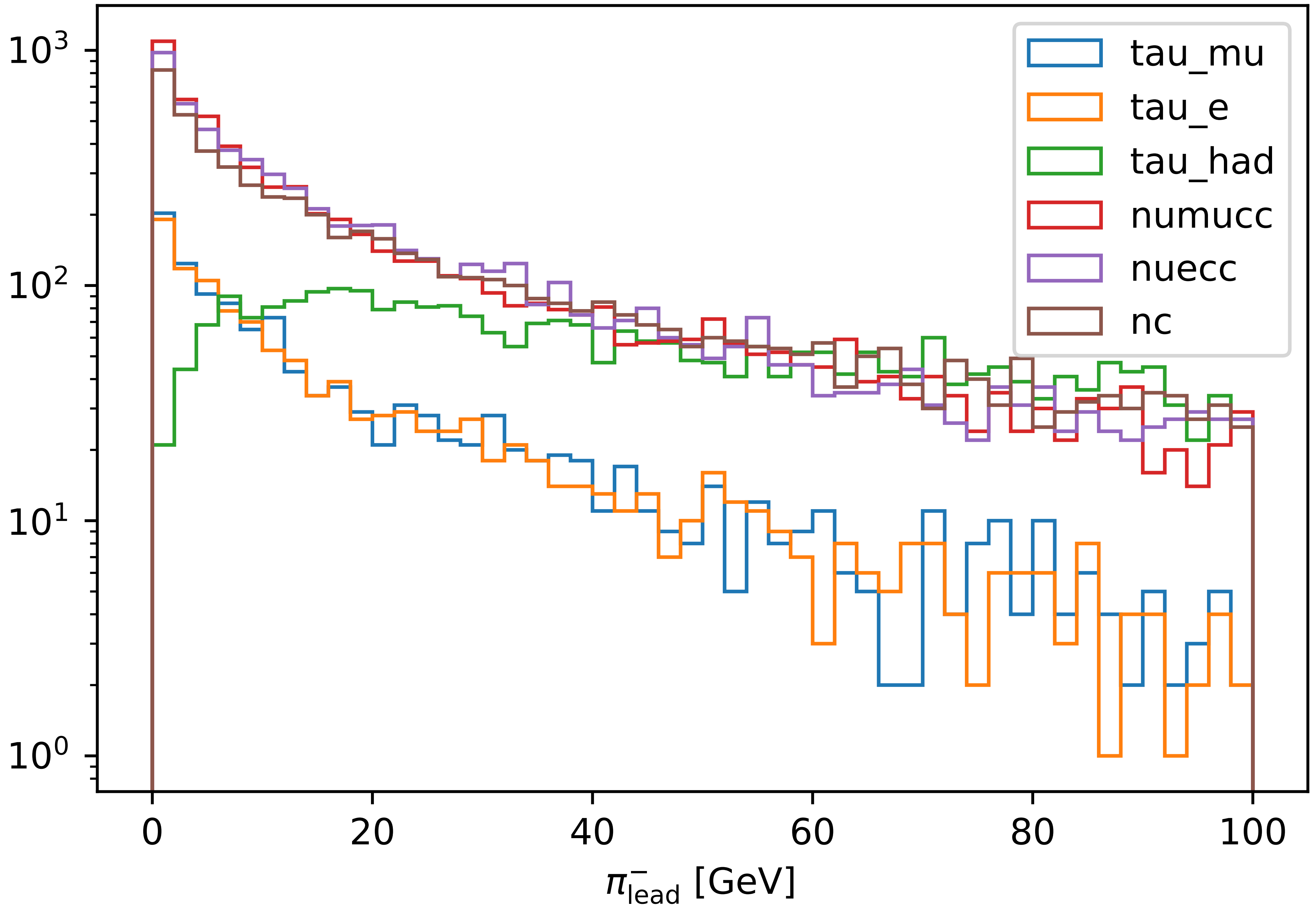




Jianming Bian, Wenjie Wu (UCI)

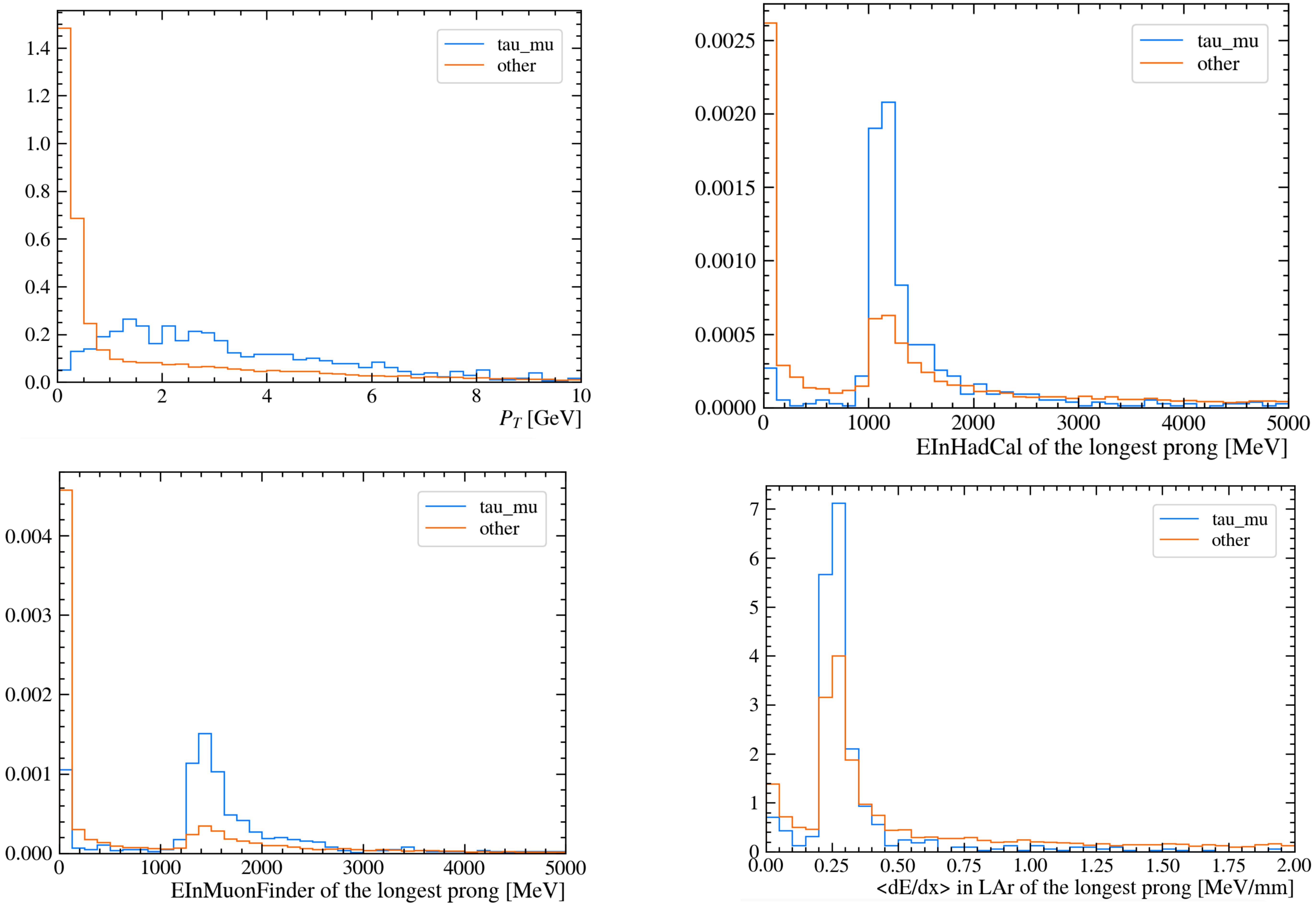
Energy of the leading π^-

- $\tau_{\rm had}$ has larger branch ratio than τ_μ and τ_e, there is potential to be a good channel to select ν_τ
- $\tau_{\rm had}$ generally have a more energetic π^- in the final state



First look of a BDT

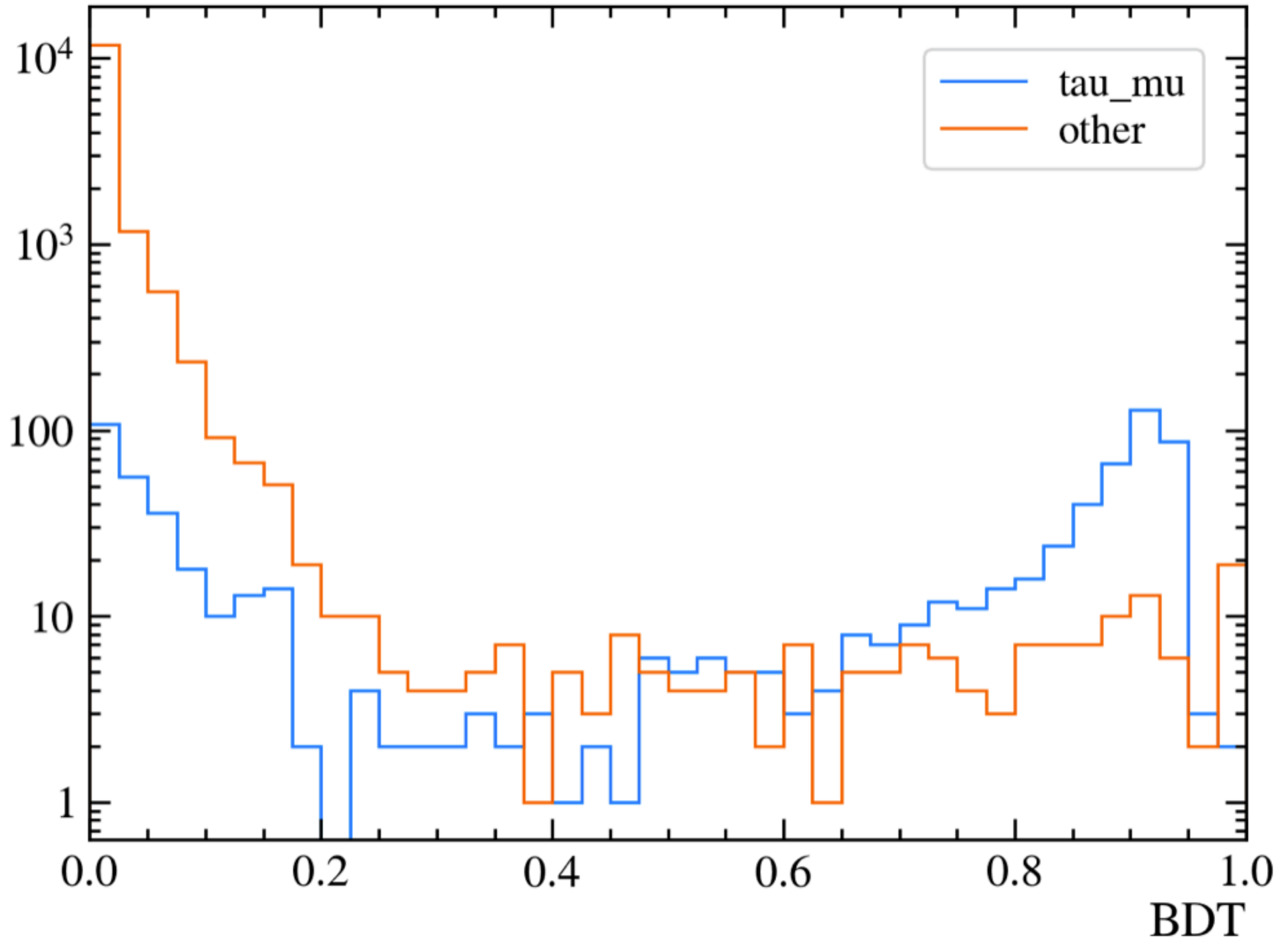
- Signal - τ_μ, Background - others
- Input: Missing transverse momentum, EInHadCal/EInMuonFinder/<dEdxInLAr> of the longest prong

