Signal and background in FLArE

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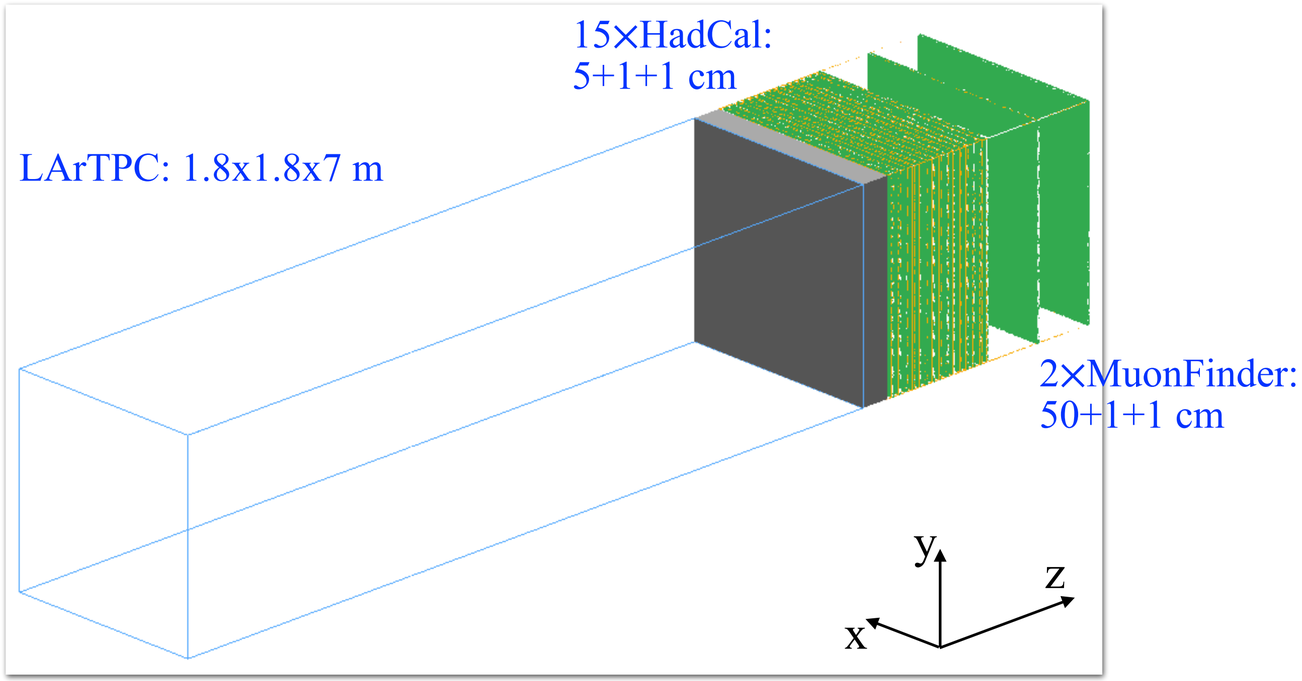
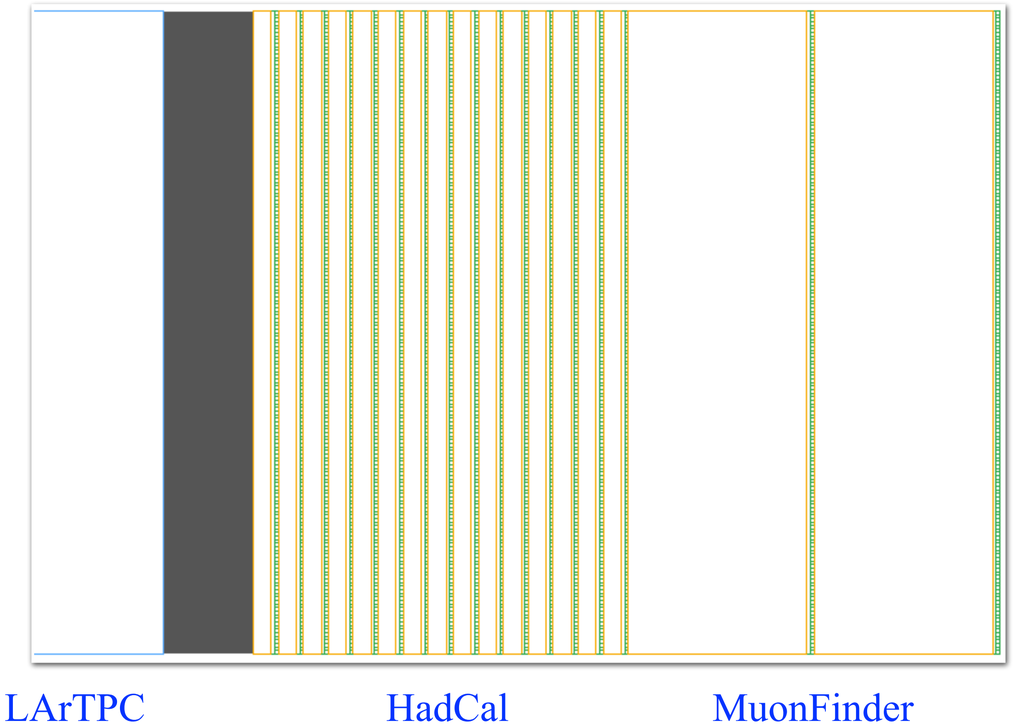
UCIrvine

Detector configuration in Geant4

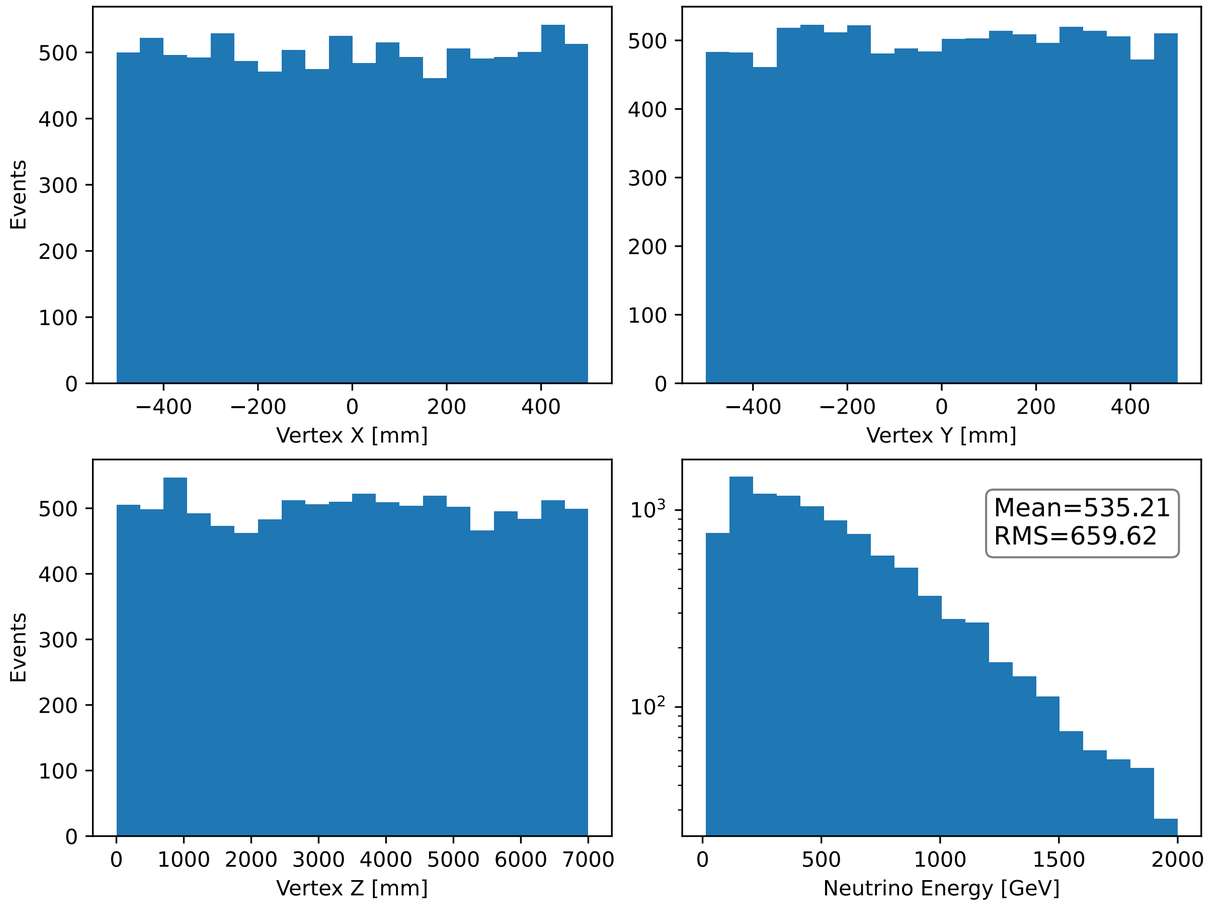
	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 9340





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



Signal and background

- Only consider beam neutrino background for now
- Decay modes of the tau lepton
  - tau_e: taus decay to electrons
  - tau_mu: taus decay to muons
  - tau_had: taus decay to hadrons
- Major background of tau_mu signal: numu CC events
- Major background of tau_e signal: nue CC events
- **Major background of tau_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%

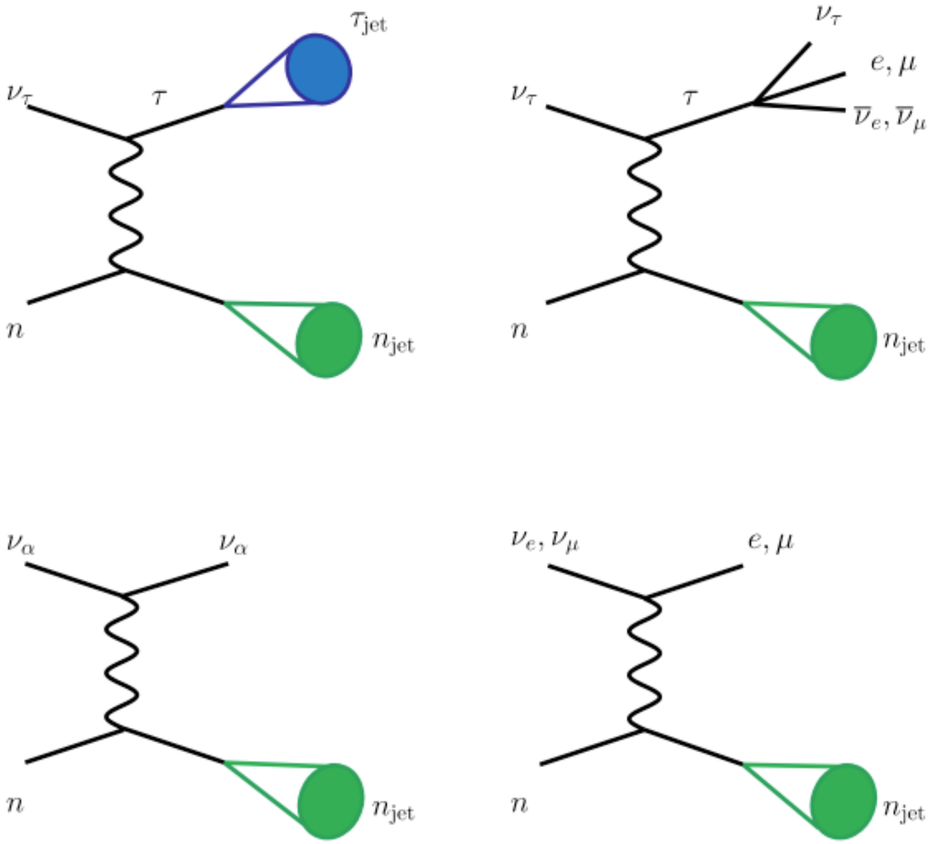
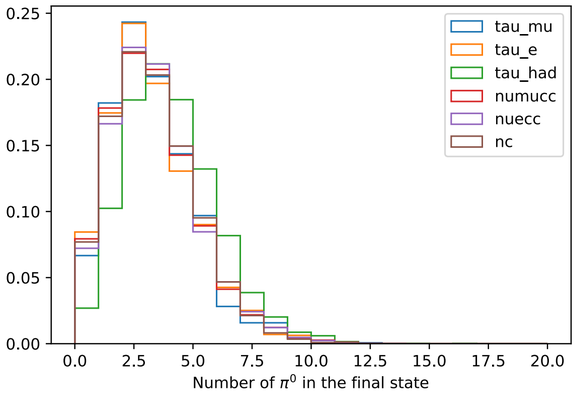


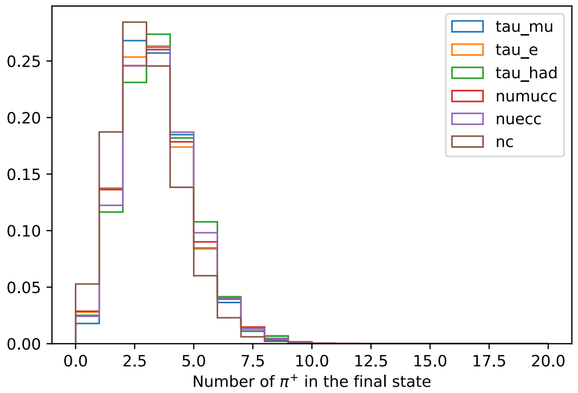
FIG. 2. Pictorial representation of hadronic tau (upper left) and leptonic tau (upper right) signals, and their corresponding backgrounds (lower).

