Detector simulation (FLArE)

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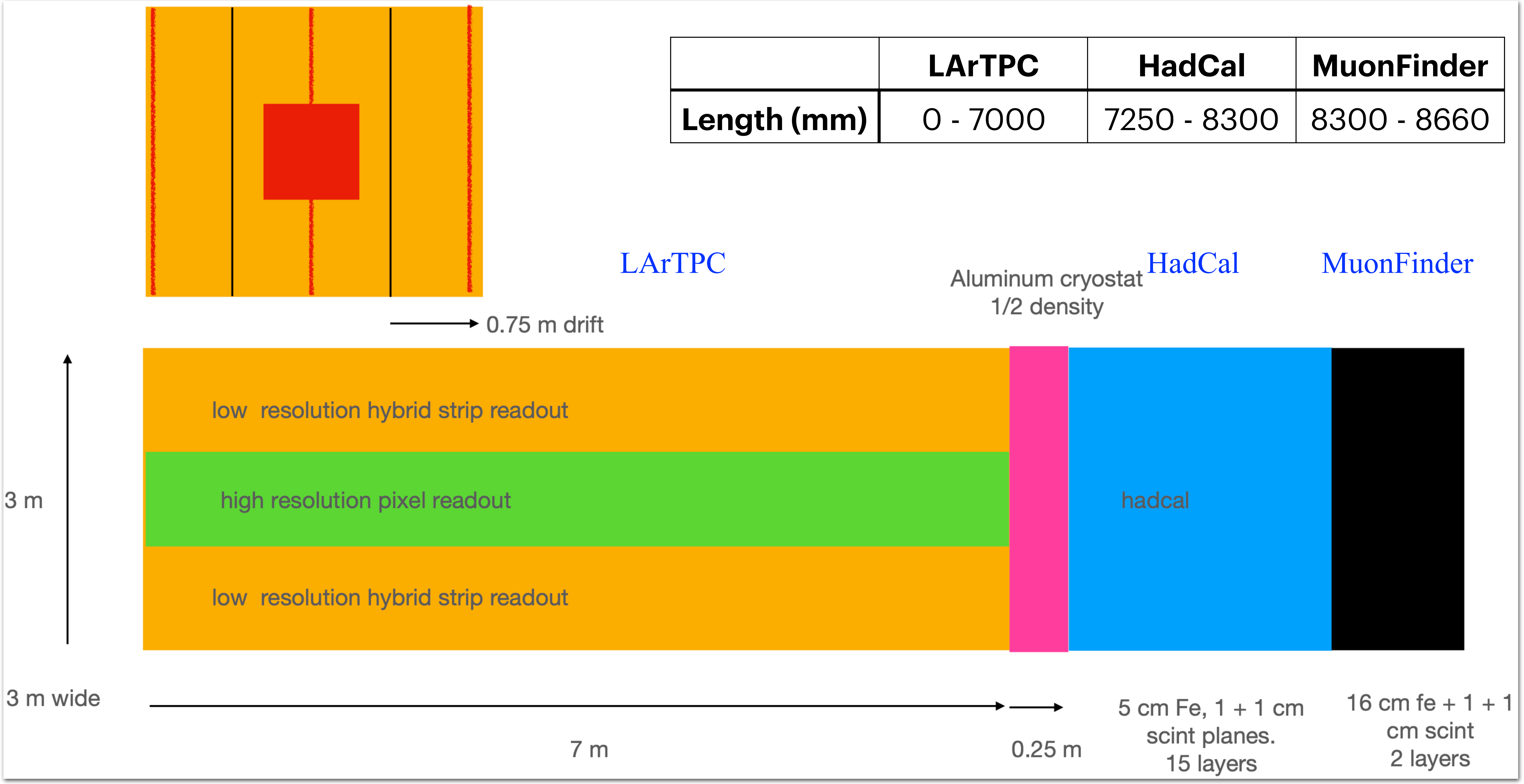
University of California, Irvine

March 31, 2022

Tentative detector configuration

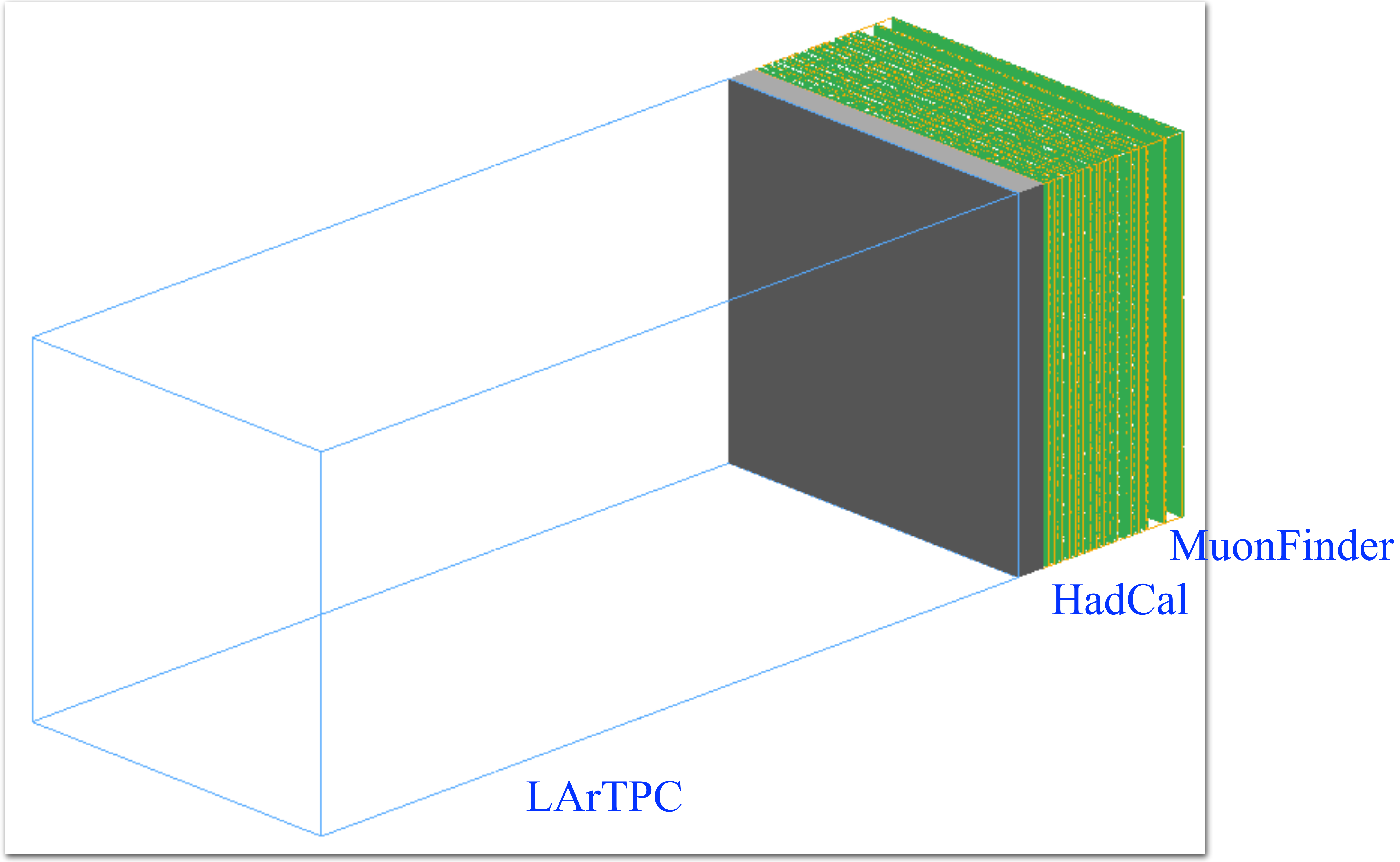
	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 8660

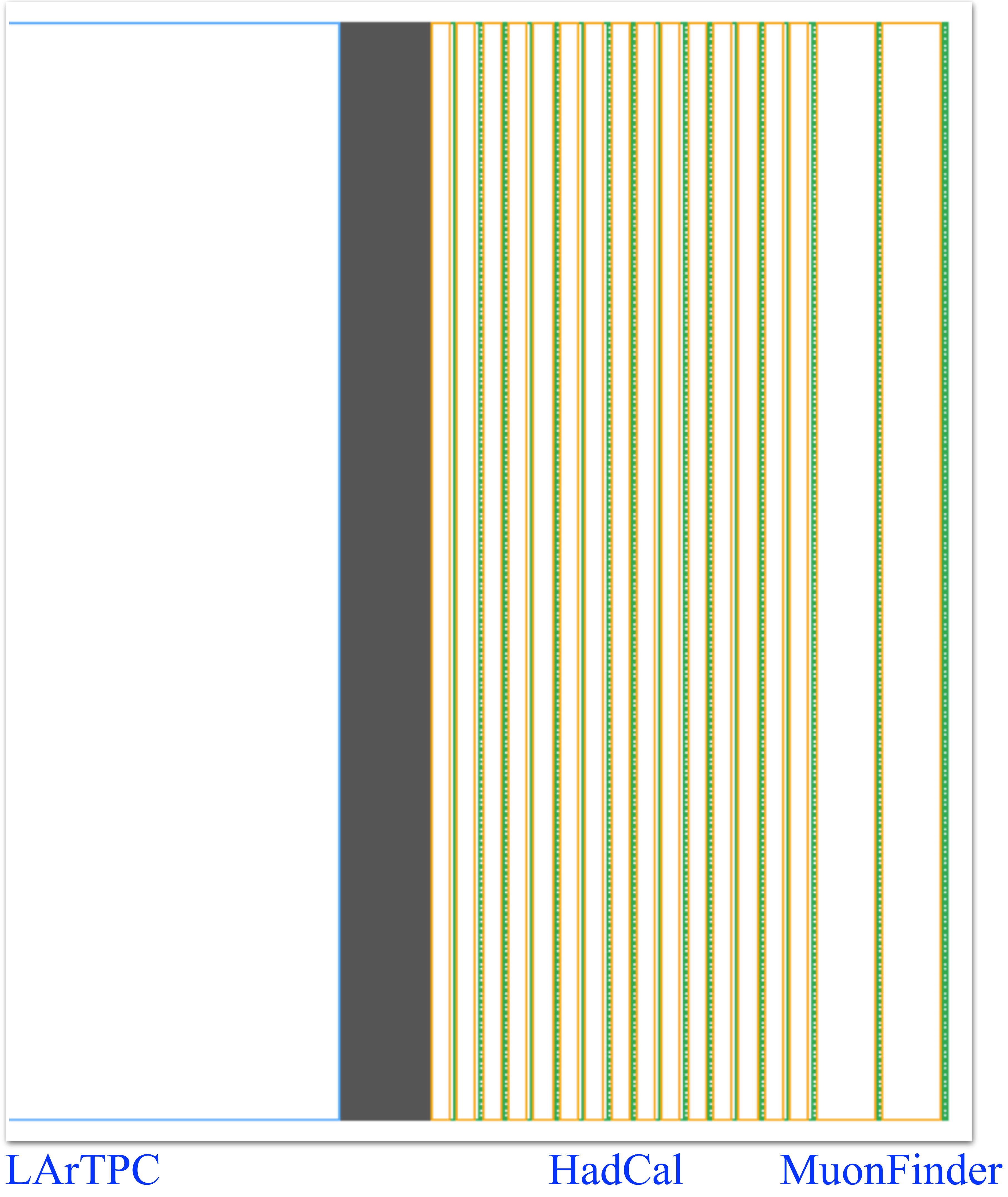


From discussion with Milind

Detector configuration in Geant4

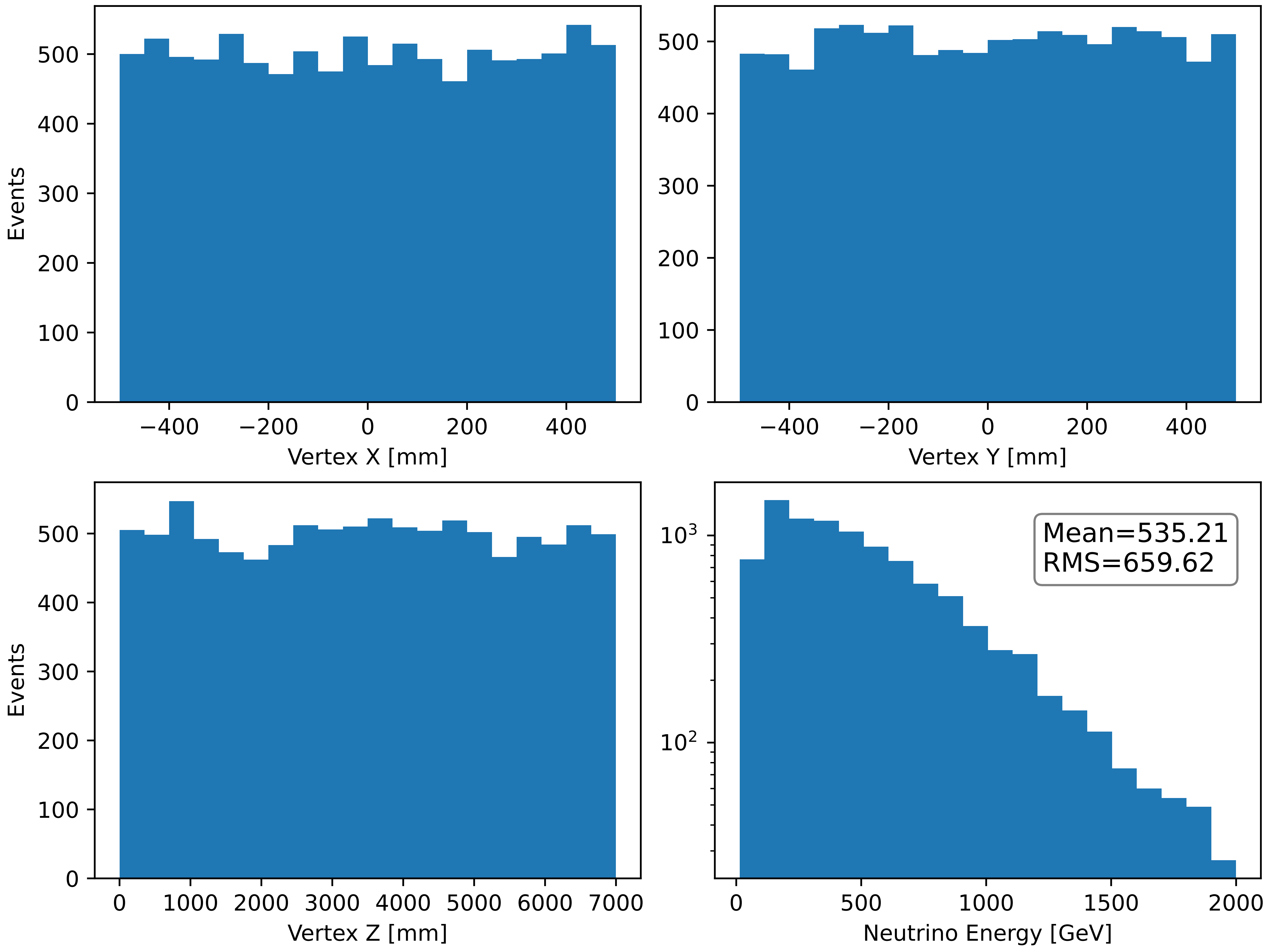
	LArTPC	HadCal	MuonFinder
Length (mm)	0 - 7000	7250 - 8300	8300 - 8660

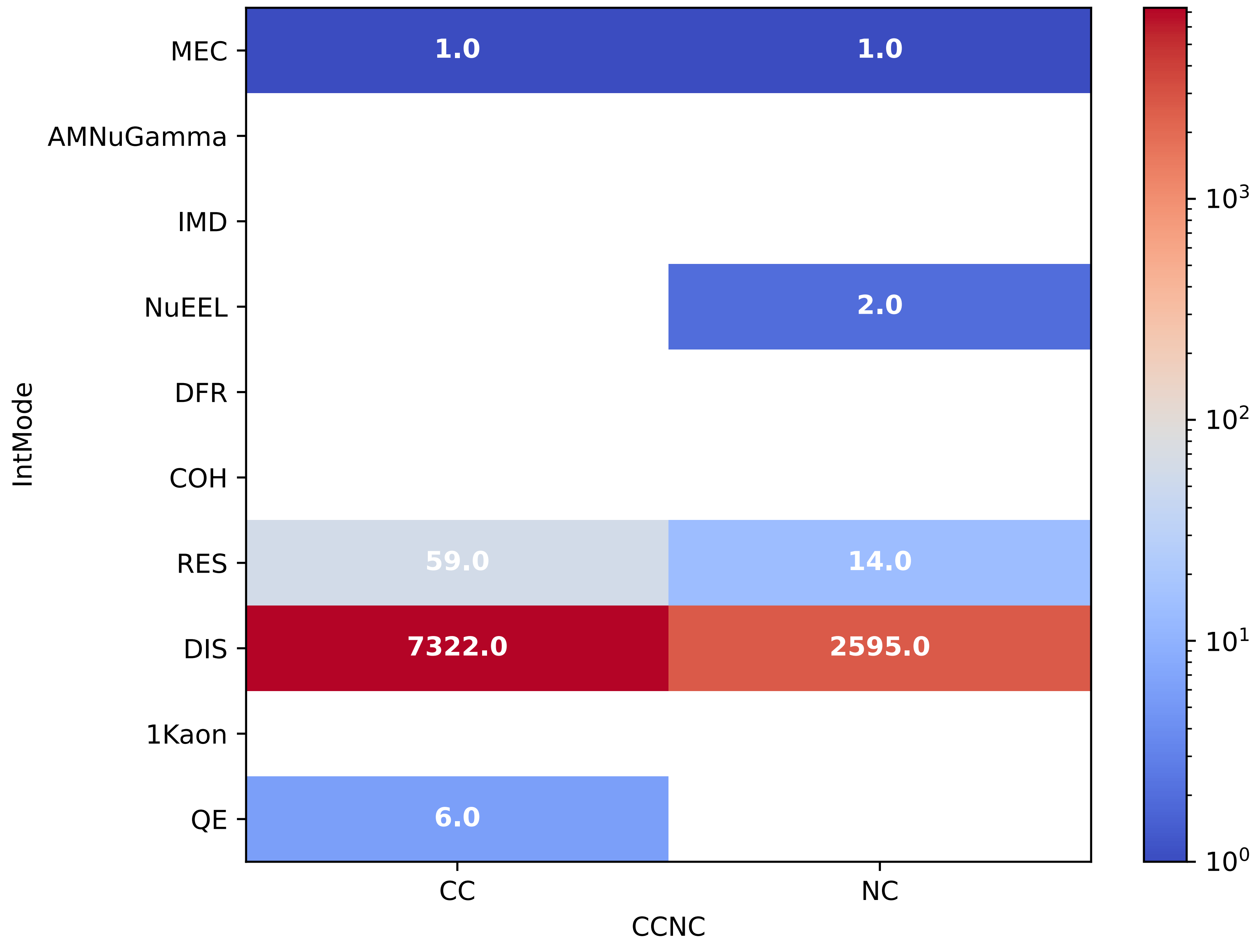


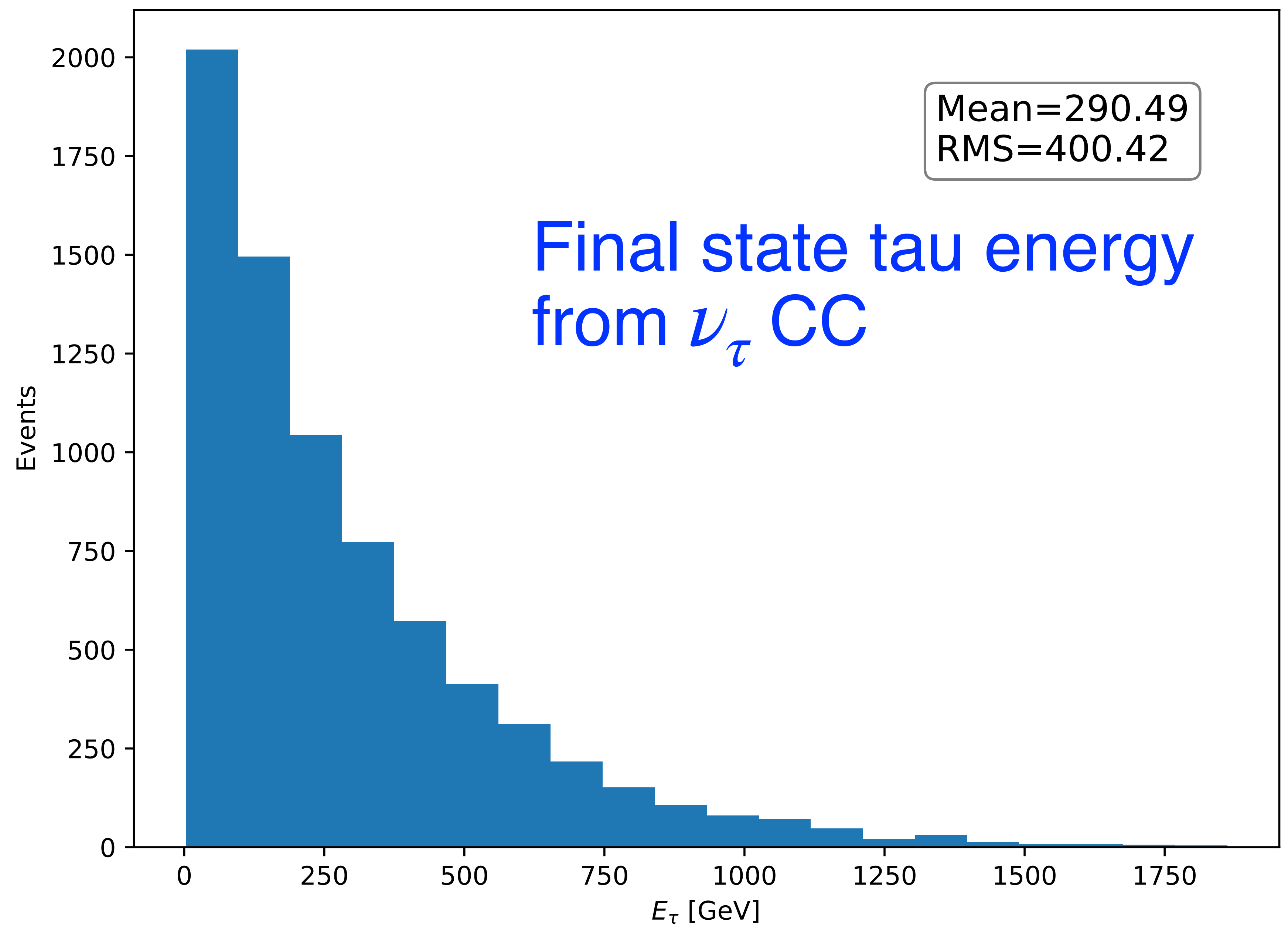


ν_τs in the detector

- 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]