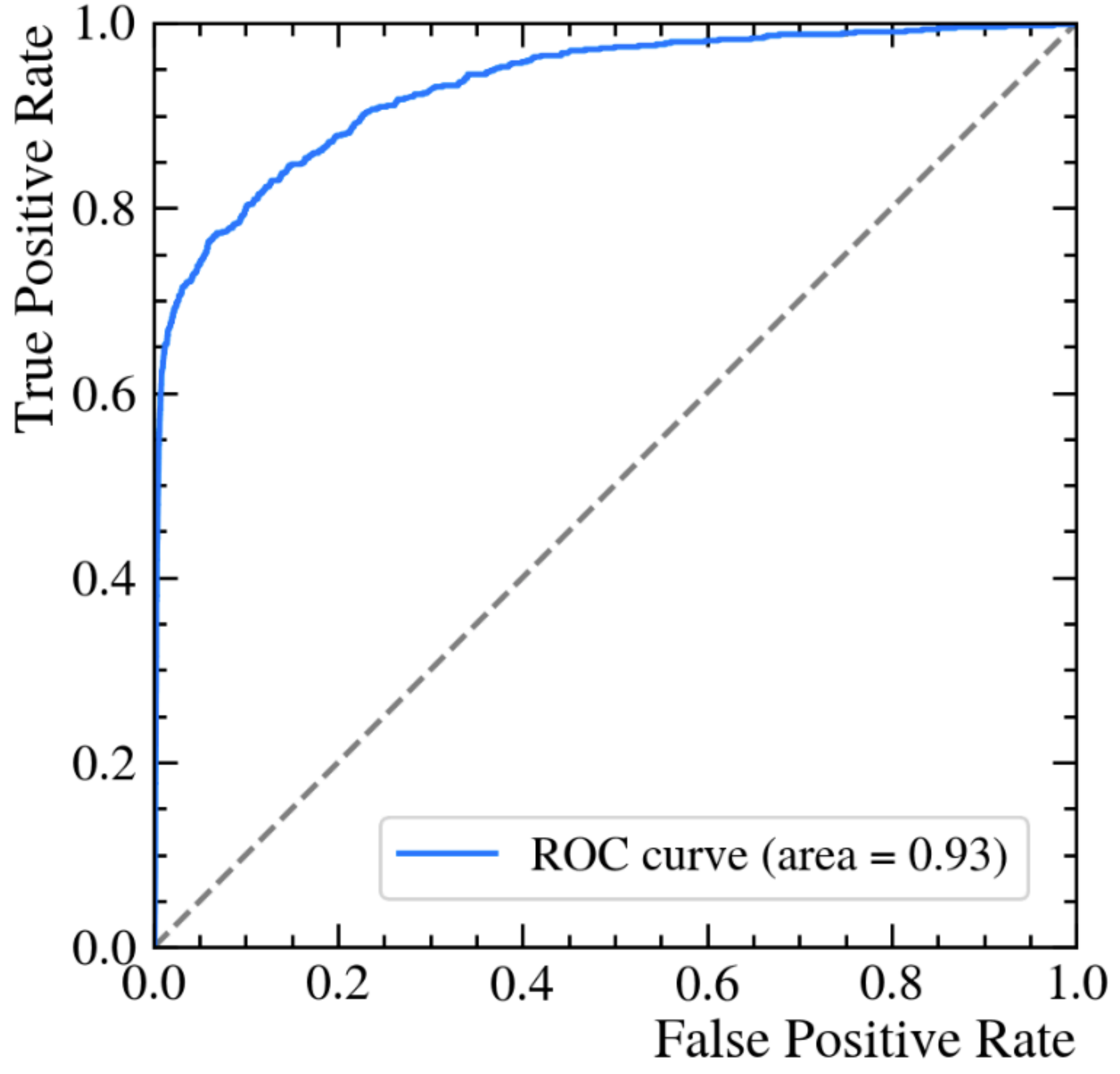


Input variables (normalized)

First look of a BDT

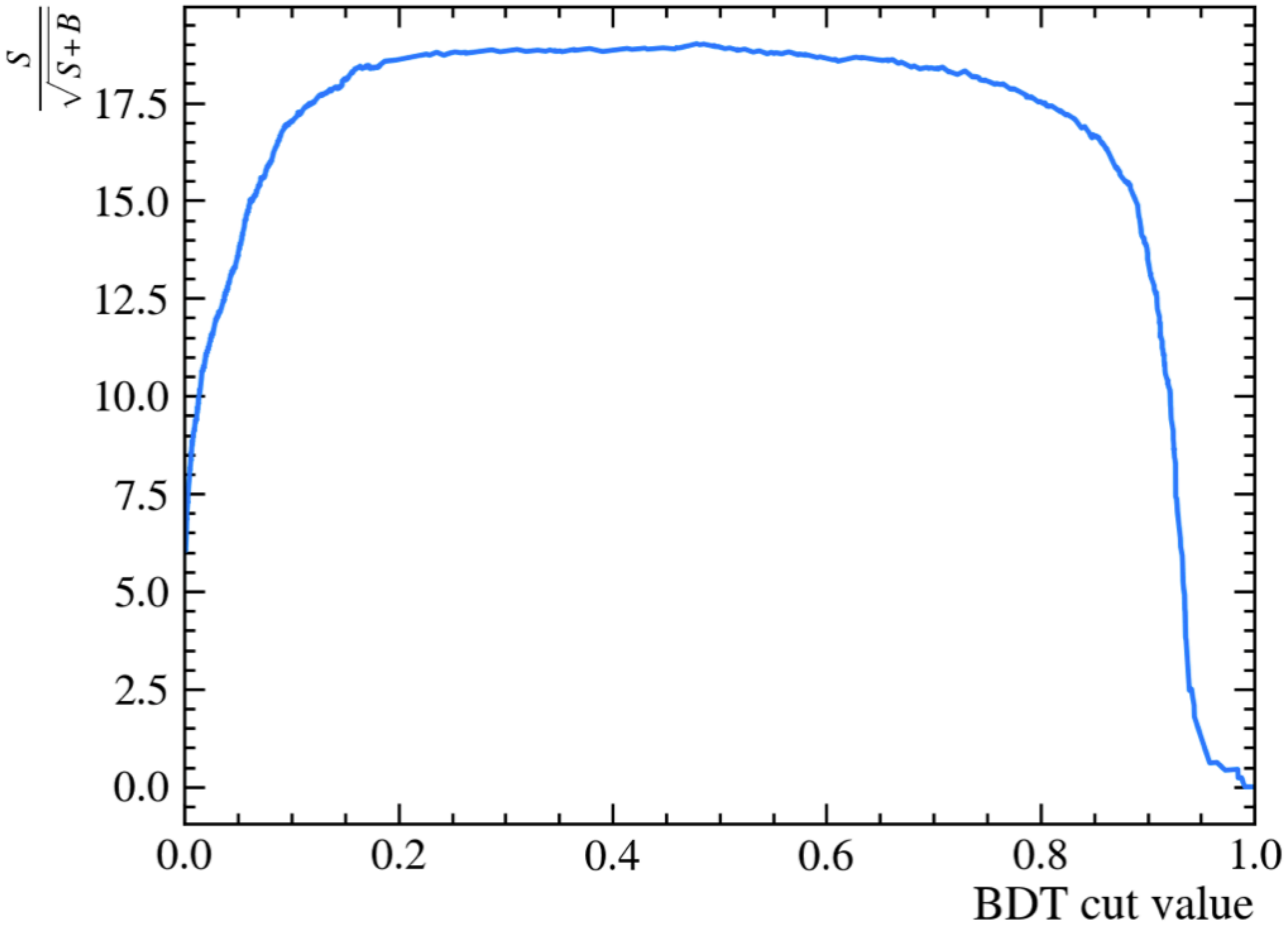
- Signal - τ_μ, Background - others
- Input: Missing transverse momentum, EInHadCal/EInMuonFinder/<dEdxInLAr> of the longest prong
- Training:validation = 15000:15000
- Validation sample: 740 signal, 14260 background





First look of a BDT

- Define FOM = $\frac{S}{\sqrt{S+B}}$, find the optimum cut value is 0.48, with N_{sig}=461, N_{bkg}=127
  - Selected background: 51 ν_μCC, 20 $\tau_{\rm had}$, 40 NC, 9 ν_eCC, 7 τ_e



Next steps

- Some of the features are promising to differentiate ν_τ CC from other
  - <dE/dx>, Missing momentum, leading π^- energy, …

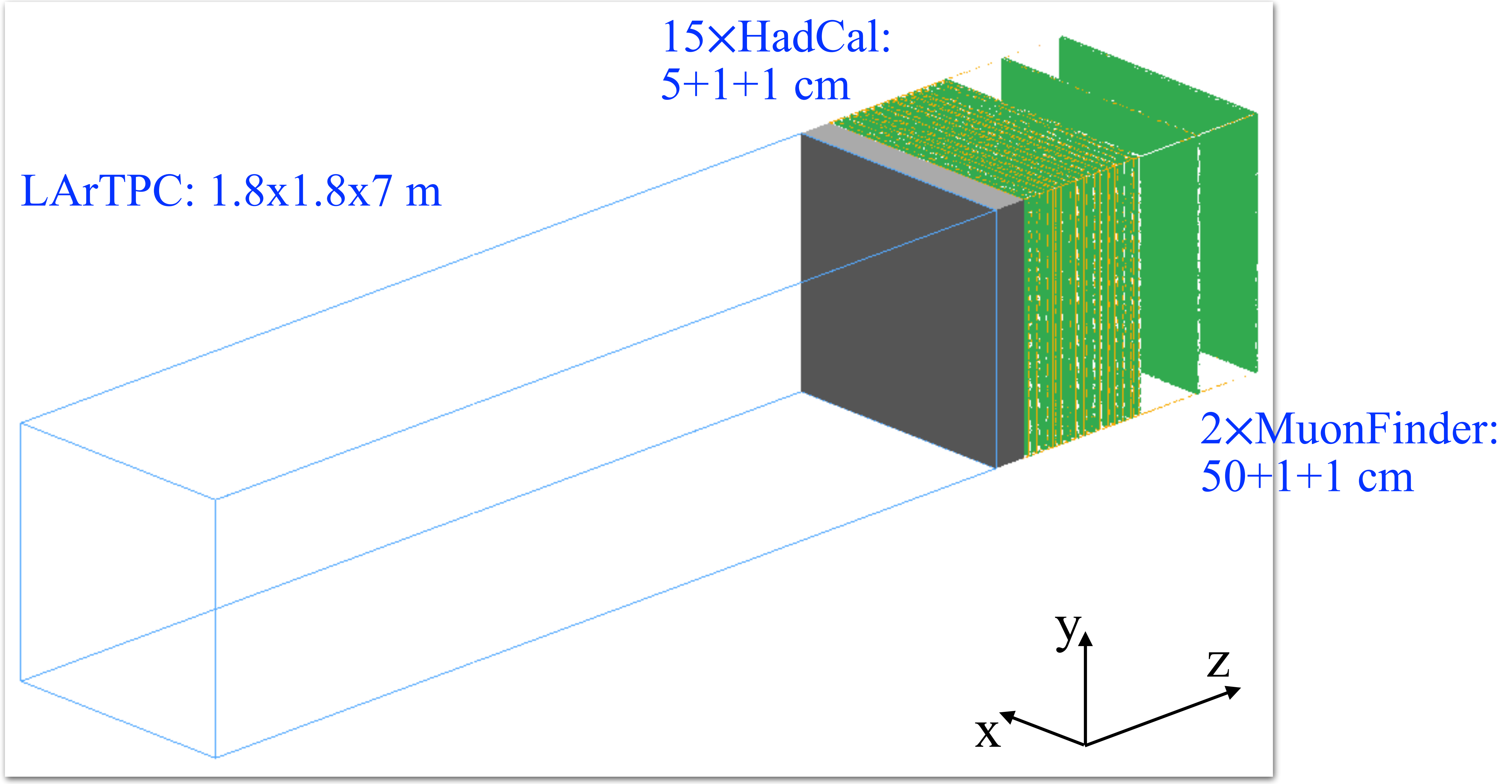
- A BDT was trained, and it looks plausible to select τ_μ events
  - Will look into other channels: τ_e and τ_{had}
  - Try to look for more features: π^0s in τ_{had} channel