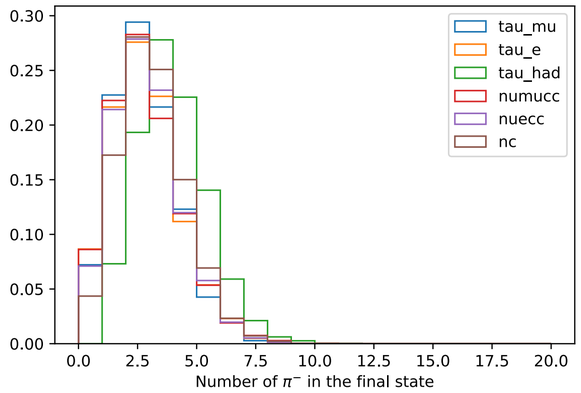
10.1103/PhysRevD.102.053010

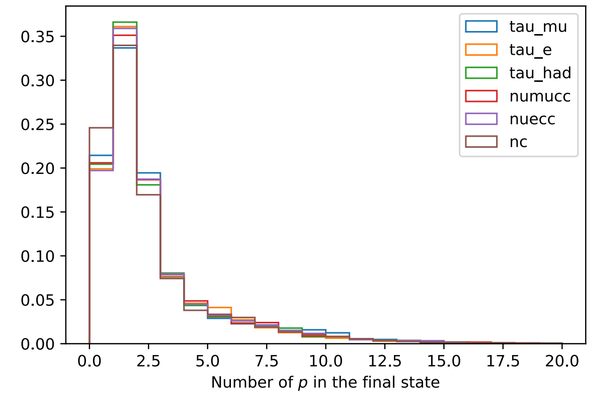
Final state particles

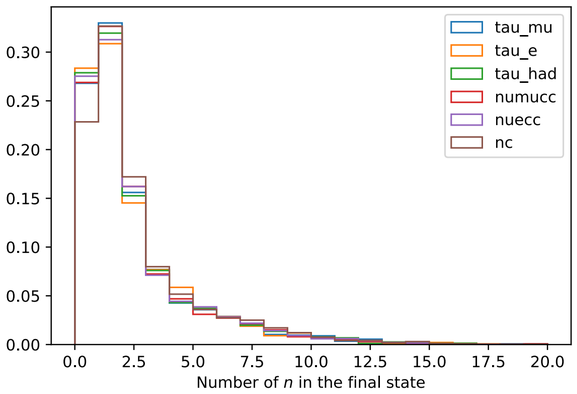
- Stable particles in the final state, including particles from tau decay
- Most tau_had have at least 1 π^- in the final state
- Neutrinos in the final state are invisible to the detector, contributing to the missing energy
  - Almost all numucc, nuecc have zero neutrino in the final state
  - NC events and tau_had have 1 neutrino, tau_mu and tau_e have 2 neutrino

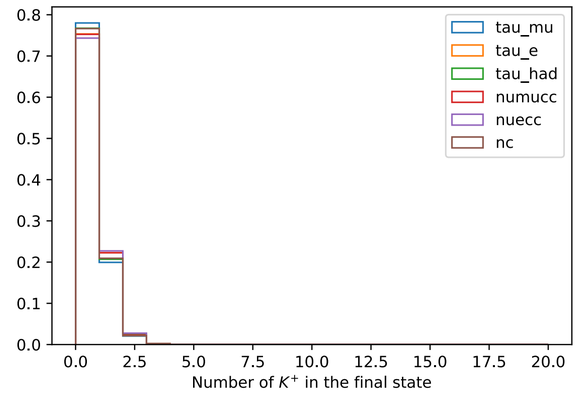


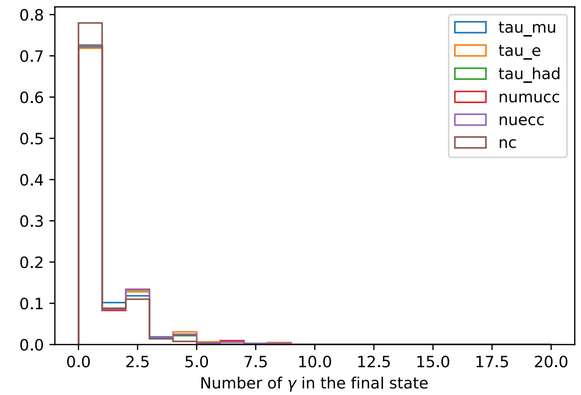


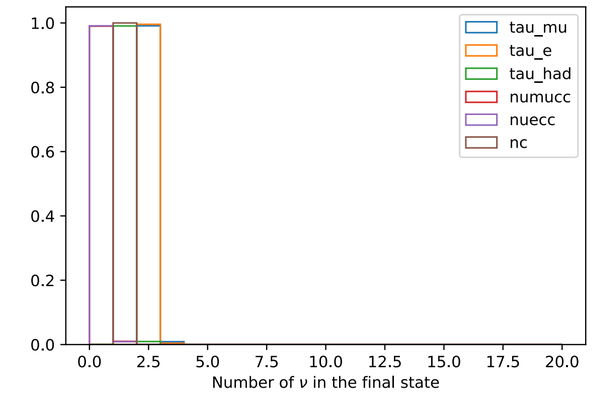




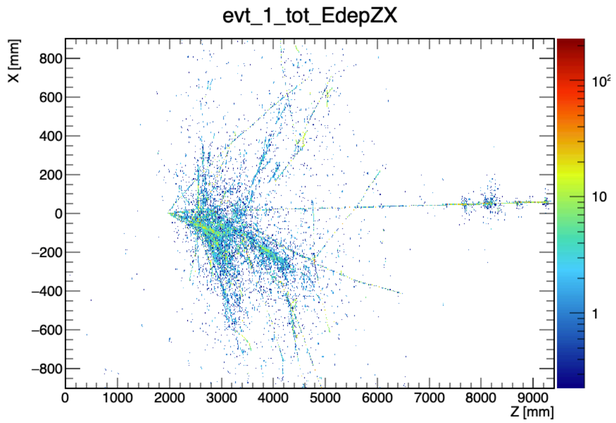


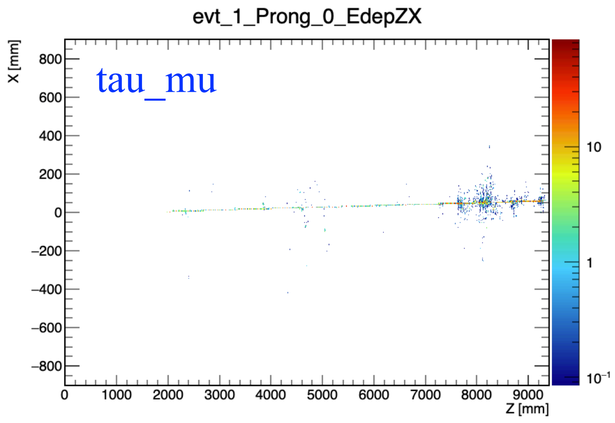


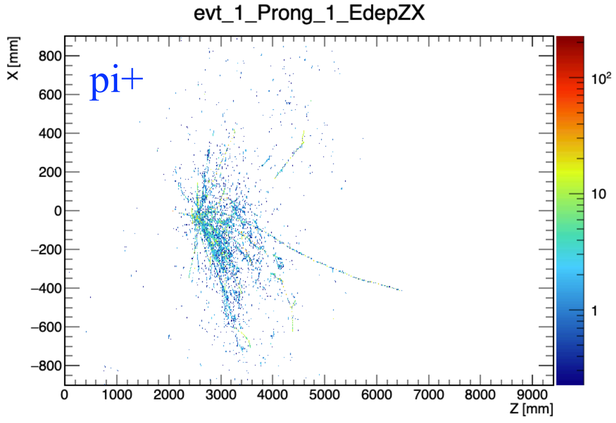


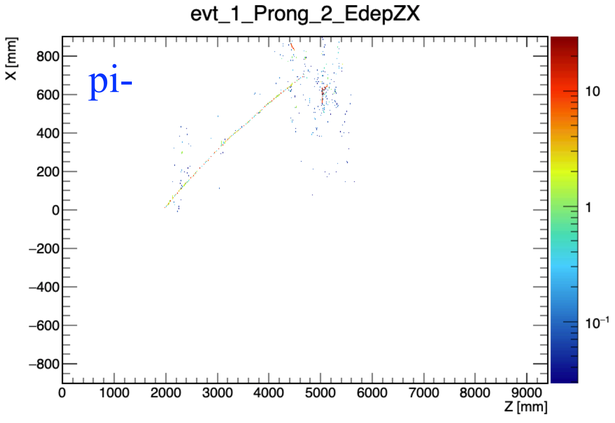


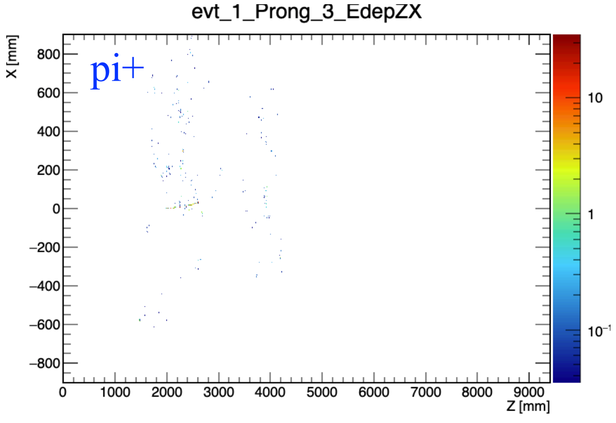
Event display of each final state particle