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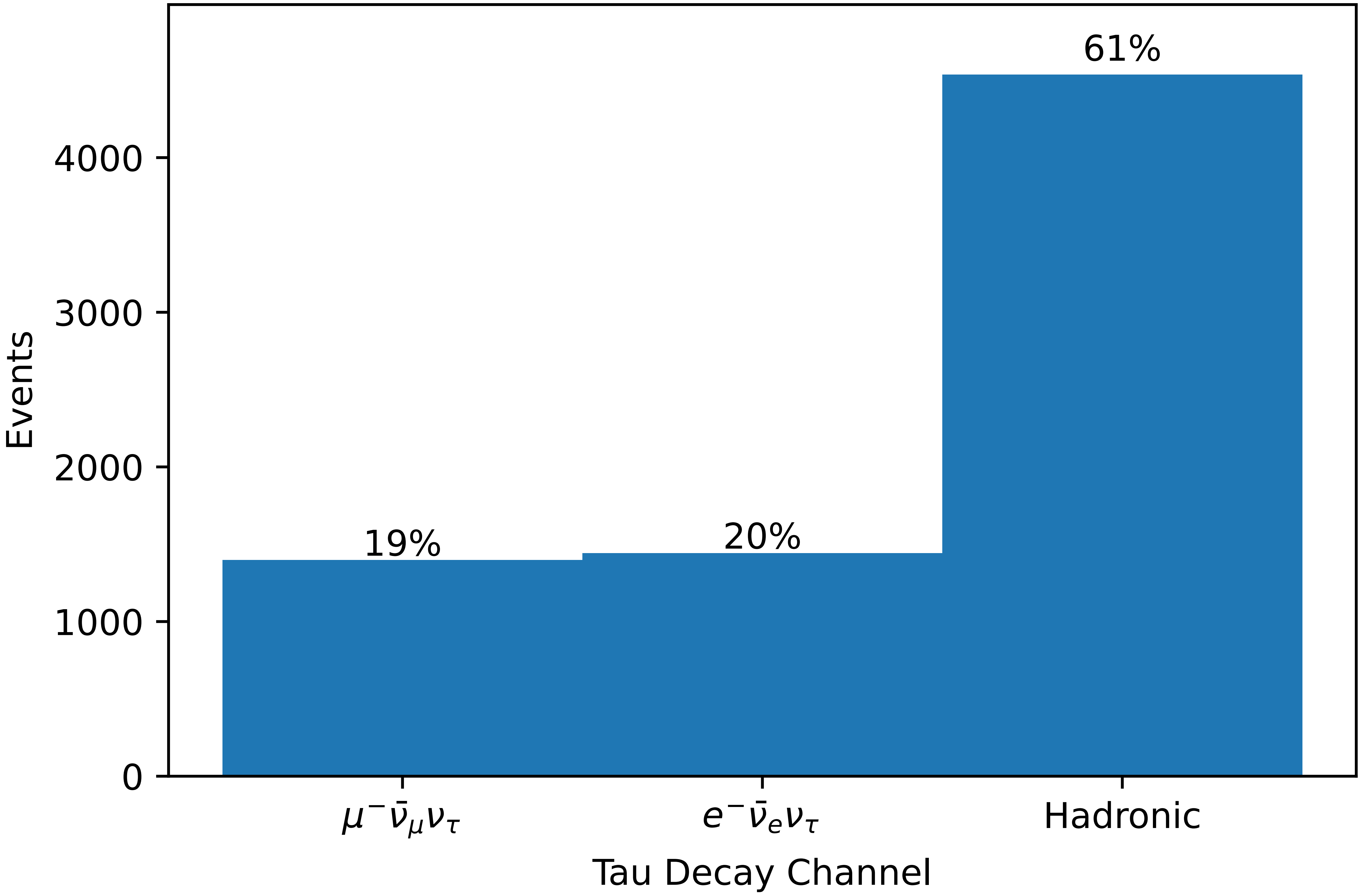
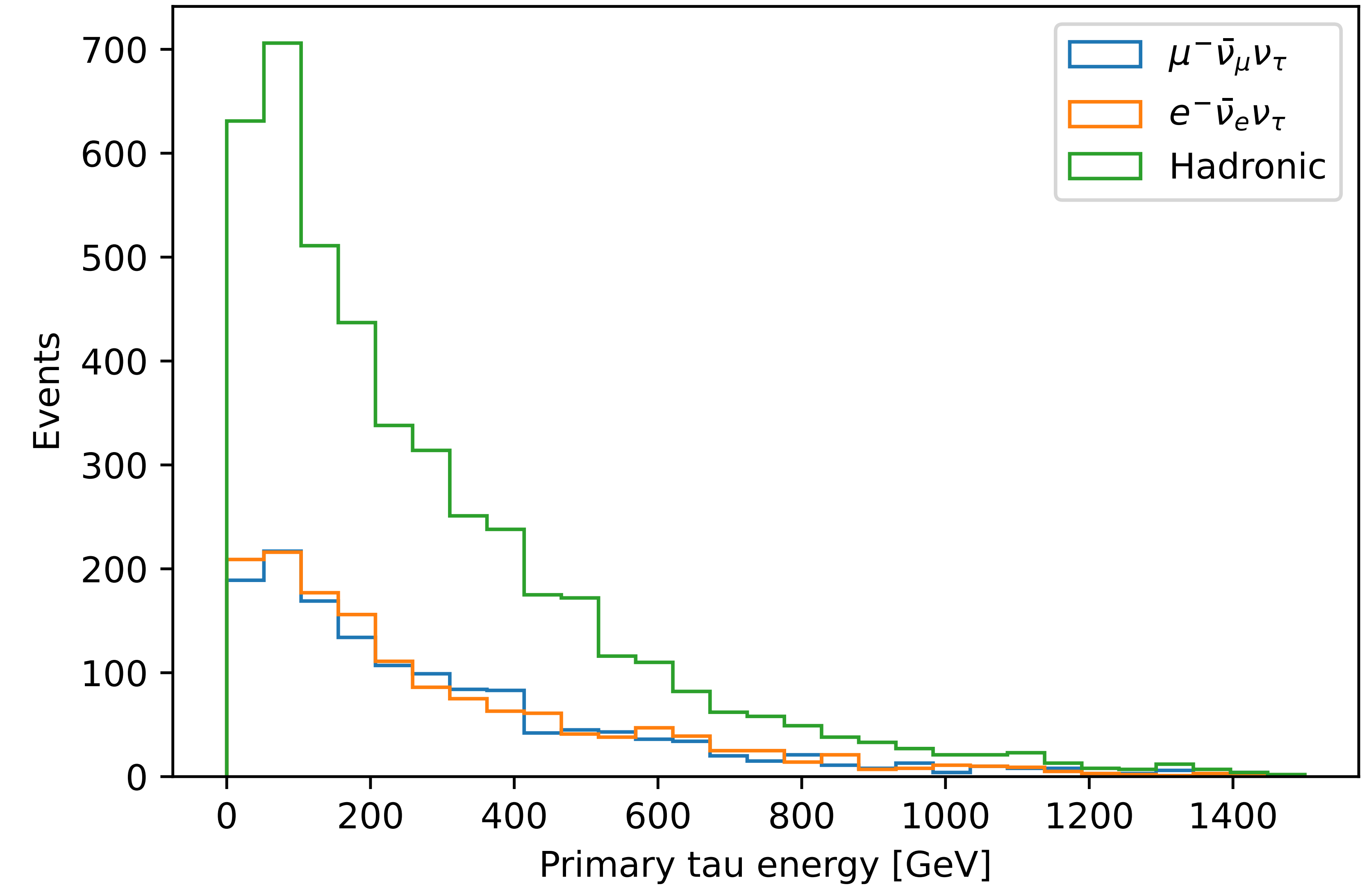
τ^-s in the detector

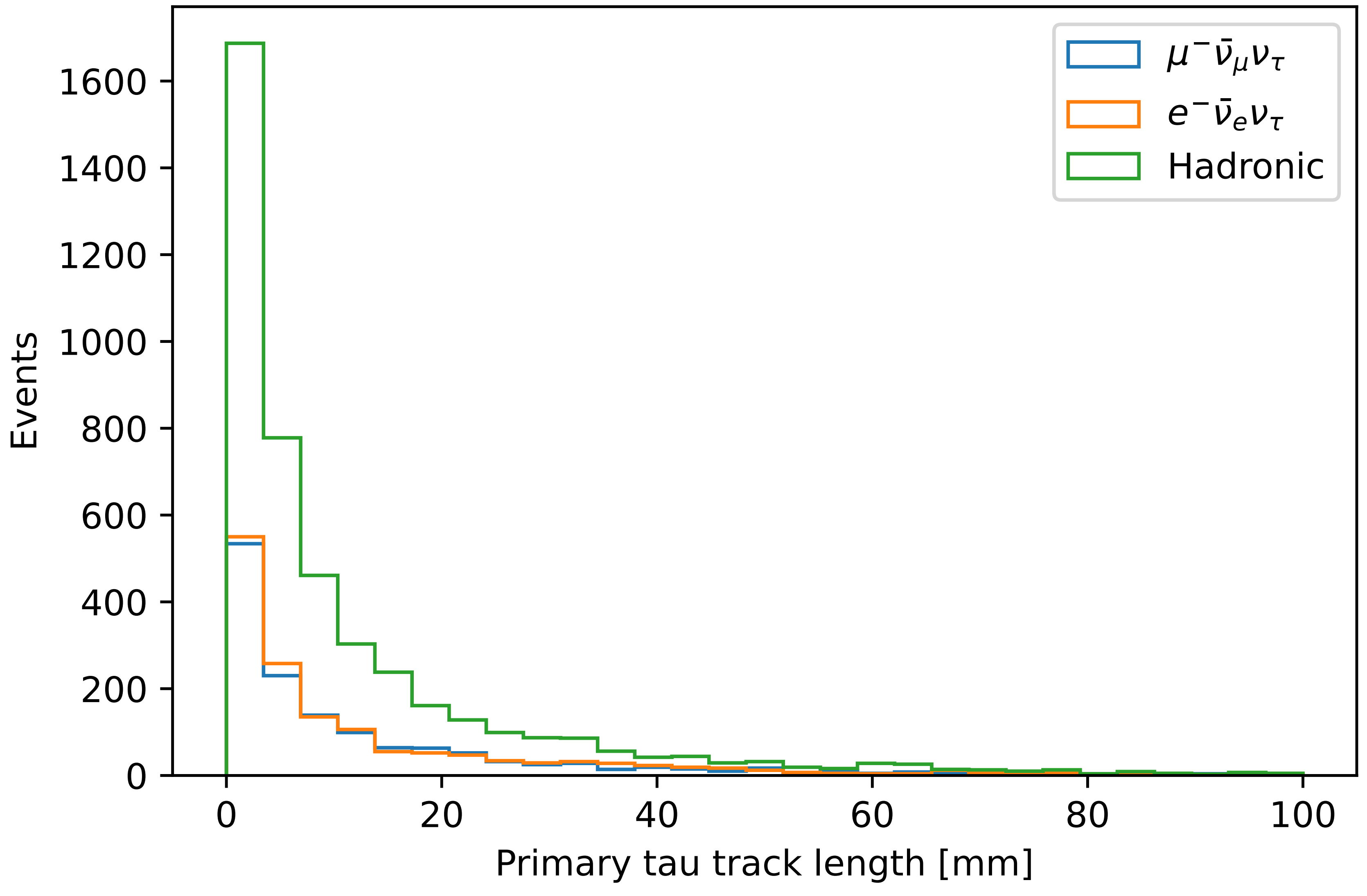


Decay mode	**Branching ratio**
Leptonic	35.2%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic	64.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\pi^0\nu_\tau$	9.3%
$\pi^-\pi^-\pi^+\nu_\tau$	9.0%
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.5%
other	5.7%

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

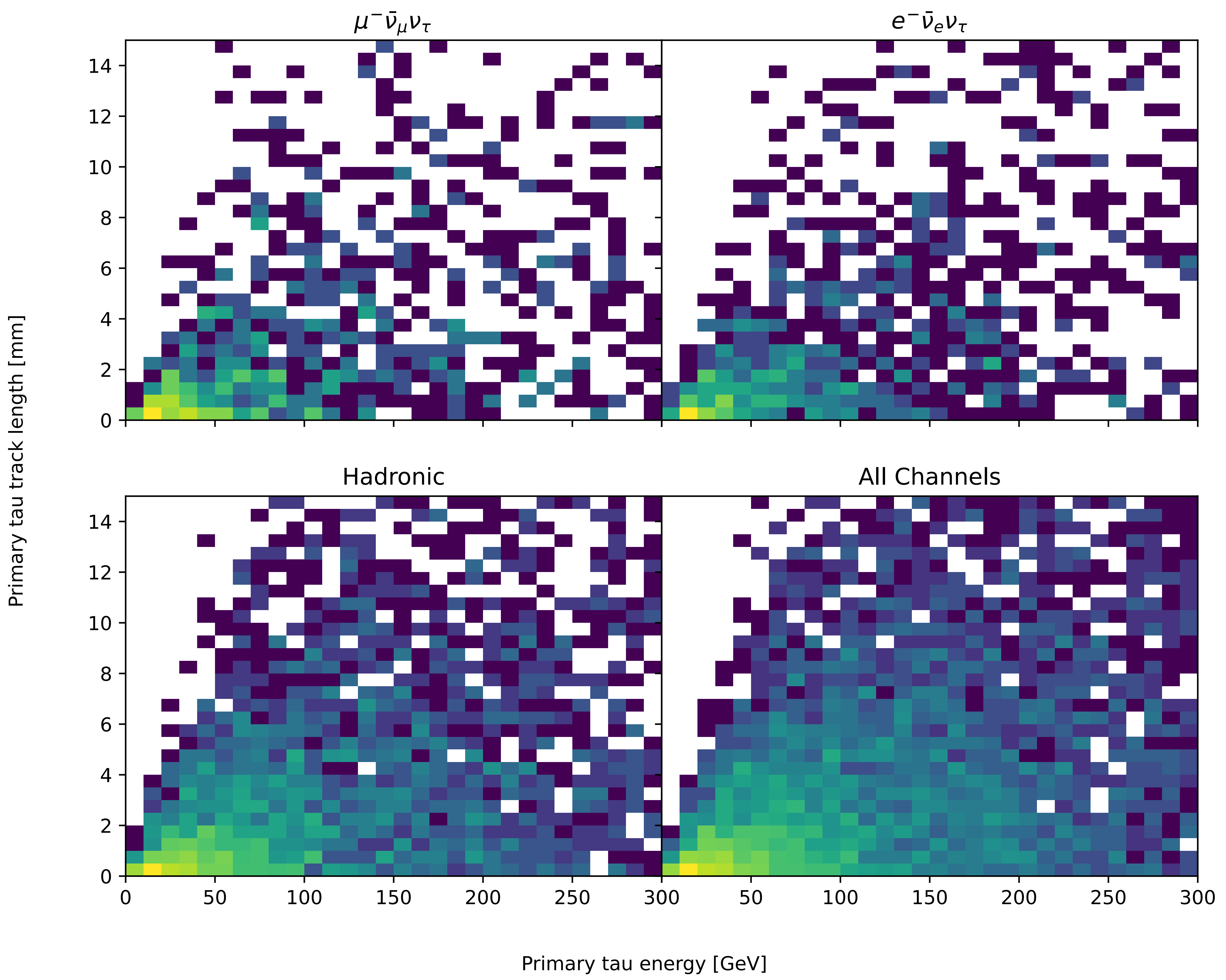
τ^-s in the detector





Primary tau energy and track length

Breakdown by tau decay channel



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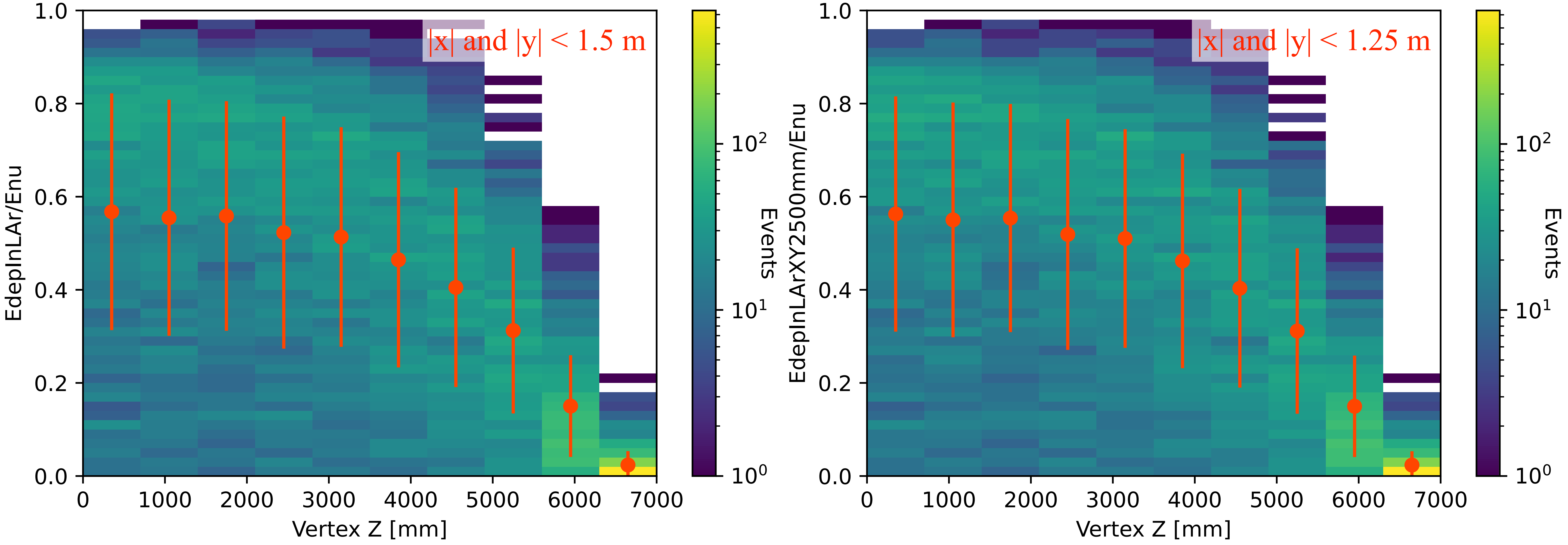
Energy containment in the LArTPC

- The ratio of the energy deposited in the LArTPC to the neutrino energy
  - The orange markers are the mean values and standard deviation as error bars
- Make transverse cuts for energy containment in different detector sizes
  - |x| and |y| < 1.5, 1.25, 1.0, 0.75, 0.5 m



Energy containment w/ the HadCal

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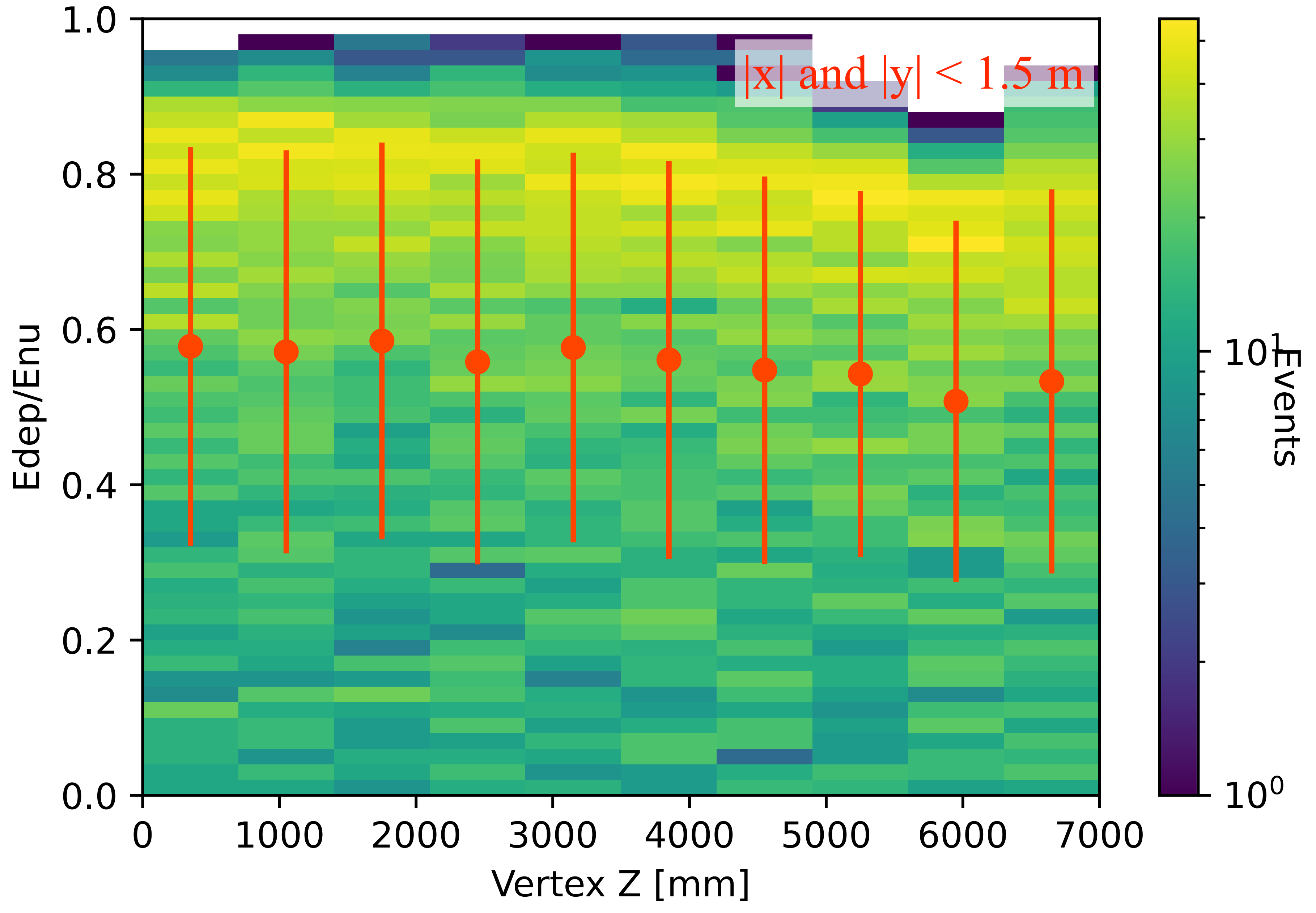
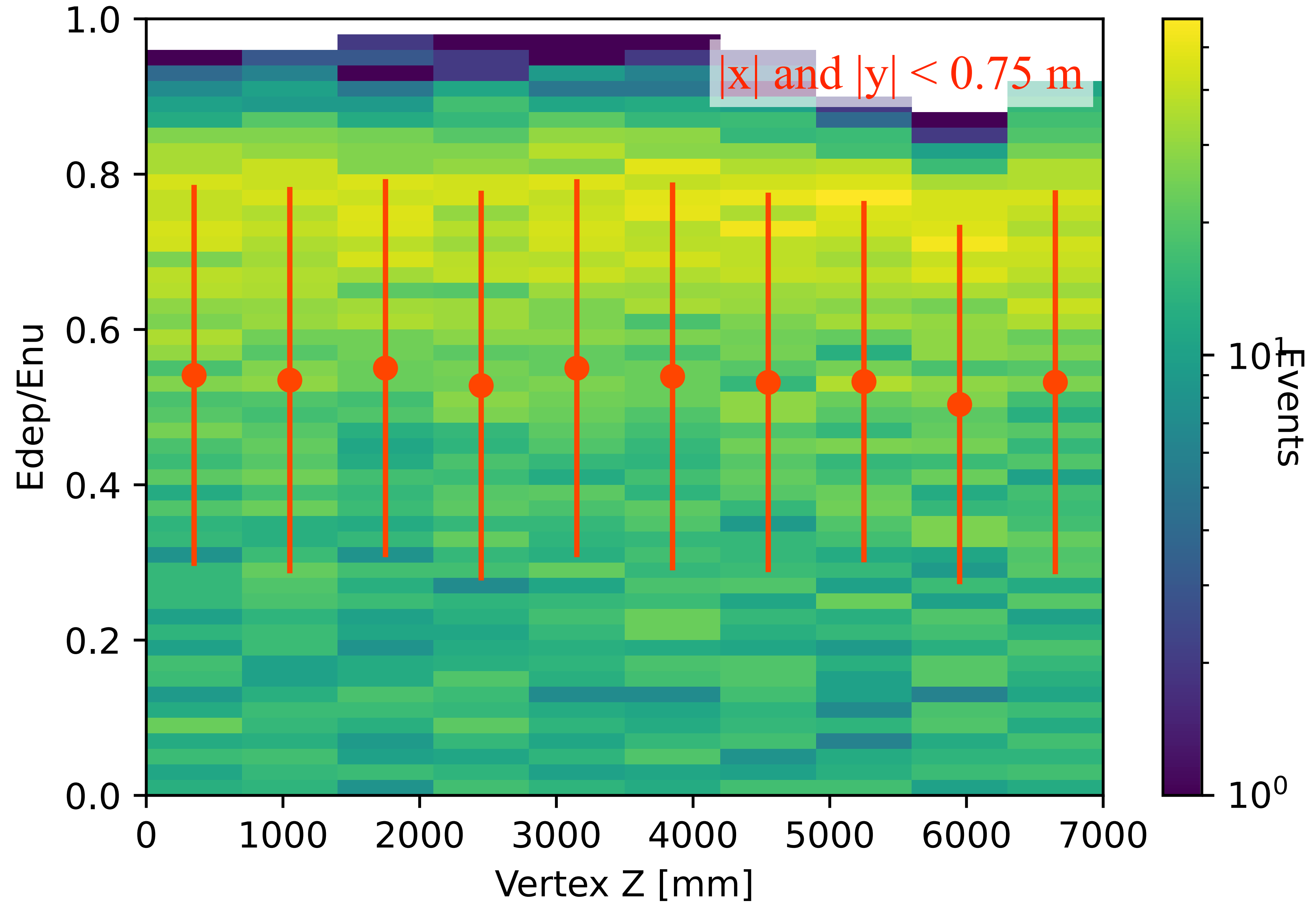
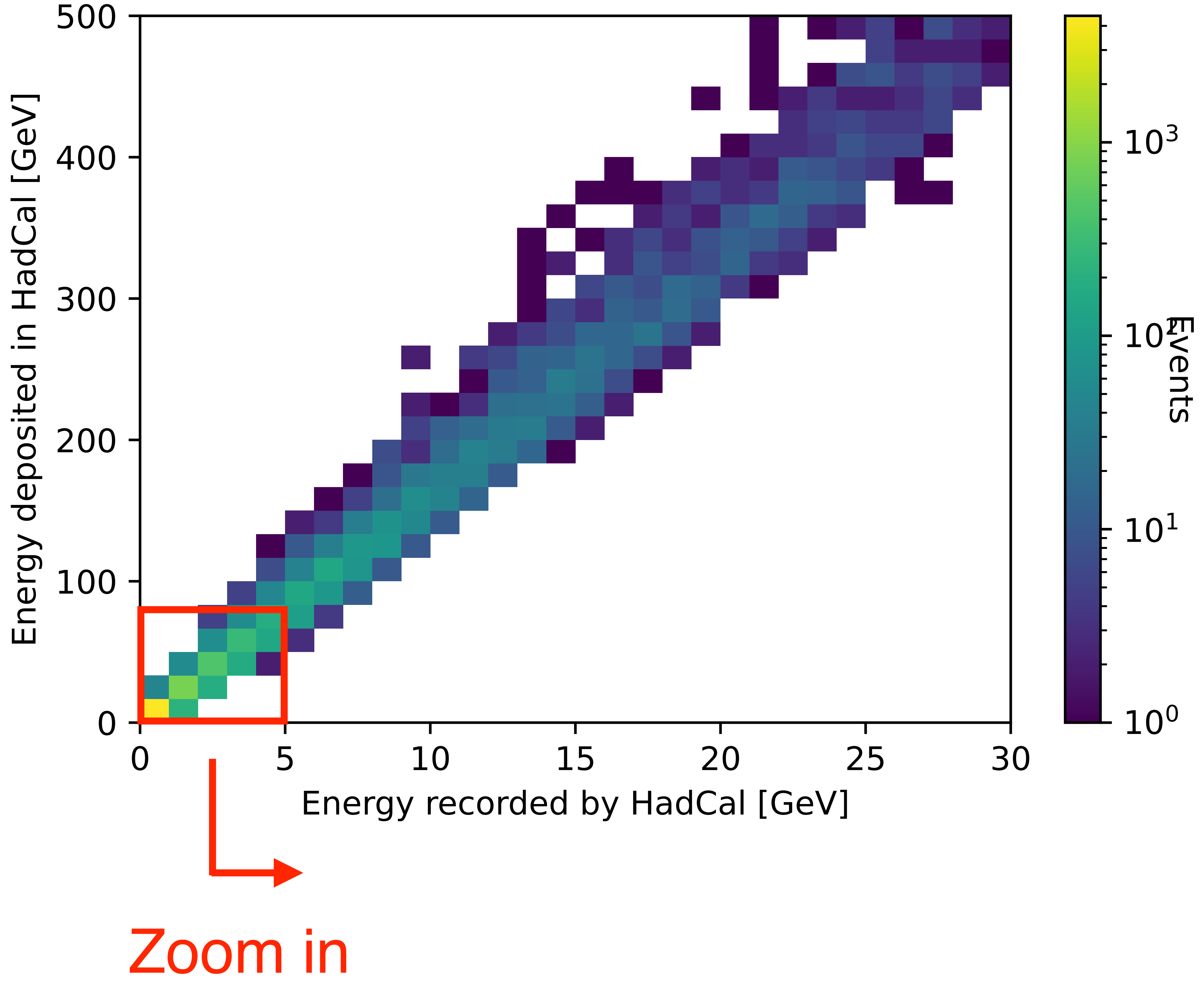
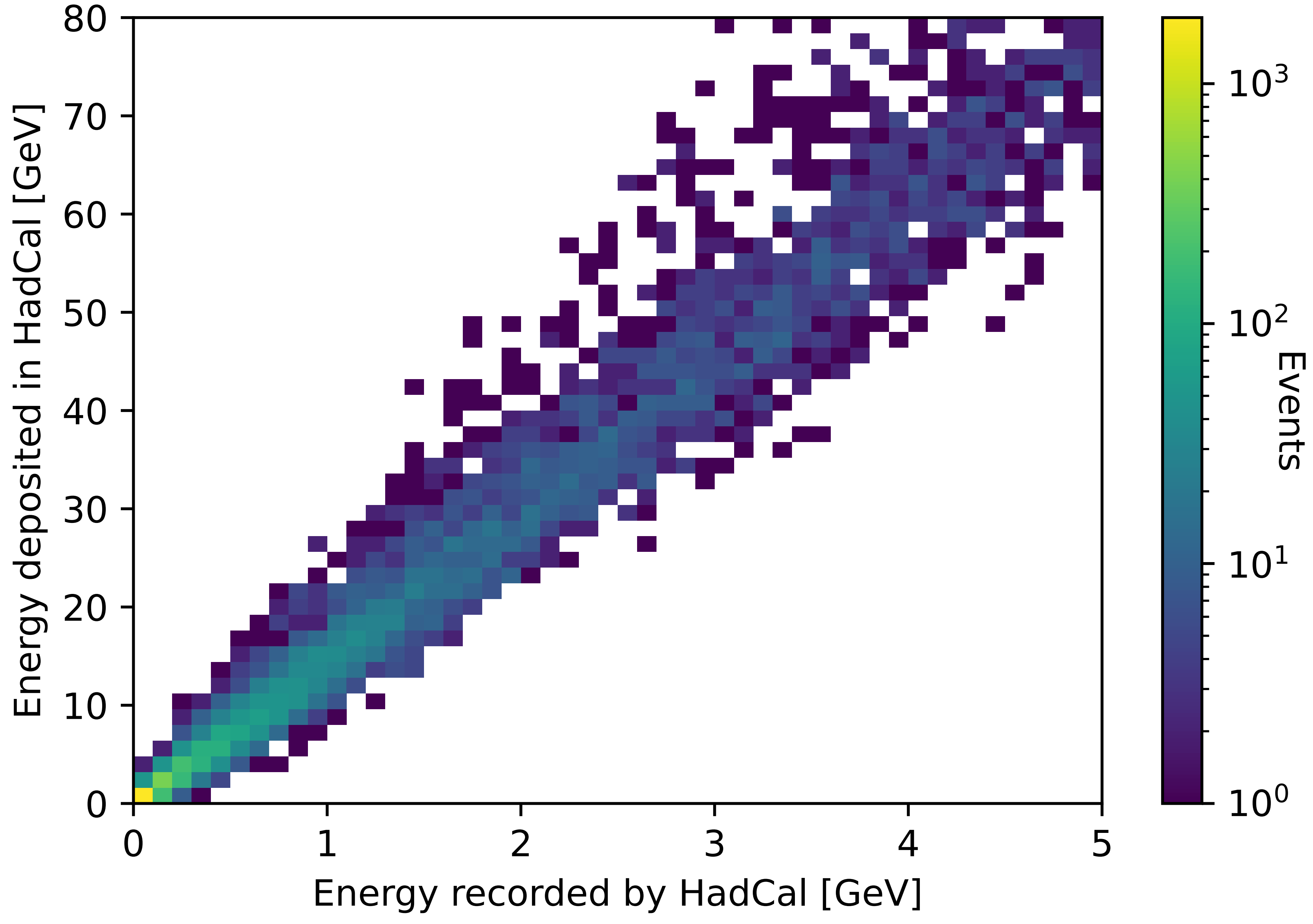




