

Cosmogenic Muons in the Far Detector

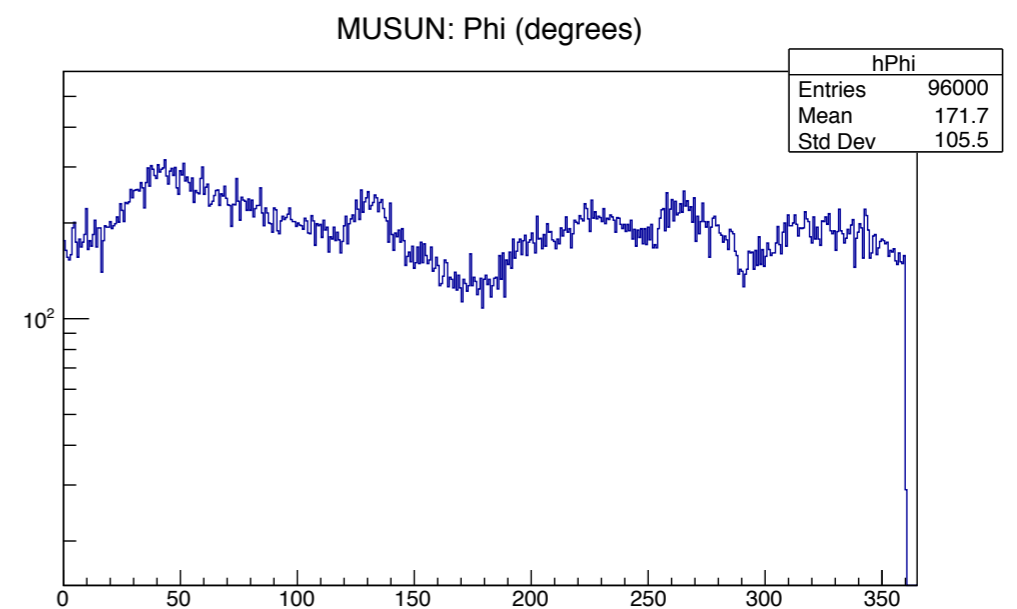
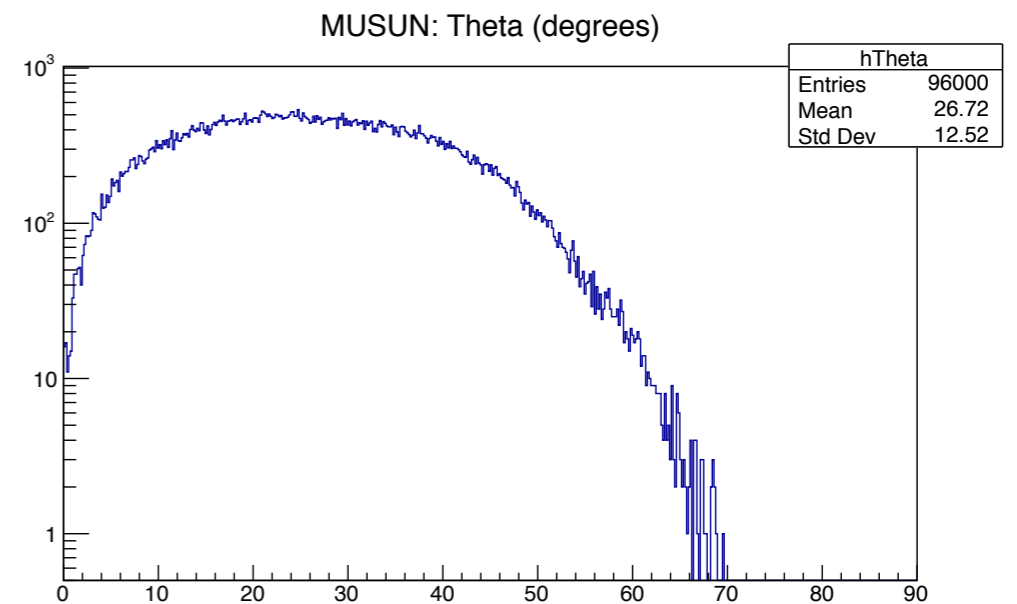
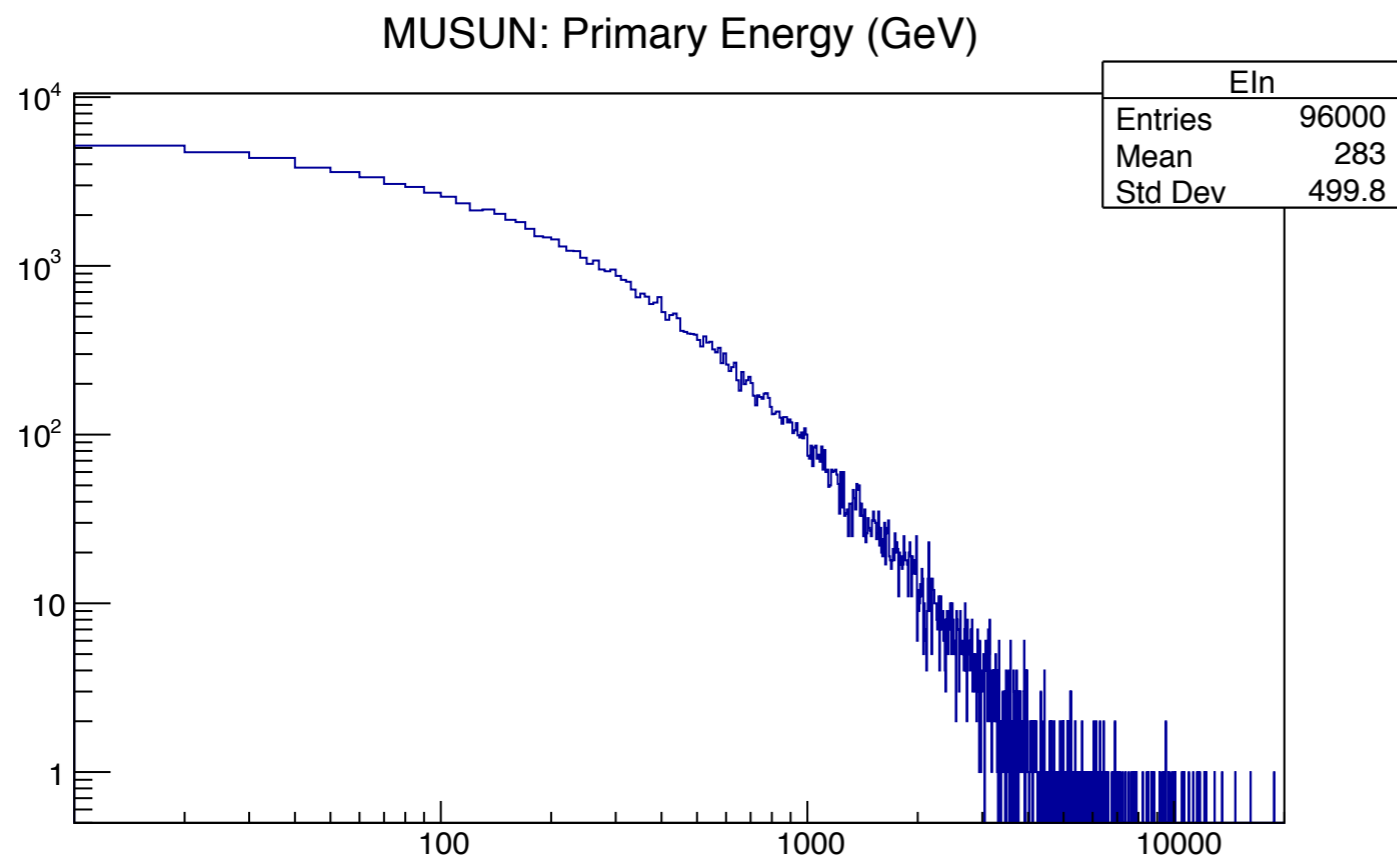
- 10^8 primary muons simulated in a volume of rock above the lab $29.54 \times 30.18 \times 74.43$ m. Muon rate: 0.1579 Hz. Approx 20 years. Analysis complete.
- Full far detector simulation performed.
- 33.5% of muons deposit energy directly in the active volume suggesting a trigger rate of 0.053 Hz. 34.3% of muons or secondaries deposited energy.
- Bug in larsoft (missing MuonNuclear physics accompanied by print statement indicating it was on) which cut Kaon production by a factor of 100 is now corrected.