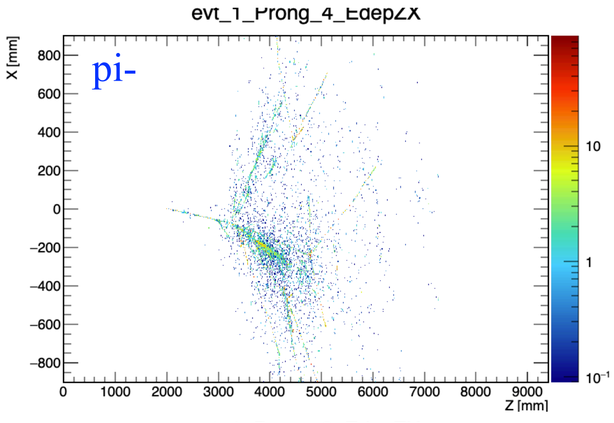


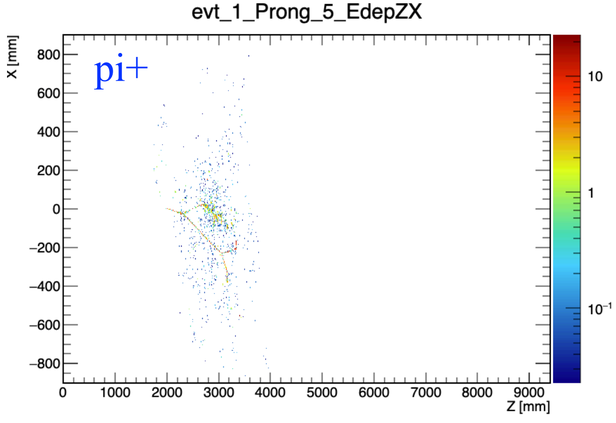


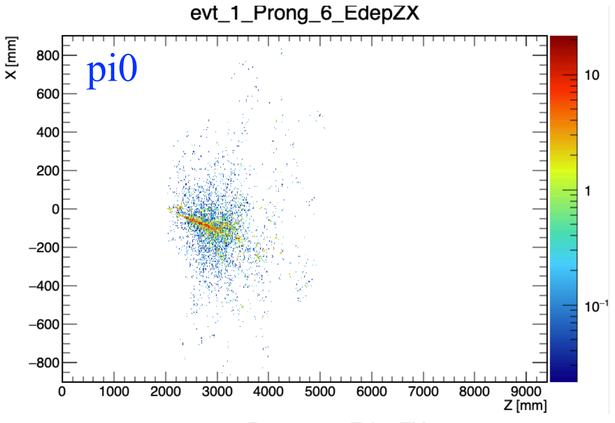


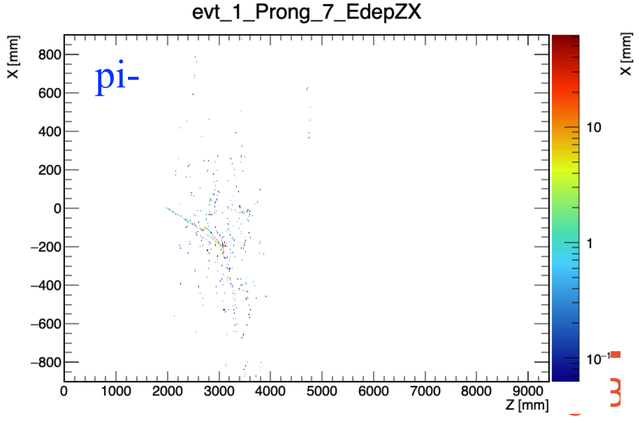


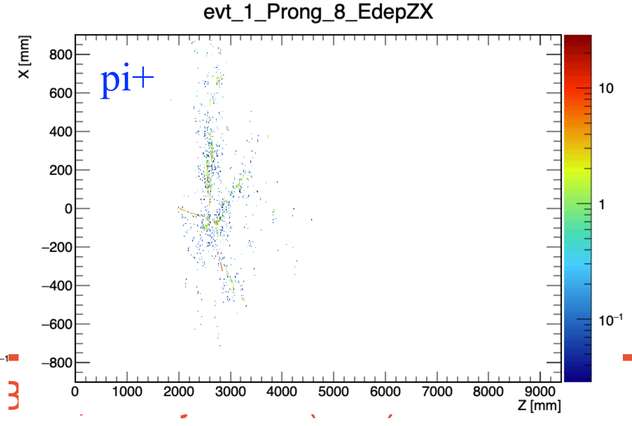


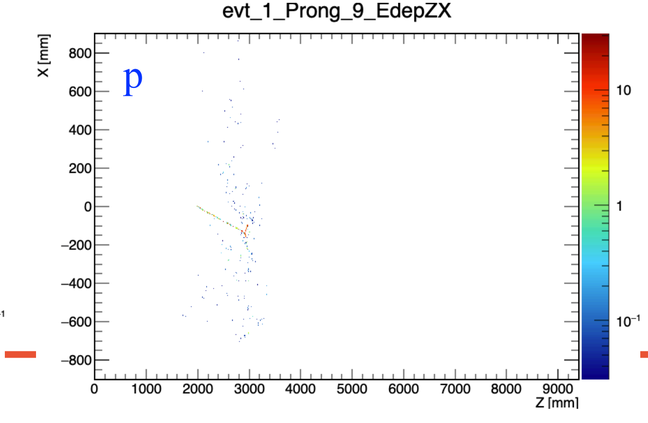


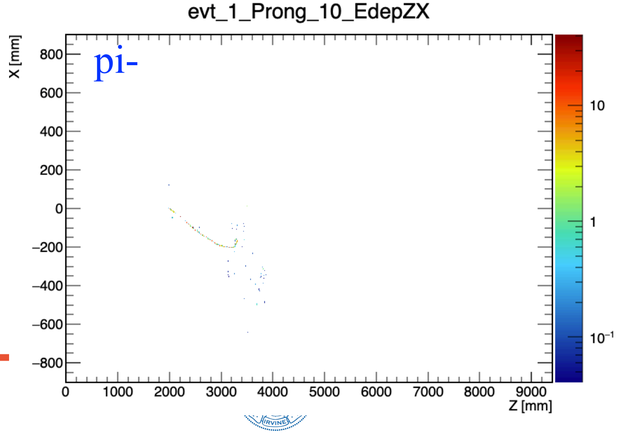






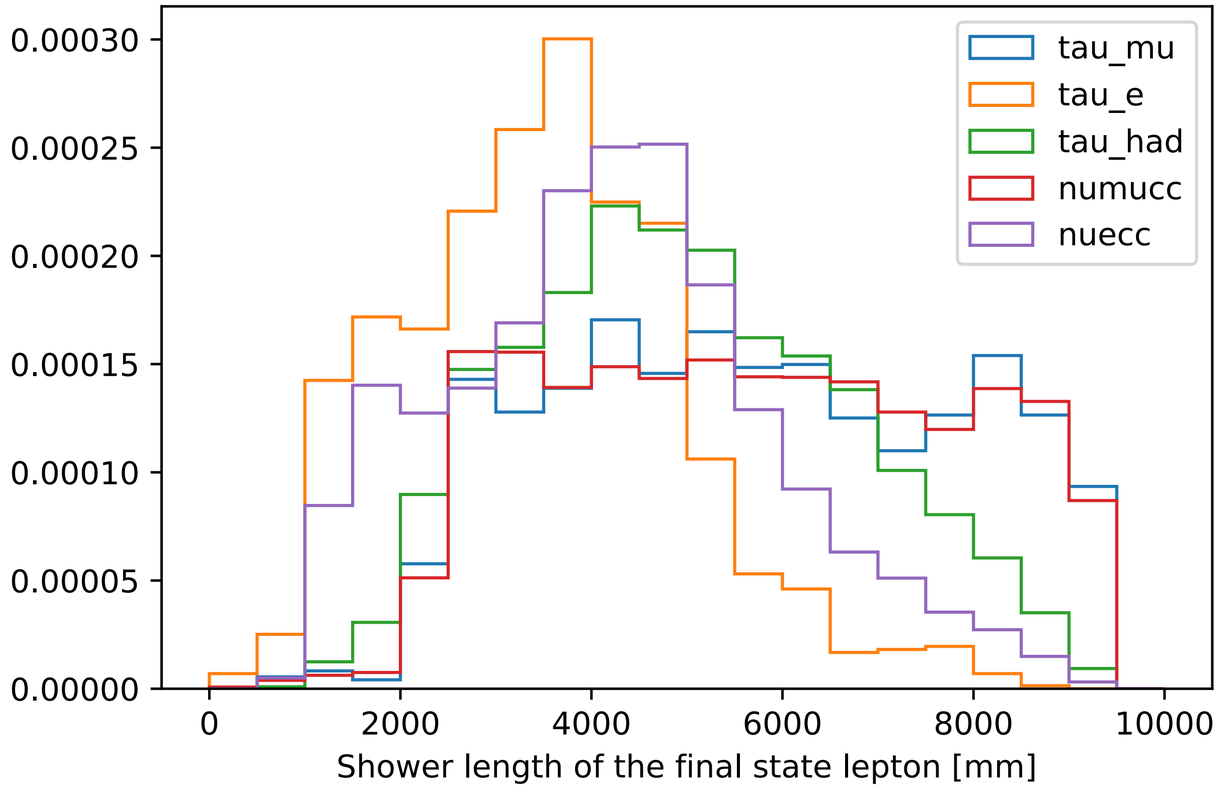




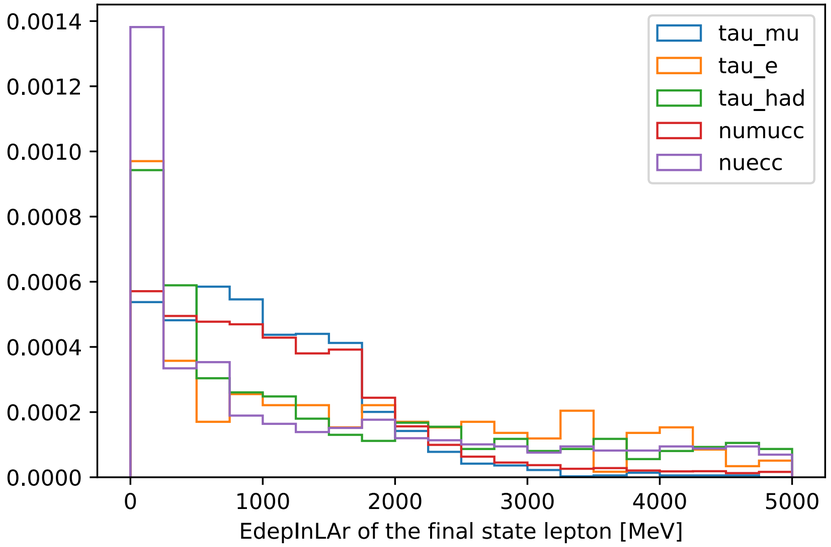


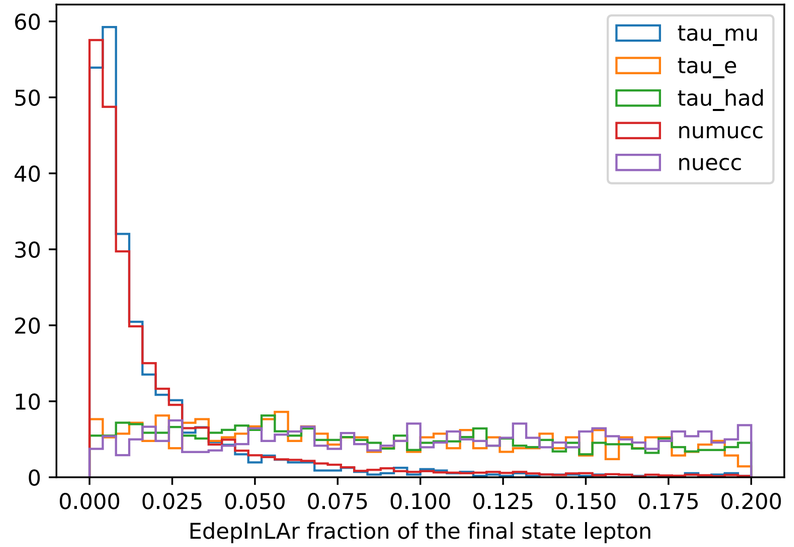
Shower length of the final state lepton

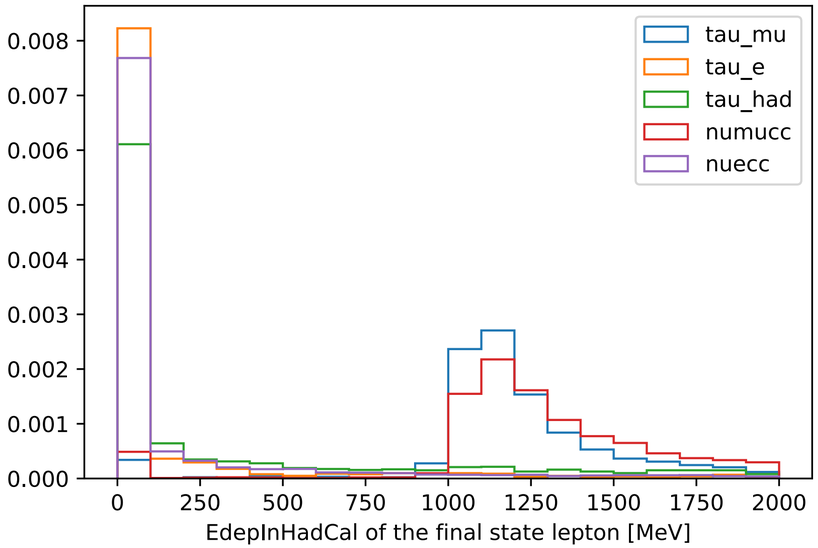
- Assume reco. can find out the shower of the final state lepton
- tau_mu/numucc > tau_had > tau_e/nuecc