HadCal Calibration

- 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





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ν_μs in the detector

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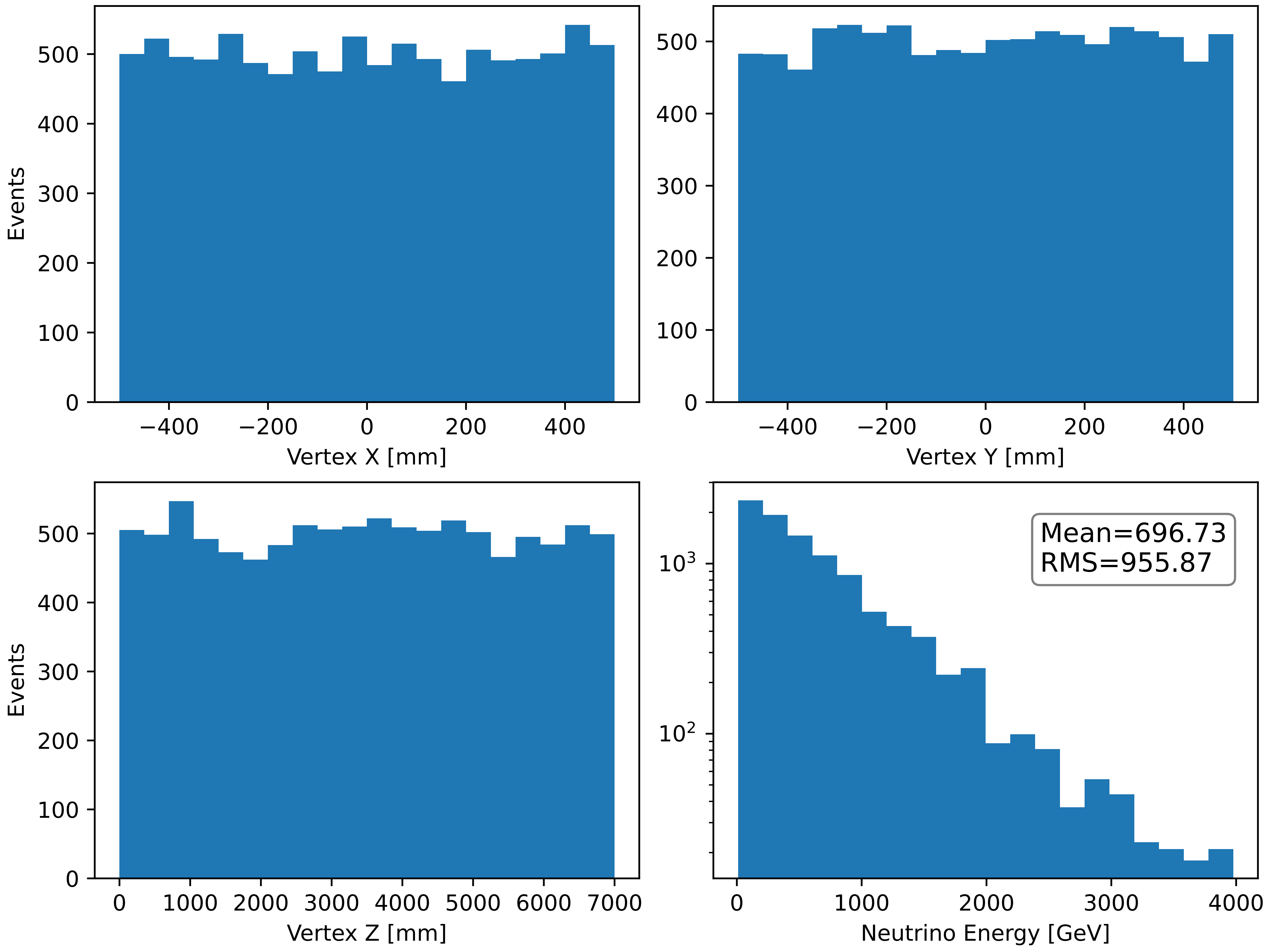
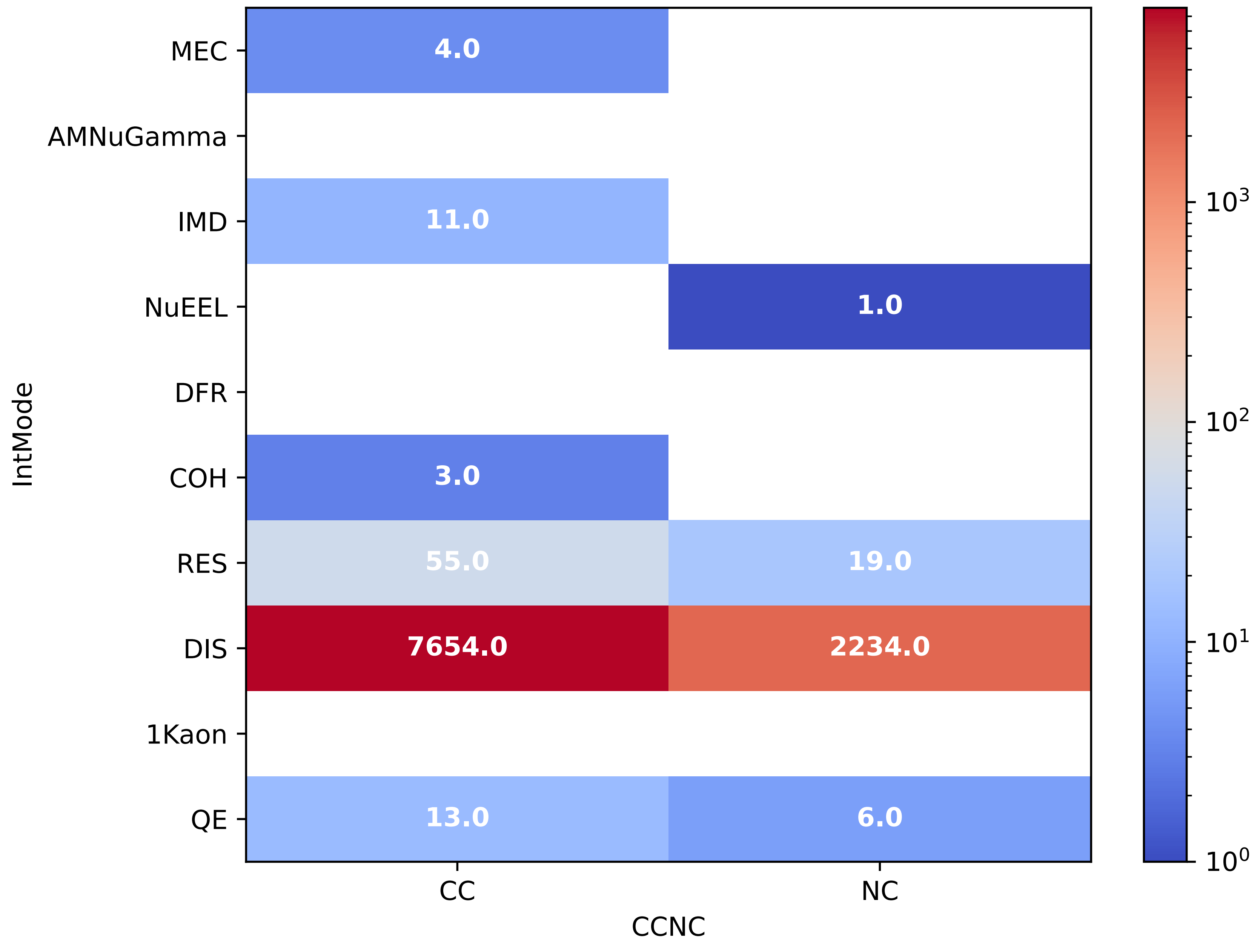
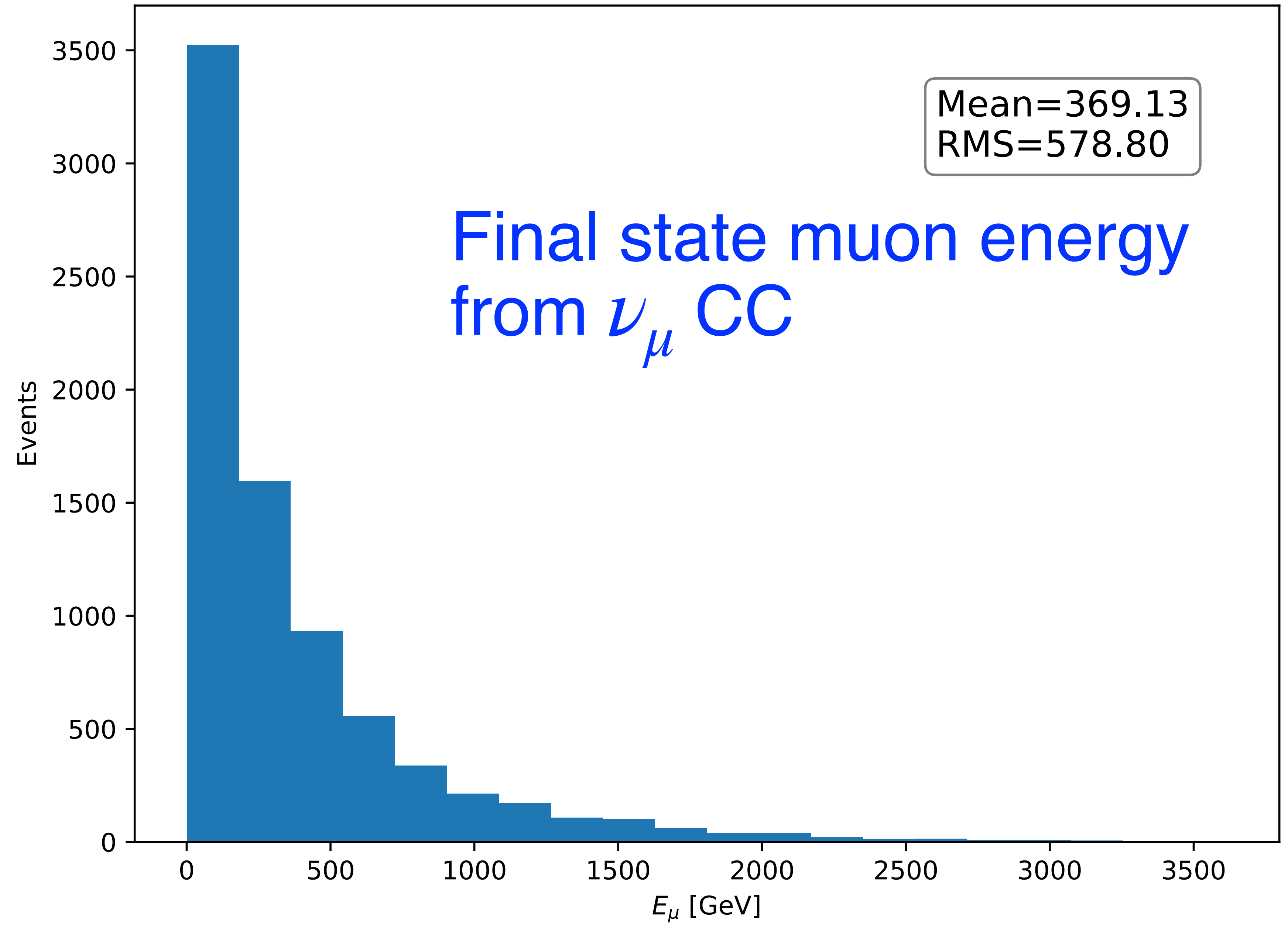
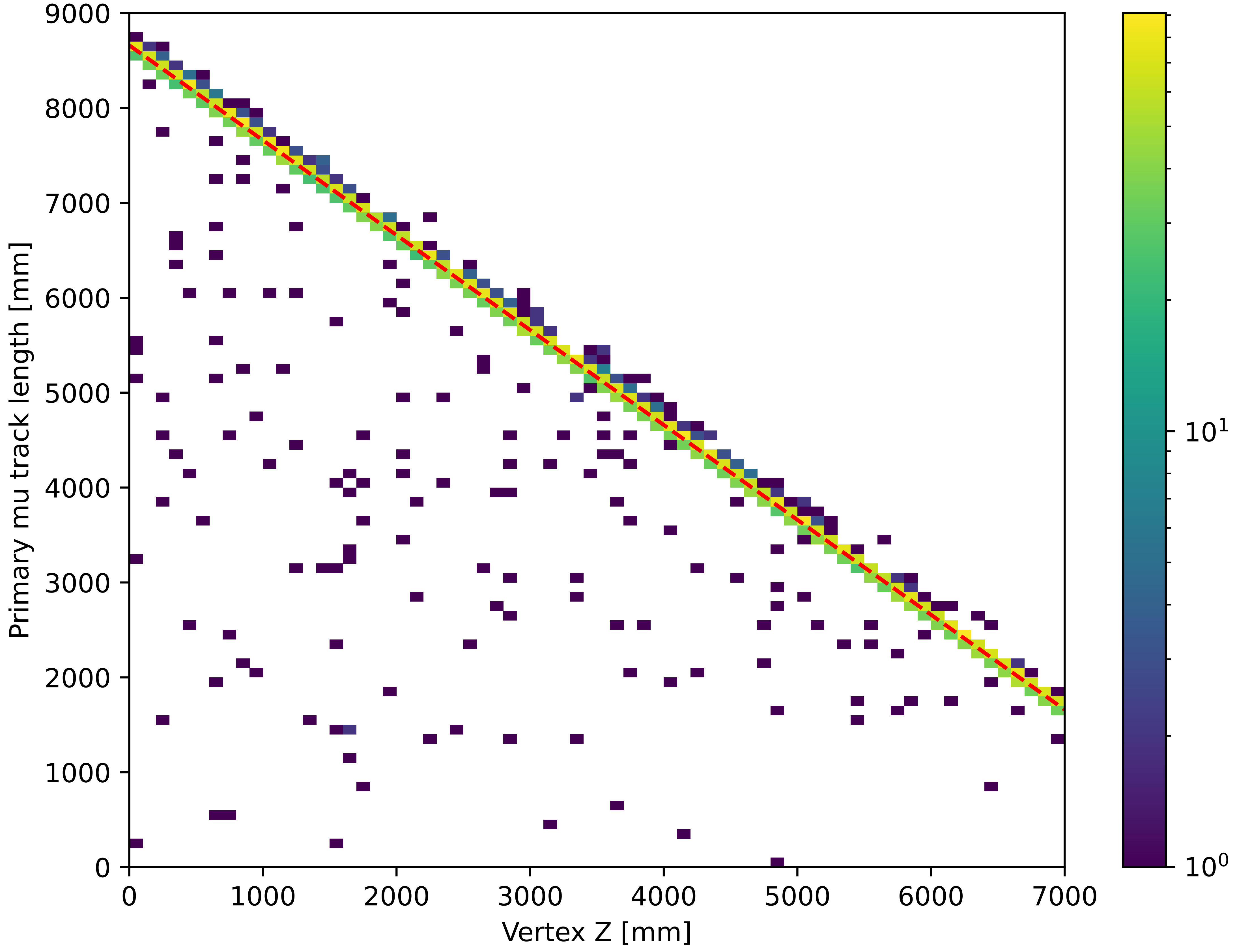






μ^-s in the detector

- Basically all muons can go through the detector till the end of the muon finder
  - Red dashed line means the distance between the vertex and the end of the MuonFinder



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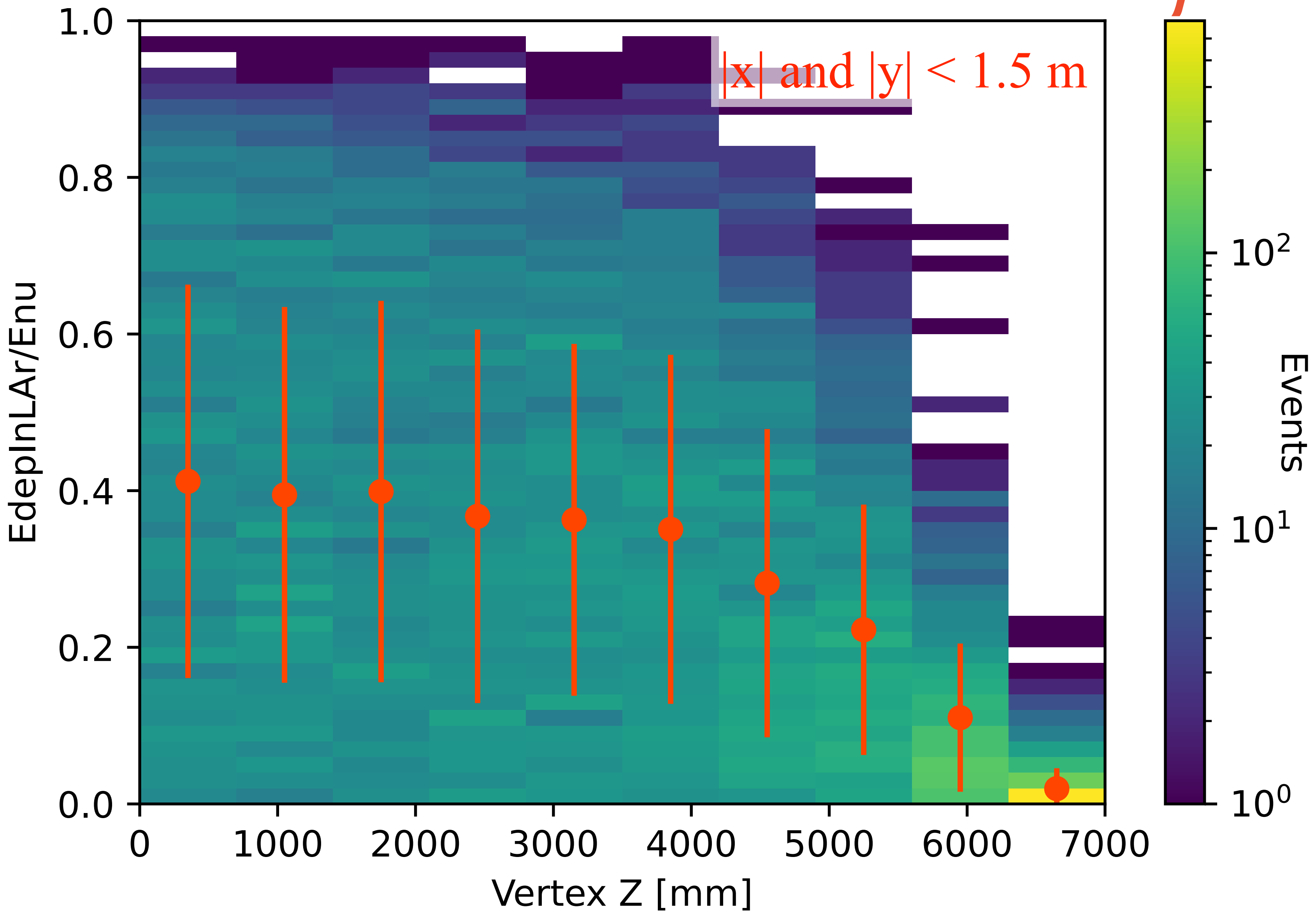