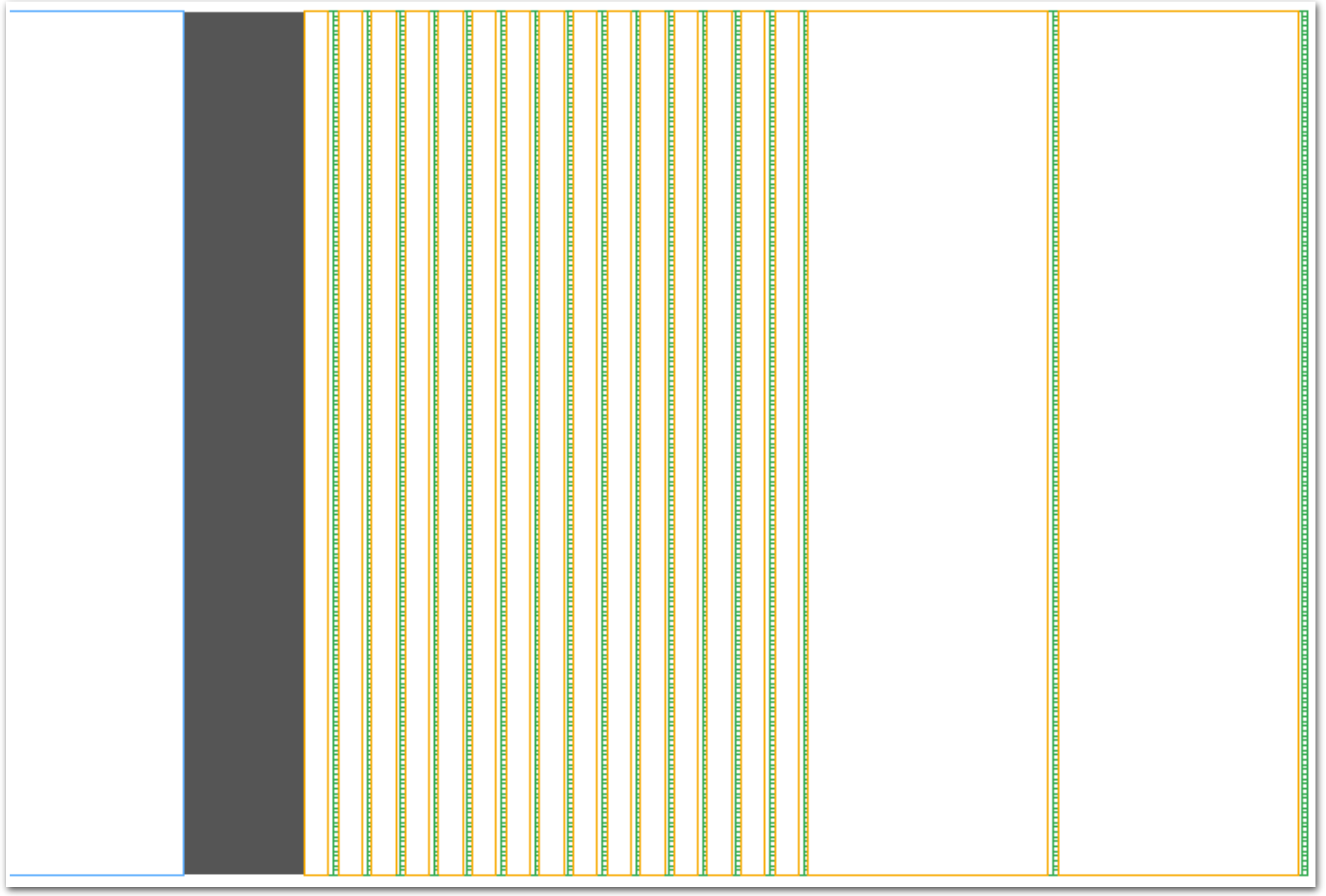
Backup

Event display of each final state particle

Detector configuration in Geant4

	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 9340



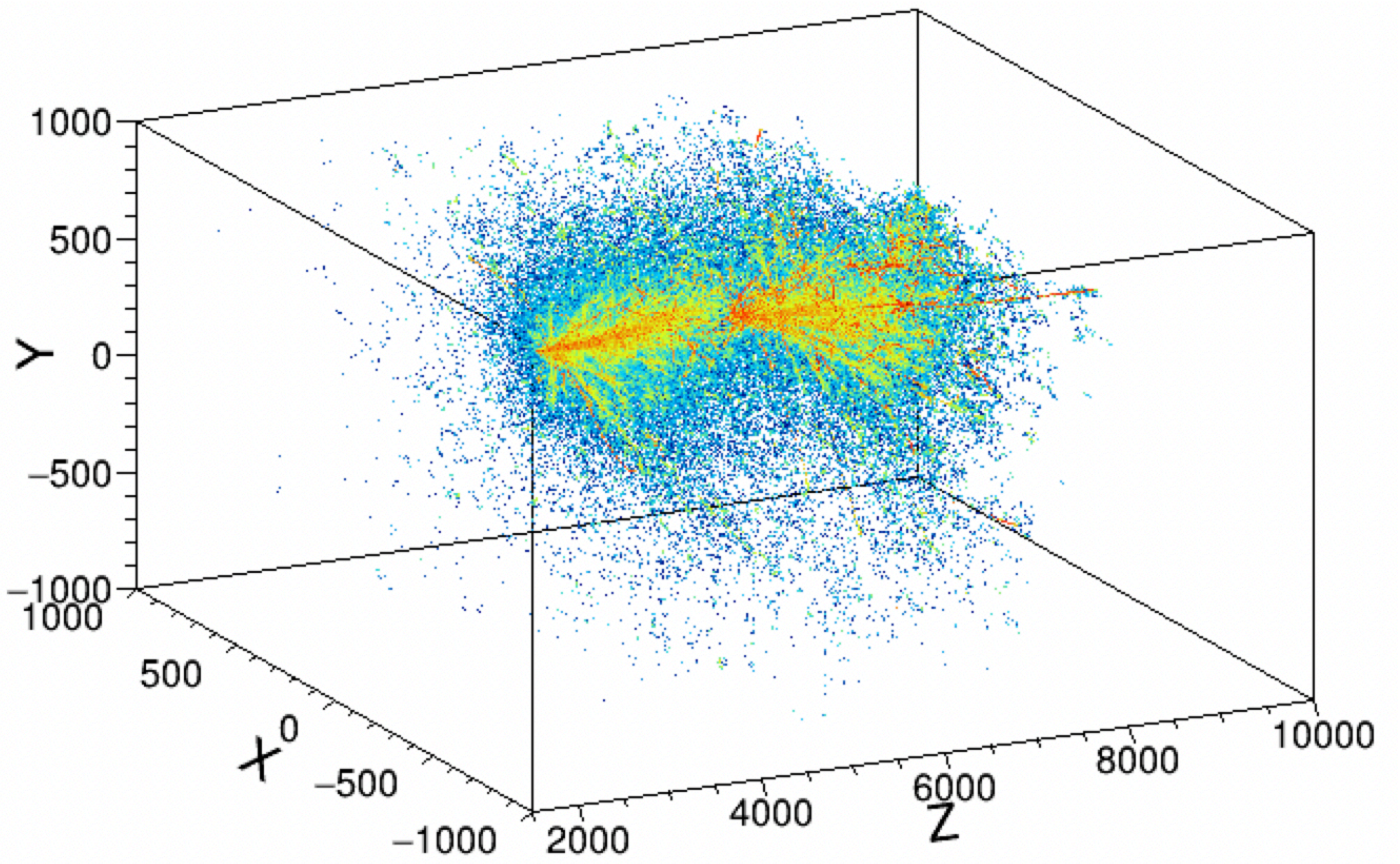


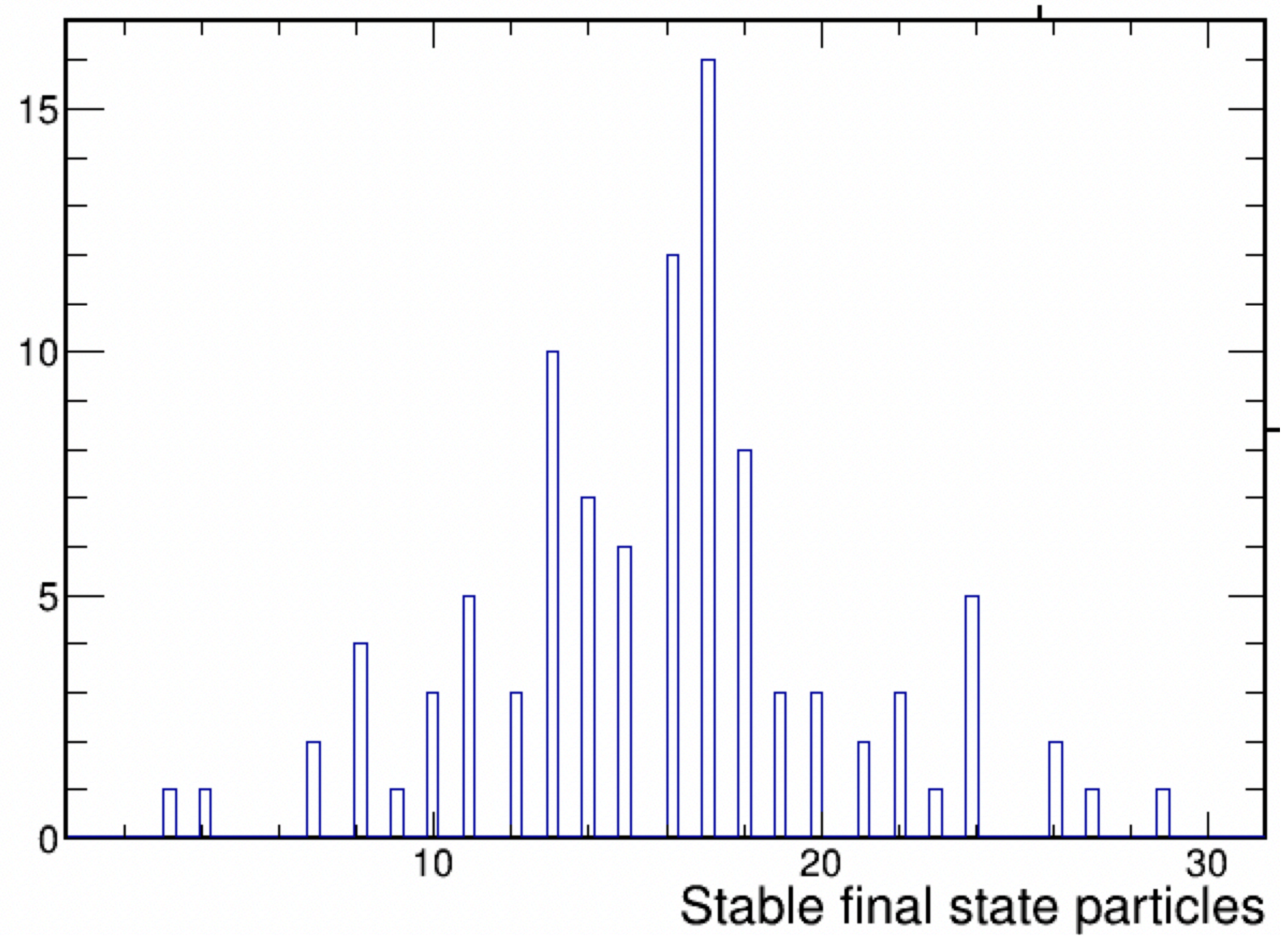
LArTPC HadCal MuonFinder

UCIrvine

Work in progress

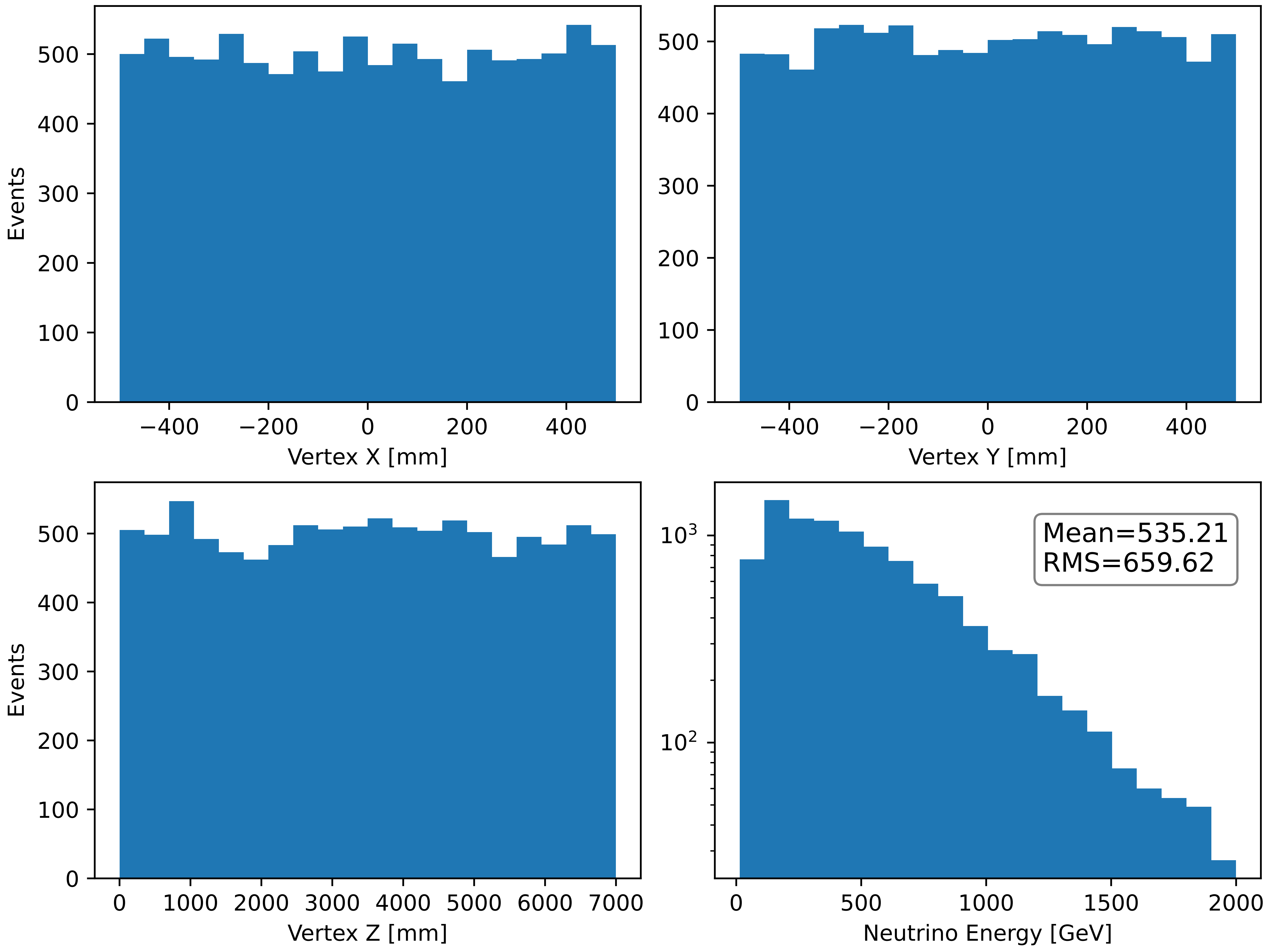
- Save all the hit information from G4 simulation
  - As the energy is very high, there is a large amount of hits for each event (~TB for 10000 neutrino events)
- Will do more analysis on the new MC data
  - Study the feature of all stable final state particles from the neutrino interaction
  - Event classification, background rejection