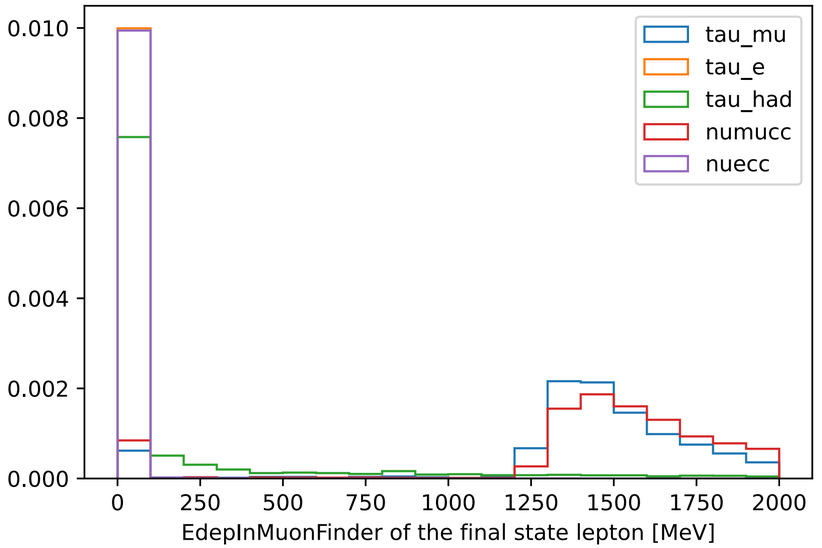


Deposited energy of the final state lepton



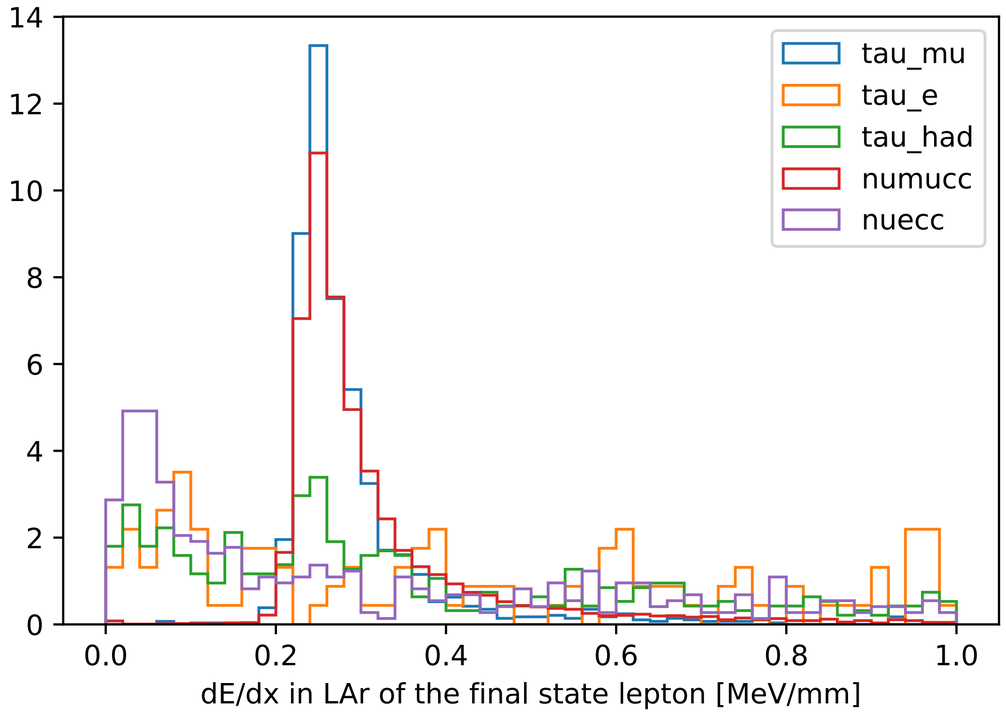






Average dE/dx in LAr of the final state lepton

- Total deposited energy in LAr / total shower length



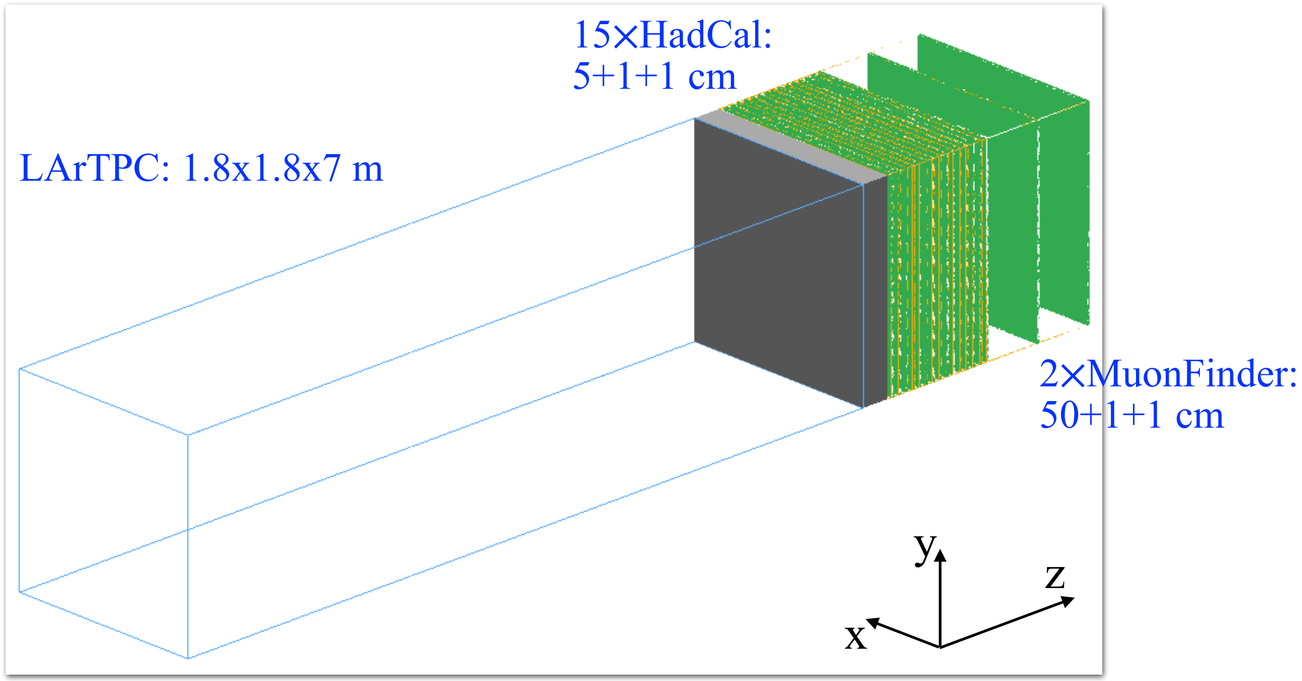
Next steps

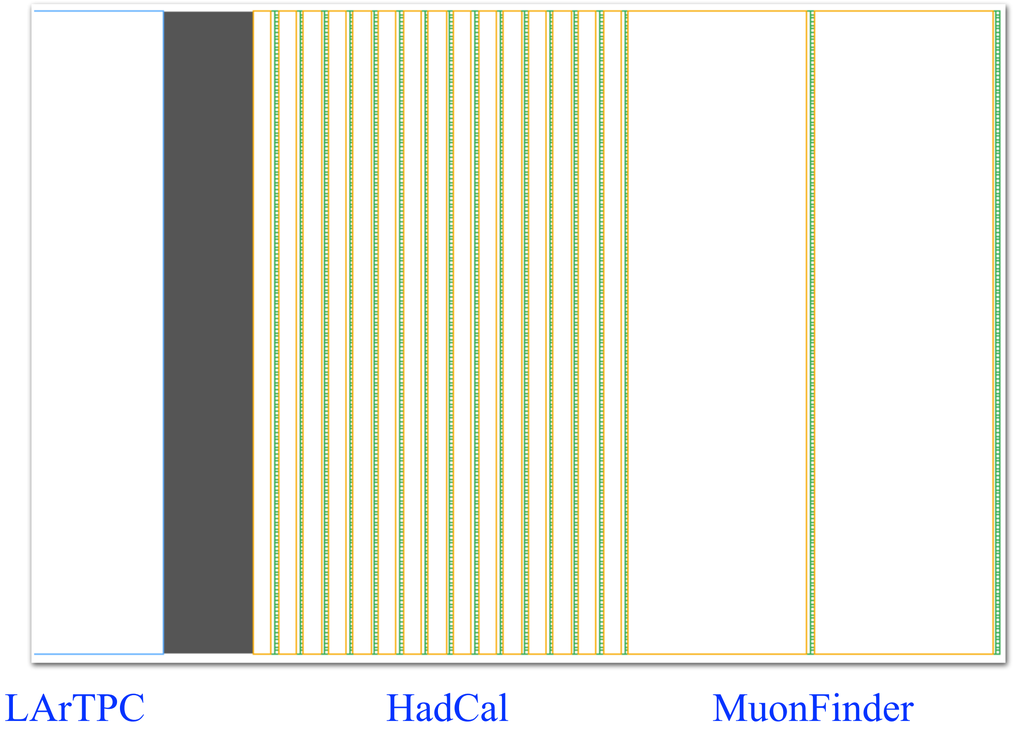
- Tau neutrino detection is challenging, giving the short lifetime of tau and the severe background
- We’re exploring how to suppress the background, with a fake reconstruction based on truth information
  - There are work similar in progress for DUNE, but the energy scale is different

Backup

Detector configuration in Geant4

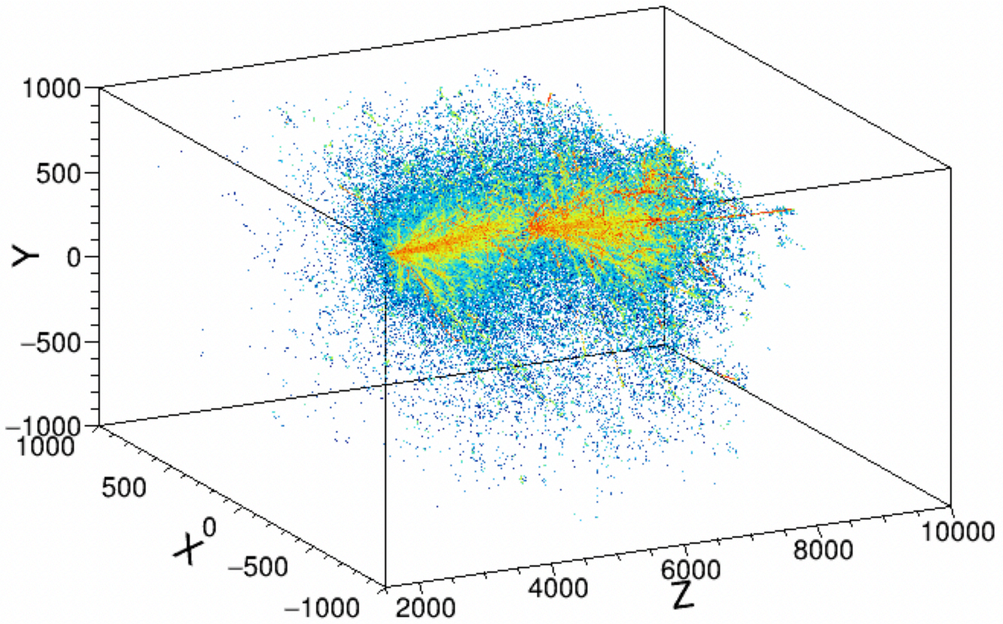
	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 9340