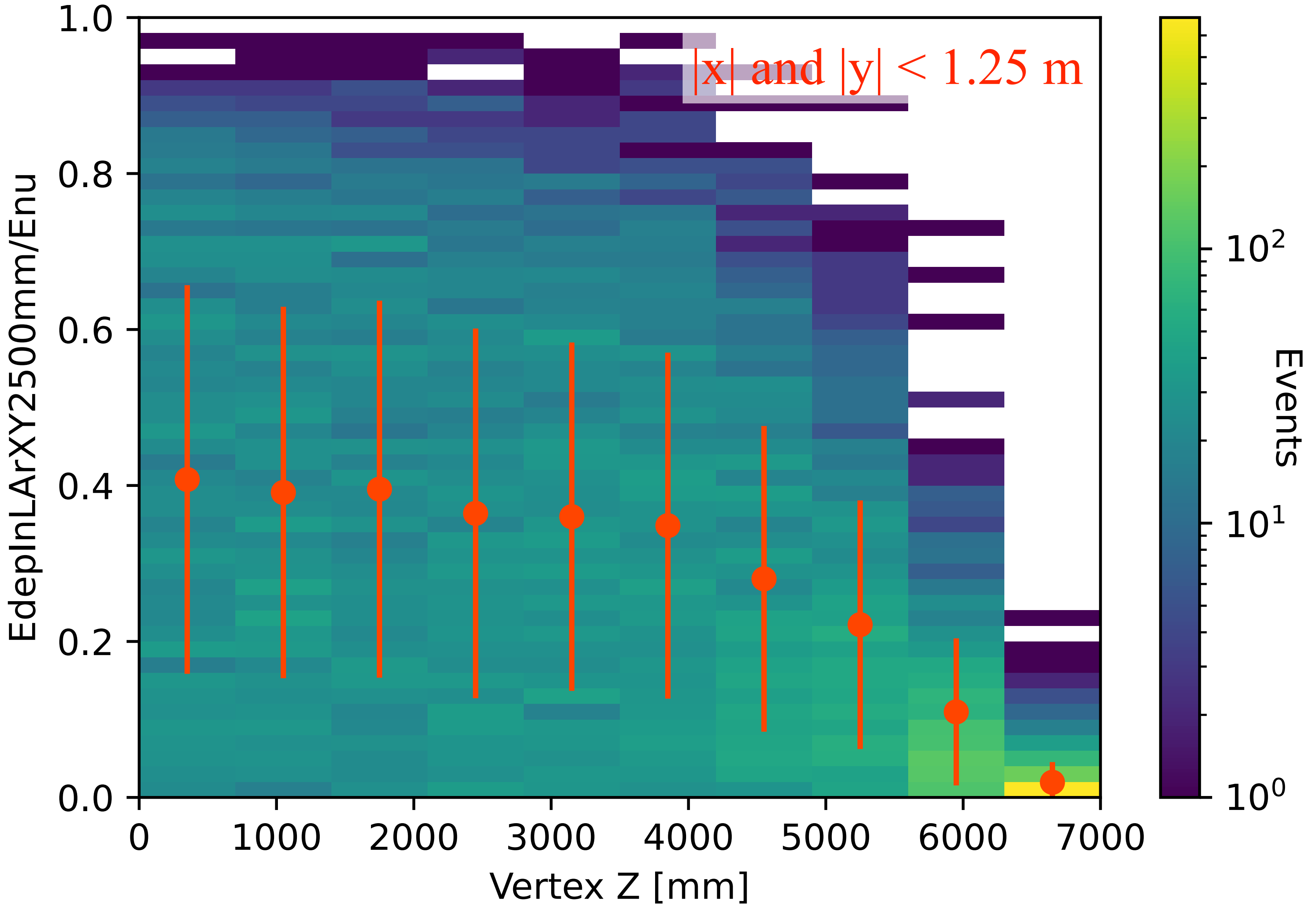

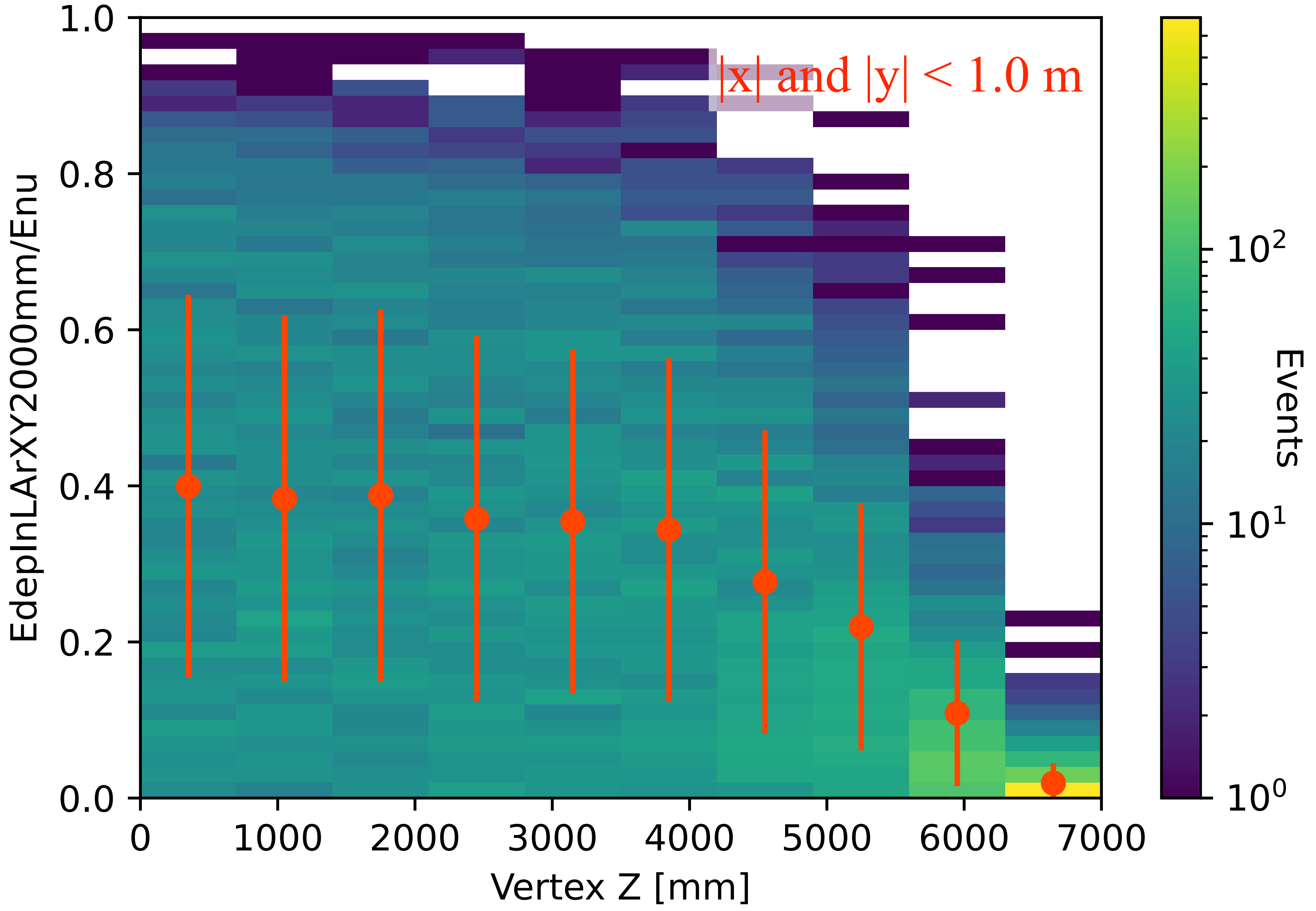

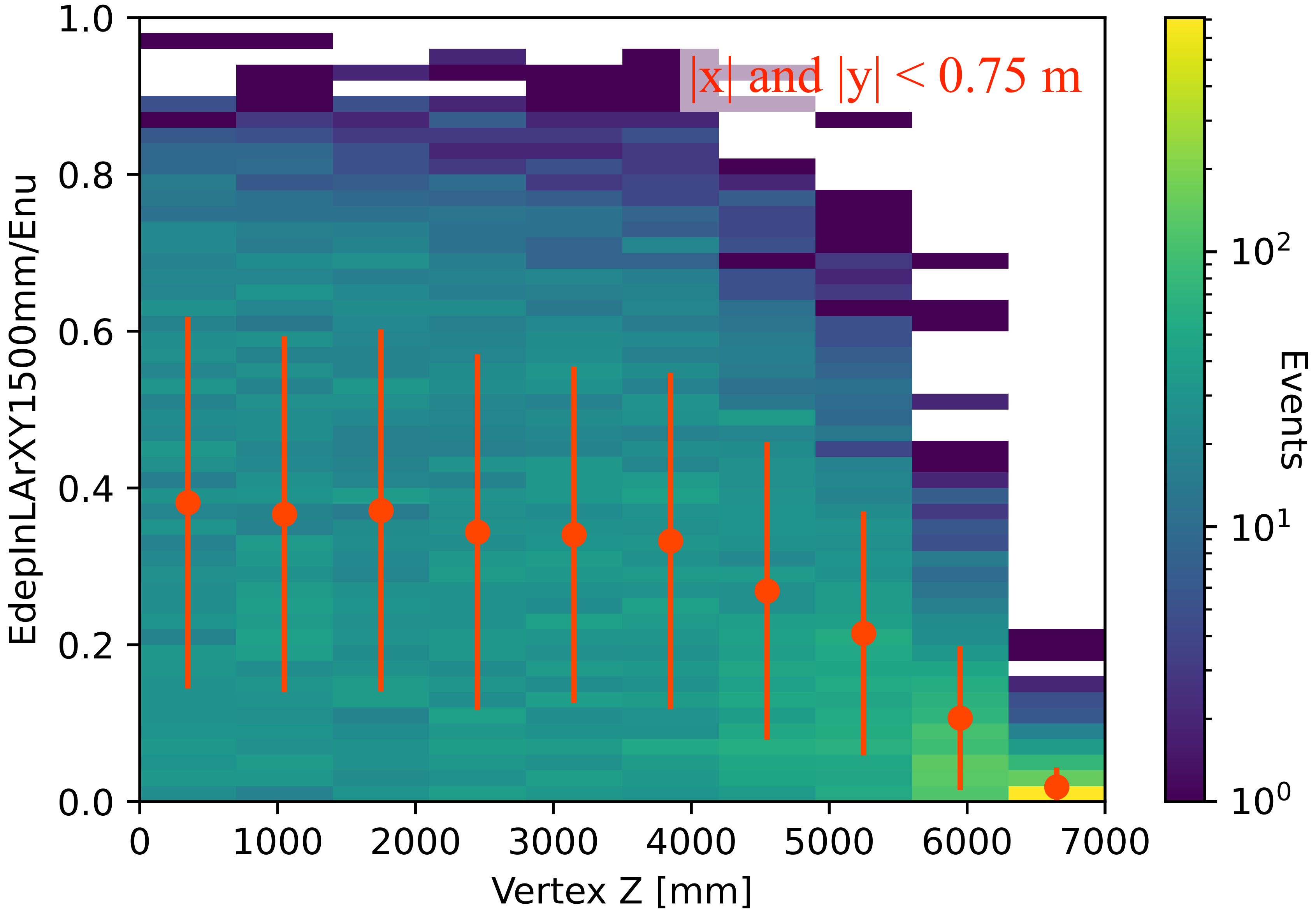

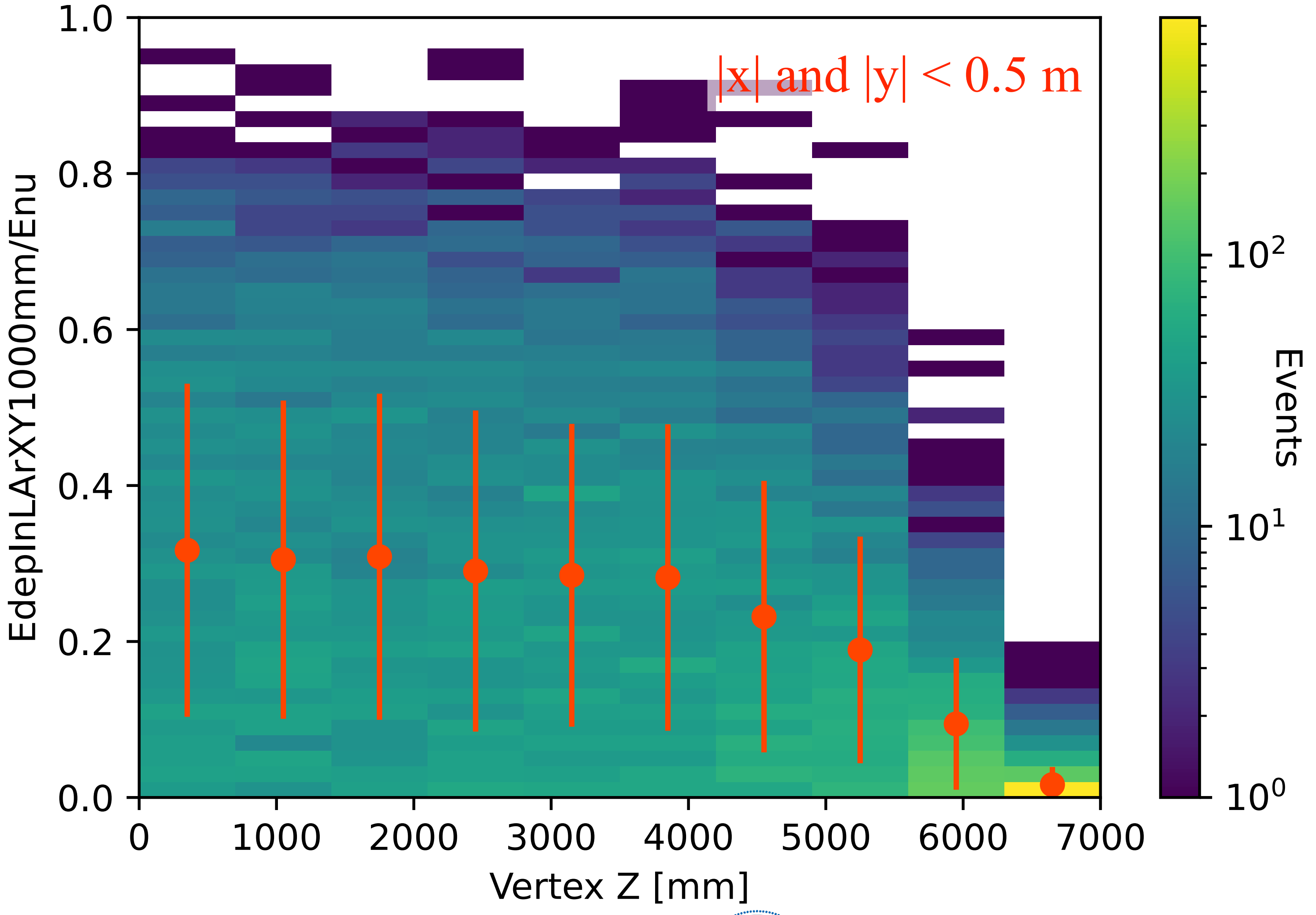

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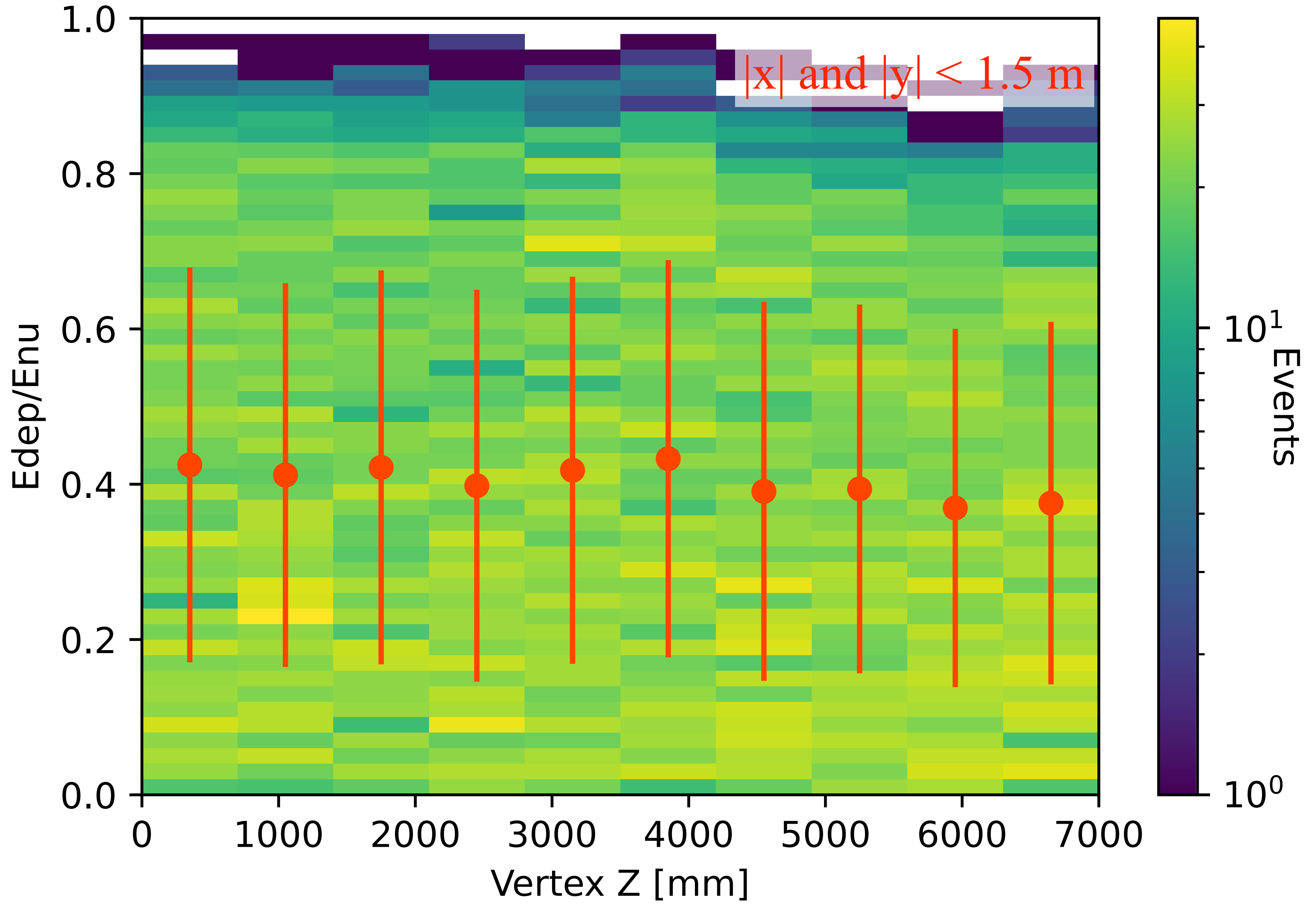

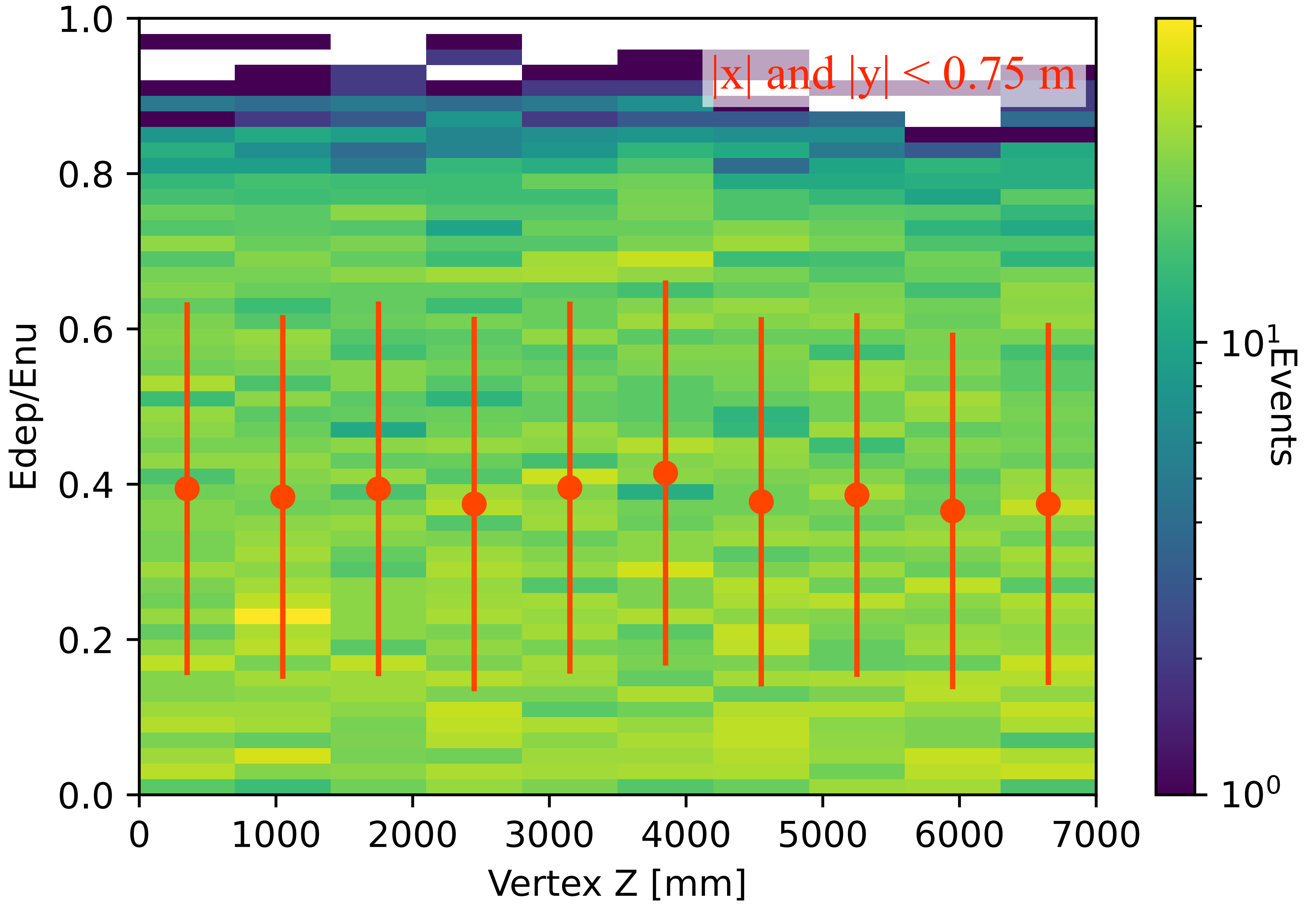

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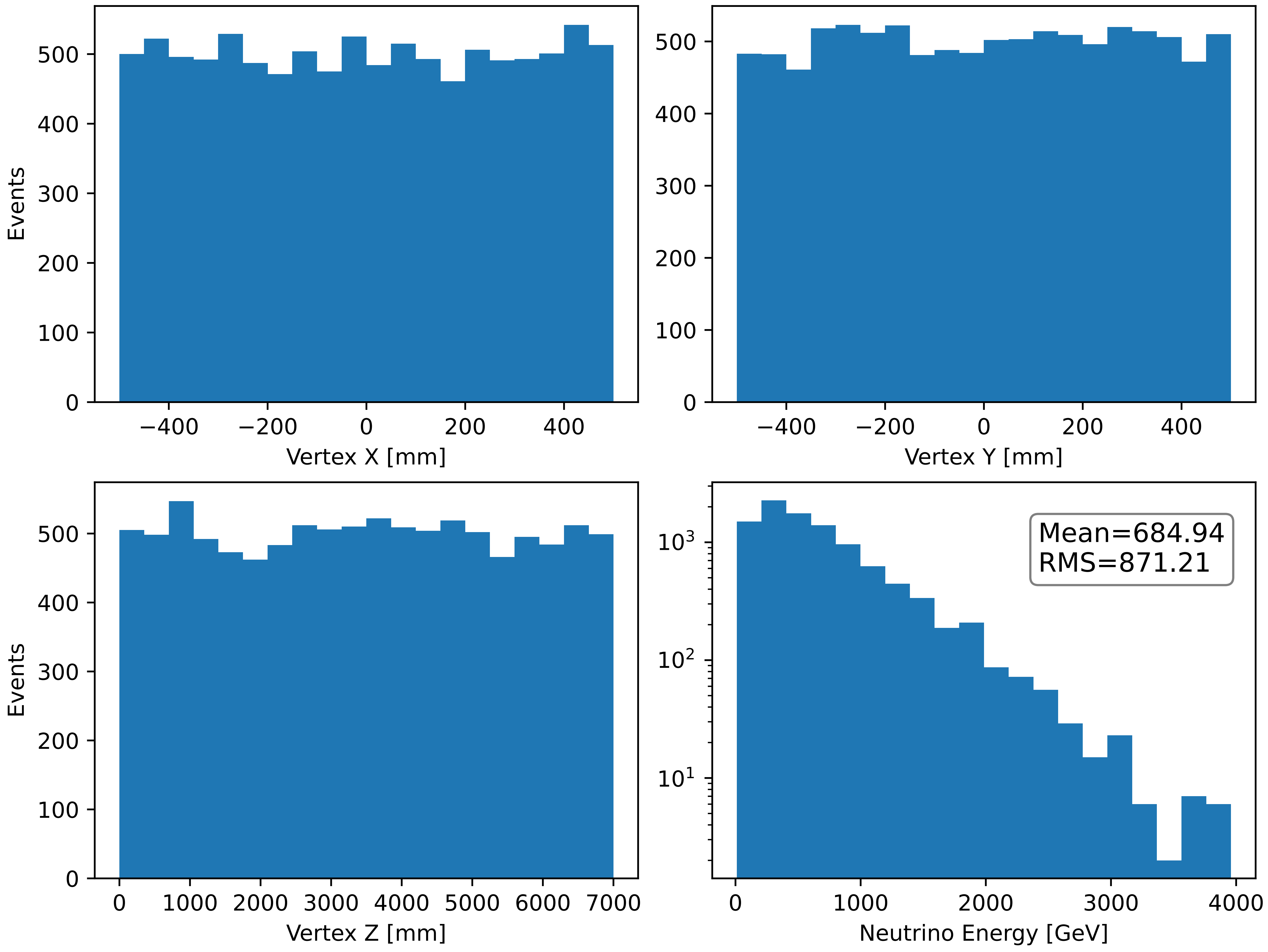