Using MUSUN module

- Karl Warburton has integrated the MUSUN module into larsim within larsoft. Some debugging was necessary. All should be well in larsoft/larsim v04_29_02 and onwards.

```
physics:
{
  producers:
  {
    rns:      { module_type: "RandomNumberSaver" }
    generator: @local::standard_MUSUN
    largeant: @local::dunefd_largeant
    daq:      @local::dunefd_simwire
    opdigi:   @local::dunefd_opdigi
  }
  ...
}
```

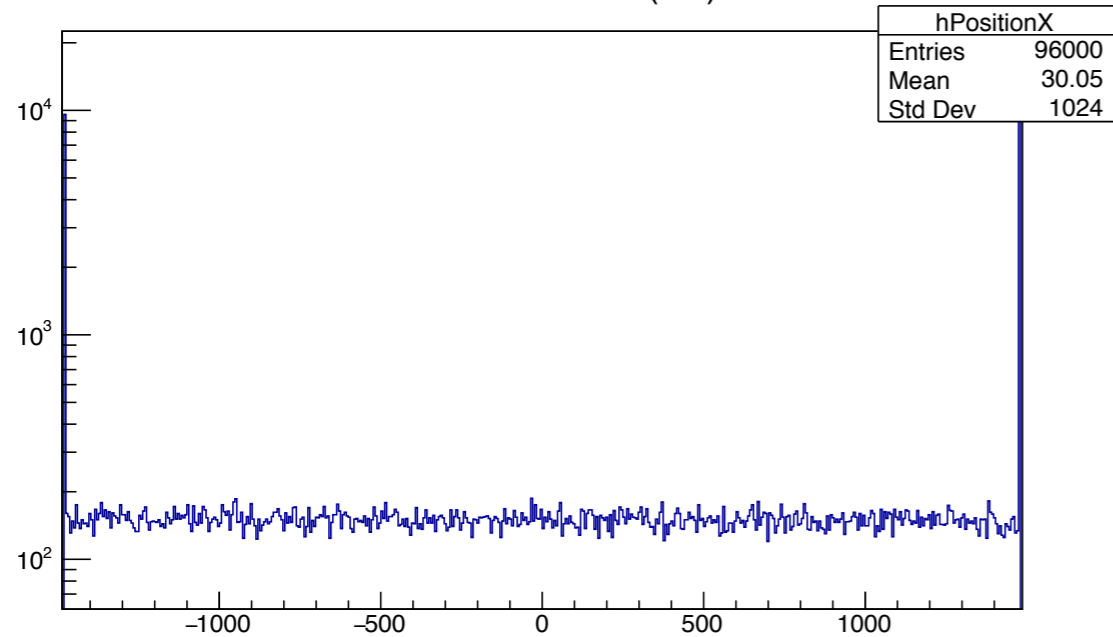
MUSUN: Primaries



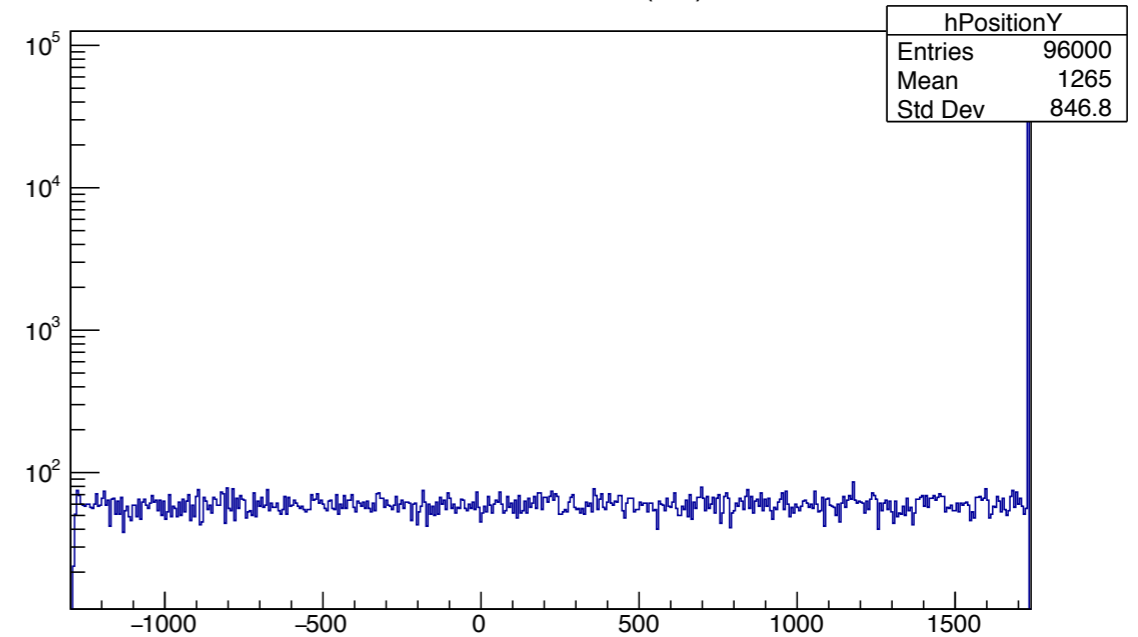
- Mean energy: 283 ± 1 GeV
- Expected 284 GeV.