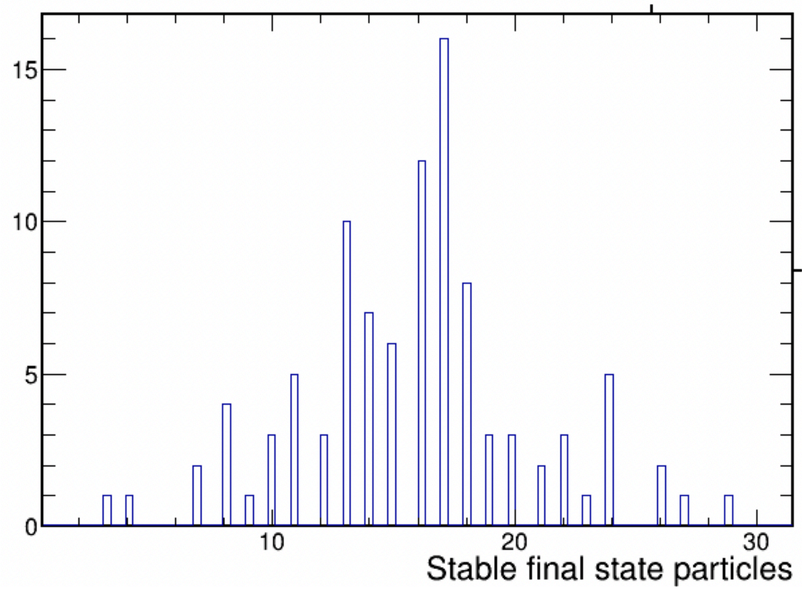




Work in progress

- 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
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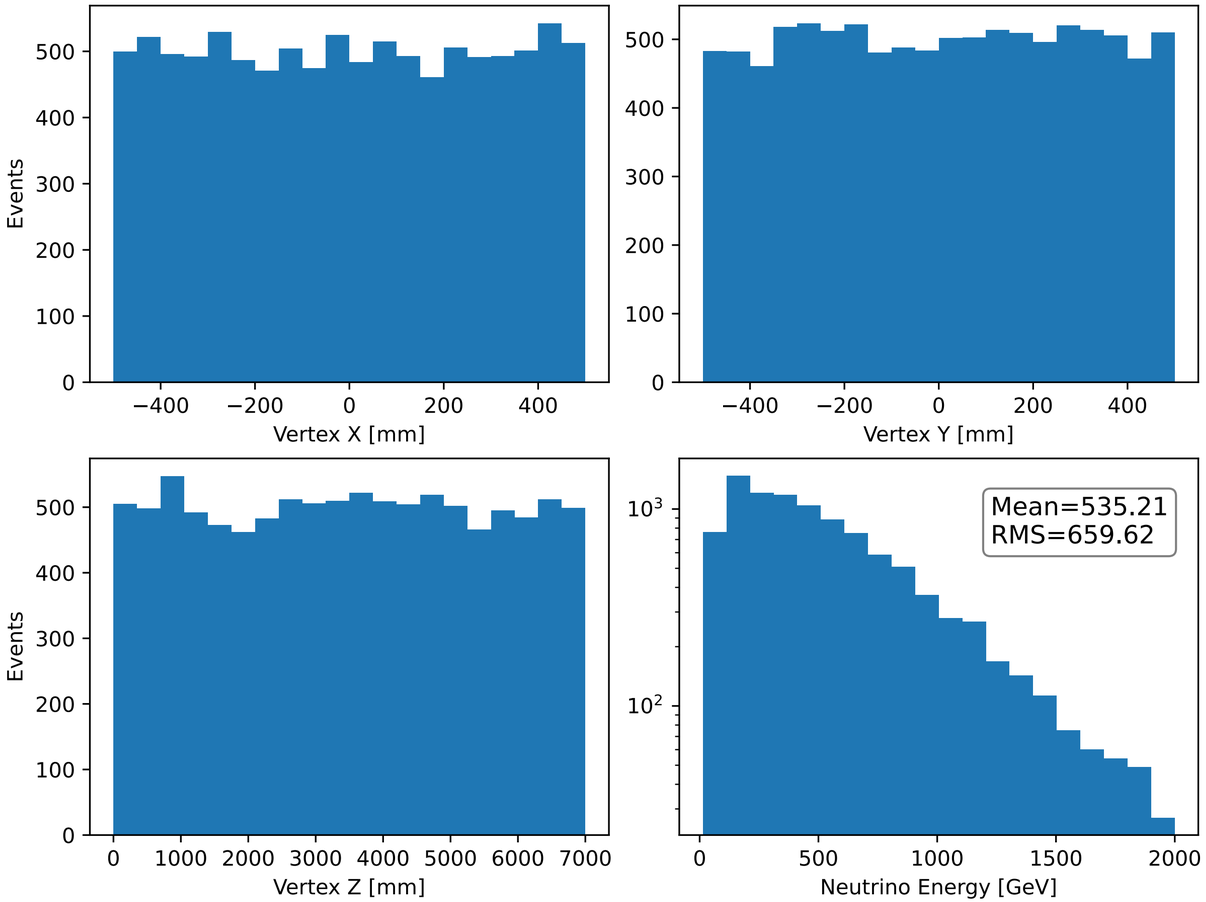
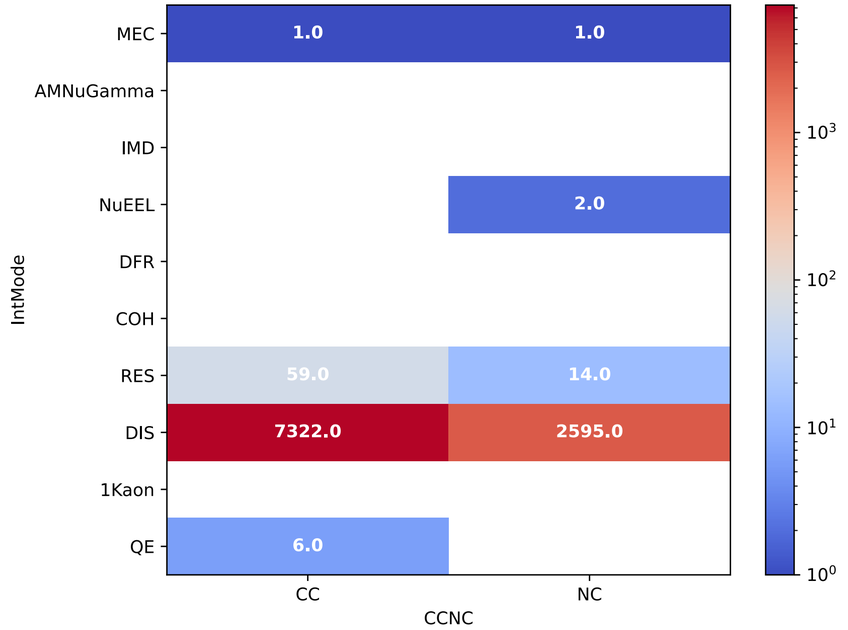
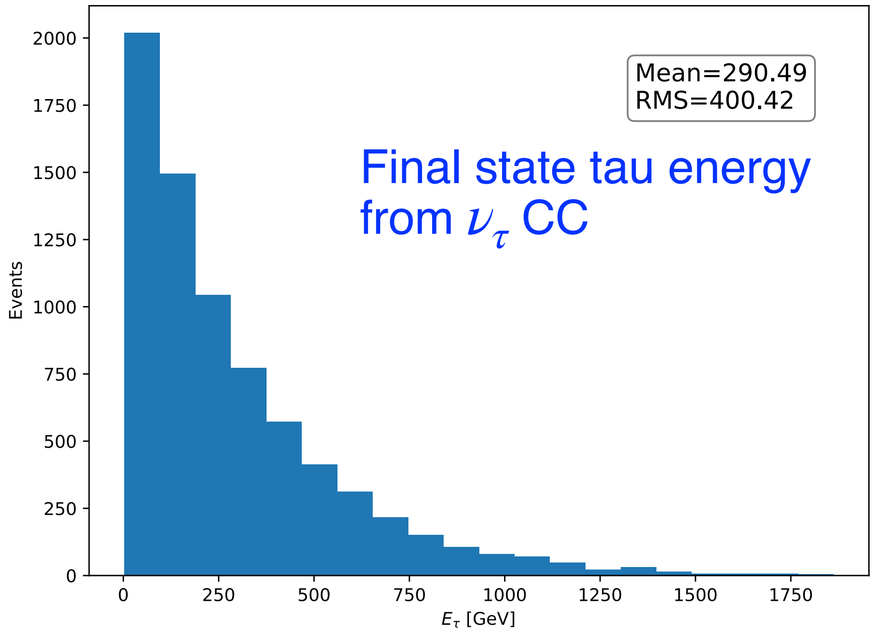
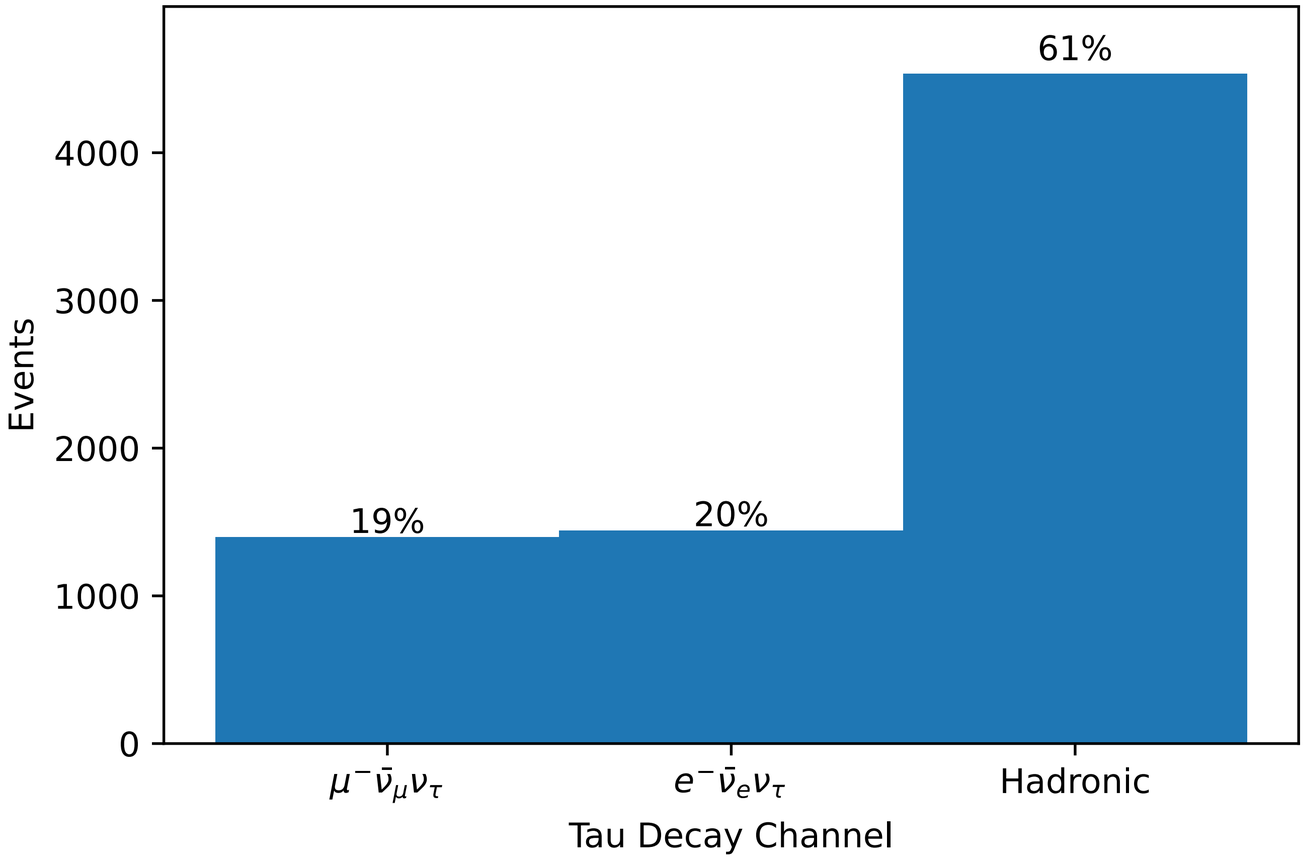