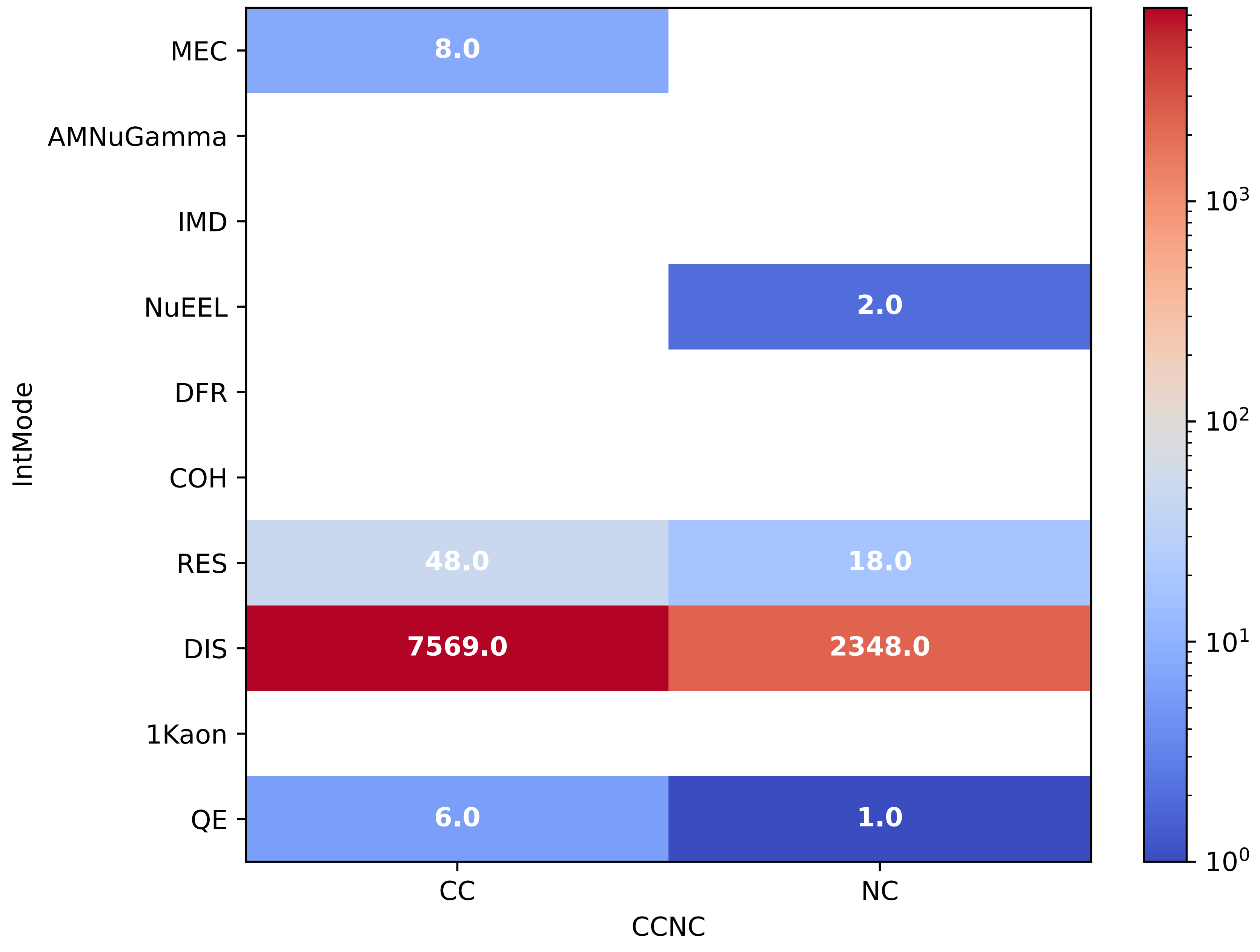

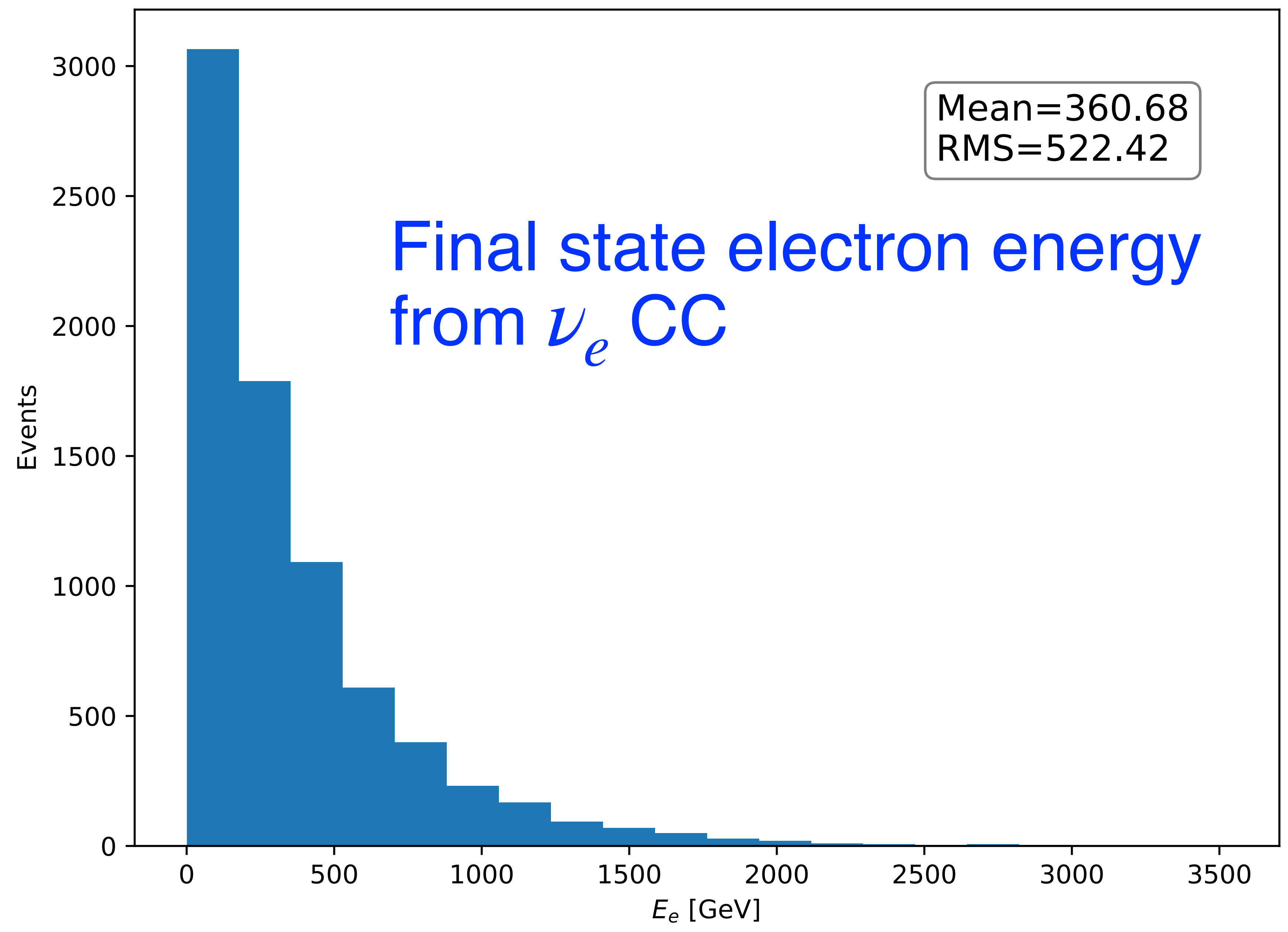

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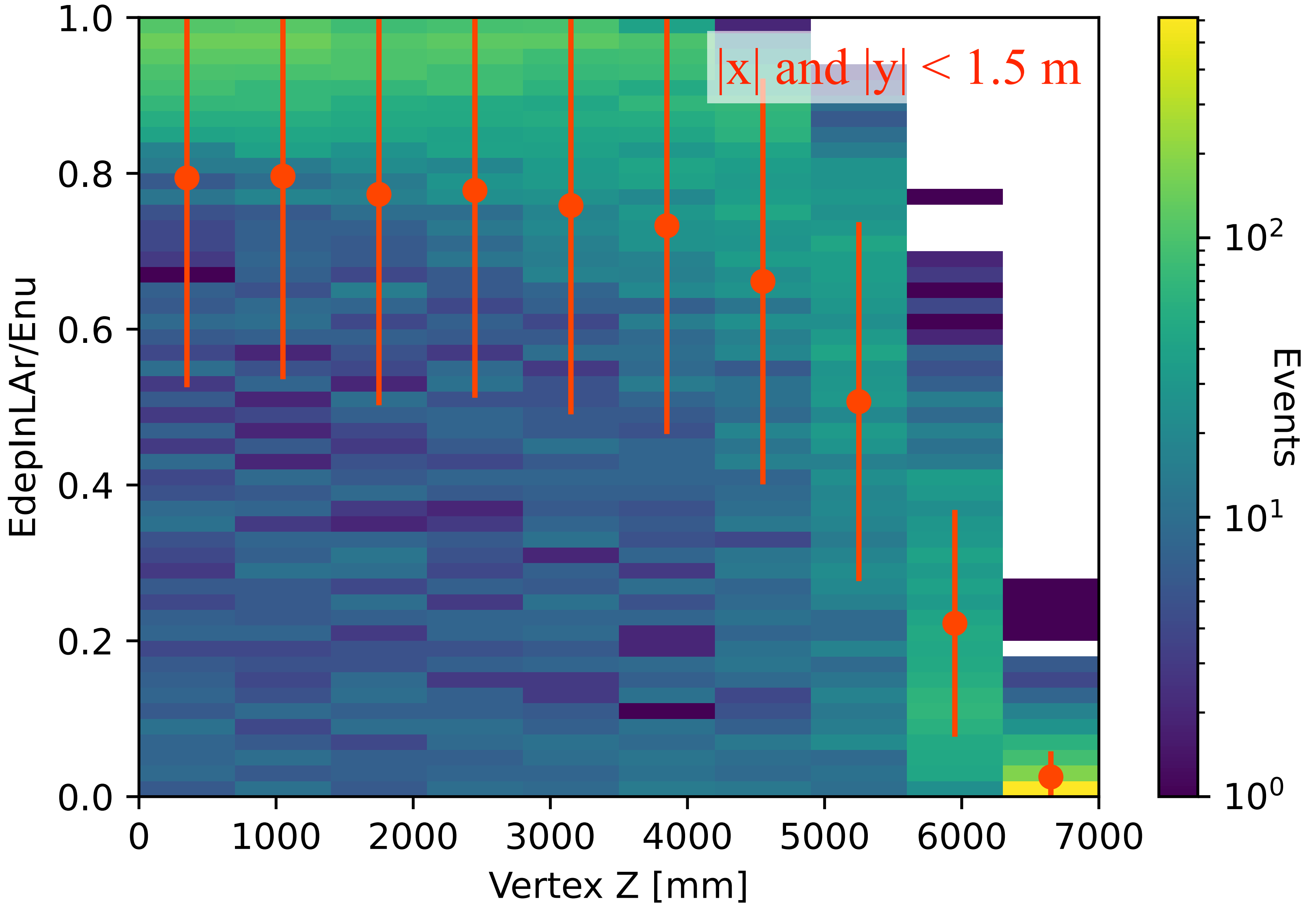

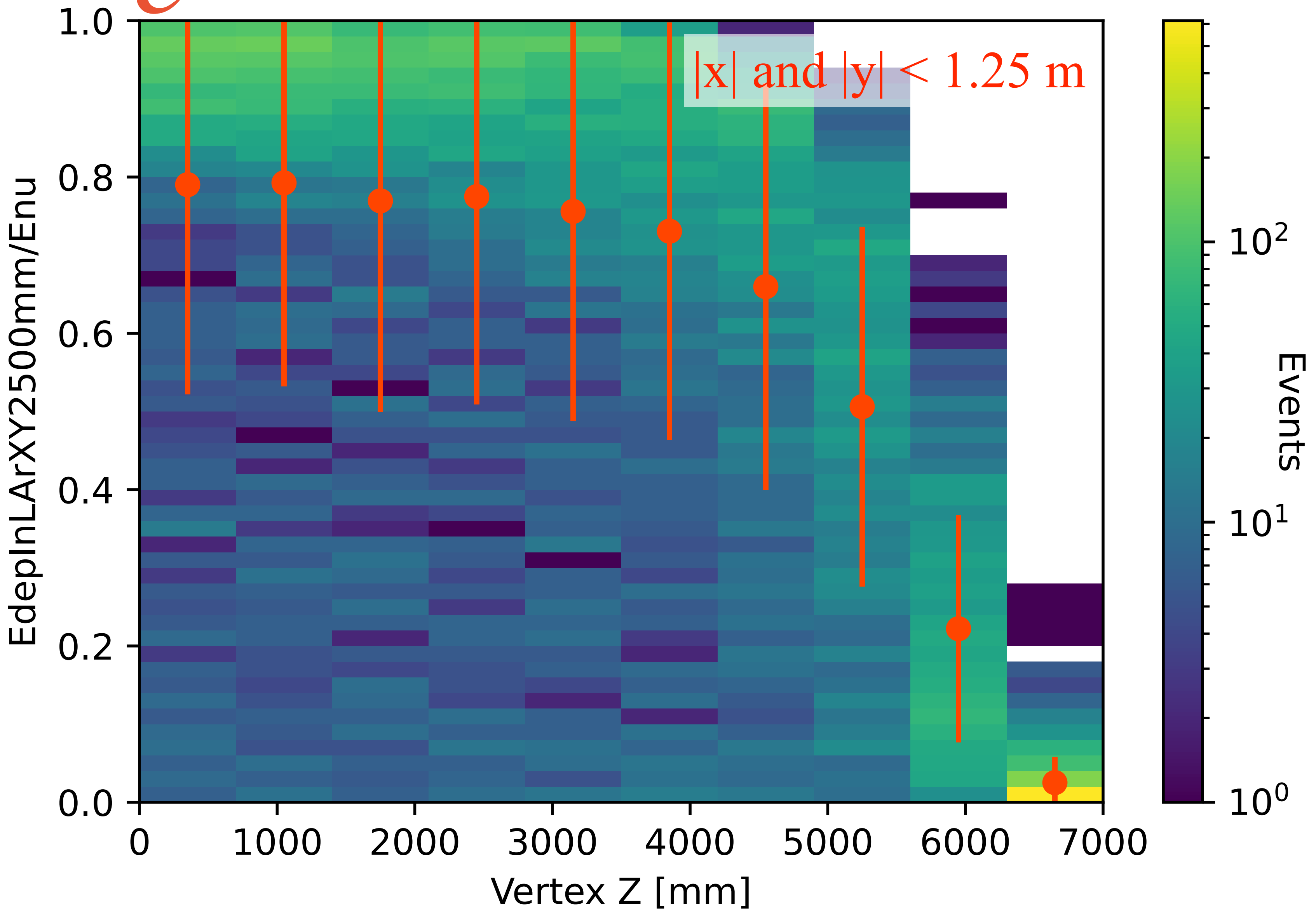

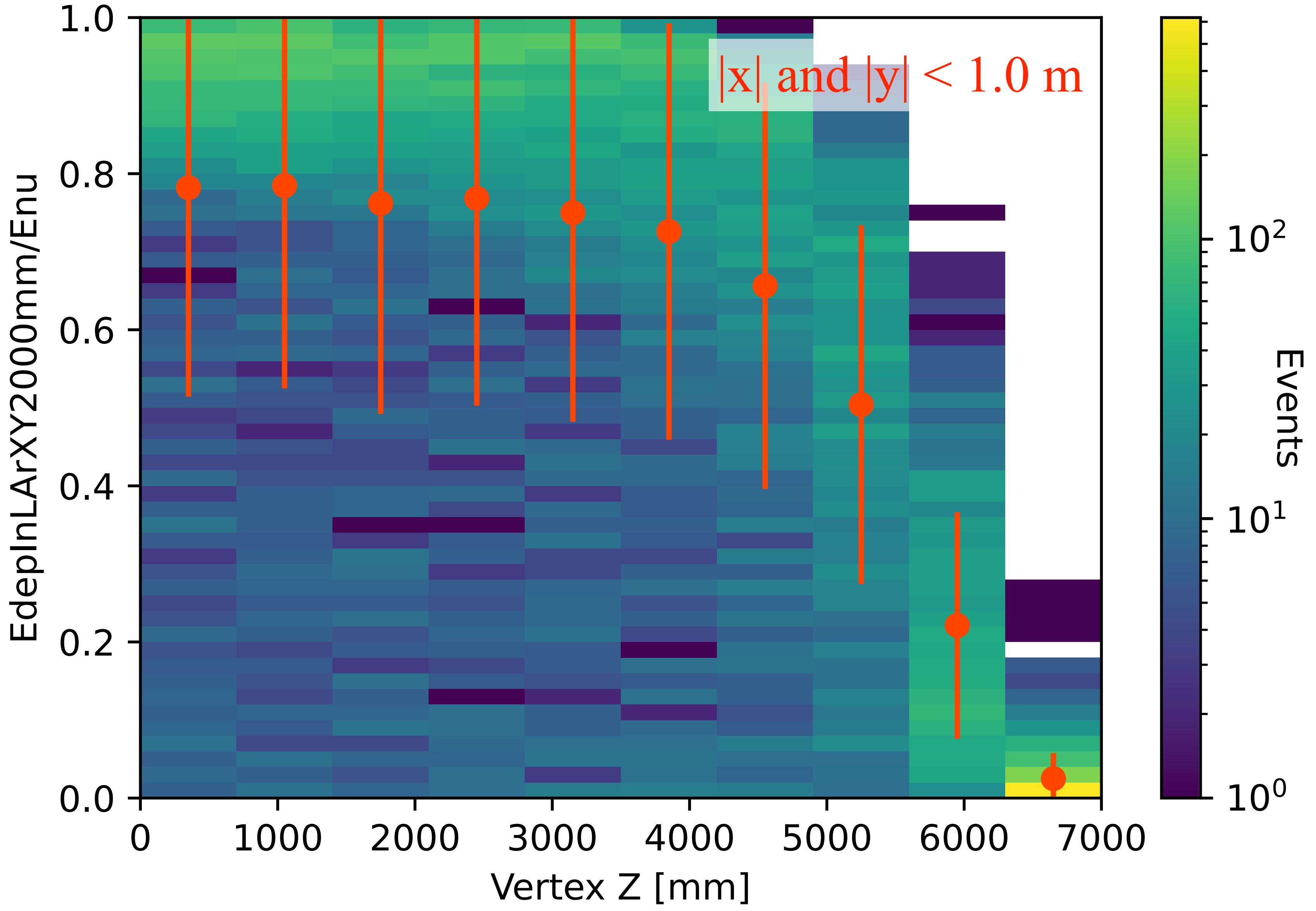

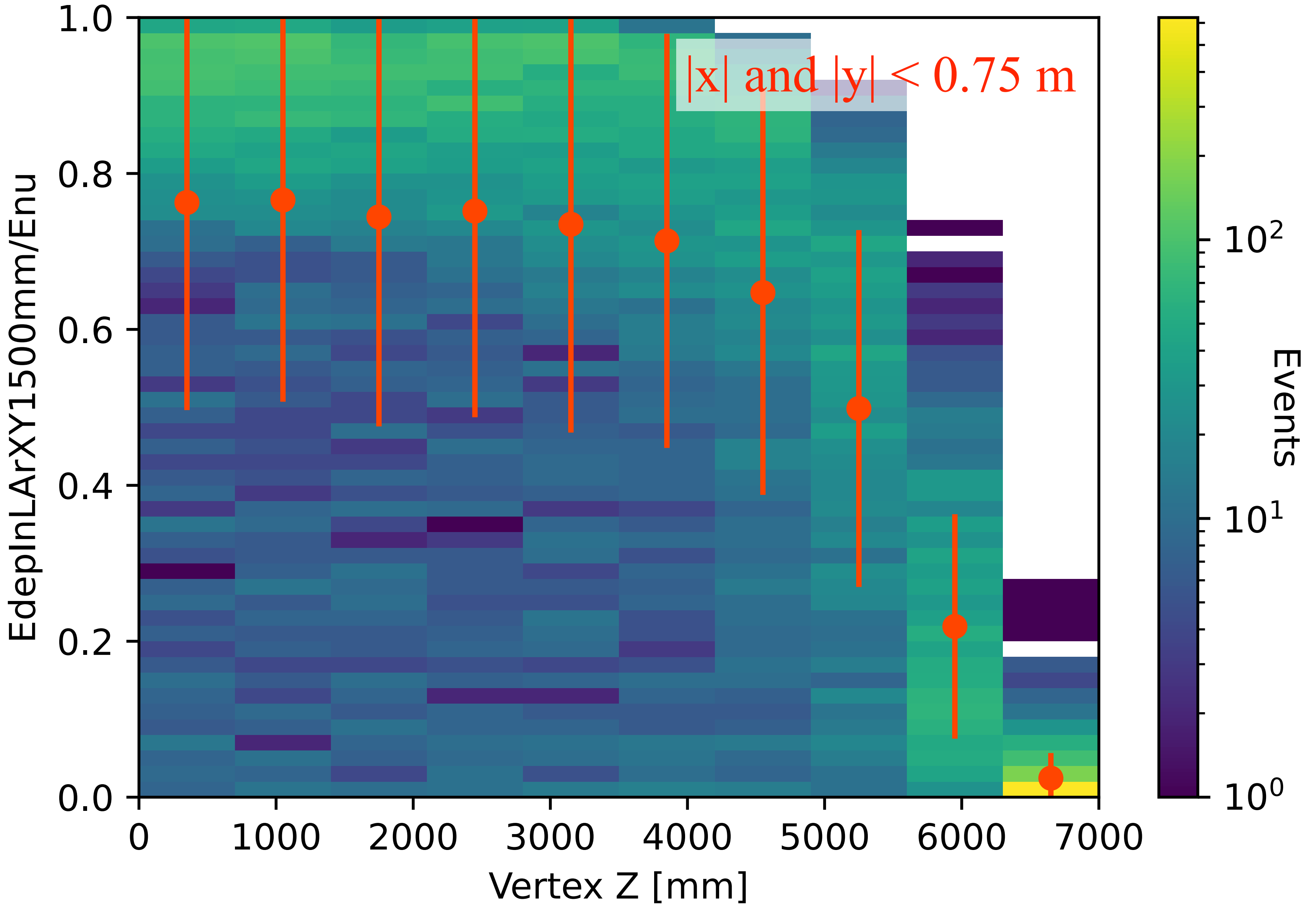

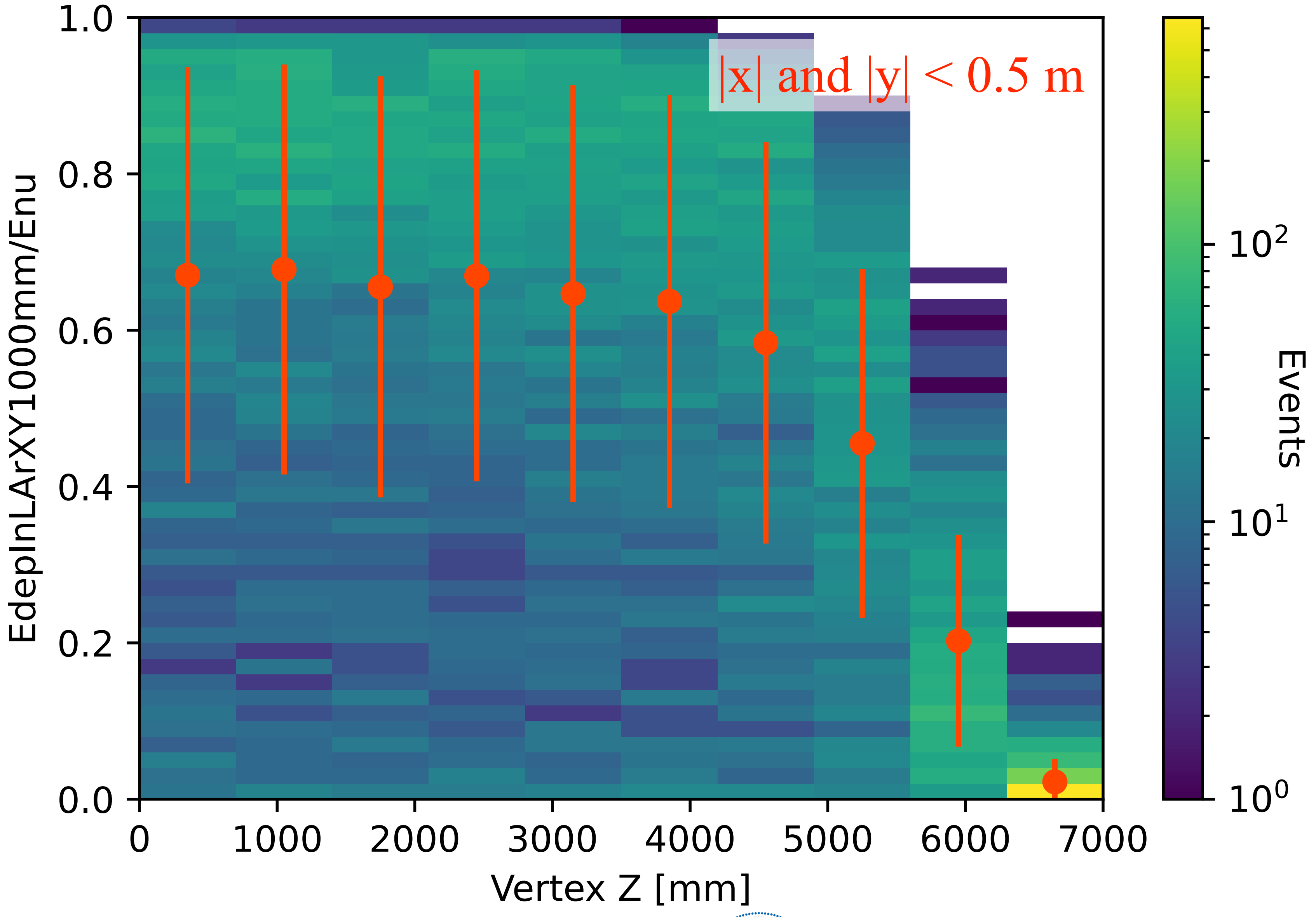

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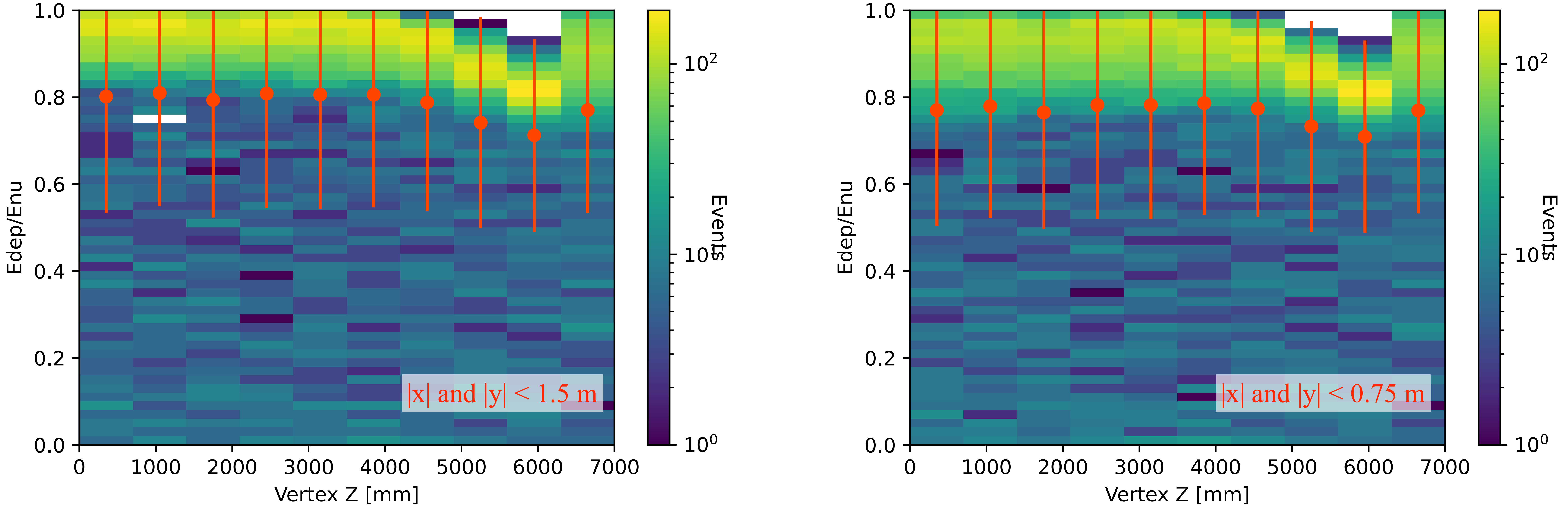