MUSUN: Primaries

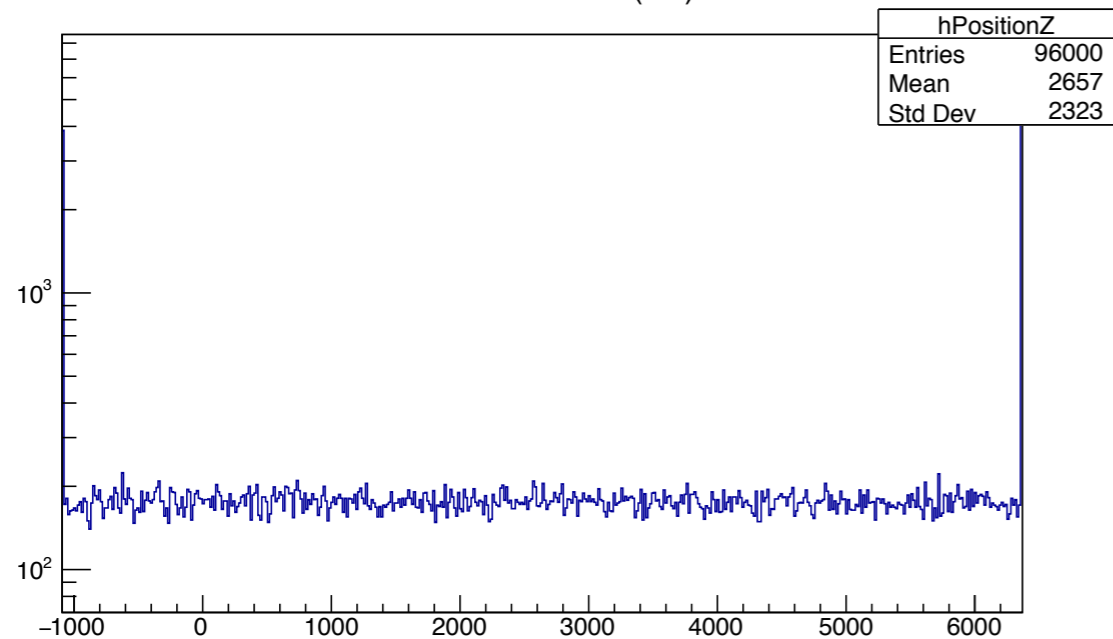
MUSUN: Initial X (cm)



MUSUN: Initial Y (cm)

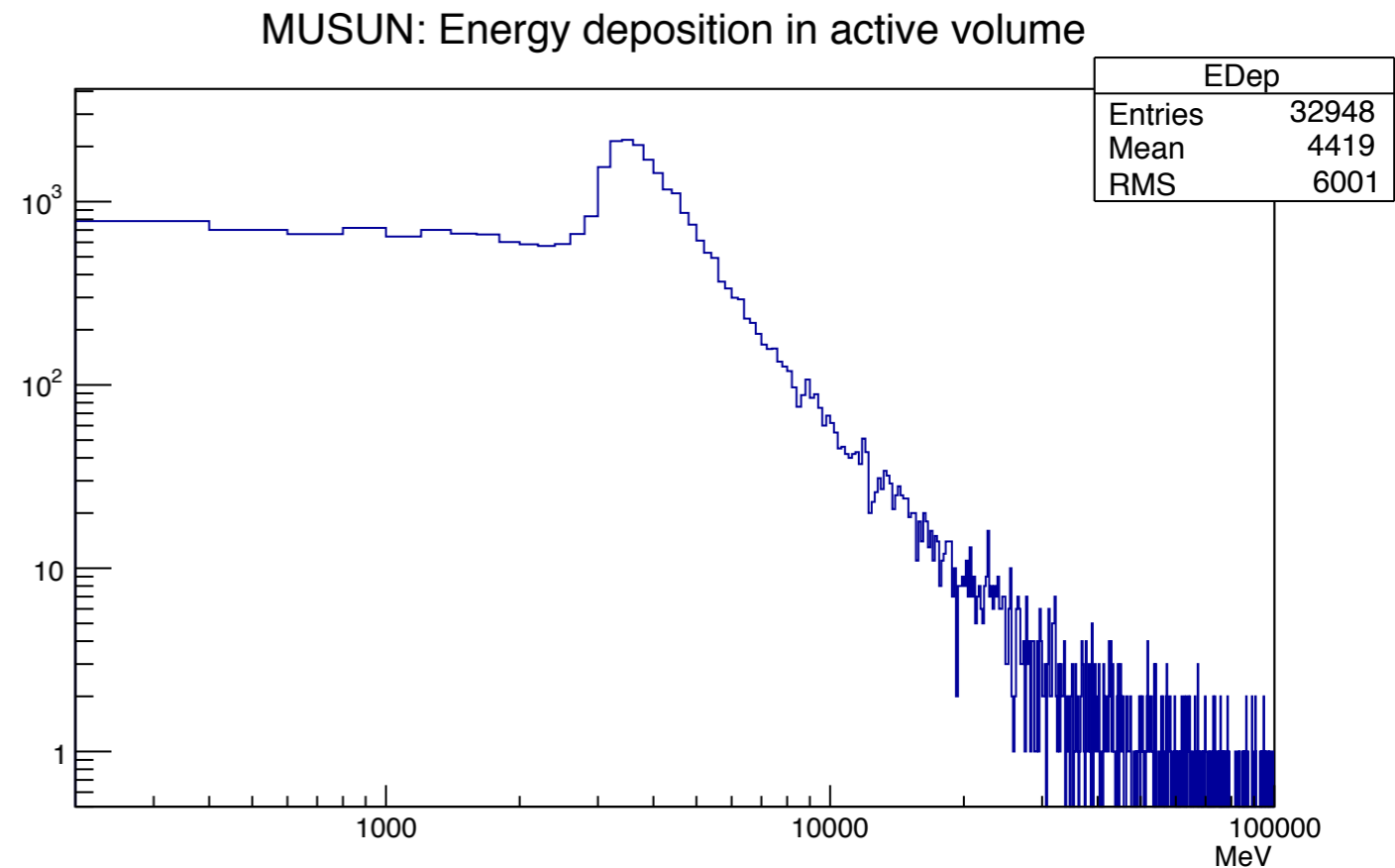
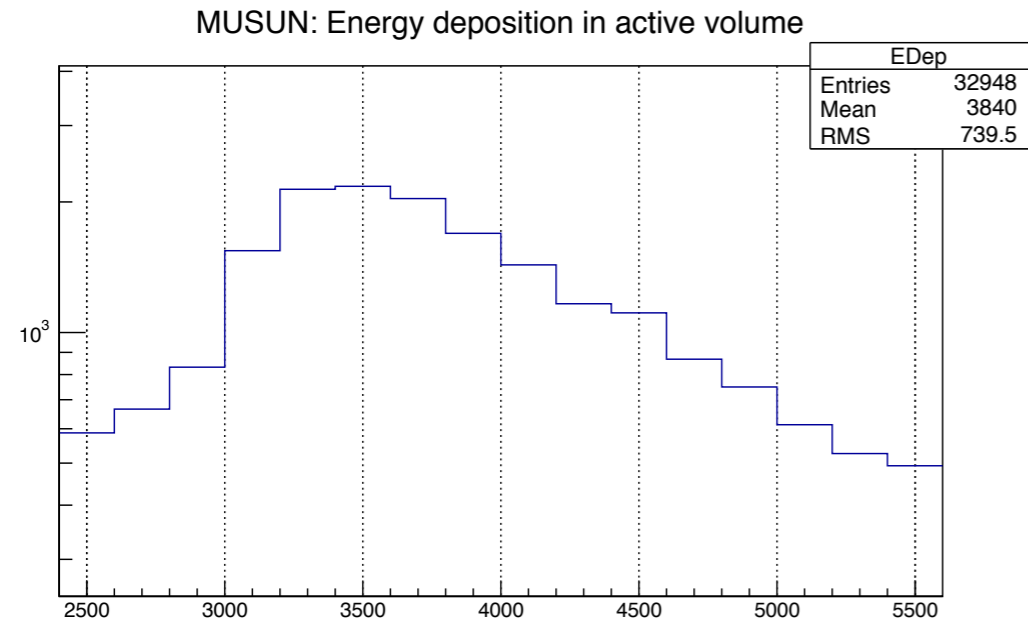


MUSUN: Initial Z (cm)



- Muon starting position uniform.