τ^-s in the detector



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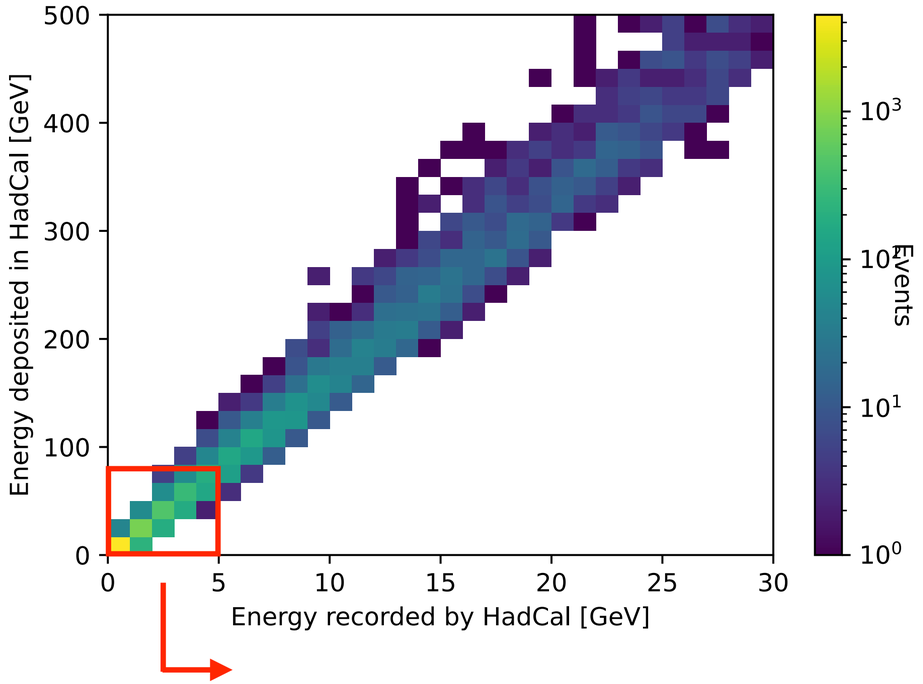
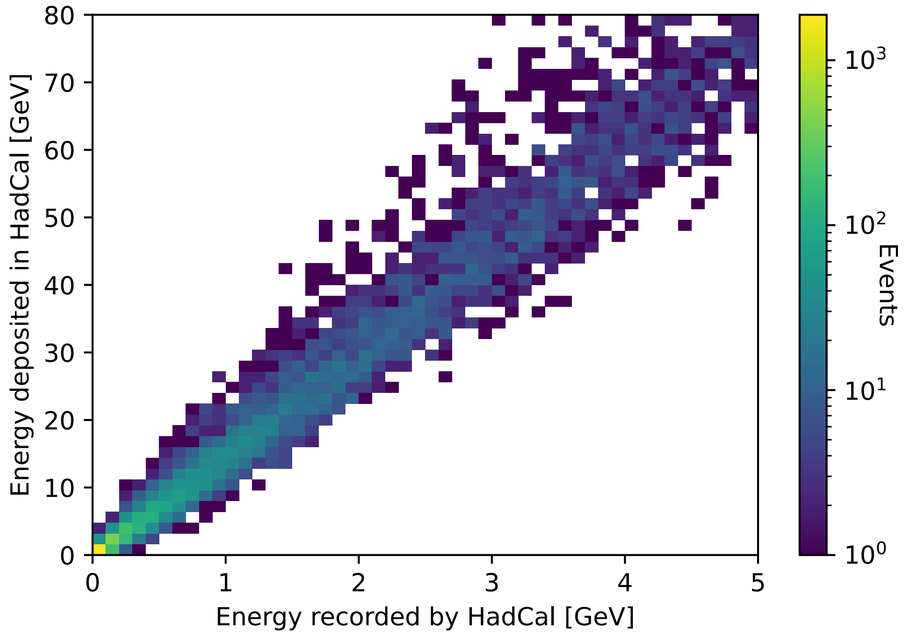
other	5.7%

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

HadCal Calibration

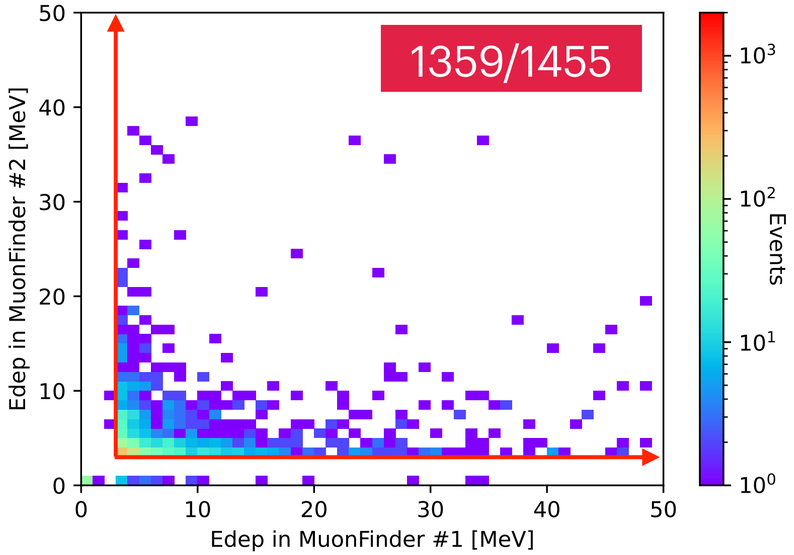
- In order to reconstruct the energy deposited in the HadCal, we'll need to calibrate it
  - The energy deposited in HadCal is proportional to the energy recorded by HadCal (the scintillator)
  - Good linearity



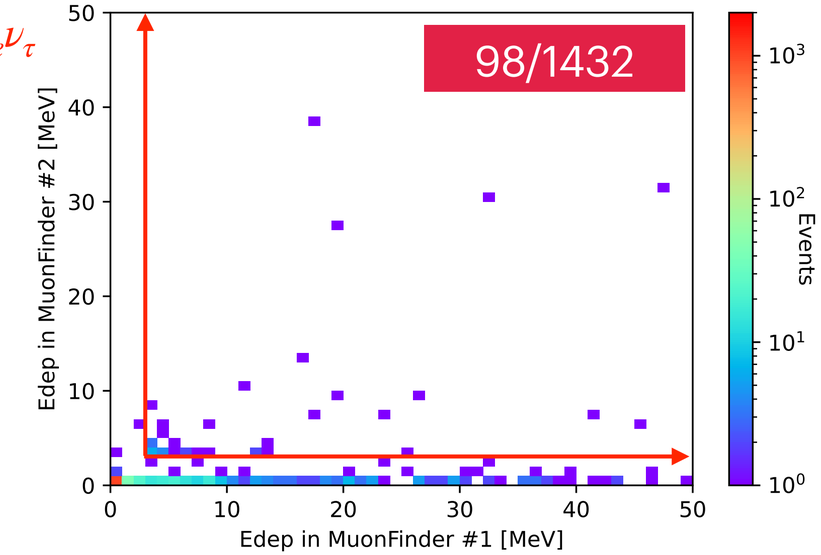


Deposited energy in MuonFinder

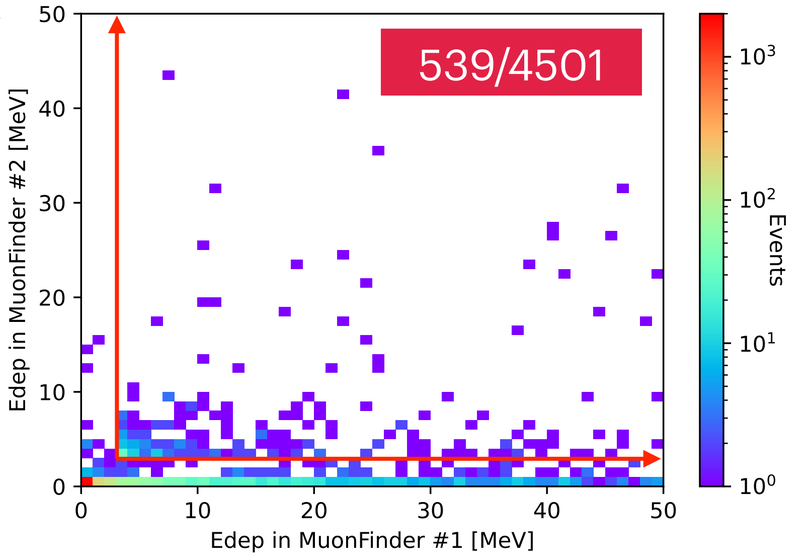
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$



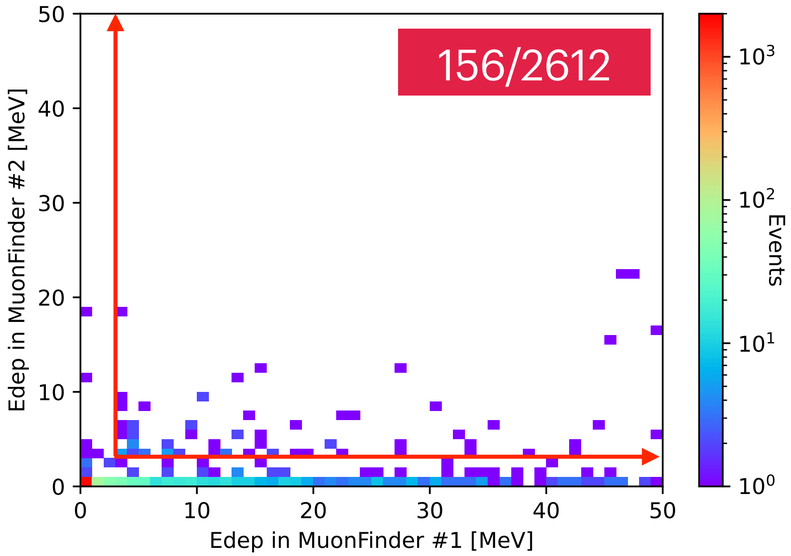
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$