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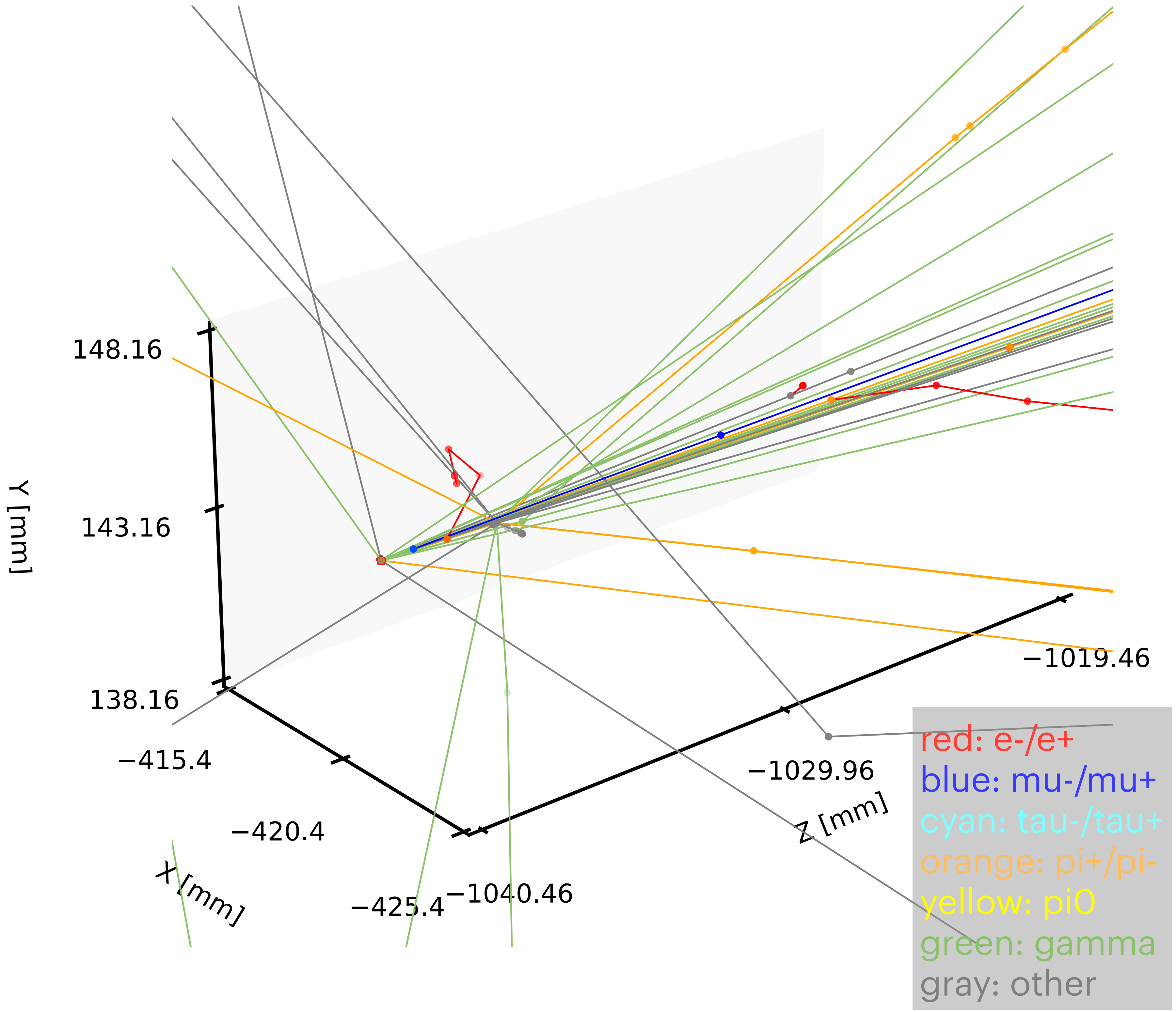
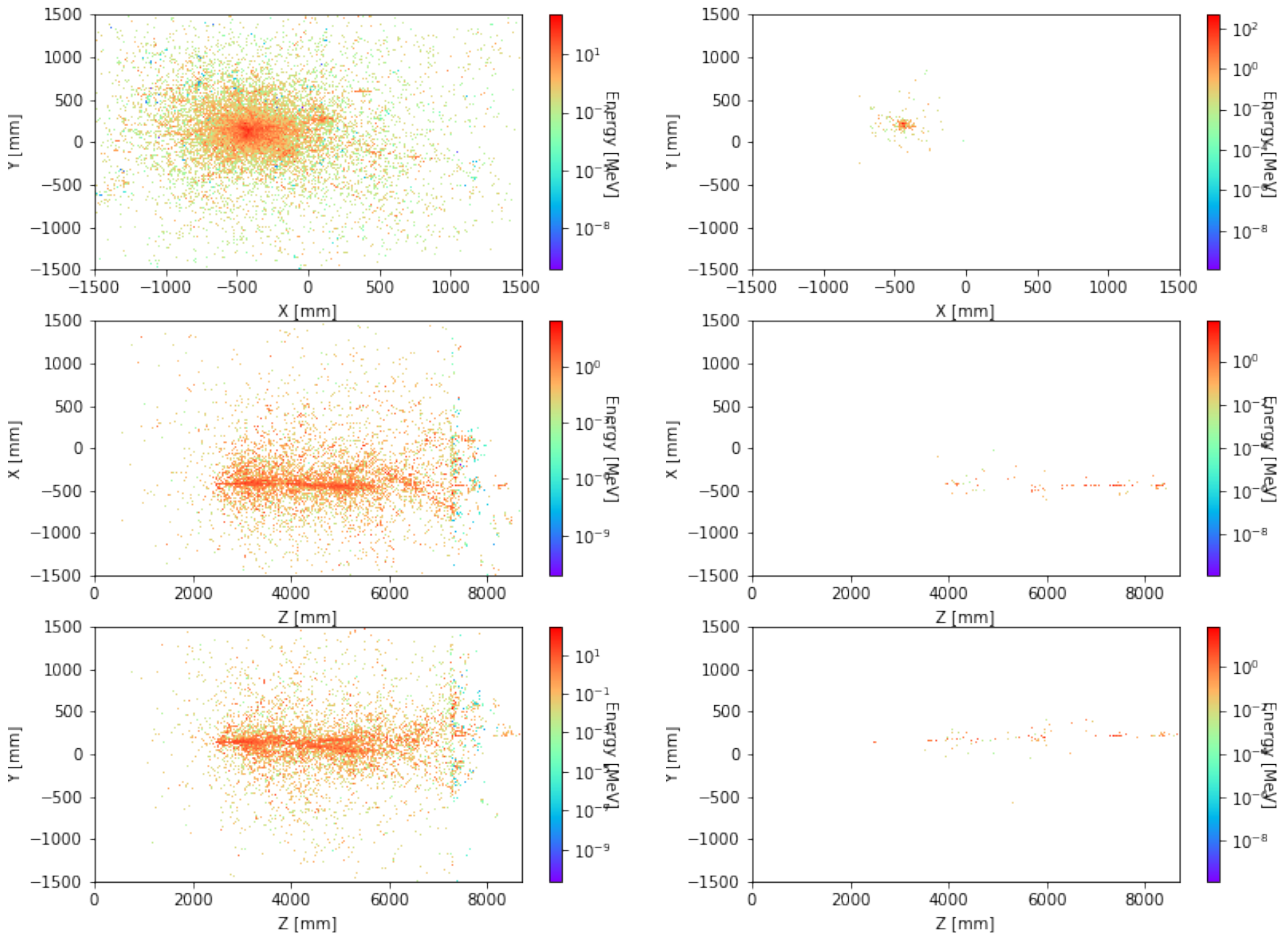
Some event displays

ν_τ CC (E_ν = 230.7 GeV)

$$\tau^-(102.9\ \text{GeV}) \rightarrow \nu_\tau + \bar{\nu}_\mu + \mu^-(74.7\ \text{GeV})$$





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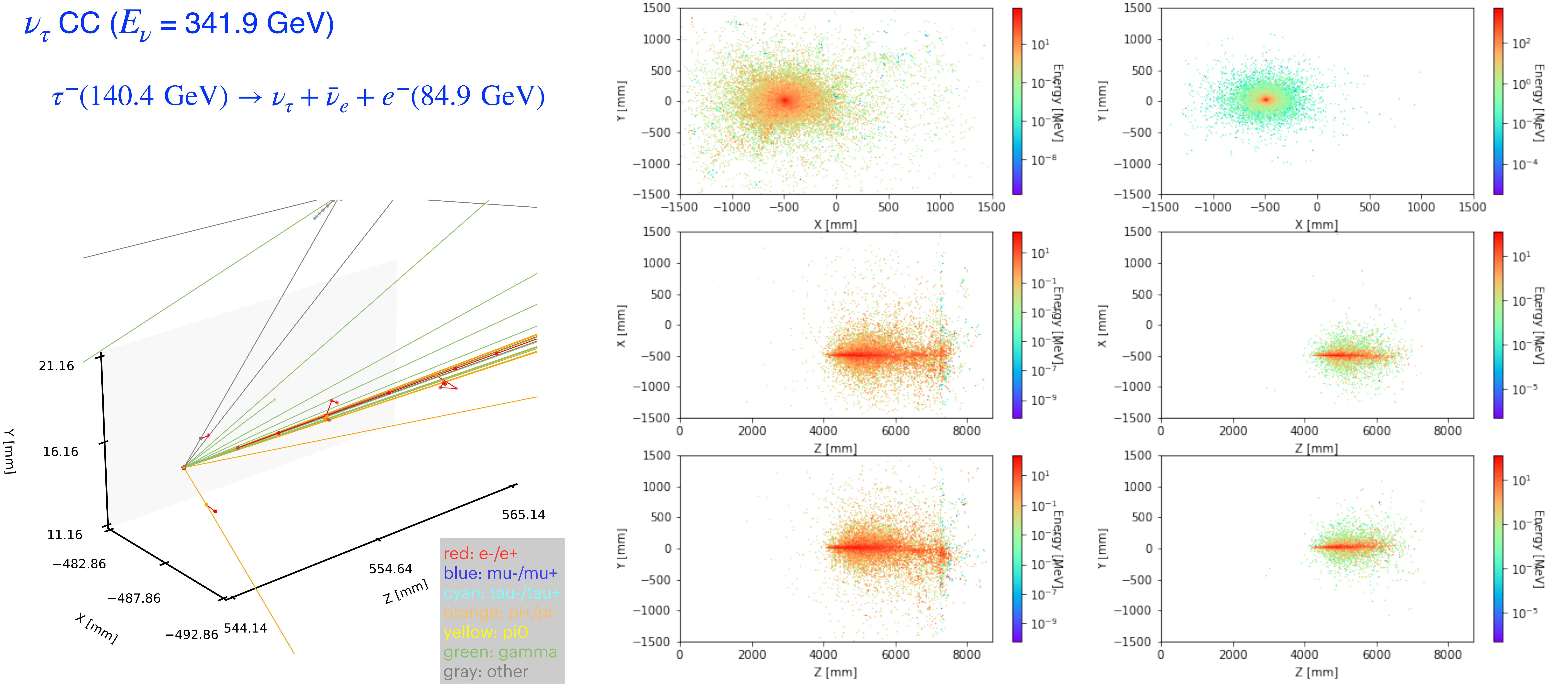
Some event displays

ν_τ CC (E_ν = 341.9 GeV)

$\tau^-(140.4\ \text{GeV}) \rightarrow \nu_\tau + \bar{\nu}_e + e^-(84.9\ \text{GeV})$



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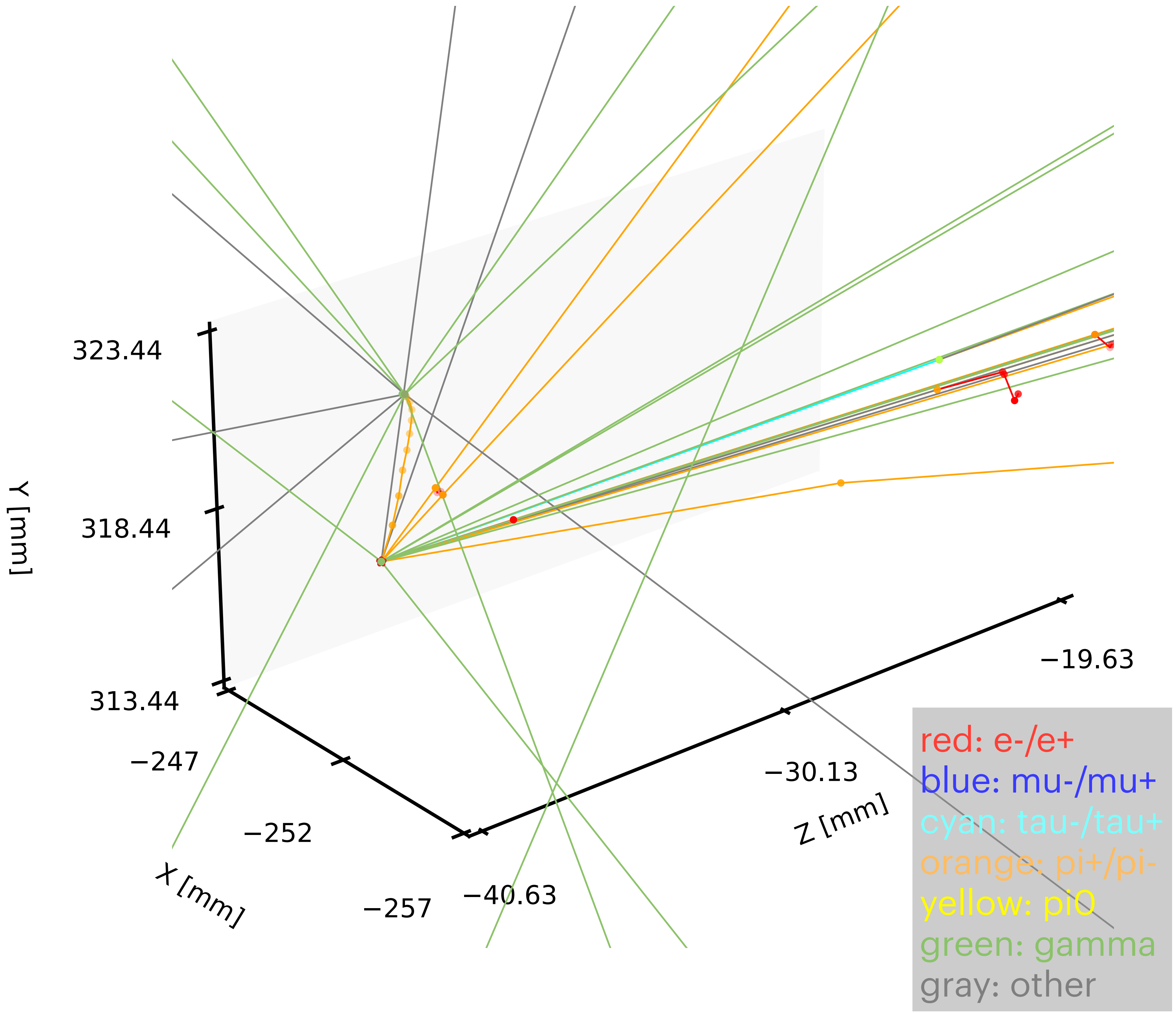
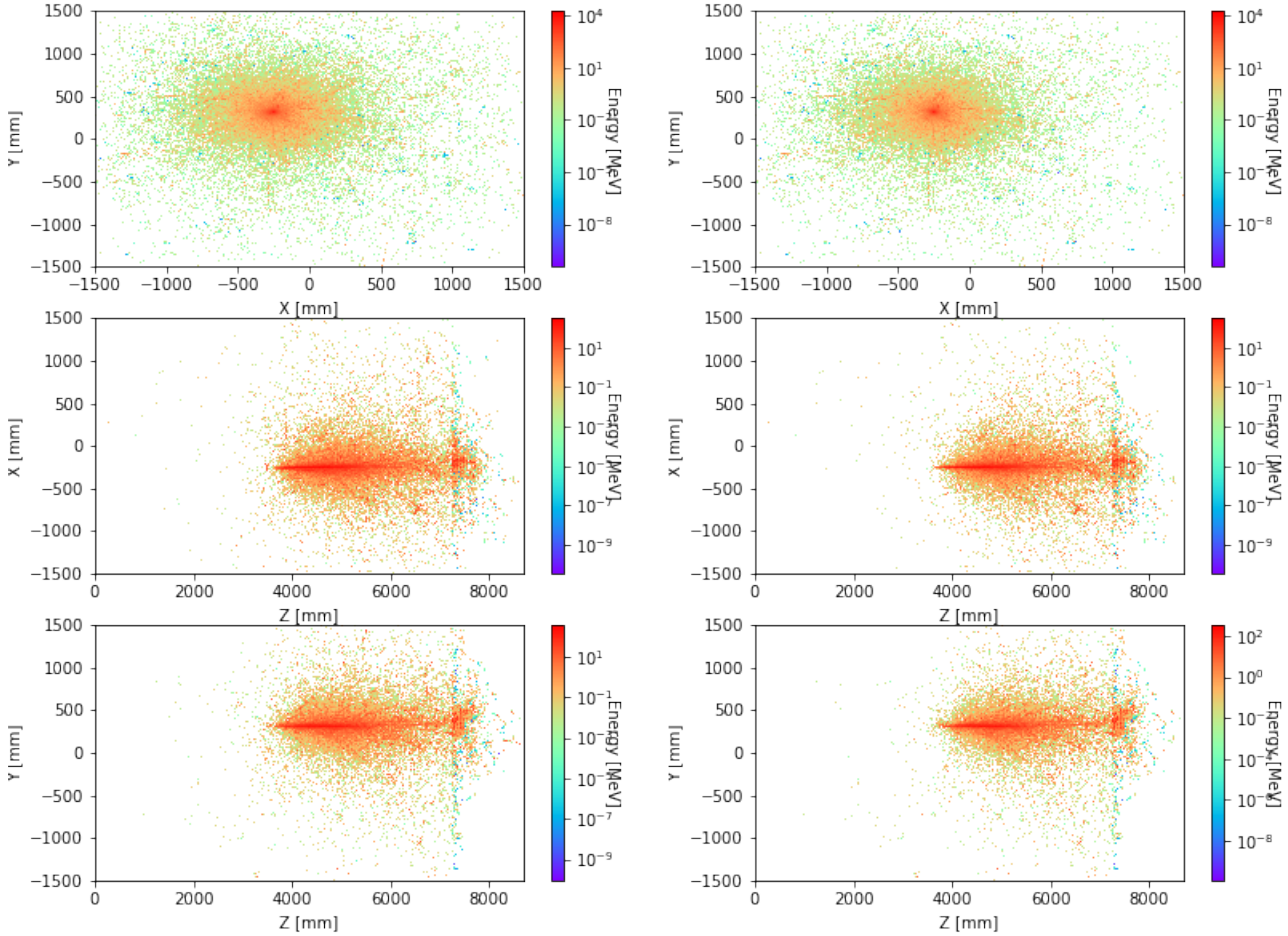
Some event displays

ν_τ CC (E_ν = 629.4 GeV)

$\tau^-(461.9\text{ GeV}) \rightarrow \nu_\tau + \pi^-(323.4\text{ GeV}) + \pi^0(98.6\text{ GeV})$