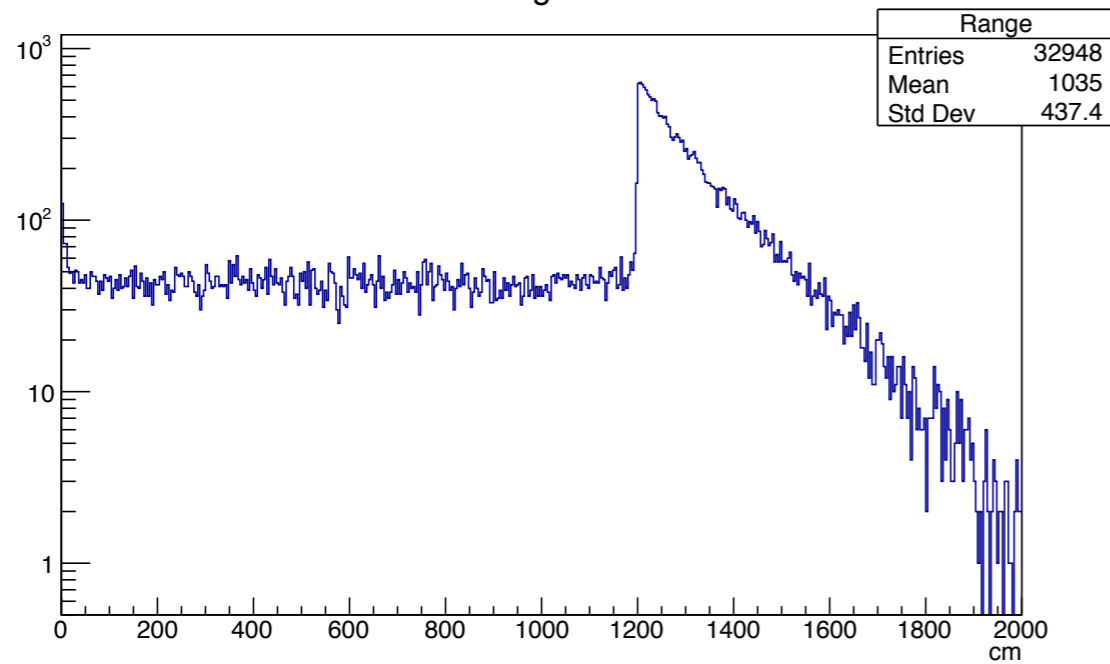
Energy deposition in active volume



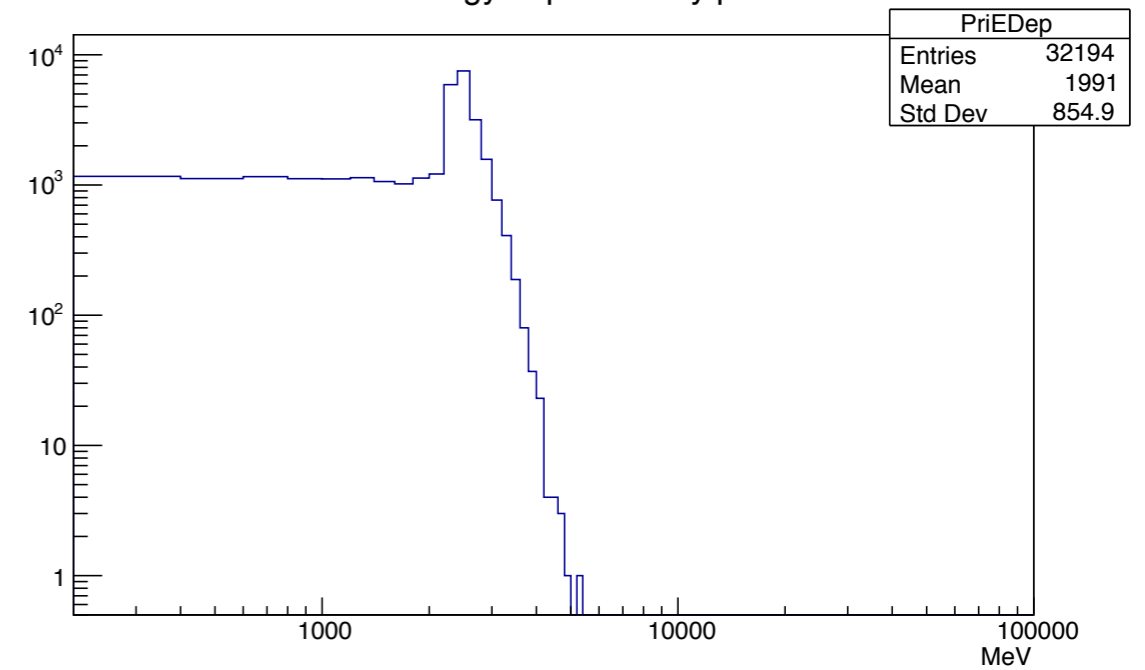
- Energy deposition peaks at 3.5 GeV. Mean is 4.4 GeV.