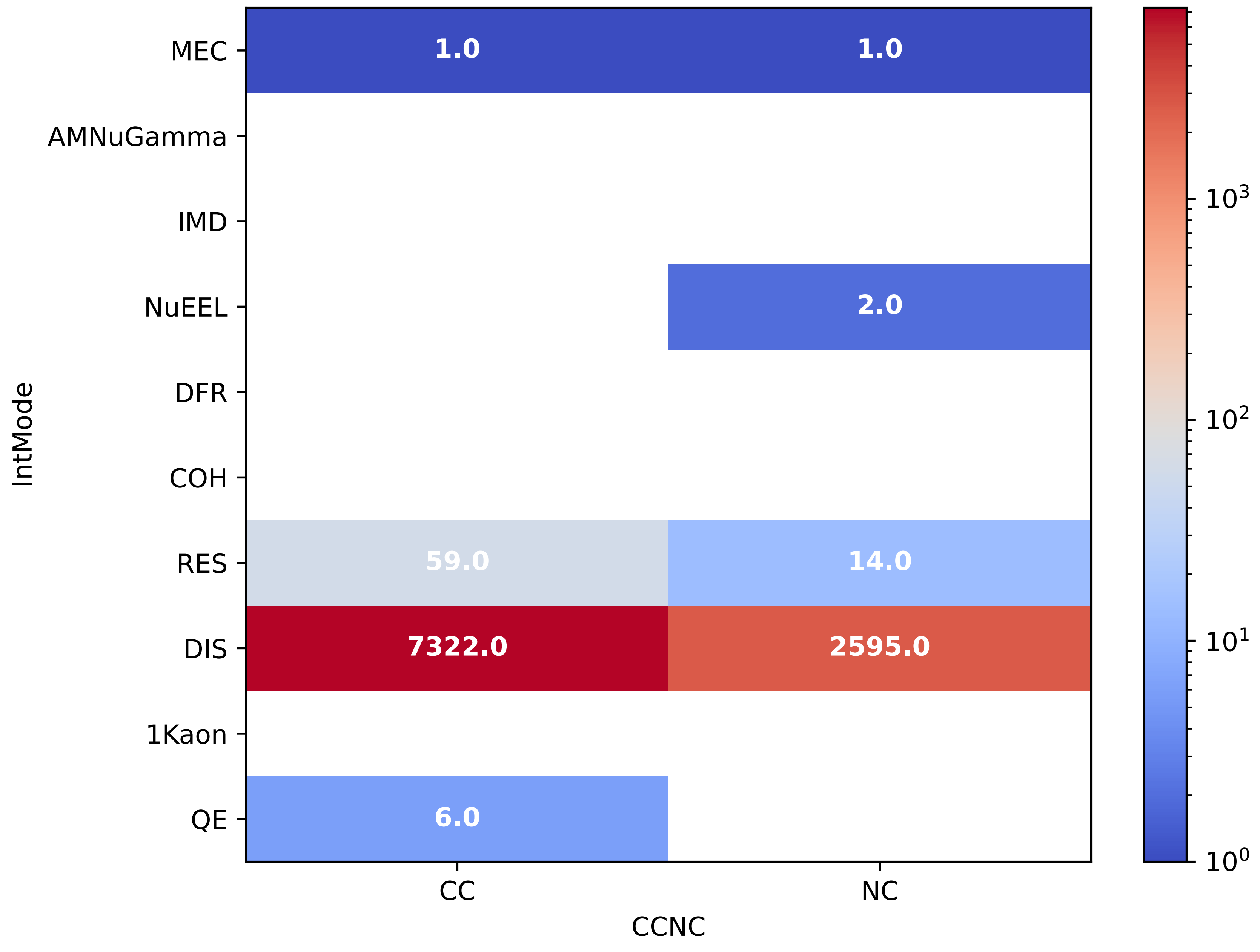


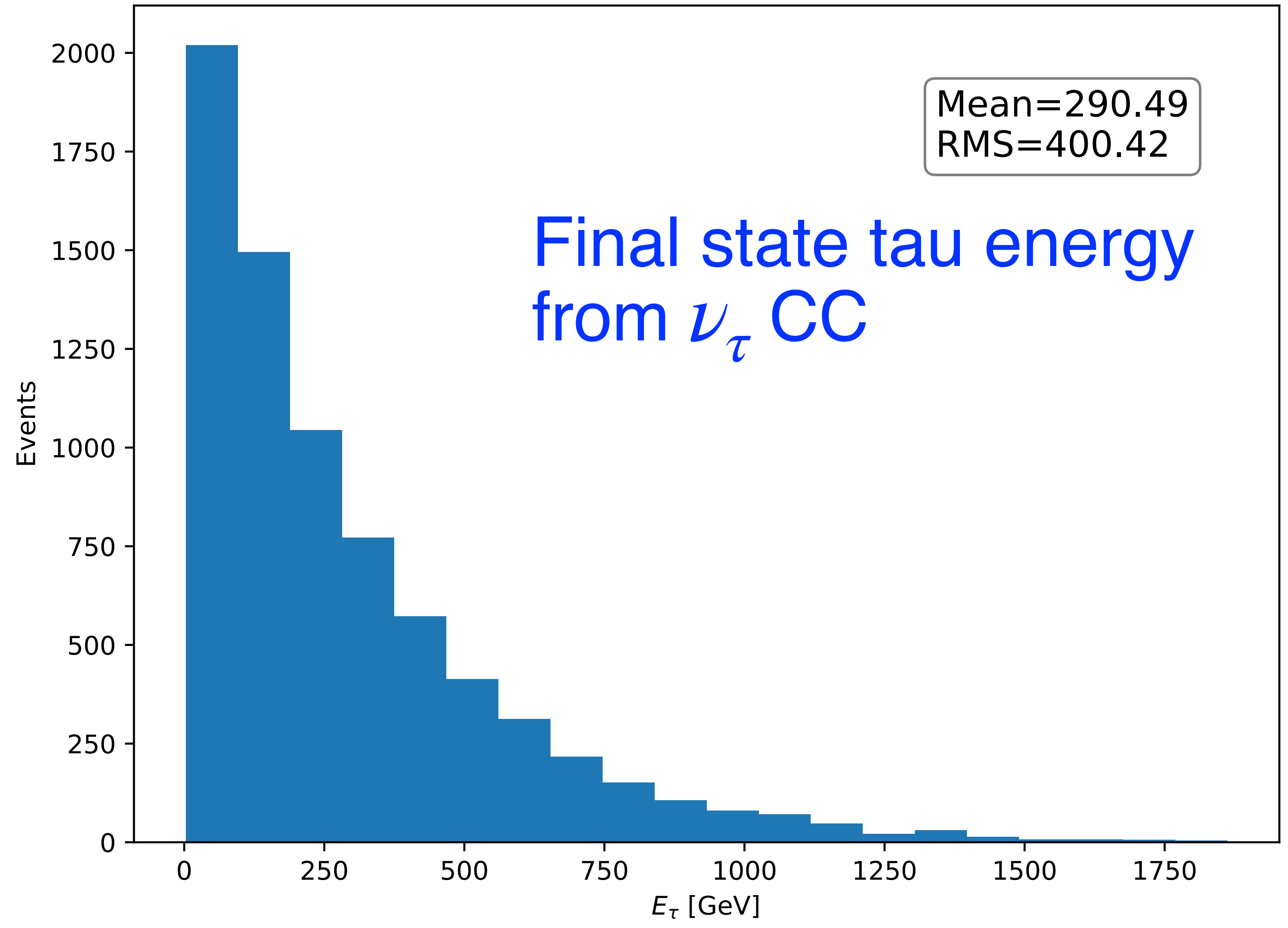


ν_τs in the detector

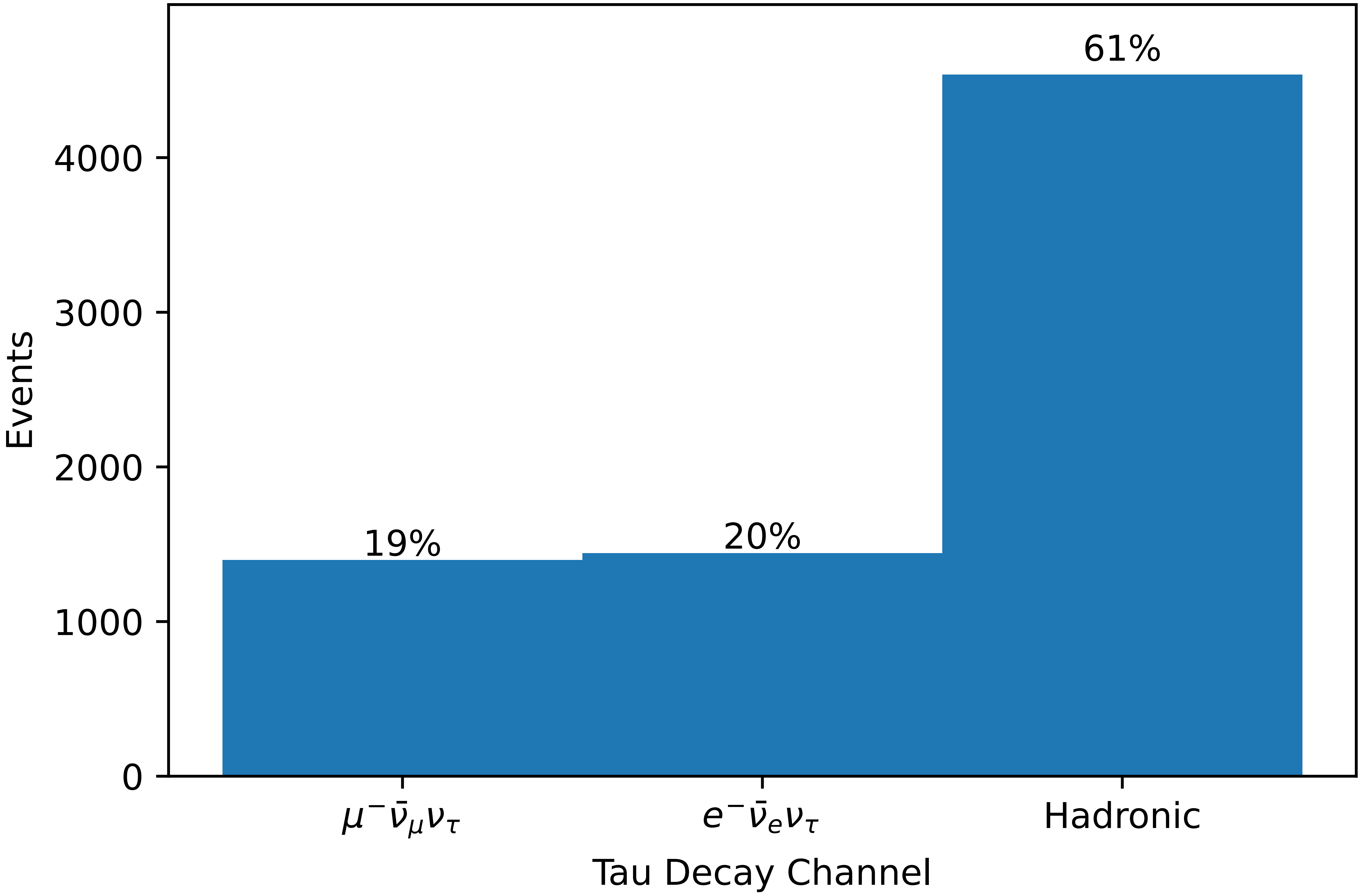
- Neutrino vertices are uniformly distributed in a 1x1x7 meter volume
- Neutrino energy/Interaction mode/FSL come from GENIE v3_00_06k
  - Flux comes from *Weidong Bai, et. al.* 2112.11605