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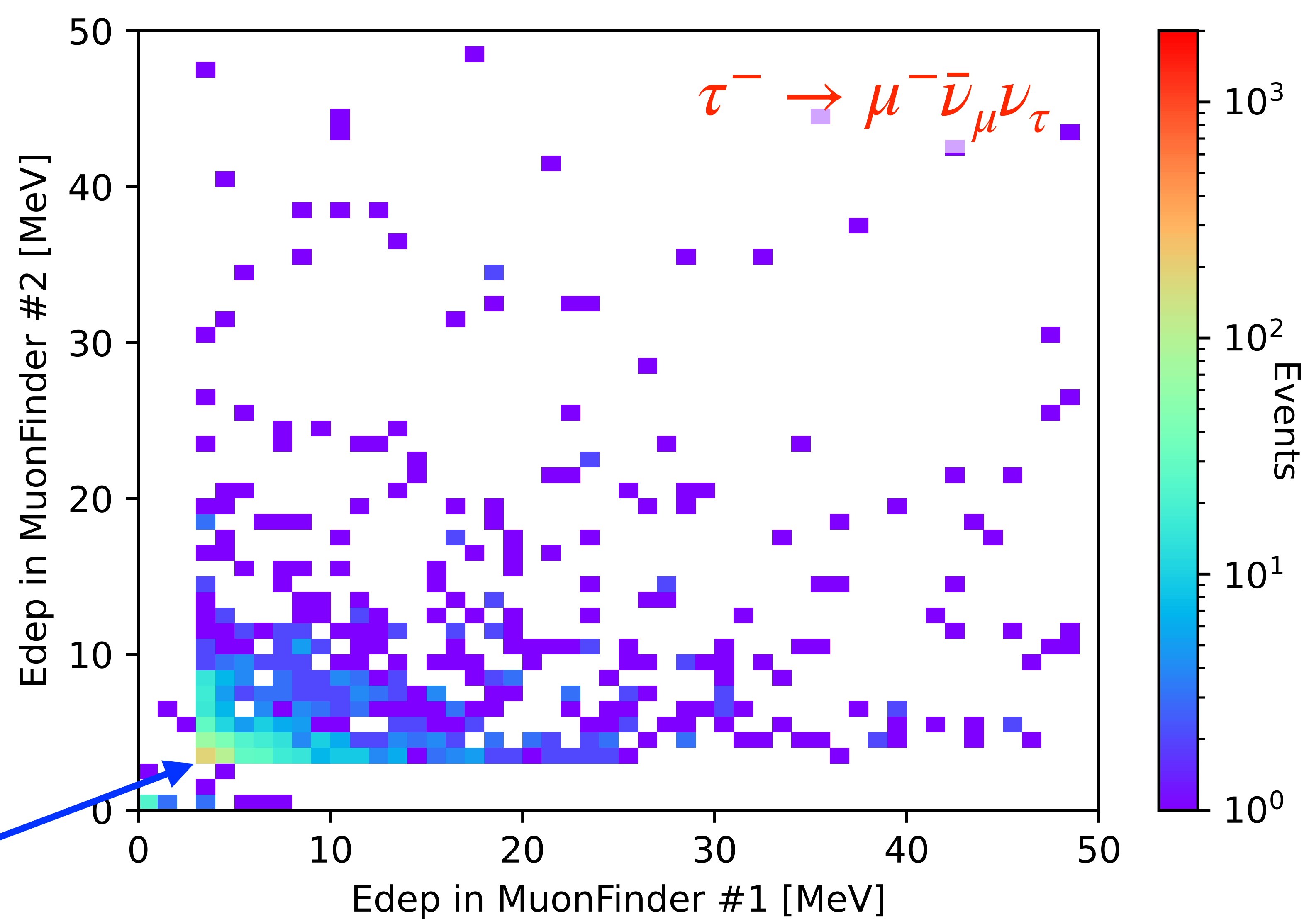
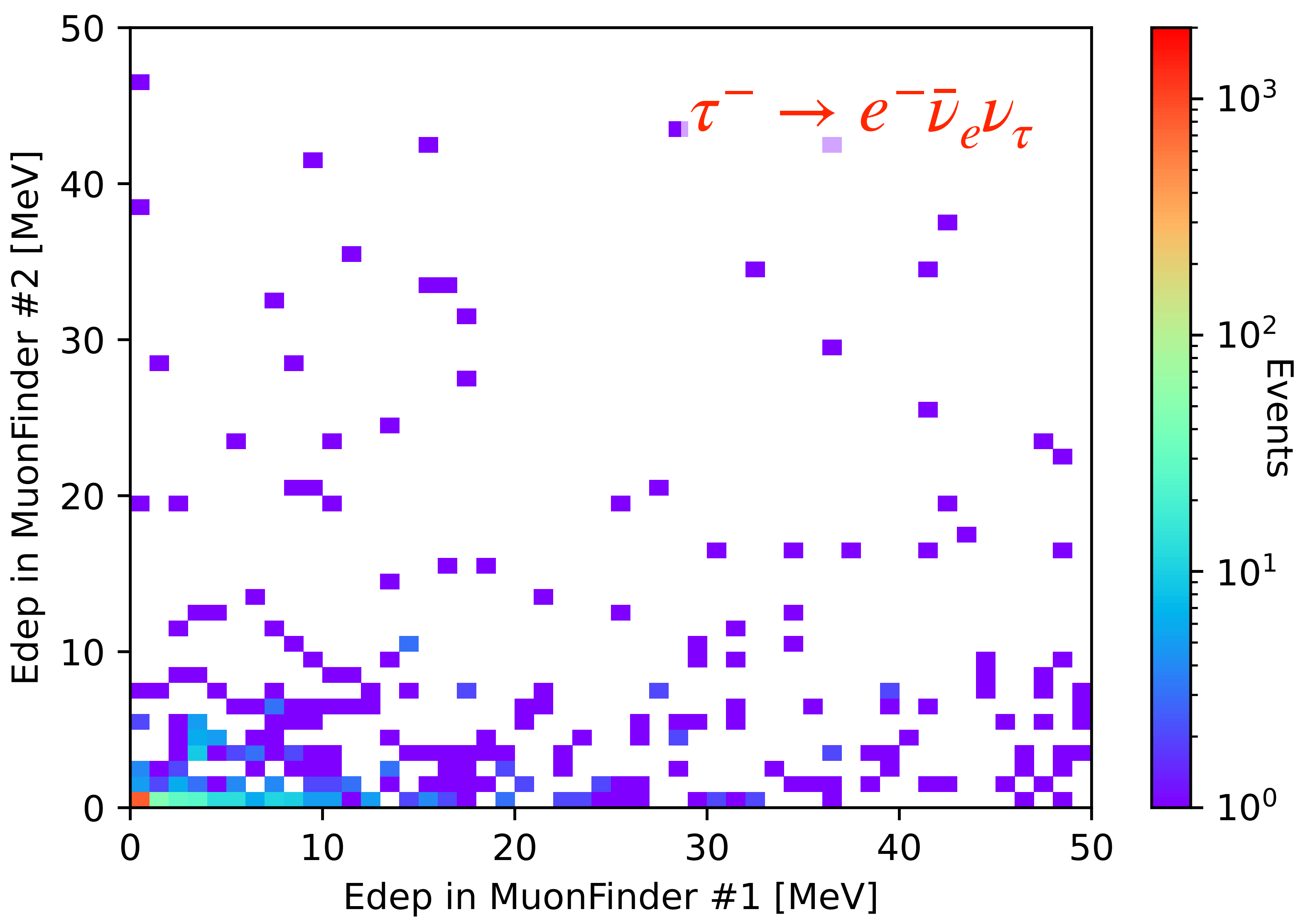
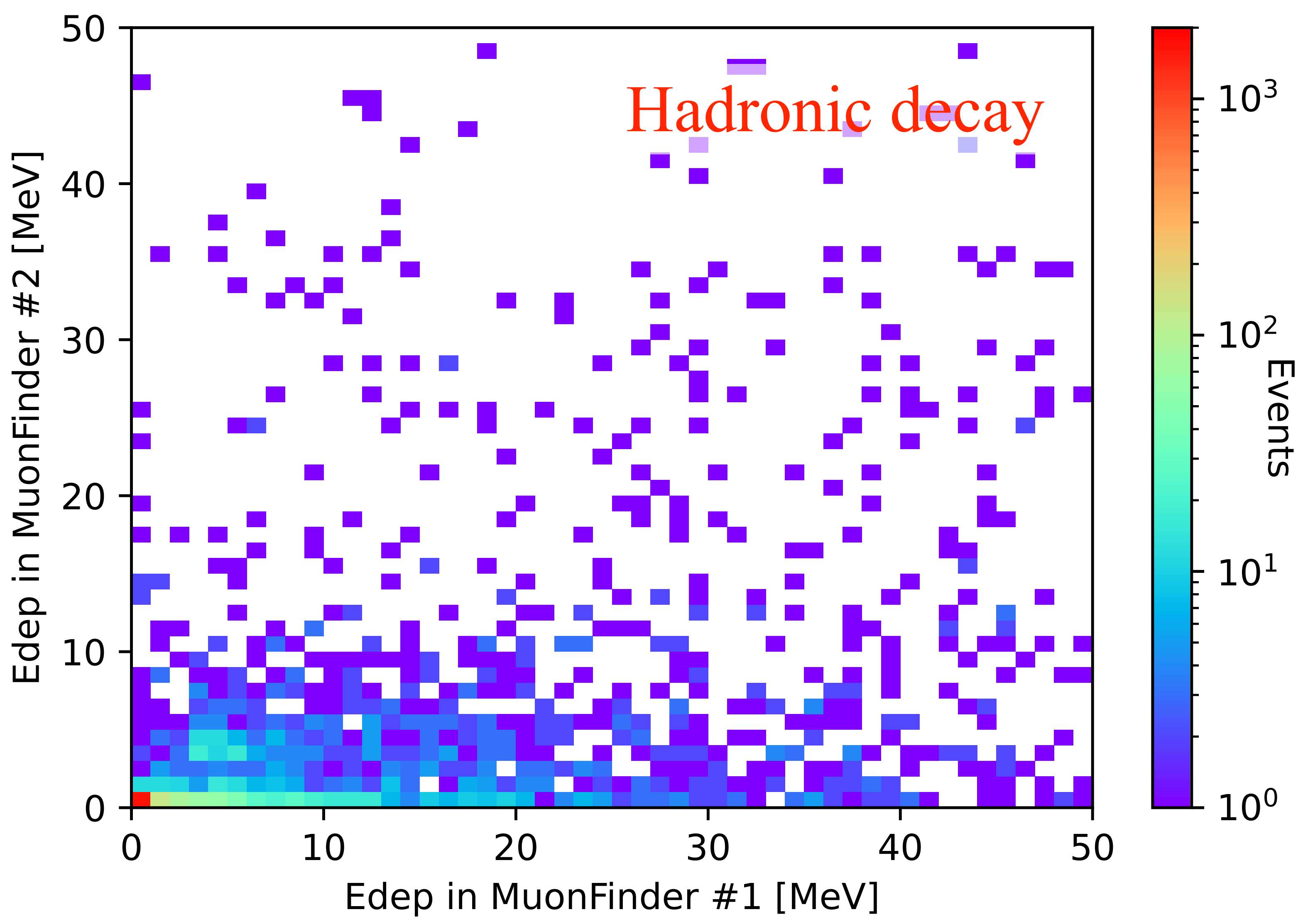
Deposited energy in MuonFinder



3~4 MeV / 2 cm





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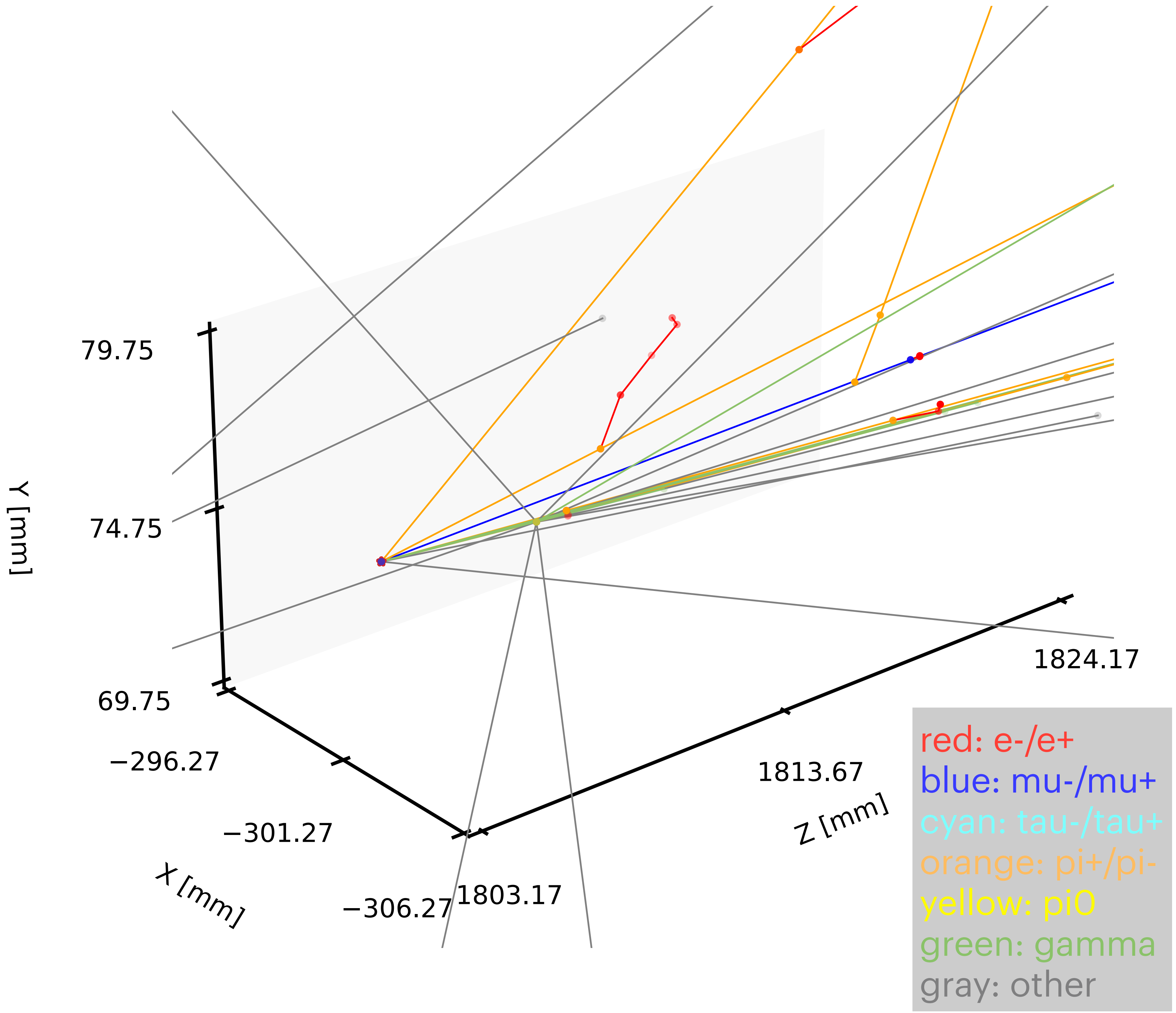
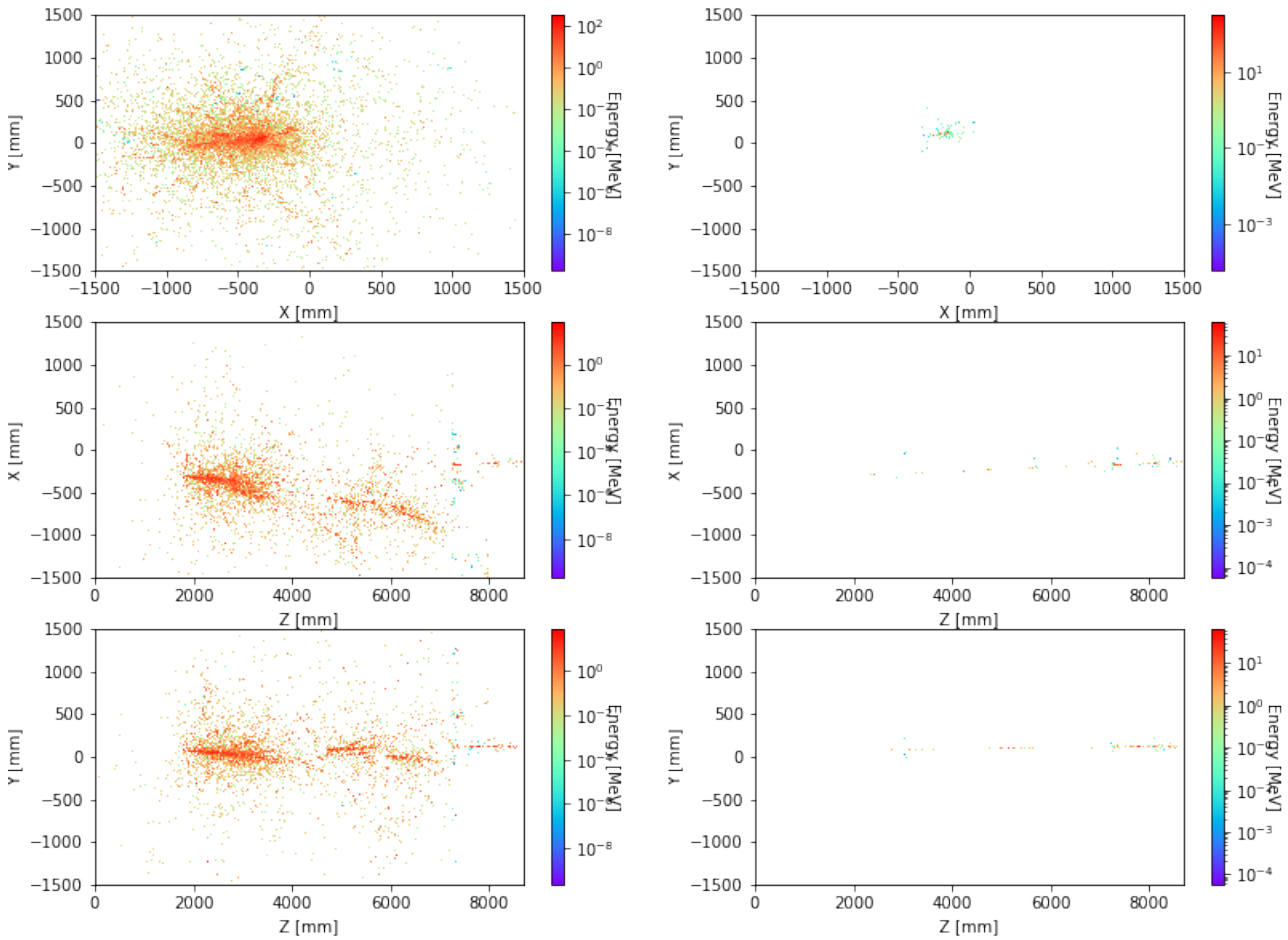
Some event displays

ν_μ CC
(E_ν = 356.4 GeV, E_μ = 283.2 GeV)





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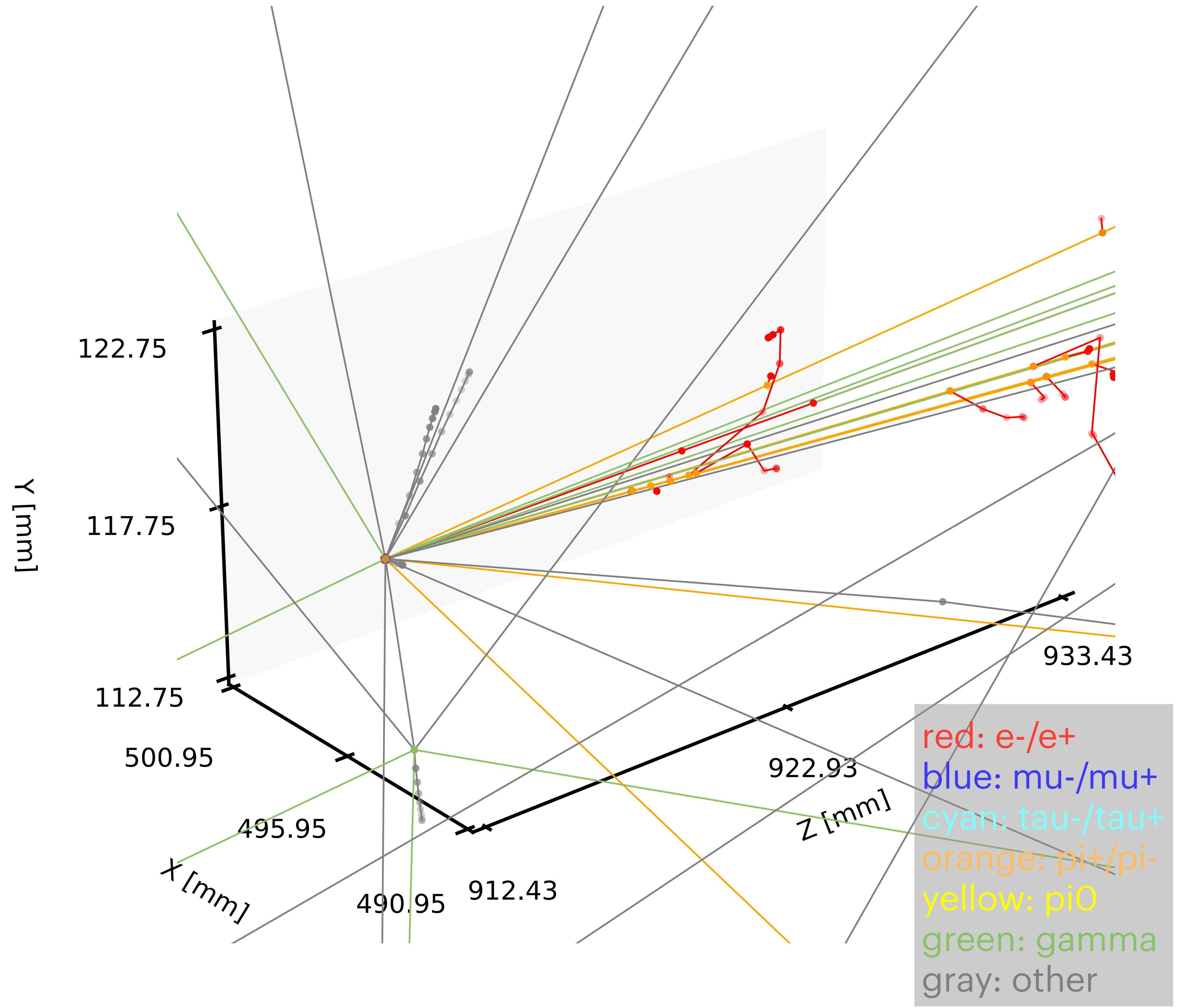
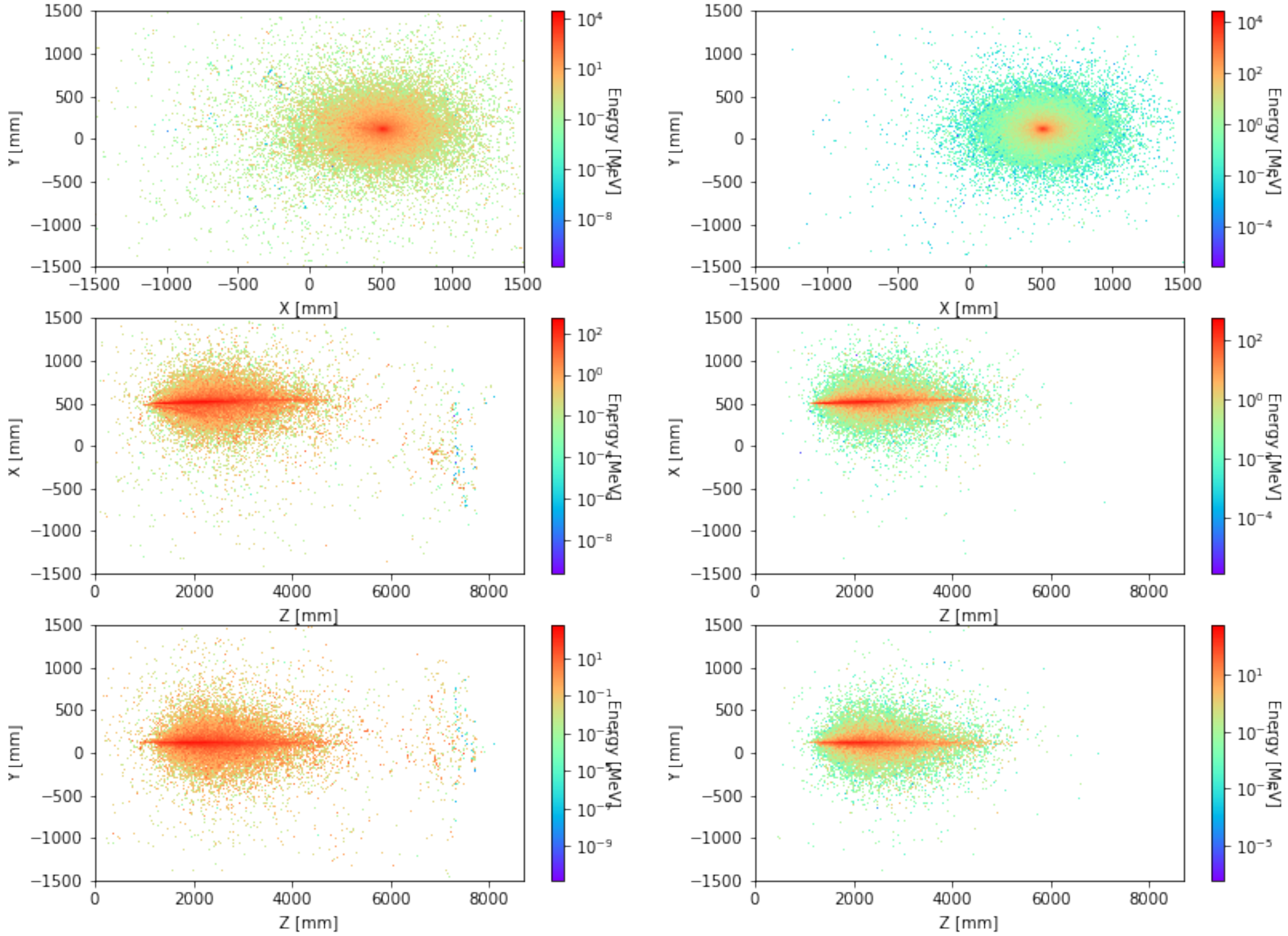
Some event displays

ν_e CC
(E_ν = 610.8 GeV, E_e = 531.6 GeV)