More on Energy deposition

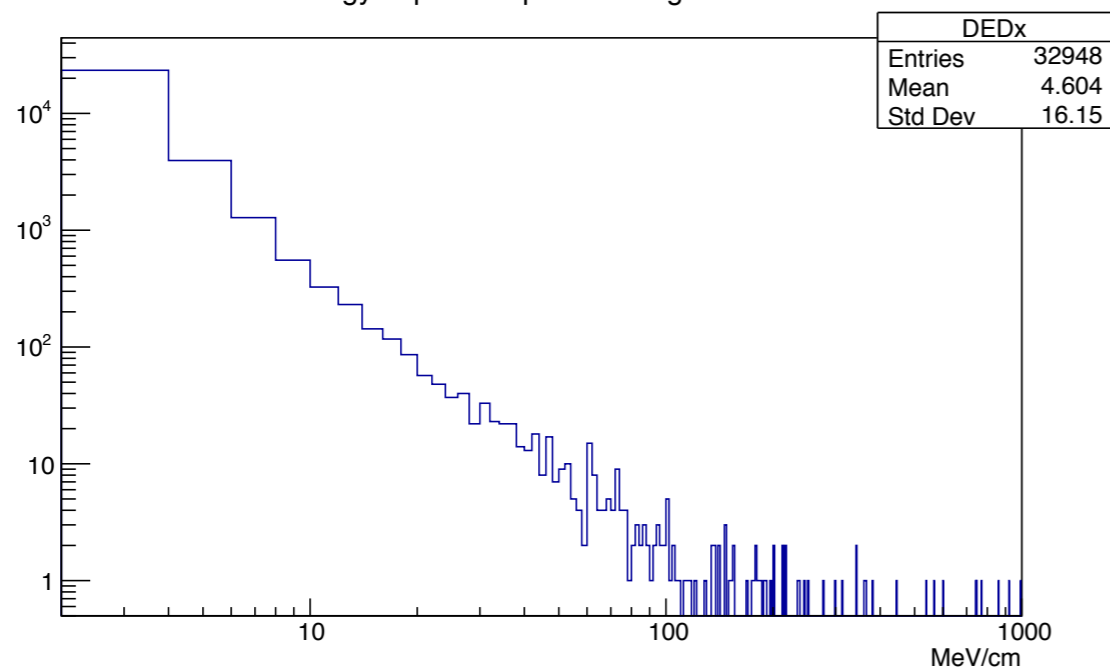
MUSUN: Track length in active volume



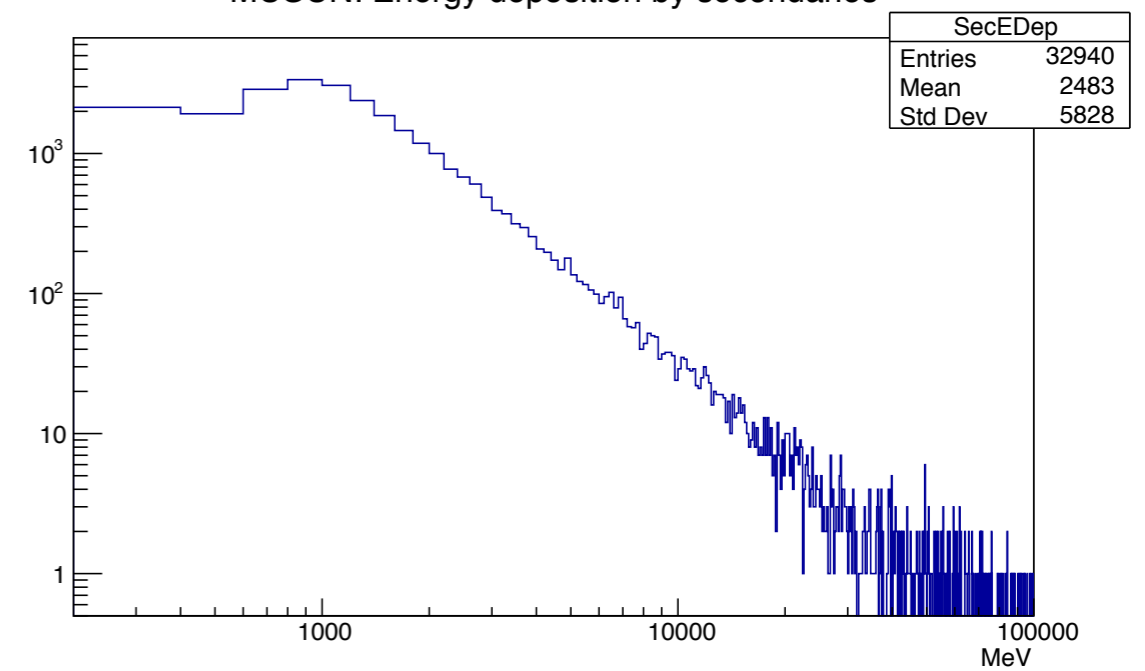
MUSUN: Energy deposition by primaries



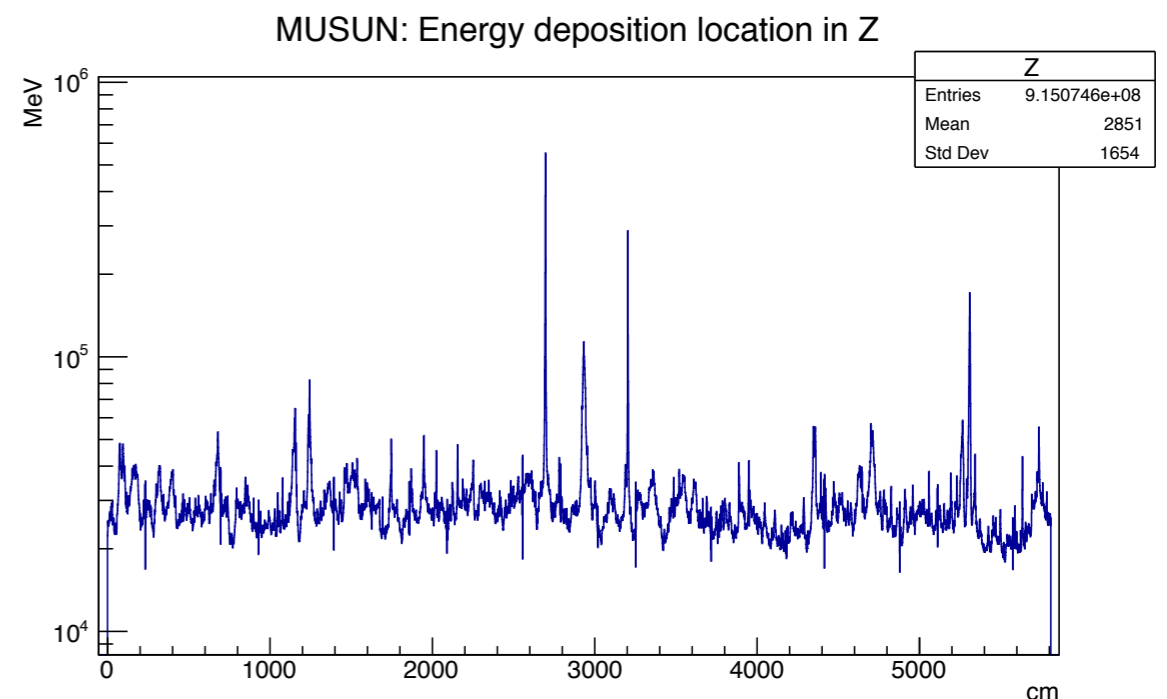
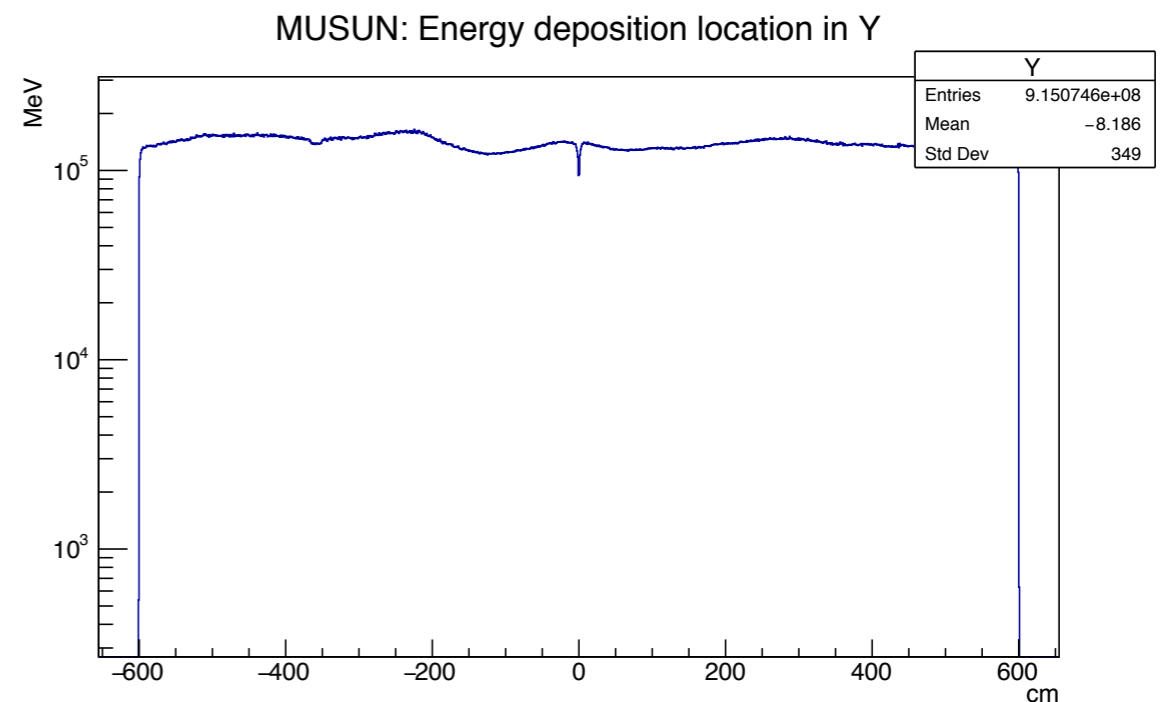