τ^-s in the detector

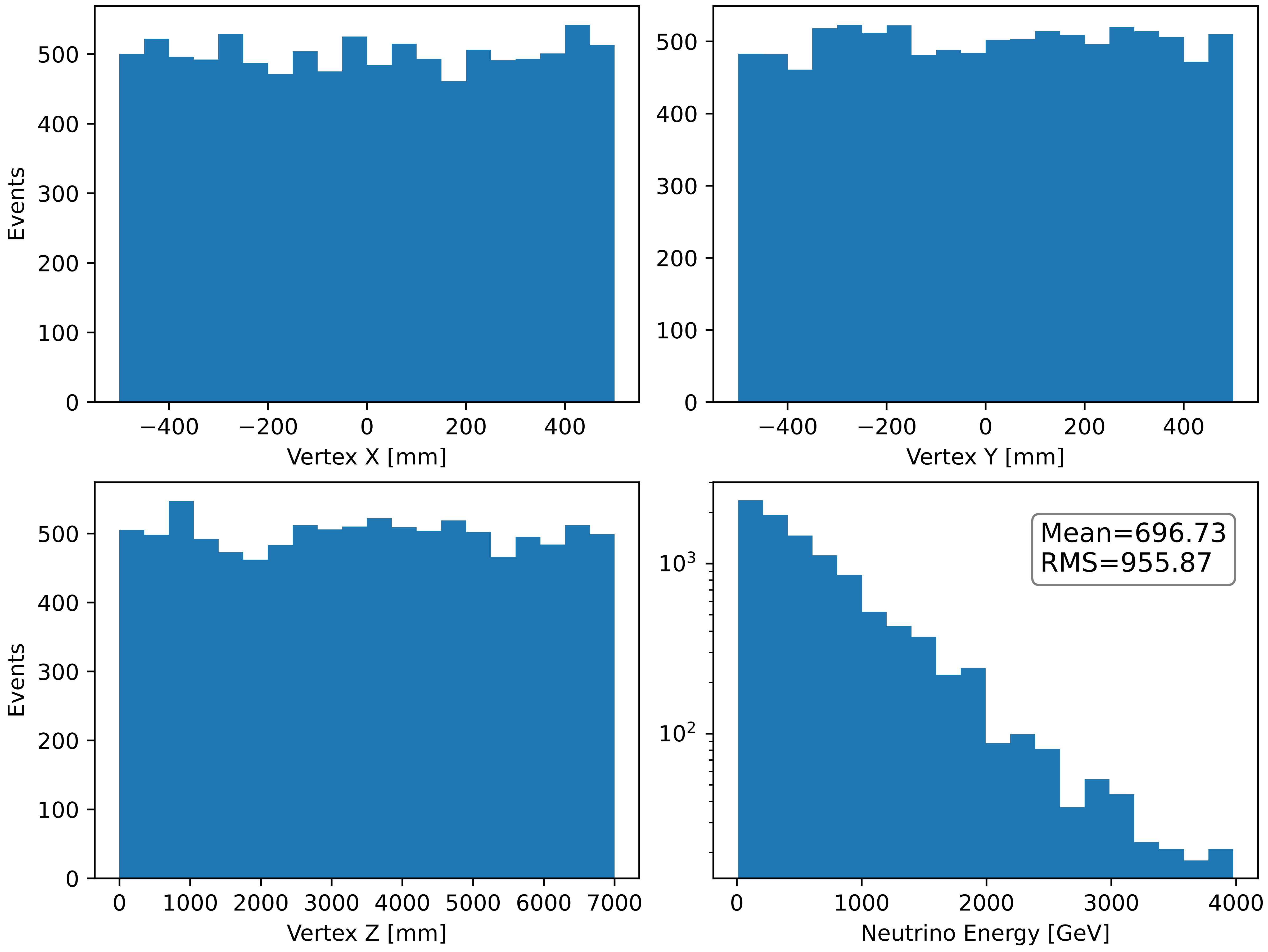


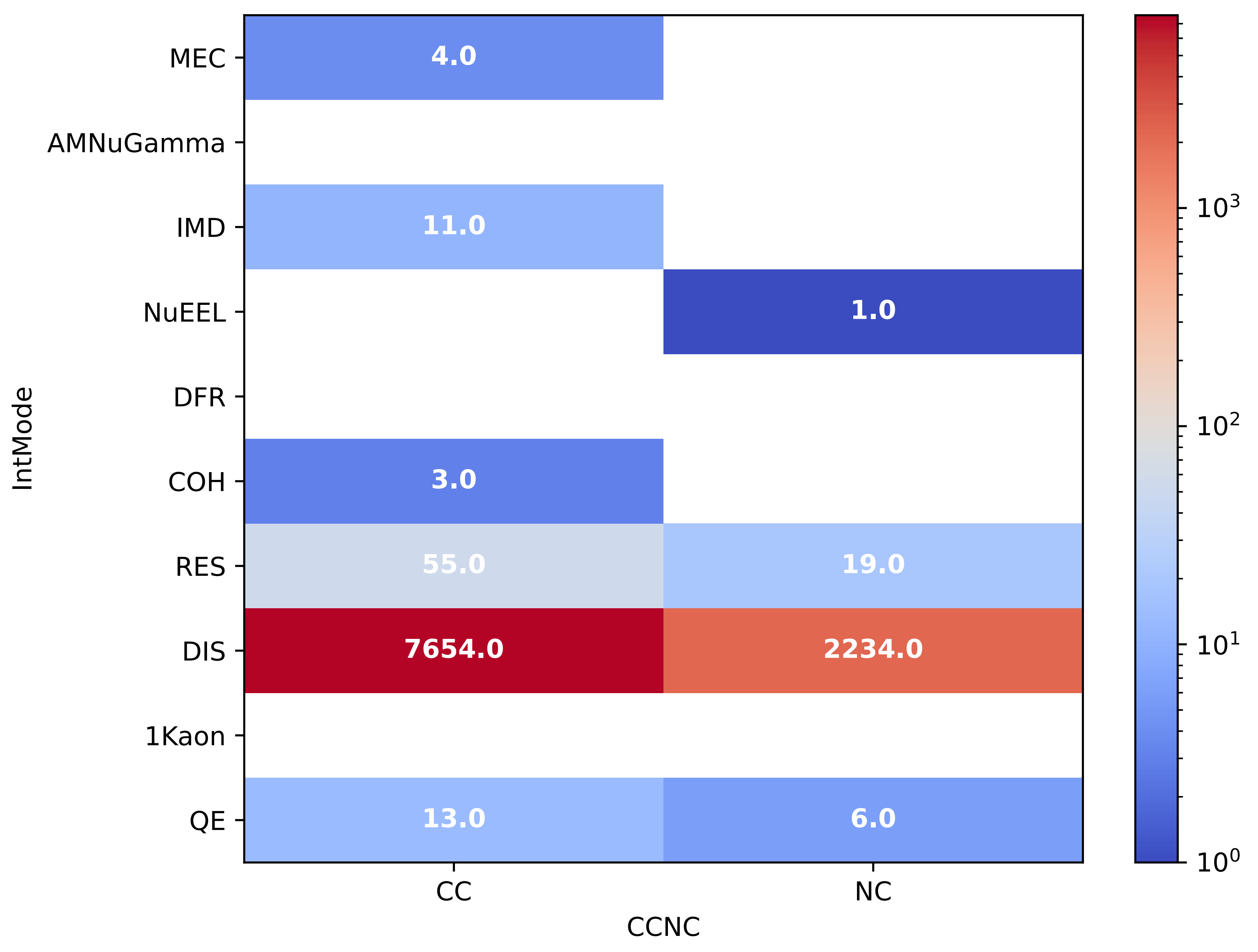
Decay mode	**Branching ratio**
Leptonic	35.2%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic	64.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\pi^0\nu_\tau$	9.3%
$\pi^-\pi^-\pi^+\nu_\tau$	9.0%
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.5%
other	5.7%

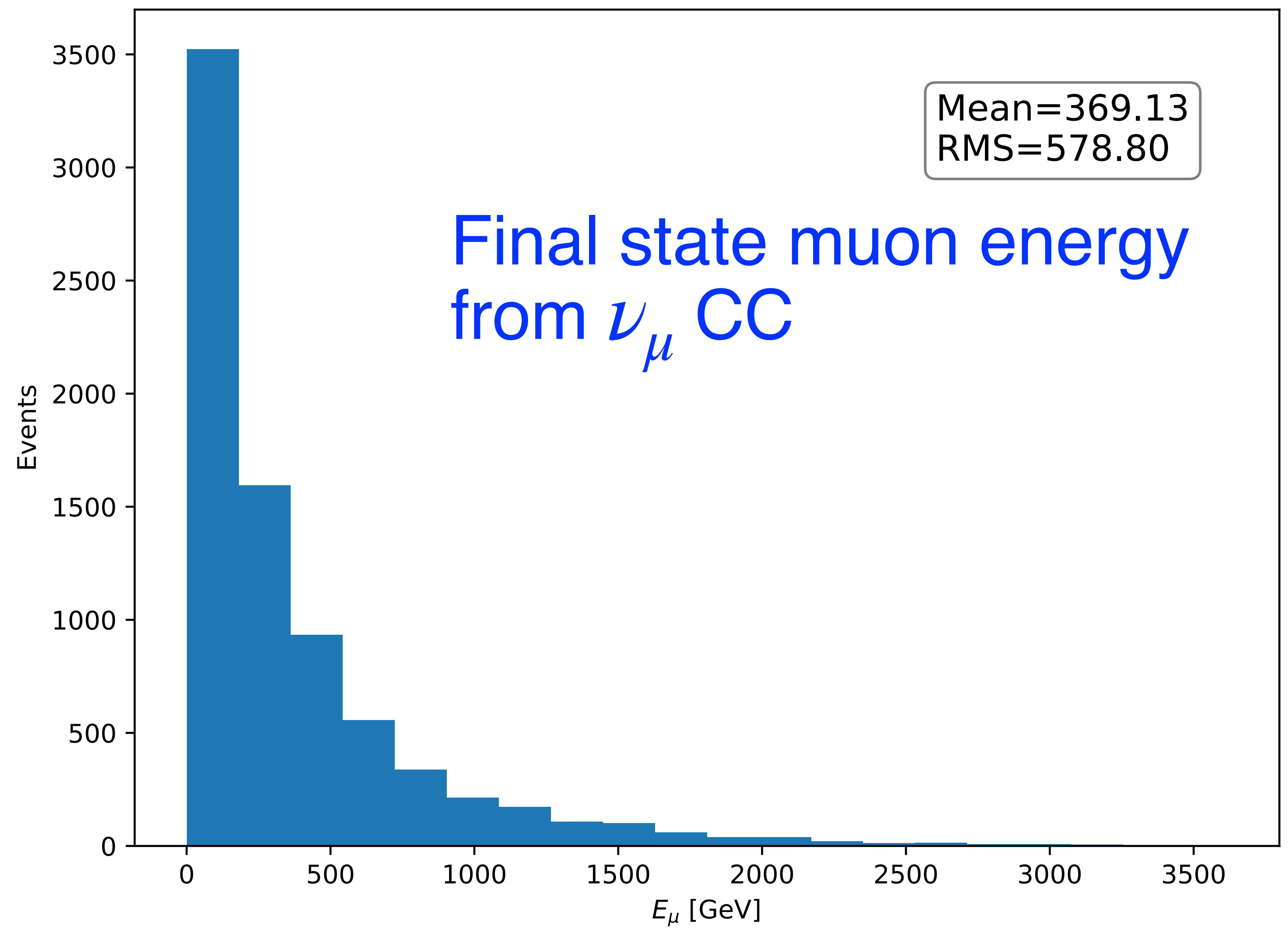
https://arxiv.org/pdf/2007.00015.pdf

ν_μs in the detector

- Neutrino vertices are uniformly distributed in a 1x1x7 meter volume
- Neutrino energy/Interaction mode/FSL come from GENIE v3_00_06k
  - Flux comes from *Felix Kling, et. al.* 2105.08270