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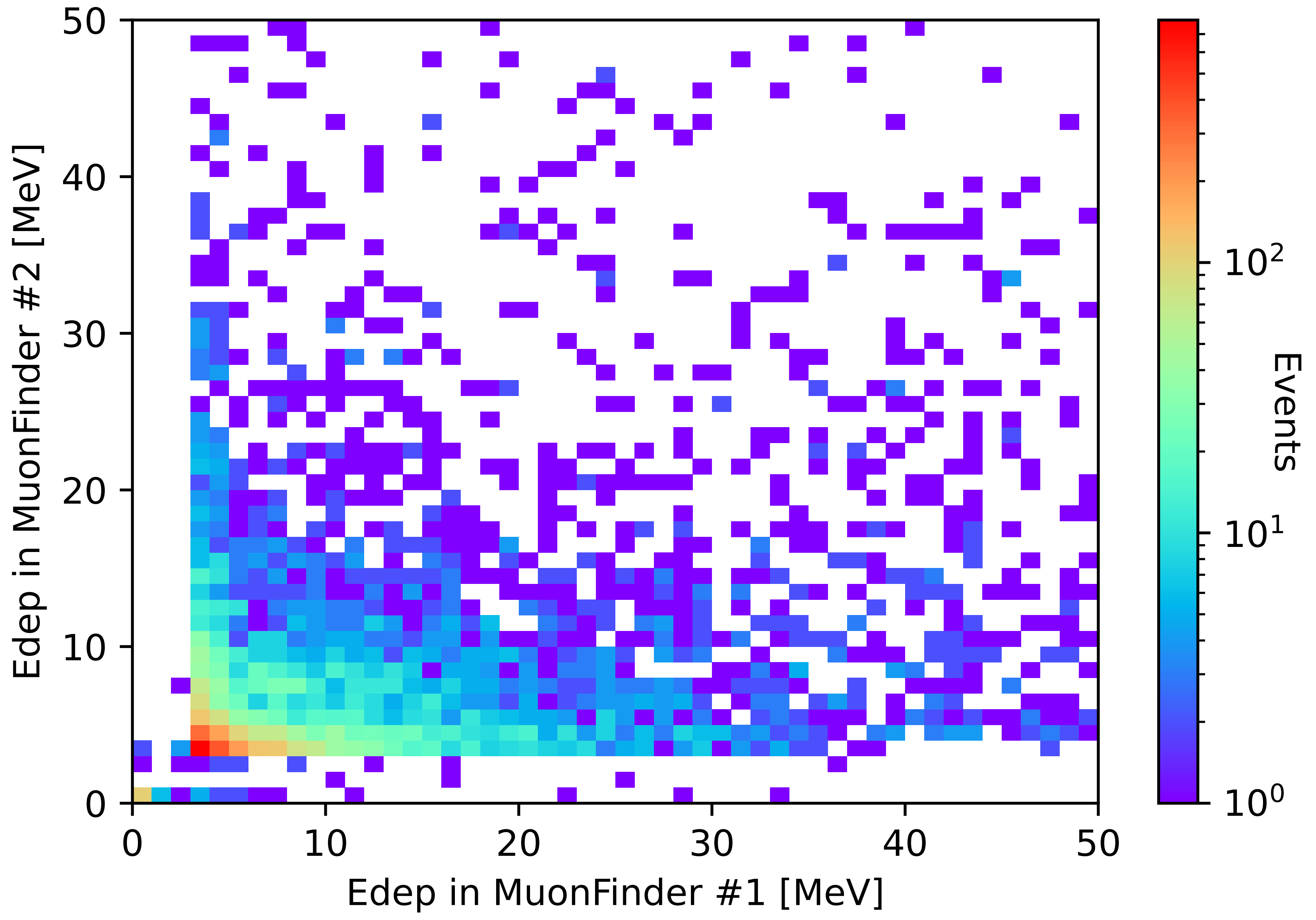
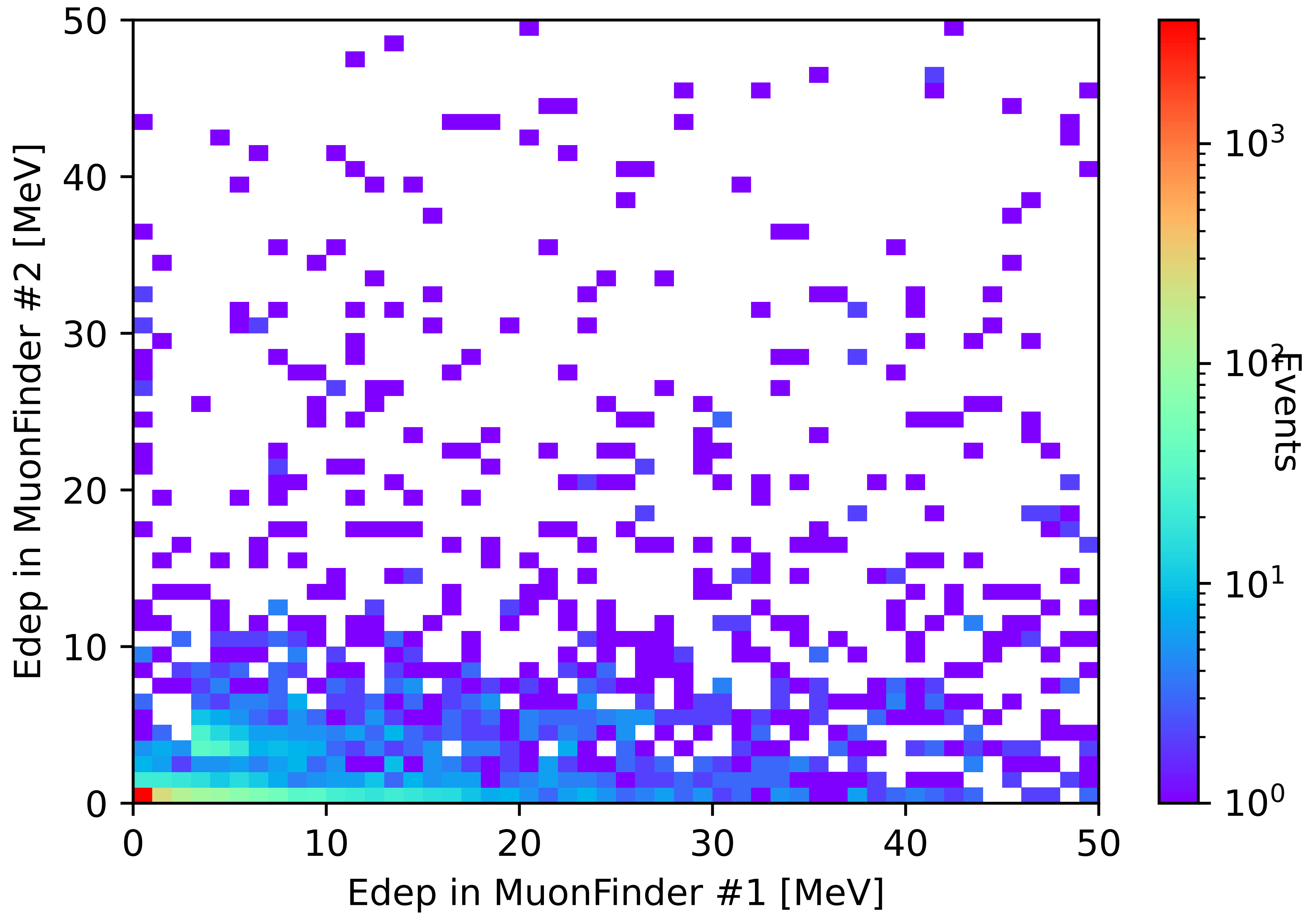
Event display

ν_μ CC



ν_e CC



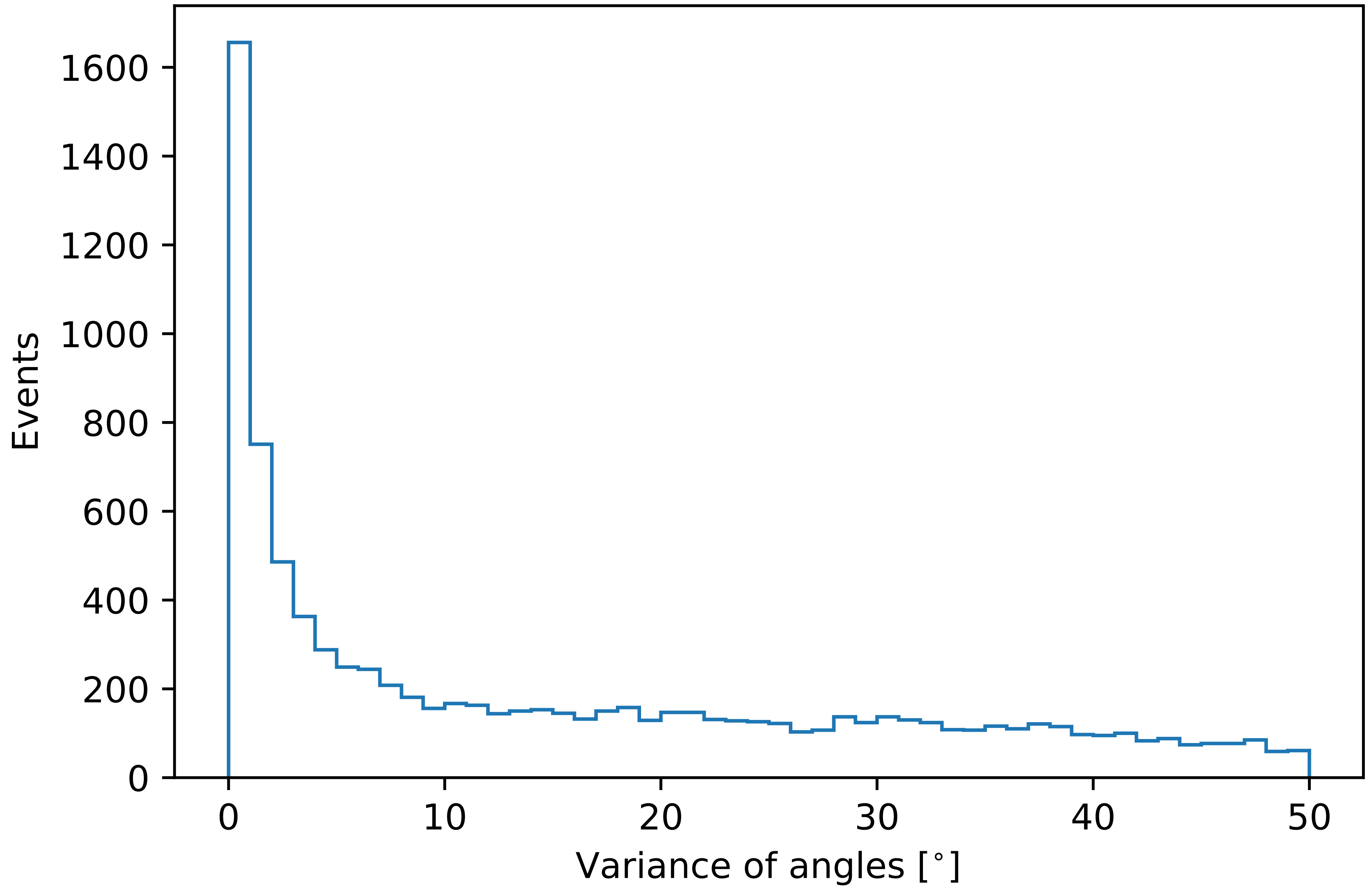
Summary

- With different transverse cuts, detector sizes with 3m - 2m width/height don't have noticeable difference
- With HadCal, energy loss for events happened at the downstream of the detector can be effectively saved
  - The energy deposited in HadCal can be reconstructed by the energy recorded in the scintillator layers
- MuonFinder can be used to effectively tag the muons
  - We can tune the thickness of steel layers or the number of layers to have a better muon acceptance

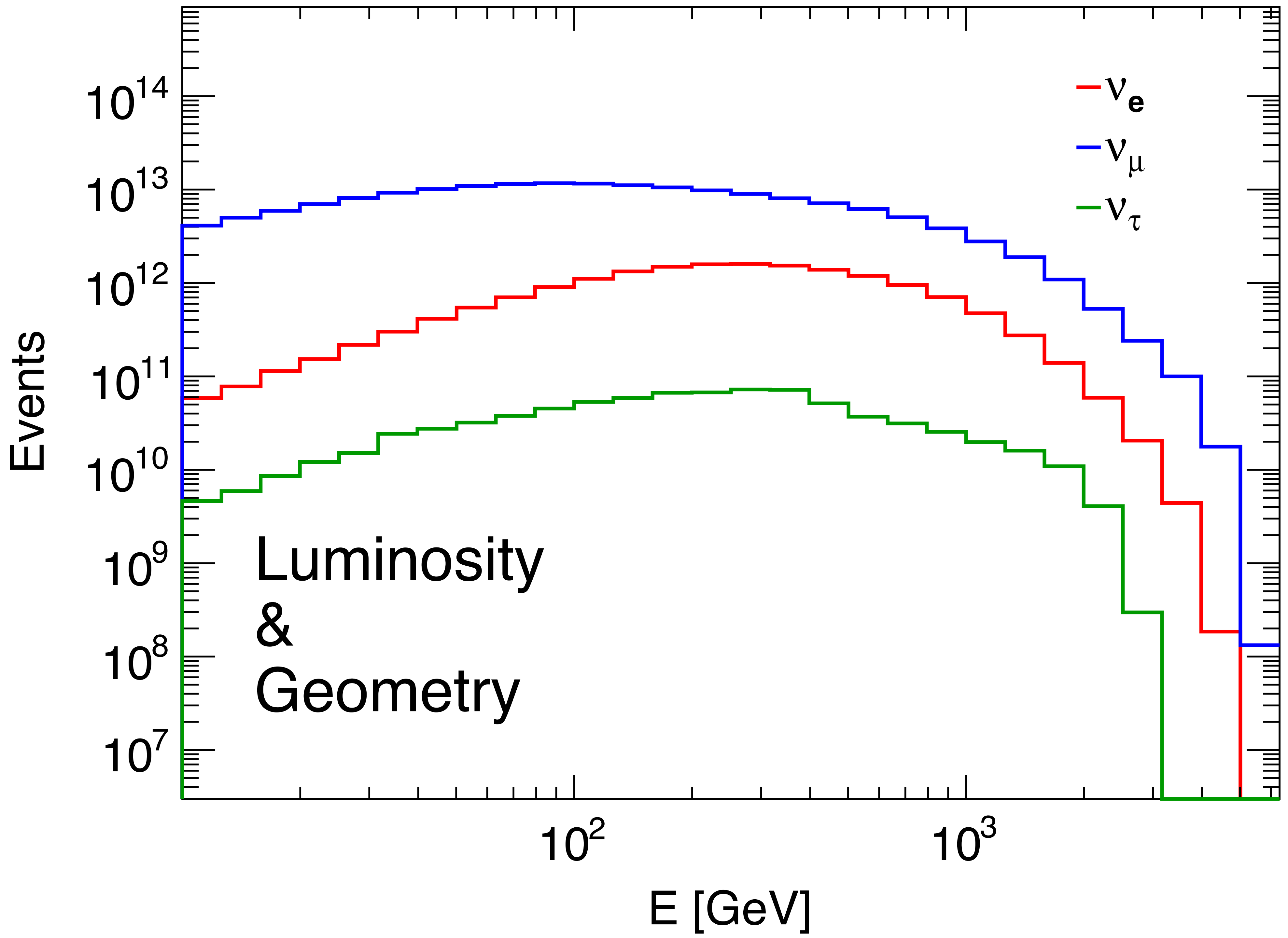
Backup

Angular variance

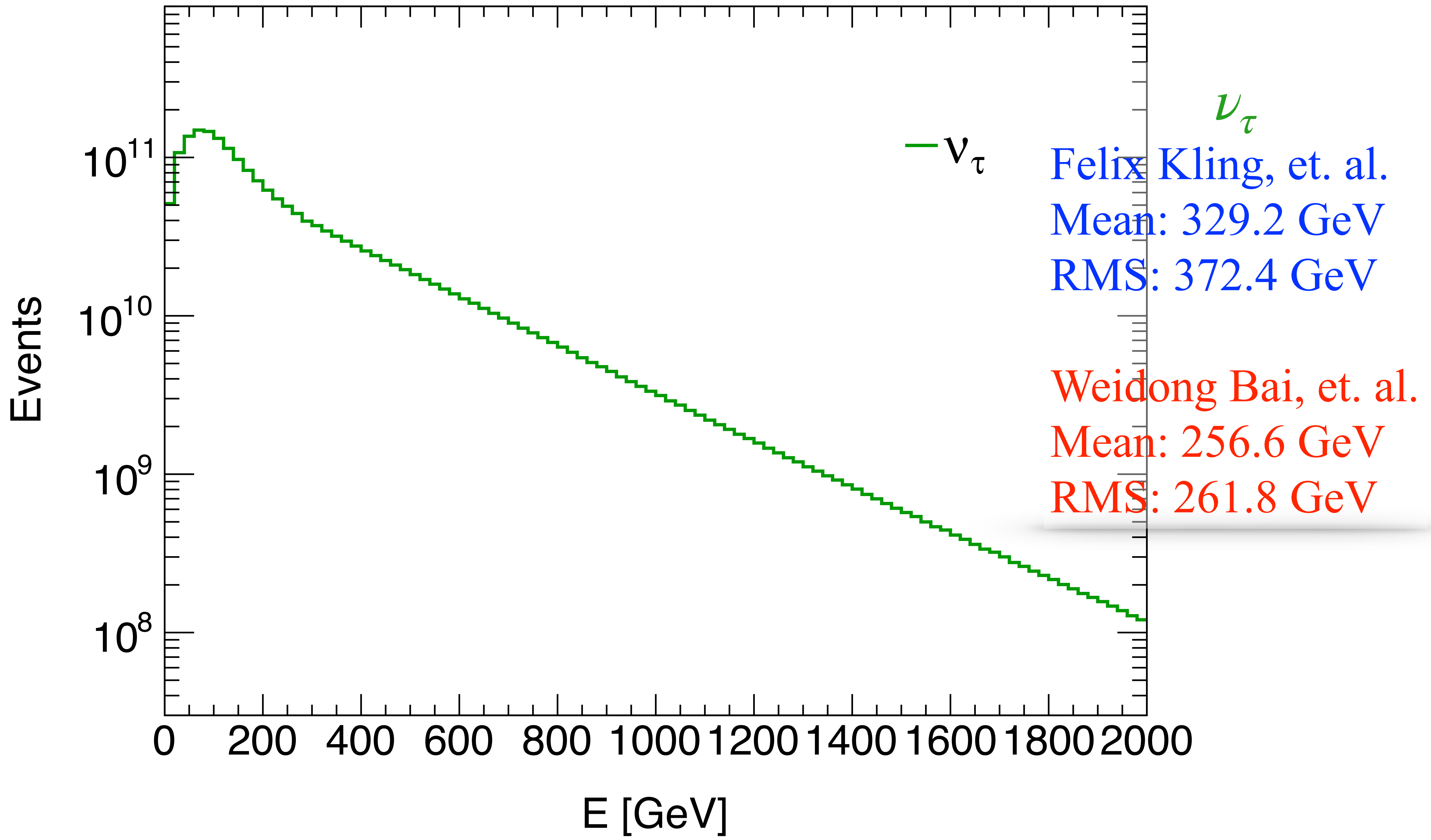
- Angular variance of charged tracks from the neutrino interaction w.r.t the direction of the neutrino beam
  - $\tau^-, \pi^+, \pi^-, p, \ldots$ (maybe we need to also include π^0 and γ)
- Most of events have tracks concentrate at one direction (variance < 5°)



Neutrino flux



x Luminosity / 2



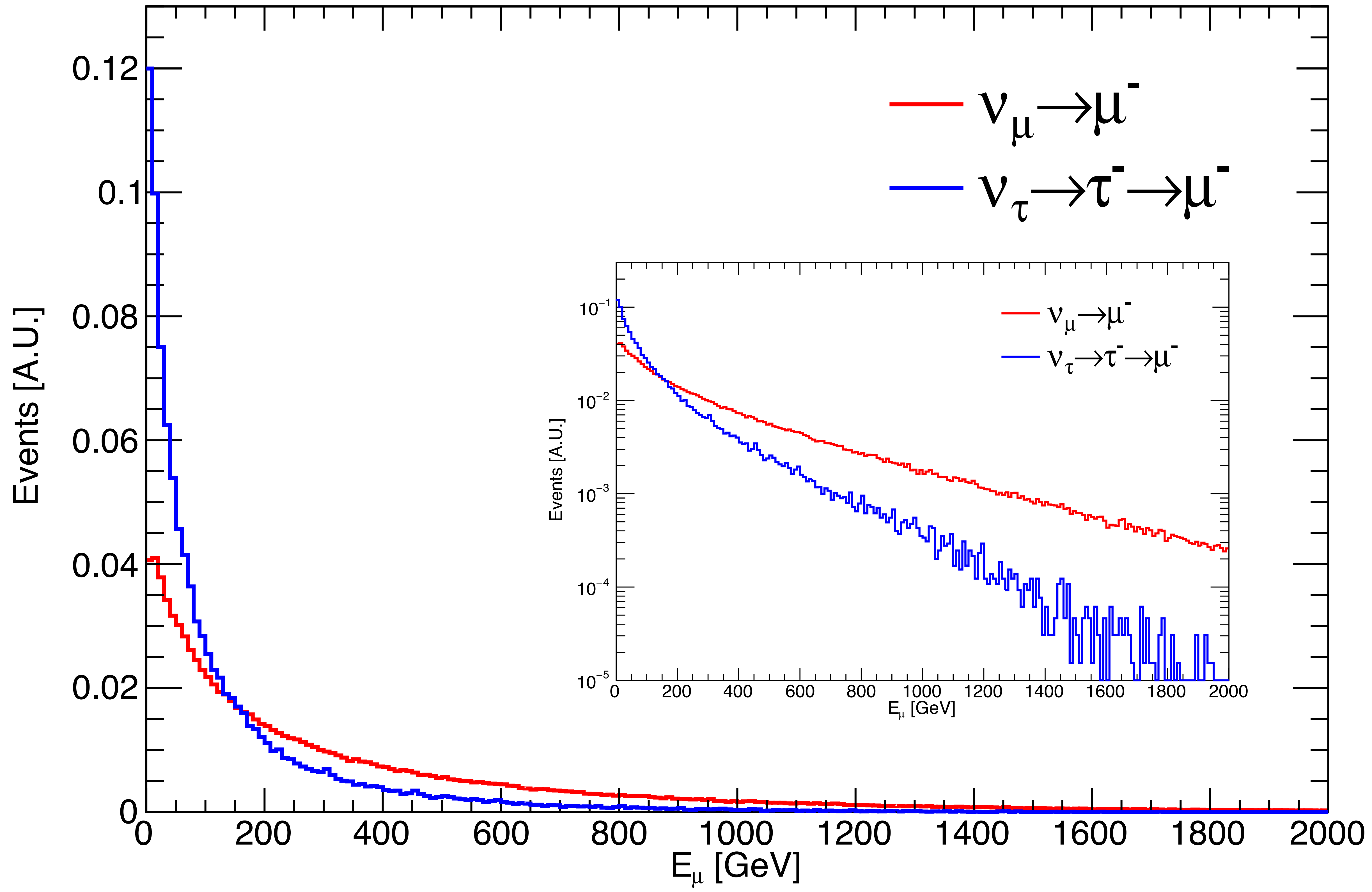
Felix Kling, et. al. 2105.08270
Github

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



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

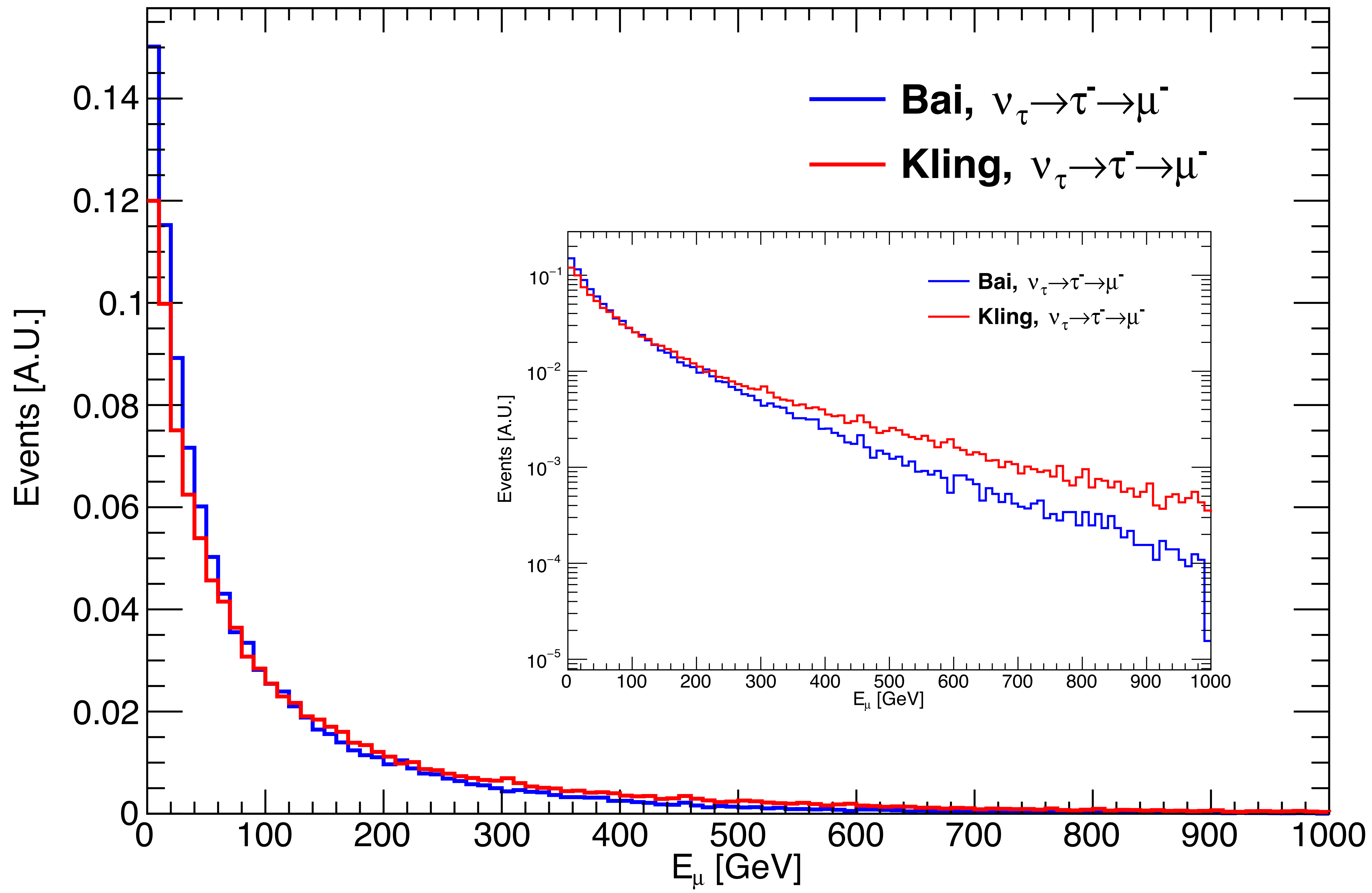
$\nu_\tau \to \tau^- \to \mu^-$
Mean: 146.0 GeV
RMS: 201.0 GeV

Felix Kling, et. al. 2105.08270

Muon energy spectrum, area normalized

Muon from tau decay is softer

GENIE simulation: muon spectrum



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

Muon energy spectrum, area normalized