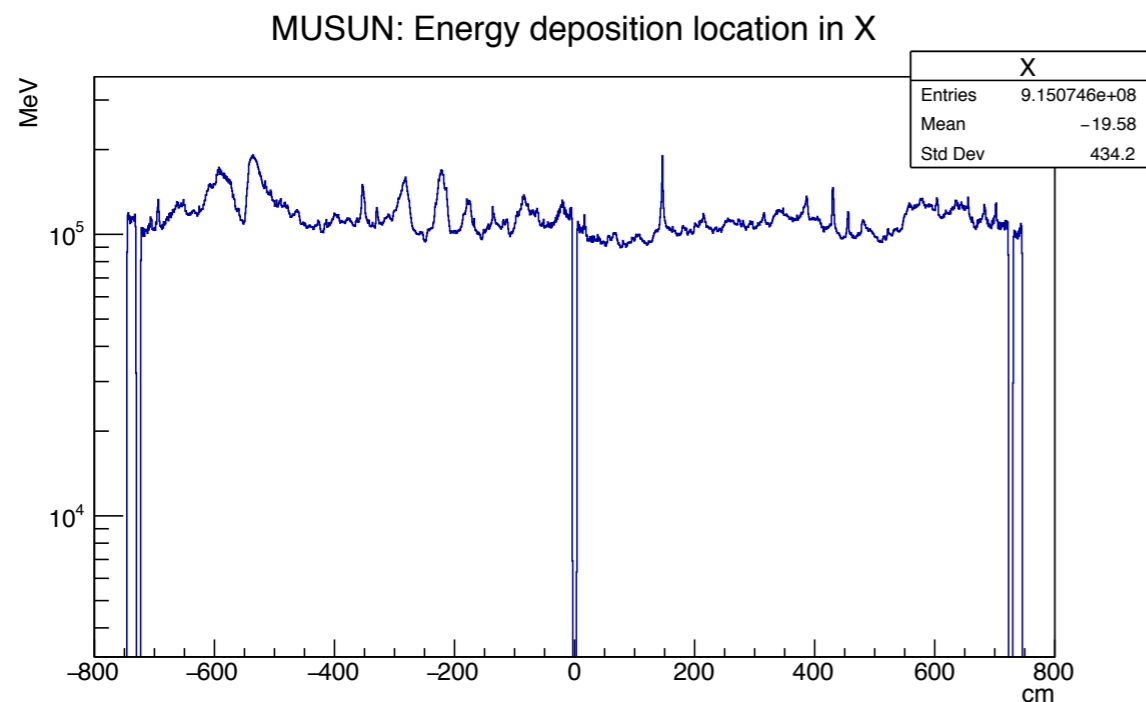
MUSUN: Energy deposition per unit length in active volume



MUSUN: Energy deposition by secondaries



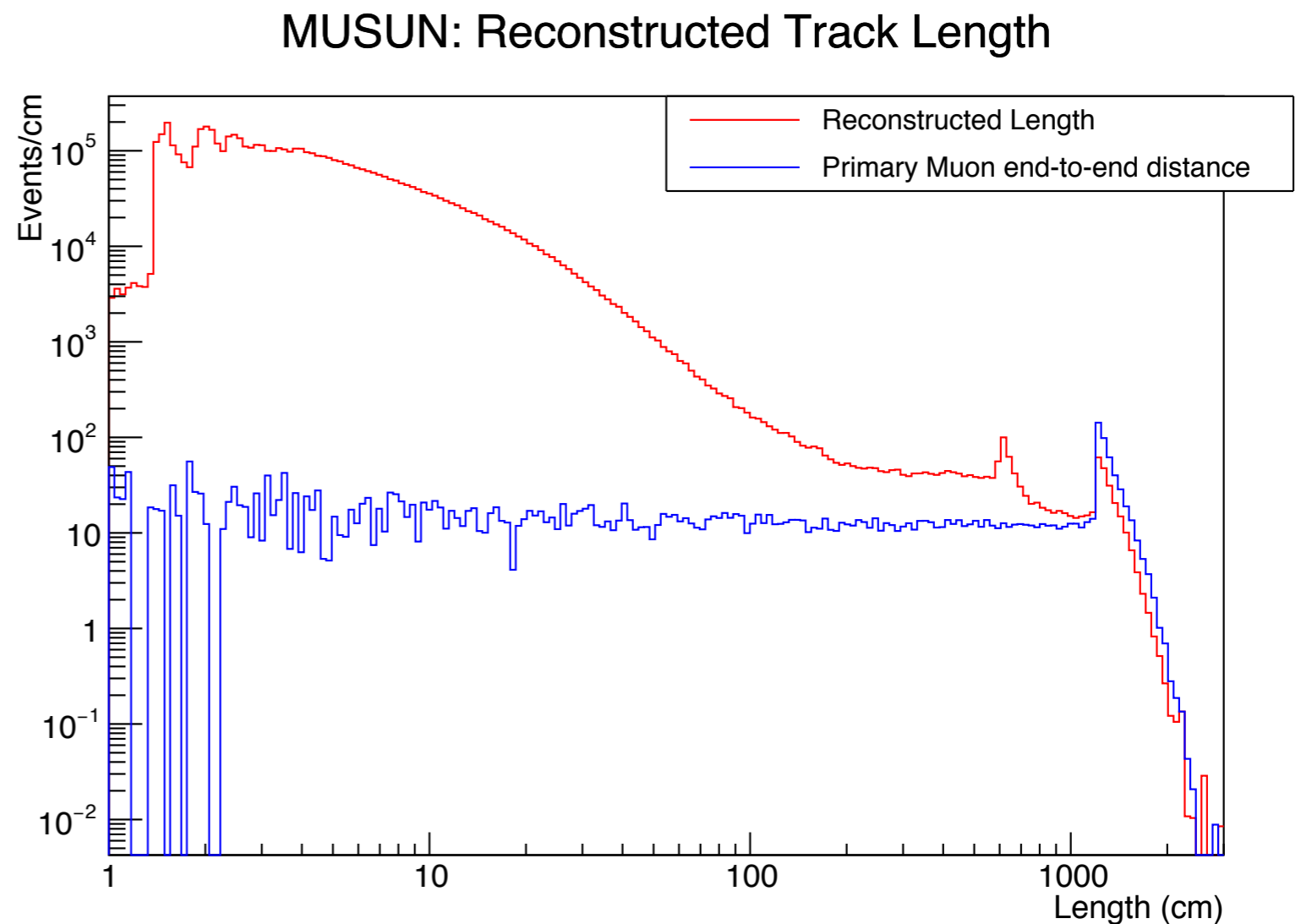
Geometric distribution of energy deposition