τ^- Hadronic decay

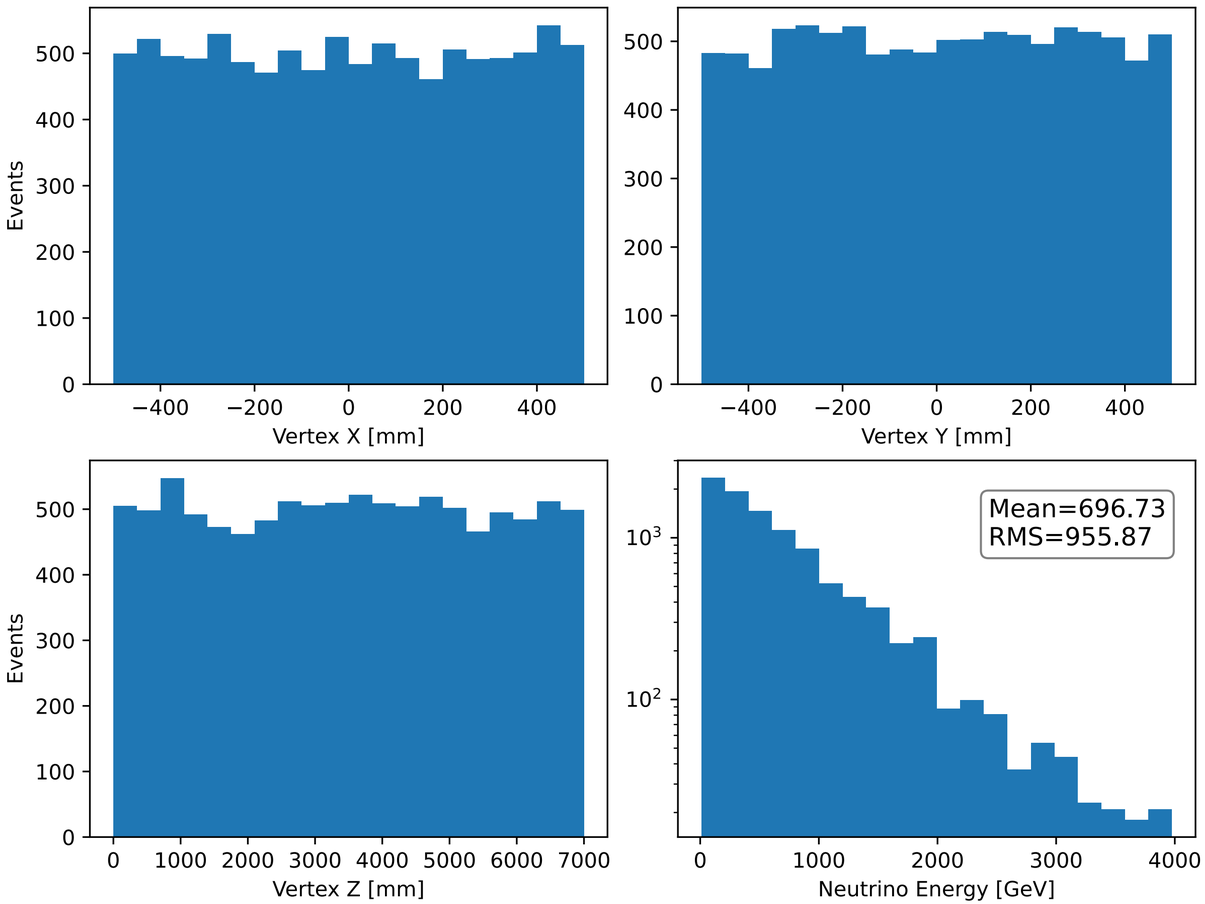


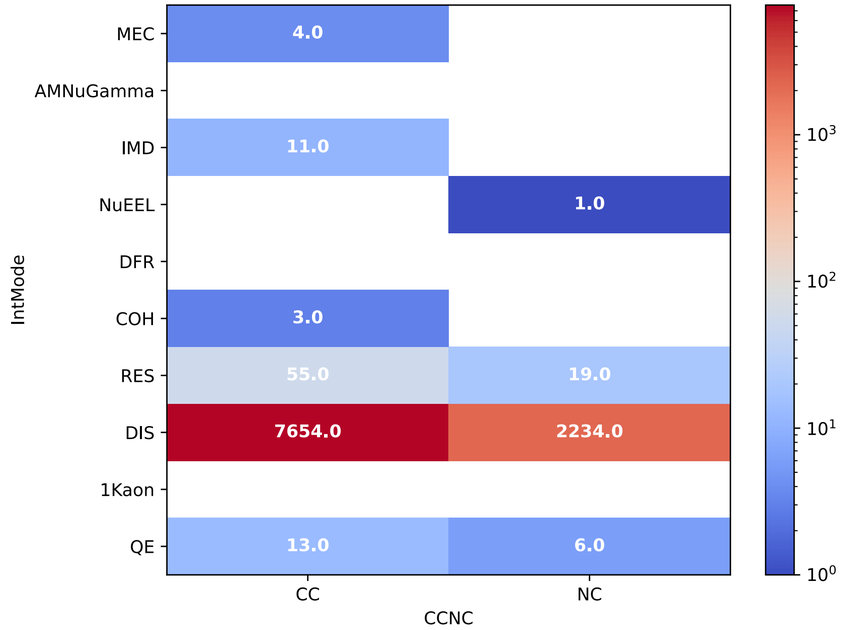
NC

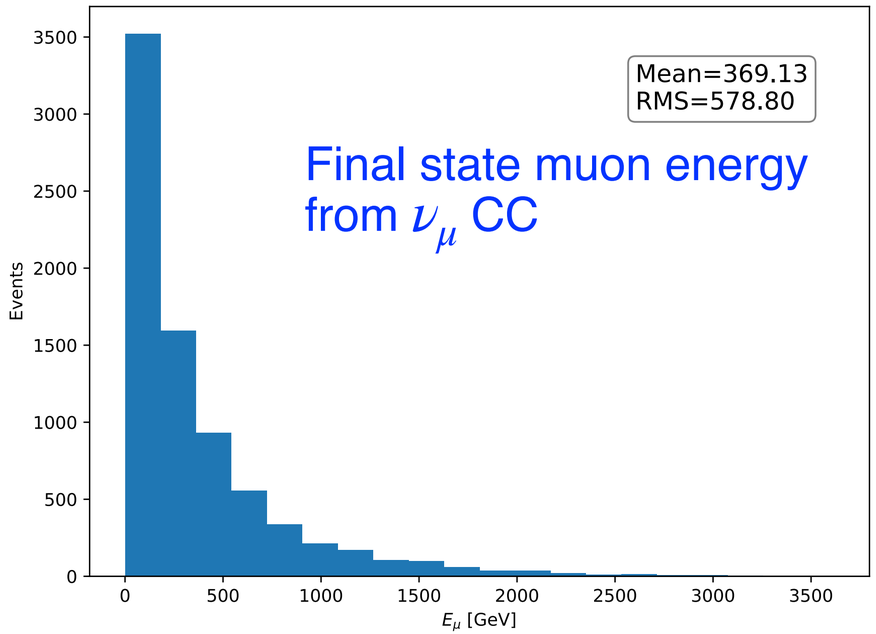


ν_μs in the detector

- 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







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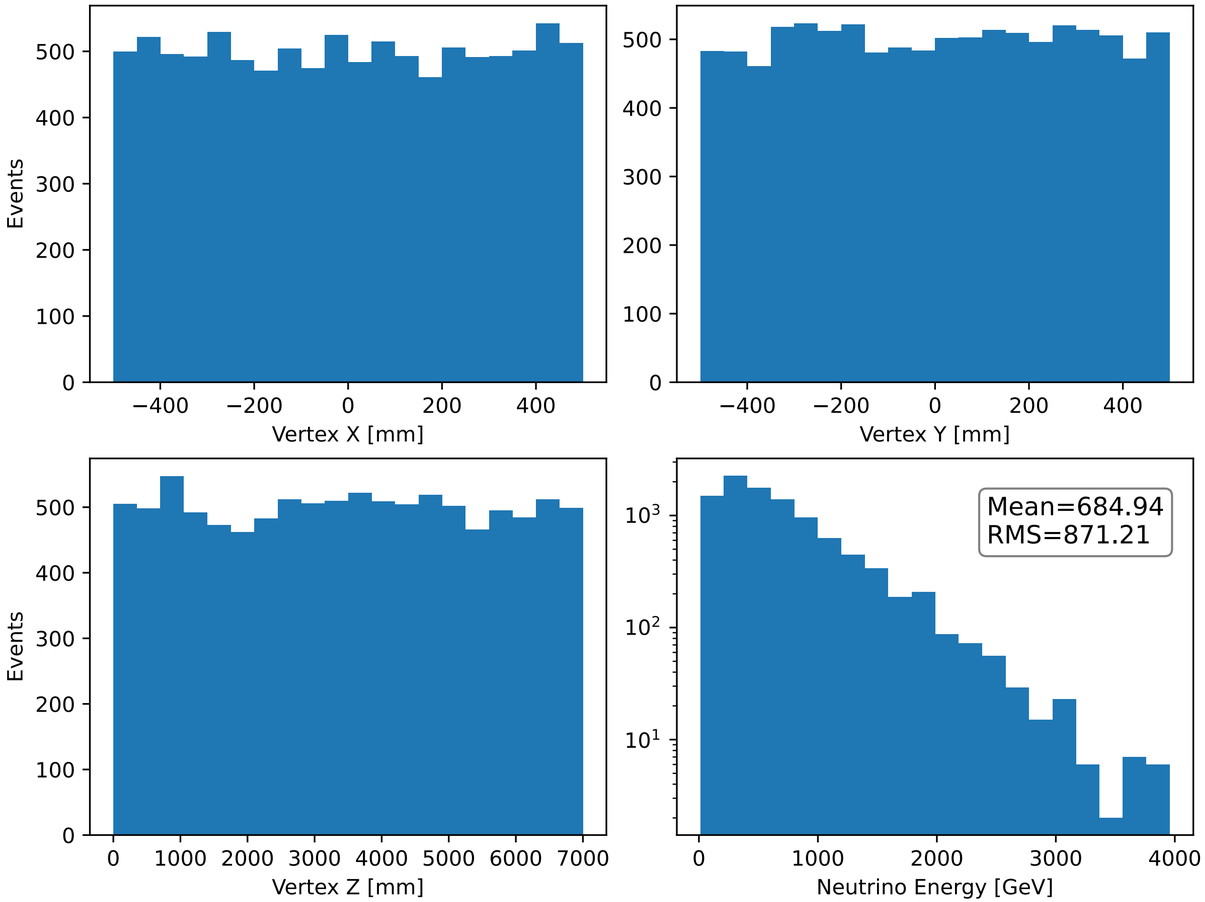
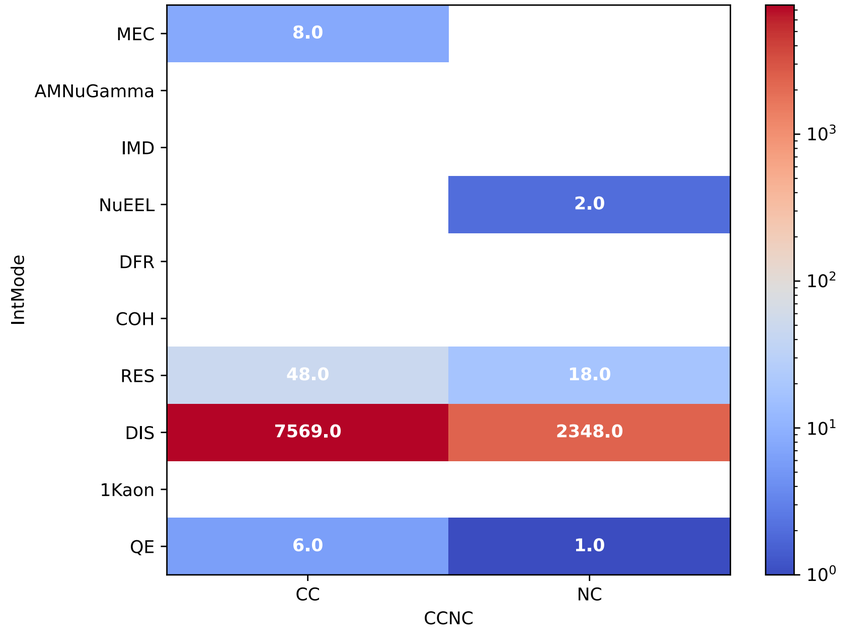
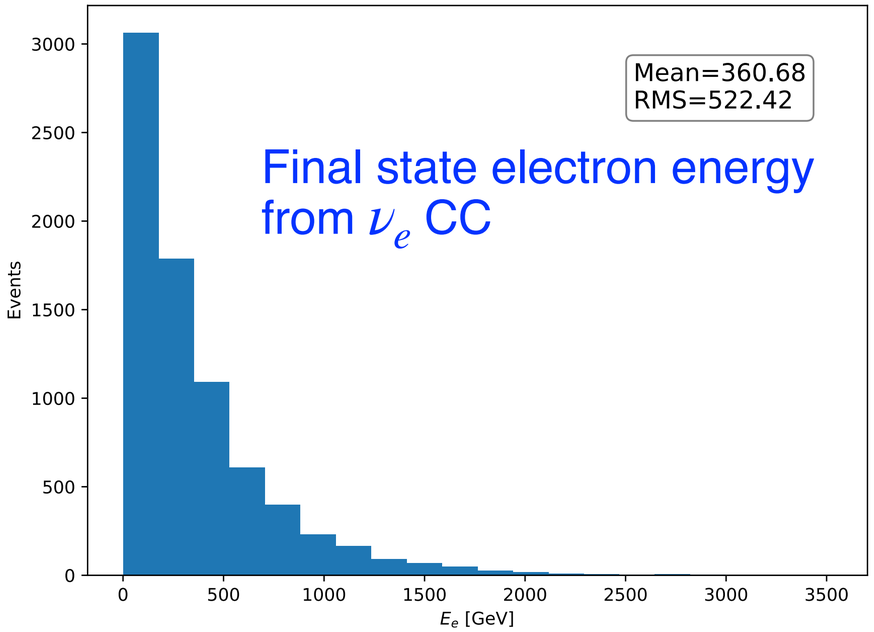
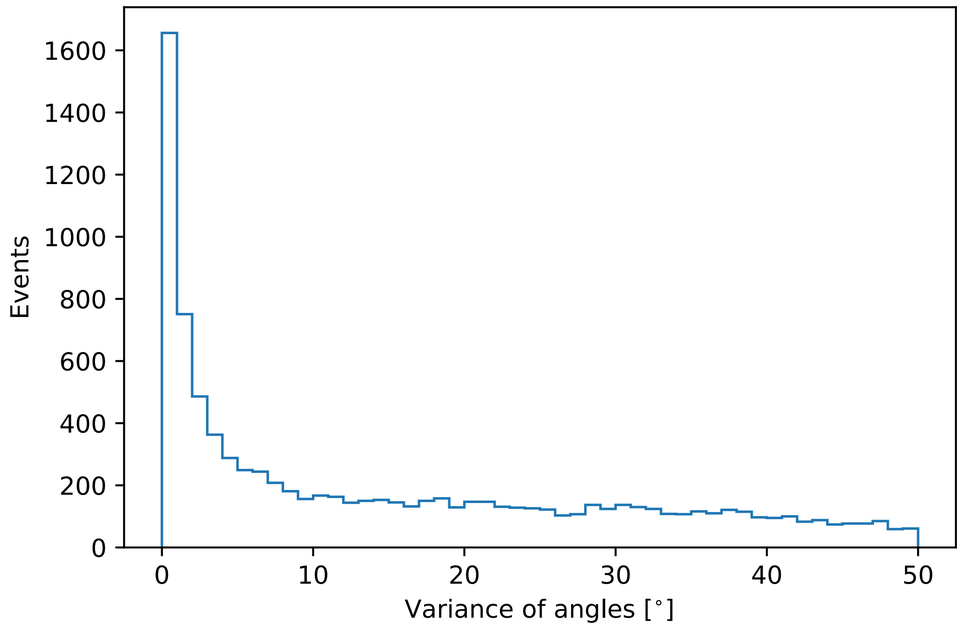