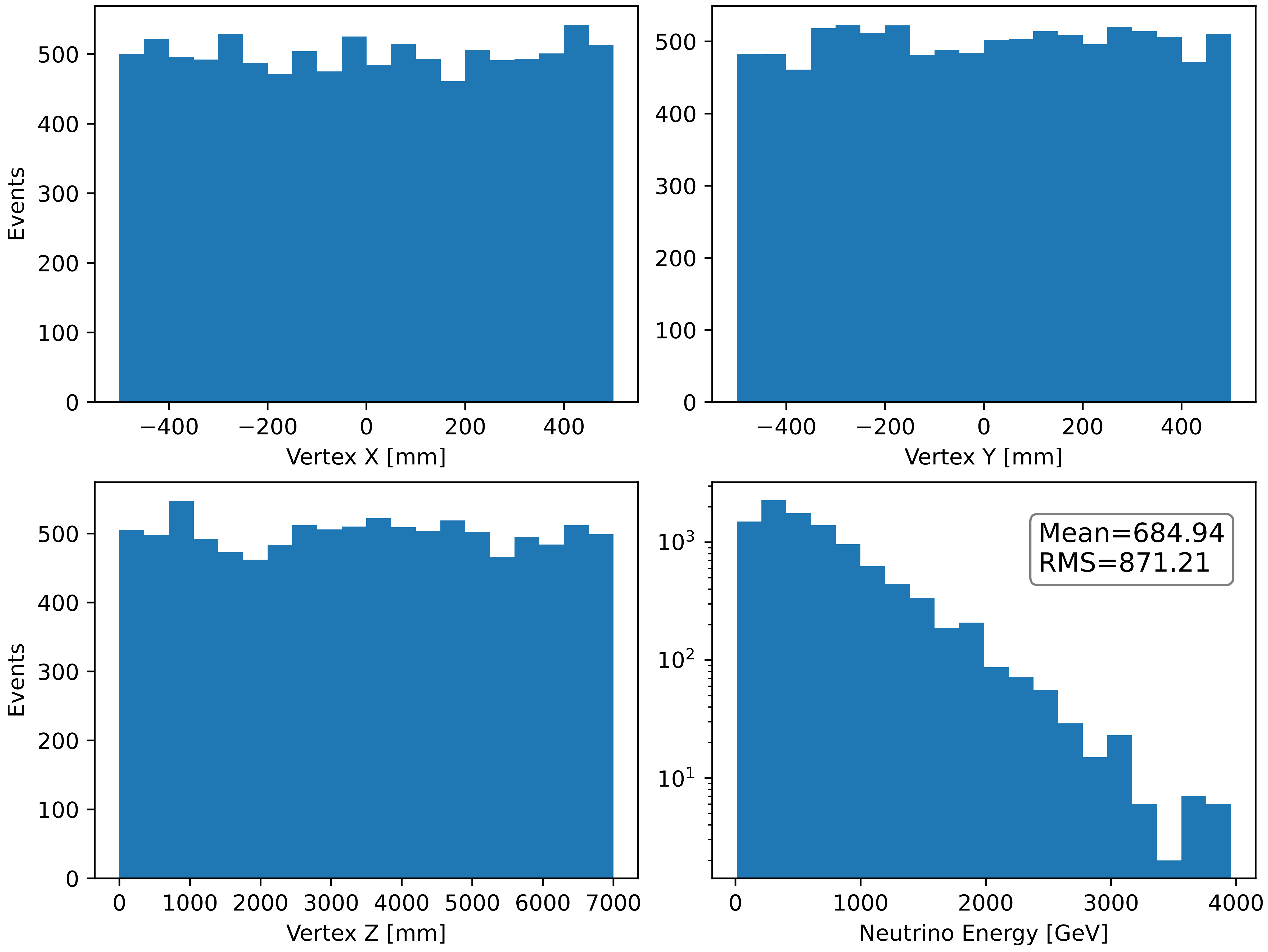


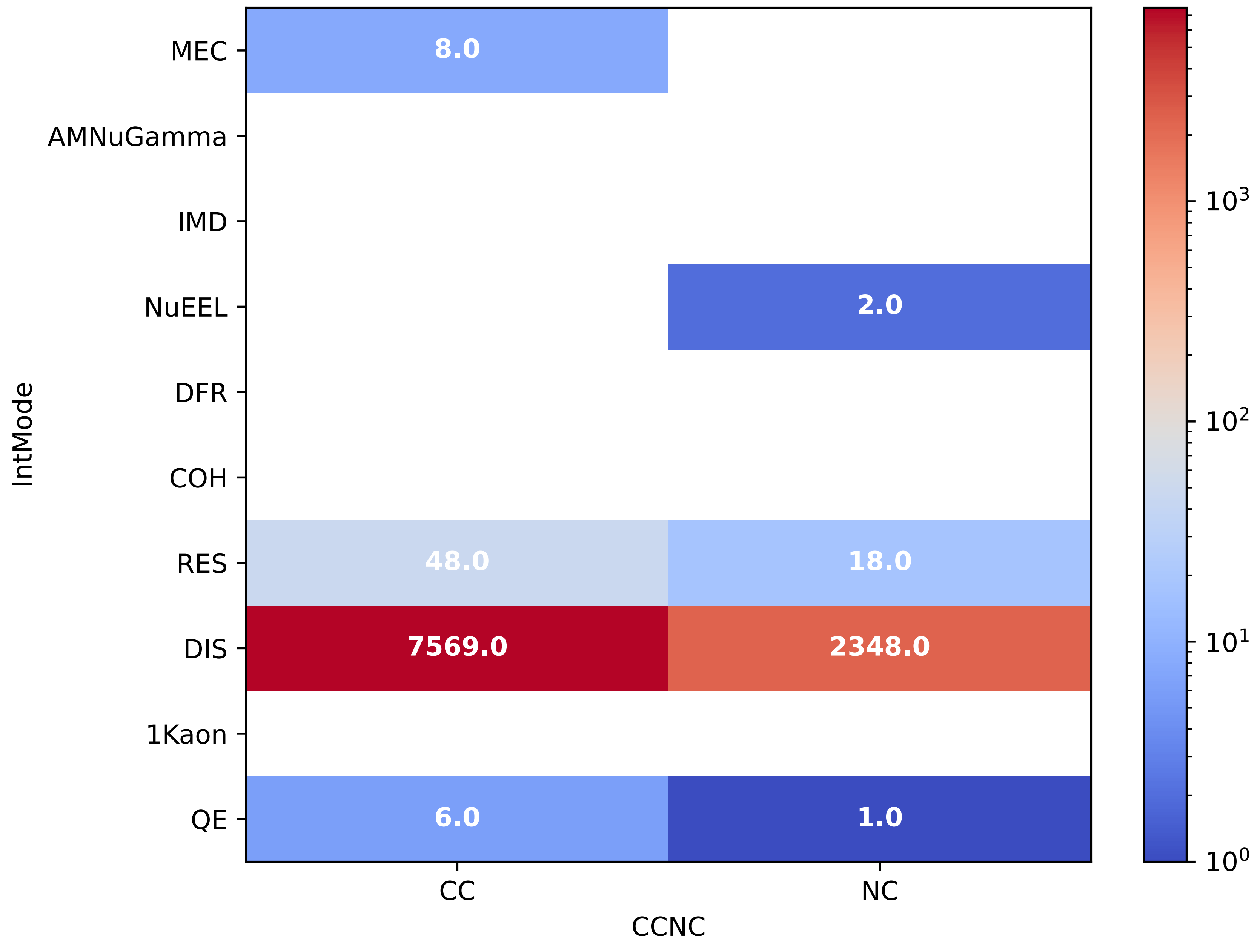


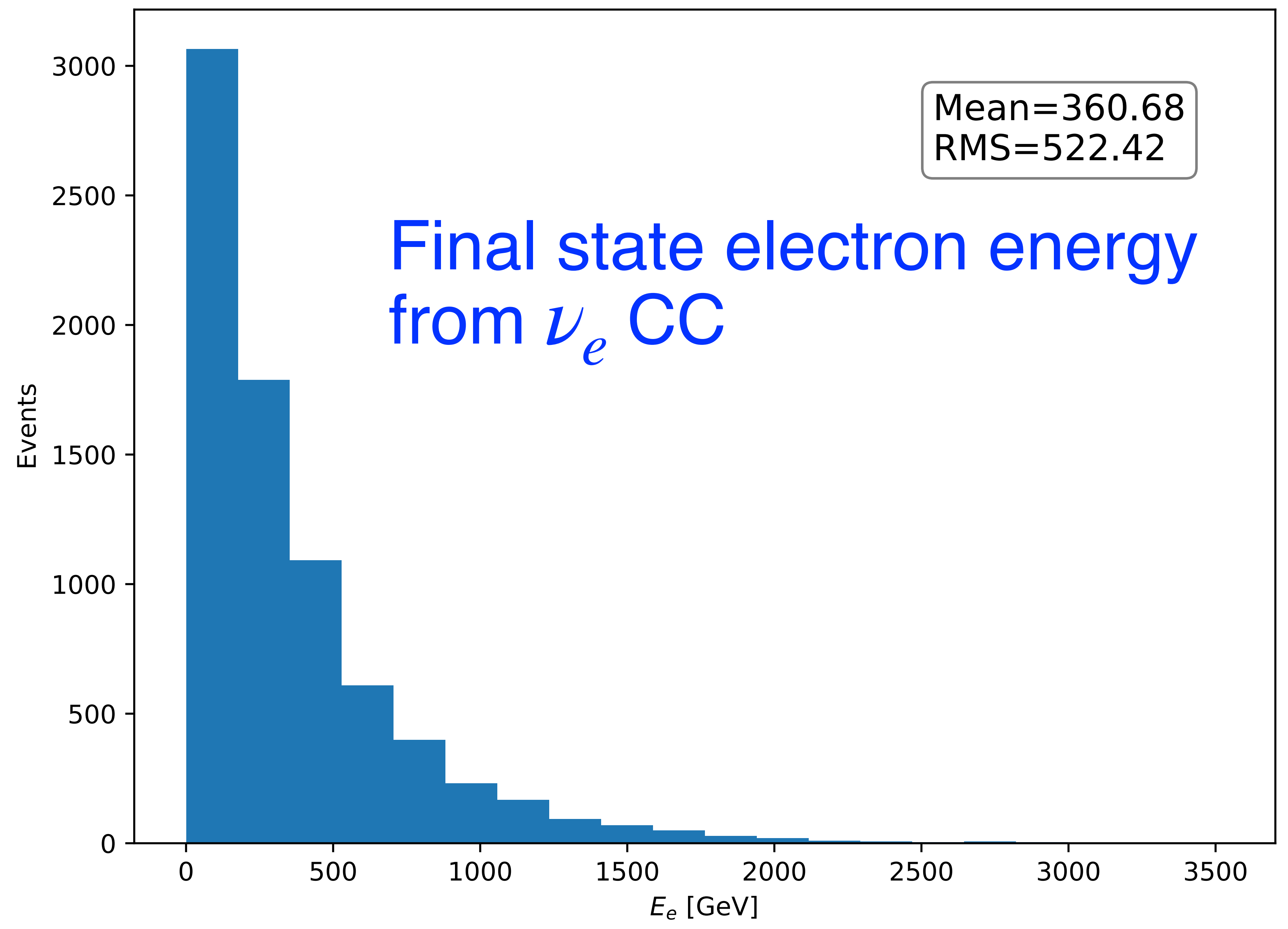


ν_es in the detector

- Neutrino vertices are uniformly distributed in a 1x1x7 meter volume
- Neutrino energy/Interaction mode/FSL come from GENIE v3_00_06k
  - Flux comes from *Felix Kling, et. al.* [*2105.08270*]