- Gaps in X associated with wire planes
- Spikes in Z?

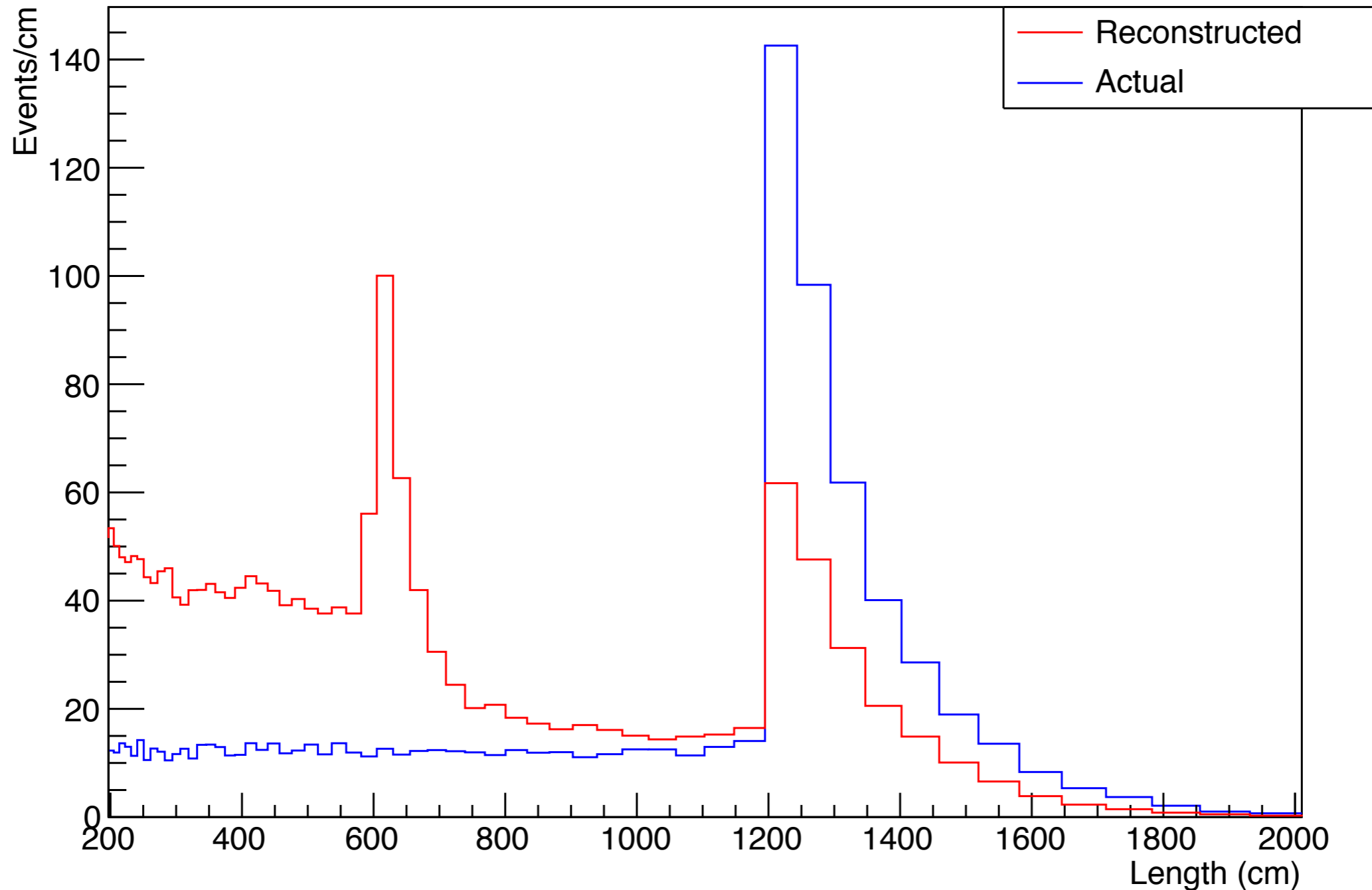
Reconstructed muon track length vs Primary end-to-end distance

- Decent match at $> 10\text{m}$
- Many additional short tracks in reconstruction
- Peak at $\sim 6\text{m}$ caused by module boundary?
- Problems handling Muon-Bremsstrahlung