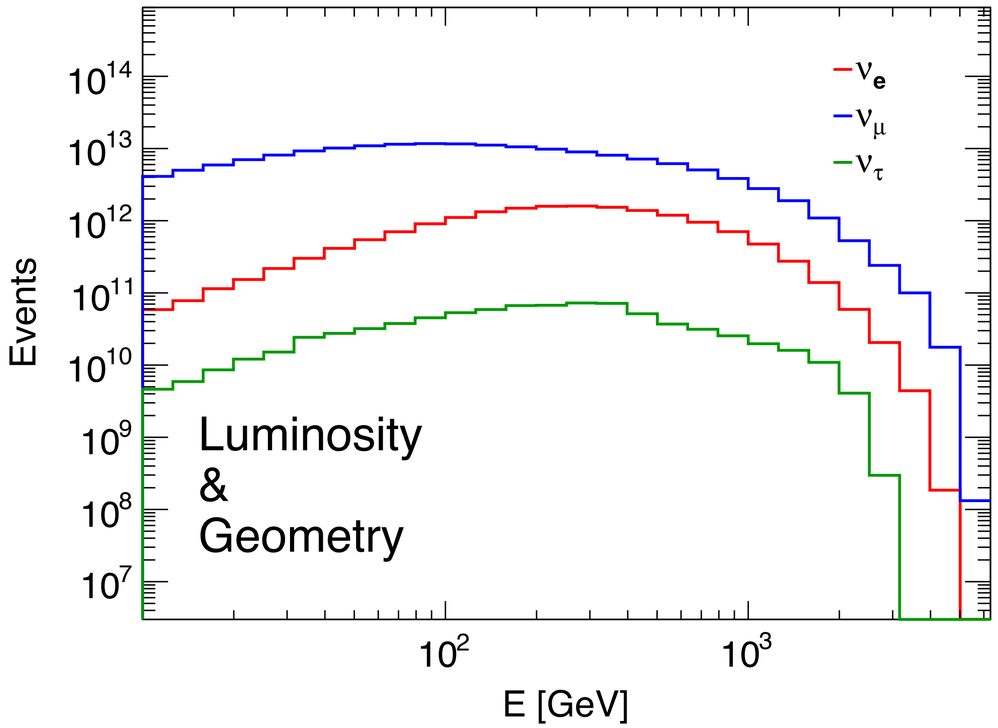


Angular variance

- Angular variance of charged tracks from the neutrino interaction w.r.t the direction of the neutrino beam
  - τ^-, π^+, π^-, p, … (maybe we need to also include π^0 and γ)
- Most of events have tracks concentrate at one direction (variance < 5°)



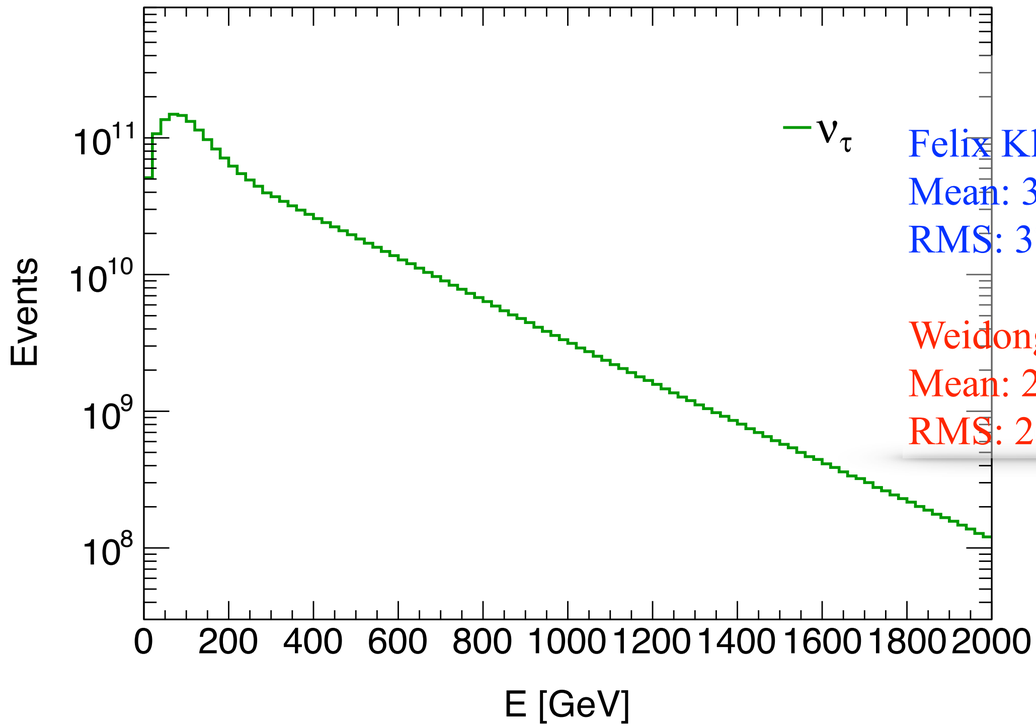
Neutrino flux



Felix Kling, et. al. 2105.08270
Github

FLArE10, 620m downstream from IP, 3000/fb

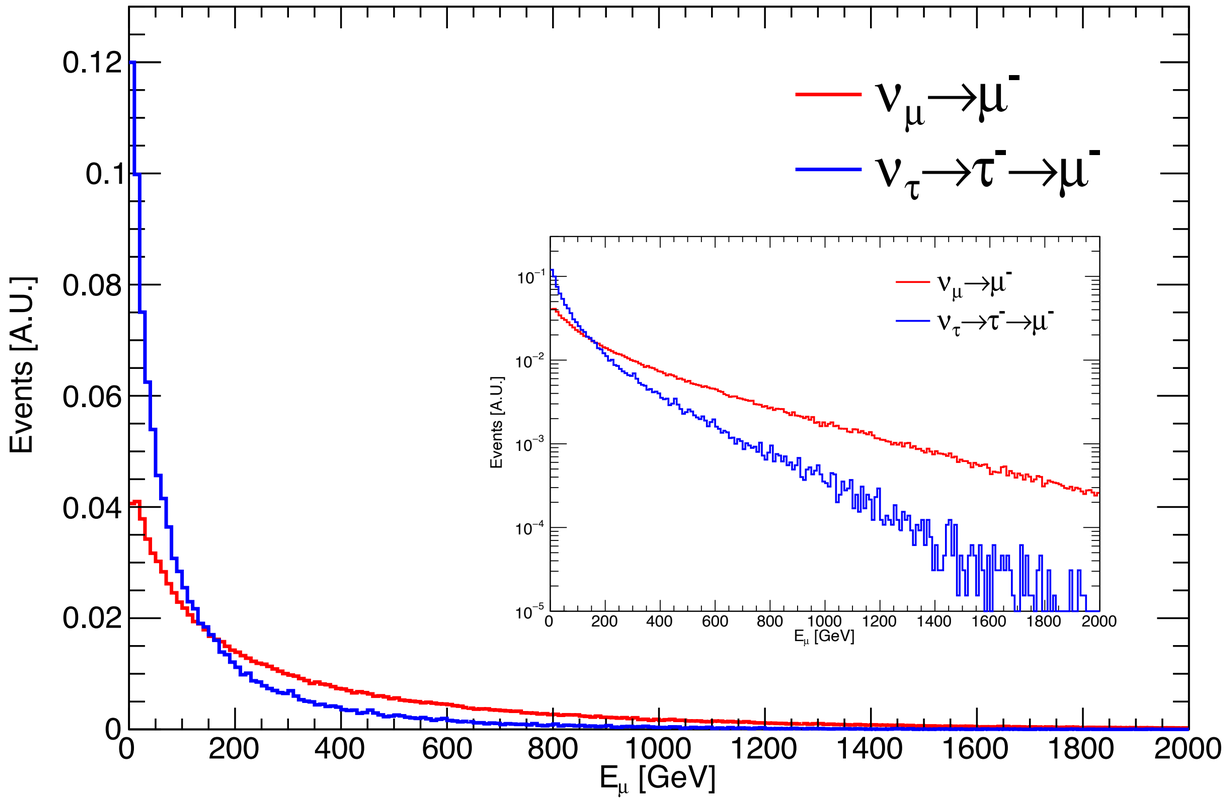
x Luminosity / 2



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



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

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

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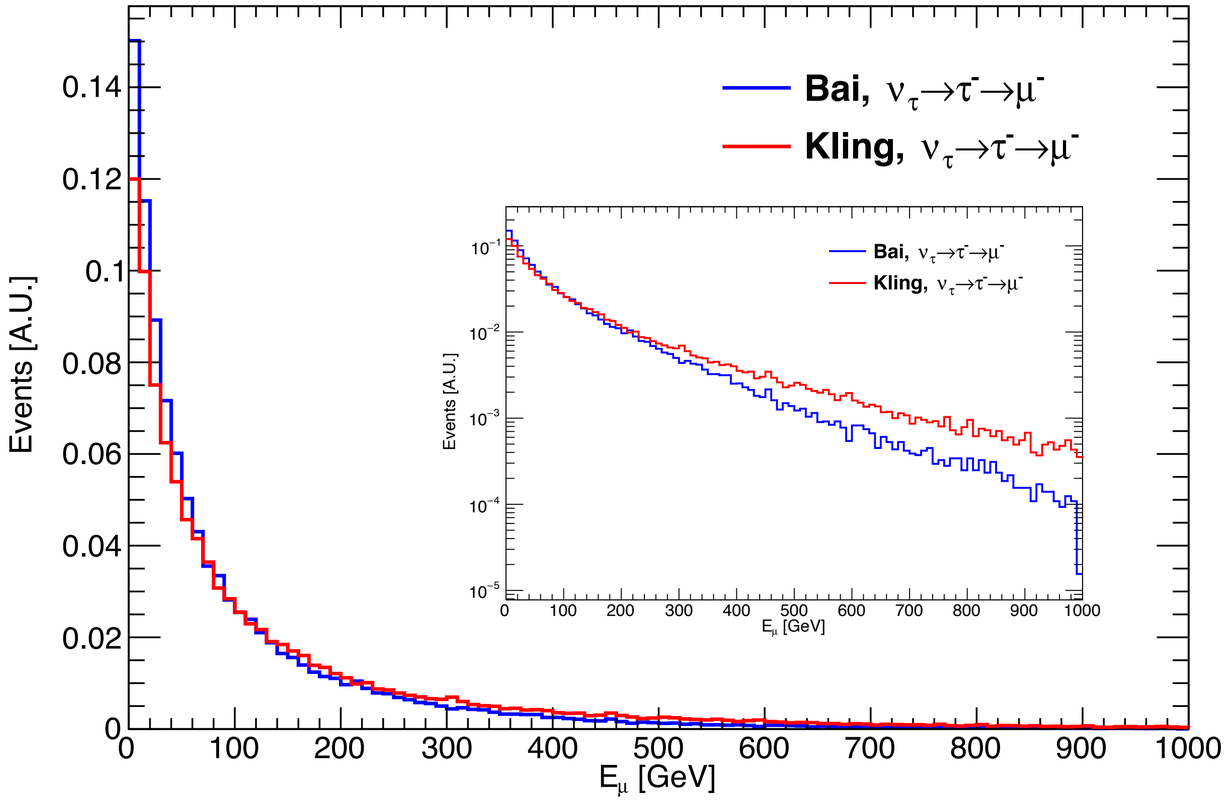
Muon energy spectrum, area normalized

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