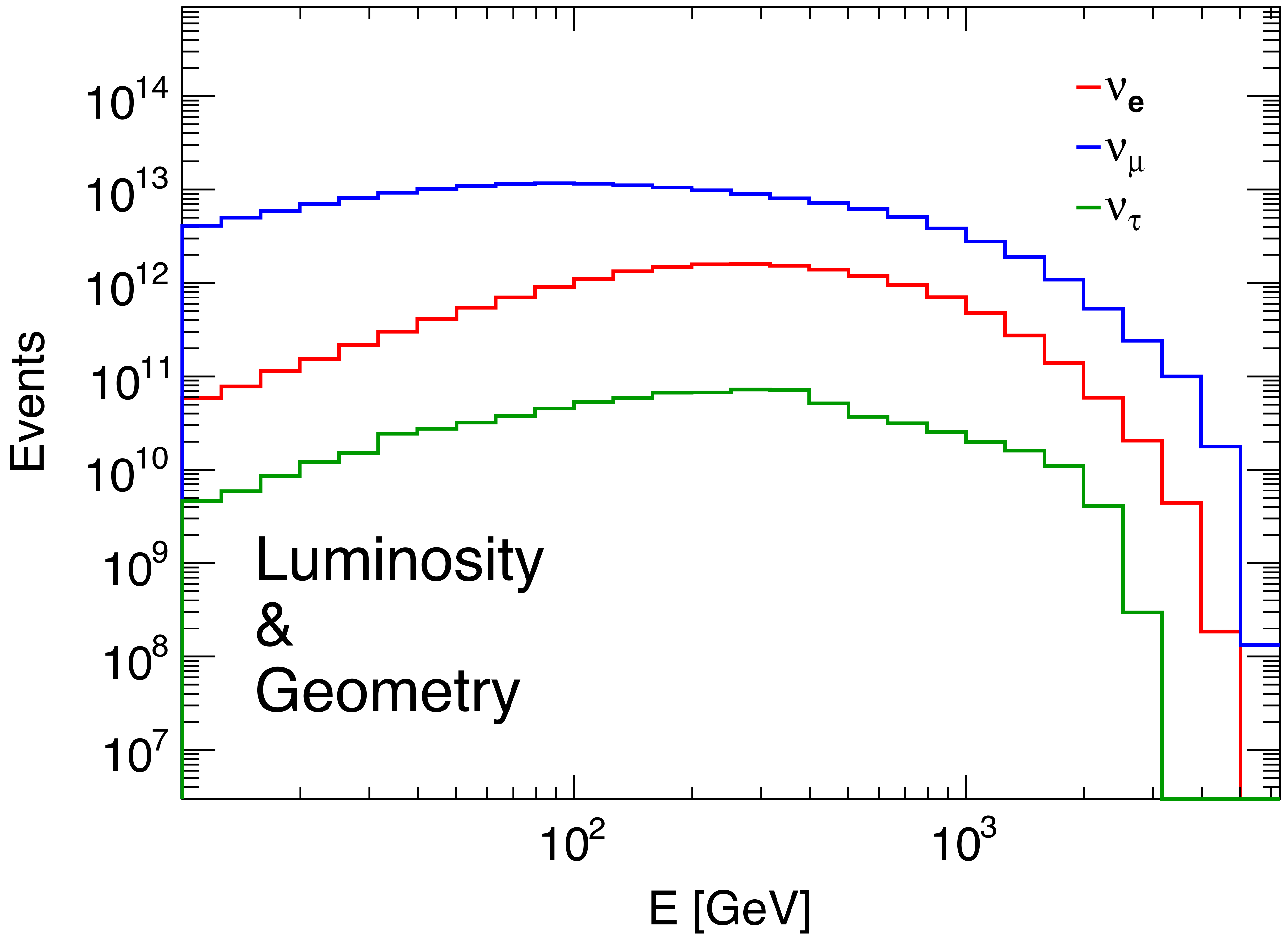


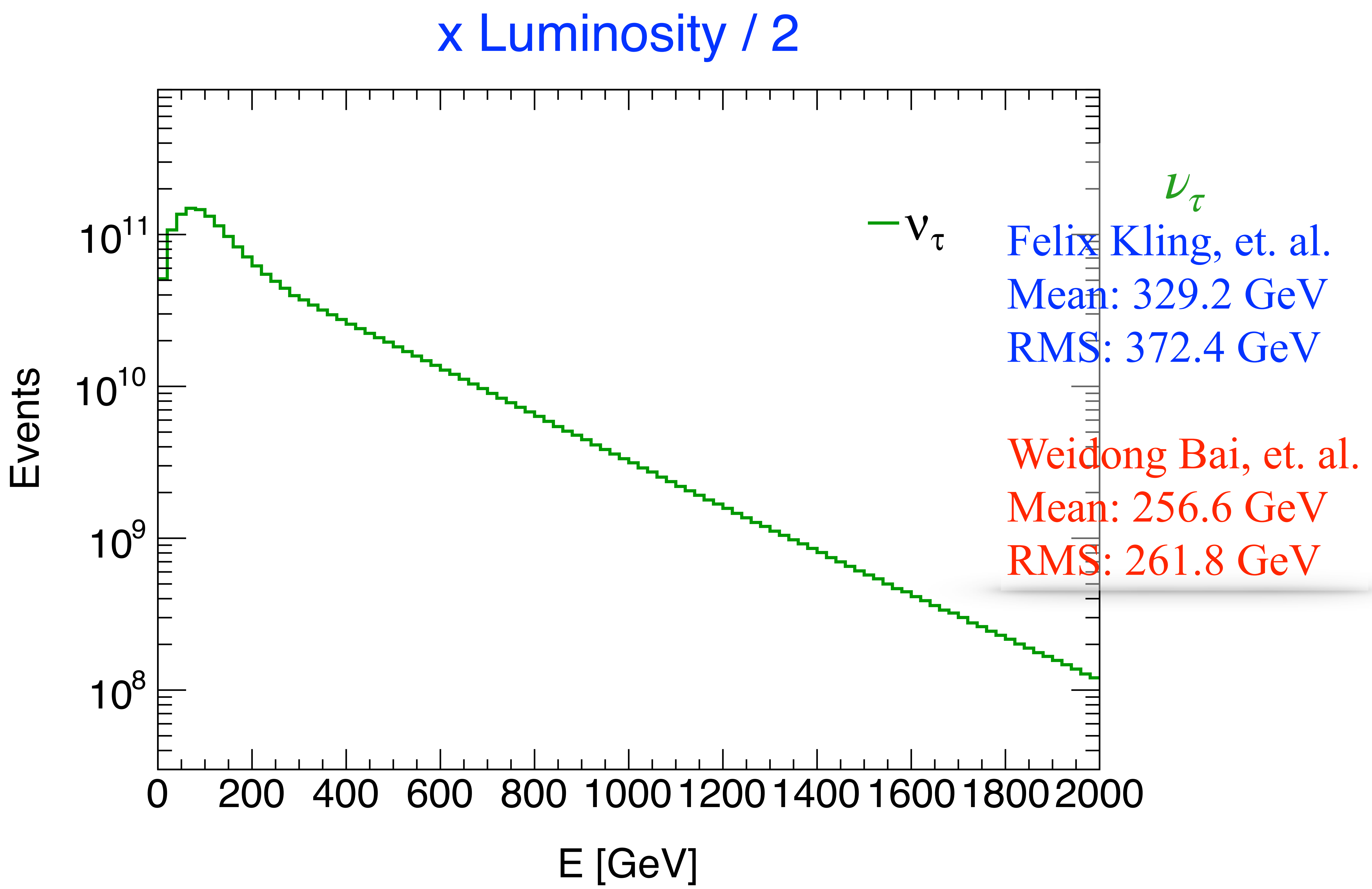




Jianming Bian, Wenjie Wu (UCI)

Neutrino flux





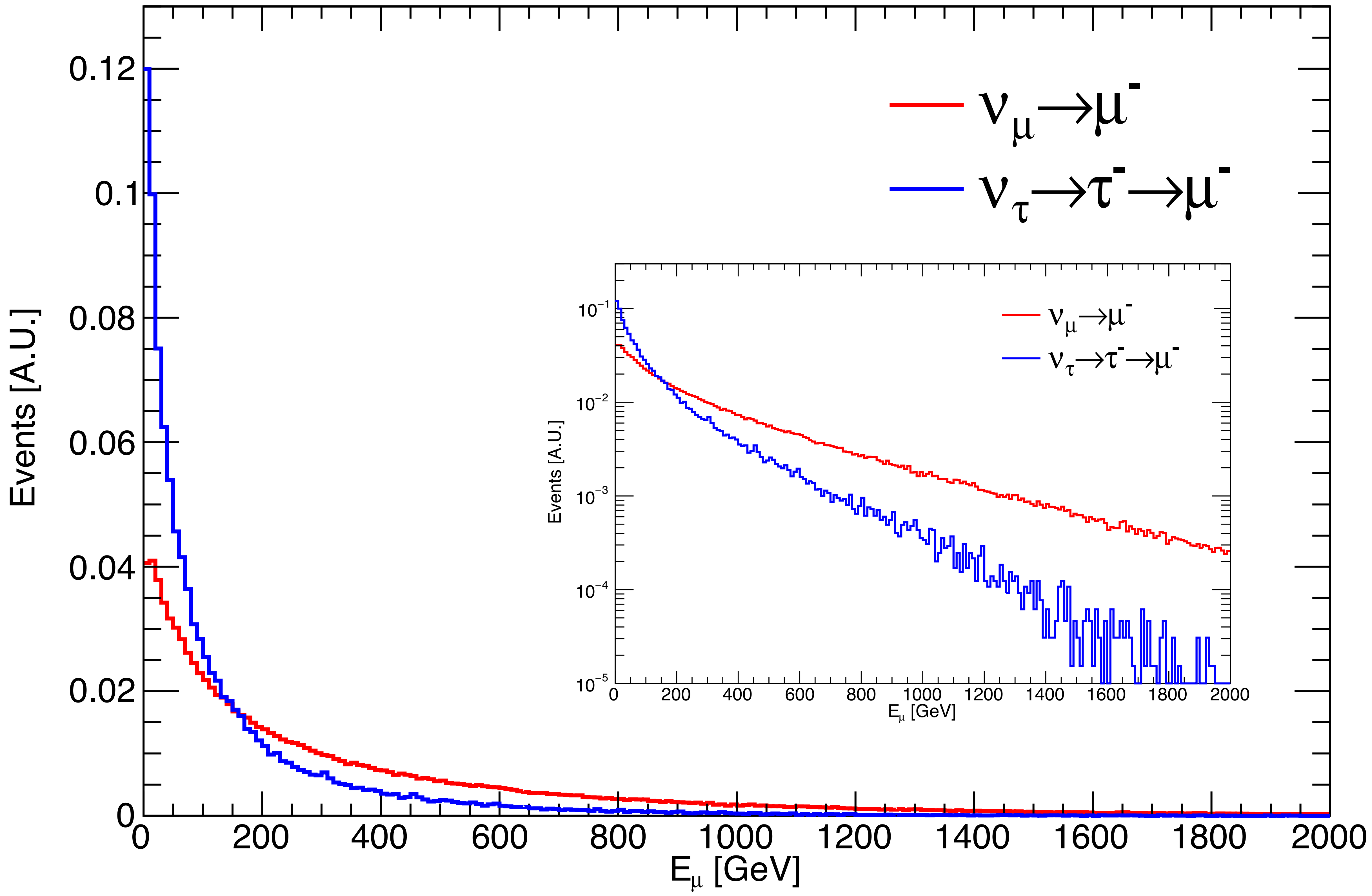
Felix Kling, et. al. 2105.08270
Github

FLArE10, 620m downstream from IP, 3000/fb

Weidong Bai, et. al. 2112.11605
Figure 12, Table 5

eta > 6.9 (radius 1 m at a distance of 480 m from IP)

GENIE simulation: muon spectrum



$\nu_\mu \rightarrow \mu^-$
Mean: 343.1 GeV
RMS: 377.6 GeV

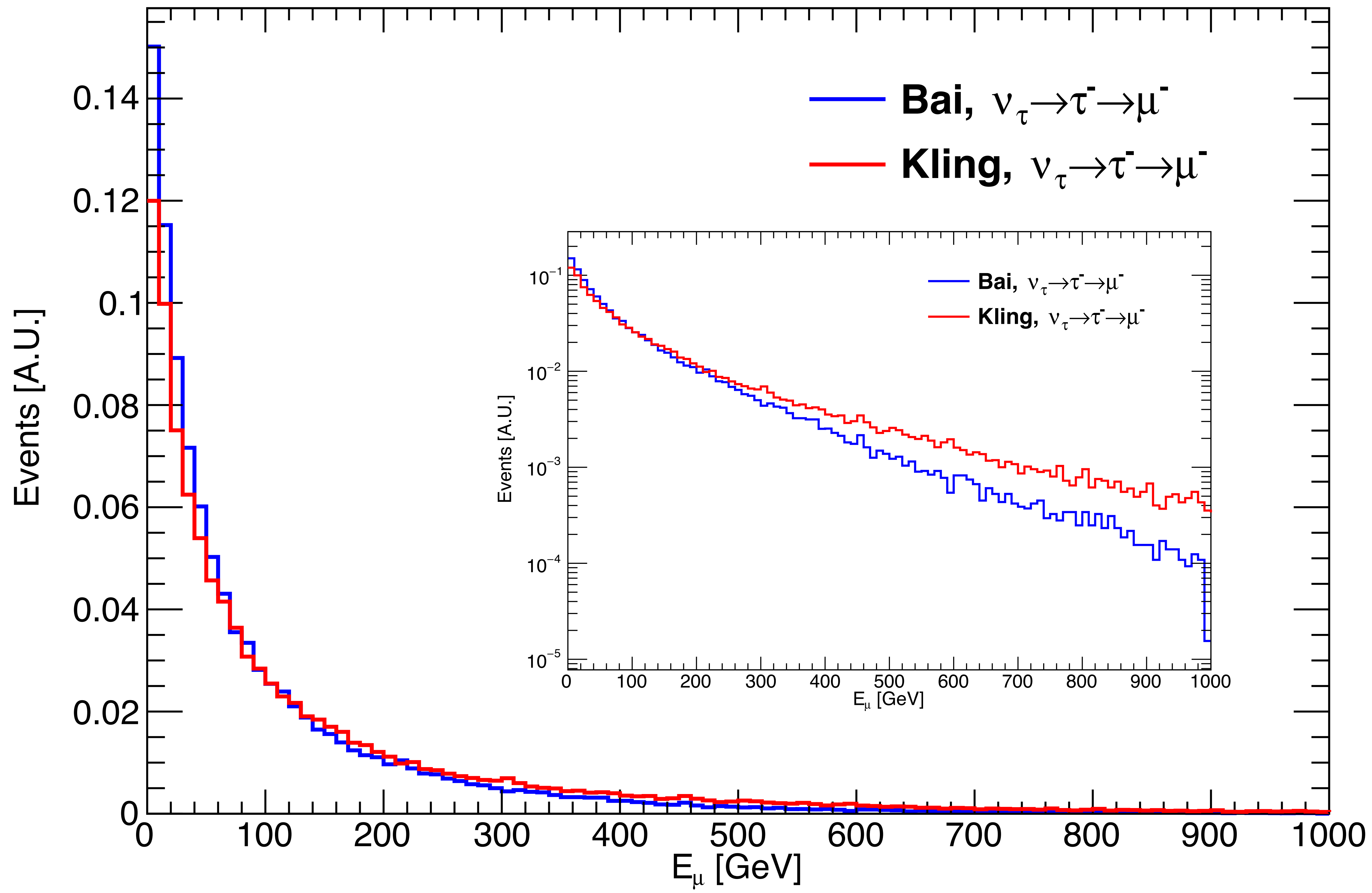
$\nu_\tau \rightarrow \tau^- \rightarrow \mu^-$
Mean: 146.0 GeV
RMS: 201.0 GeV

Felix Kling, et. al. 2105.08270

Muon energy spectrum, area normalized

Muon from tau decay is softer

GENIE simulation: muon spectrum



Muon energy spectrum, area normalized

Bai, $\nu_\tau \to \tau^- \to \mu^-$
Mean: 102.9 GeV
RMS: 136.7 GeV

Kling, $\nu_\tau \to \tau^- \to \mu^-$
Mean: 146.0 GeV
RMS: 201.0 GeV