Reconstruction vs end-to-end: Linear

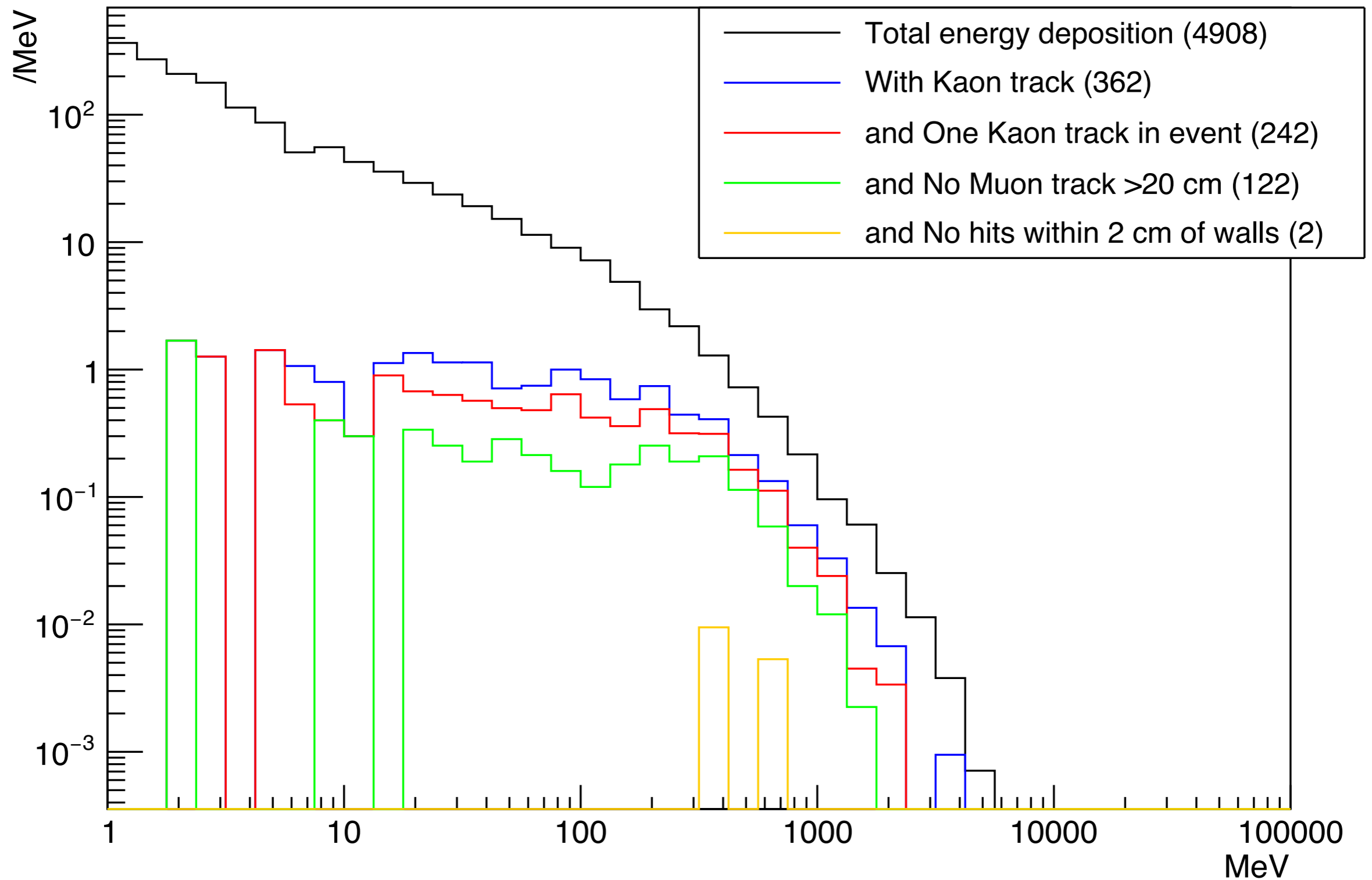
MUSUN: Track length in active volume



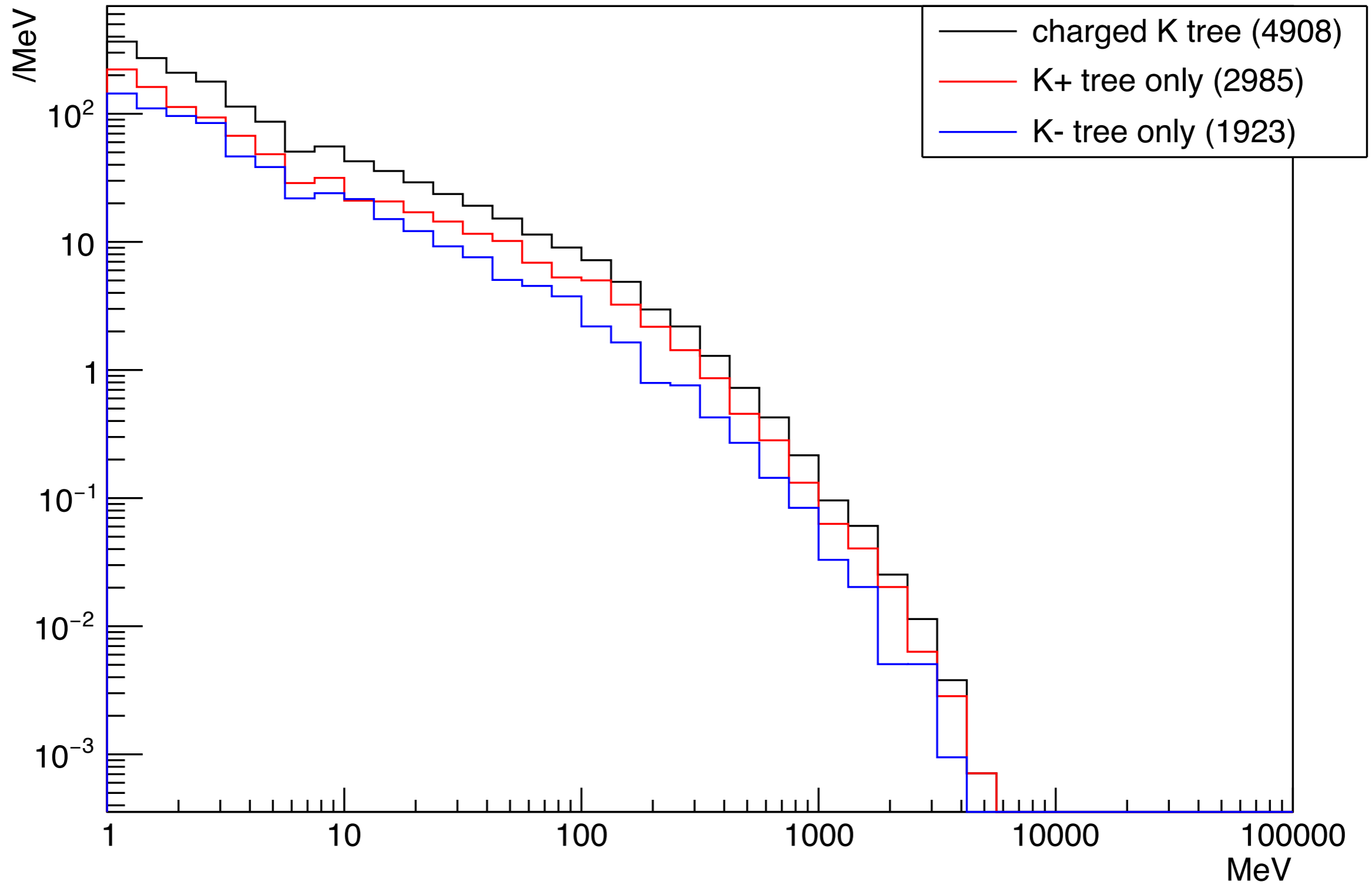
Analysis and Cuts

- Using 'truth' (LArG4 data) as reconstruction not working well enough.
- Accept only events with a single charged Kaon.
- Reject all events containing a Muon track $>20\text{cm}$ in length.
- Reject all events with energy deposition within 2cm of edge of active volume. Assumes no dead regions between TPCs.
- Look for events in the energy region of interest.

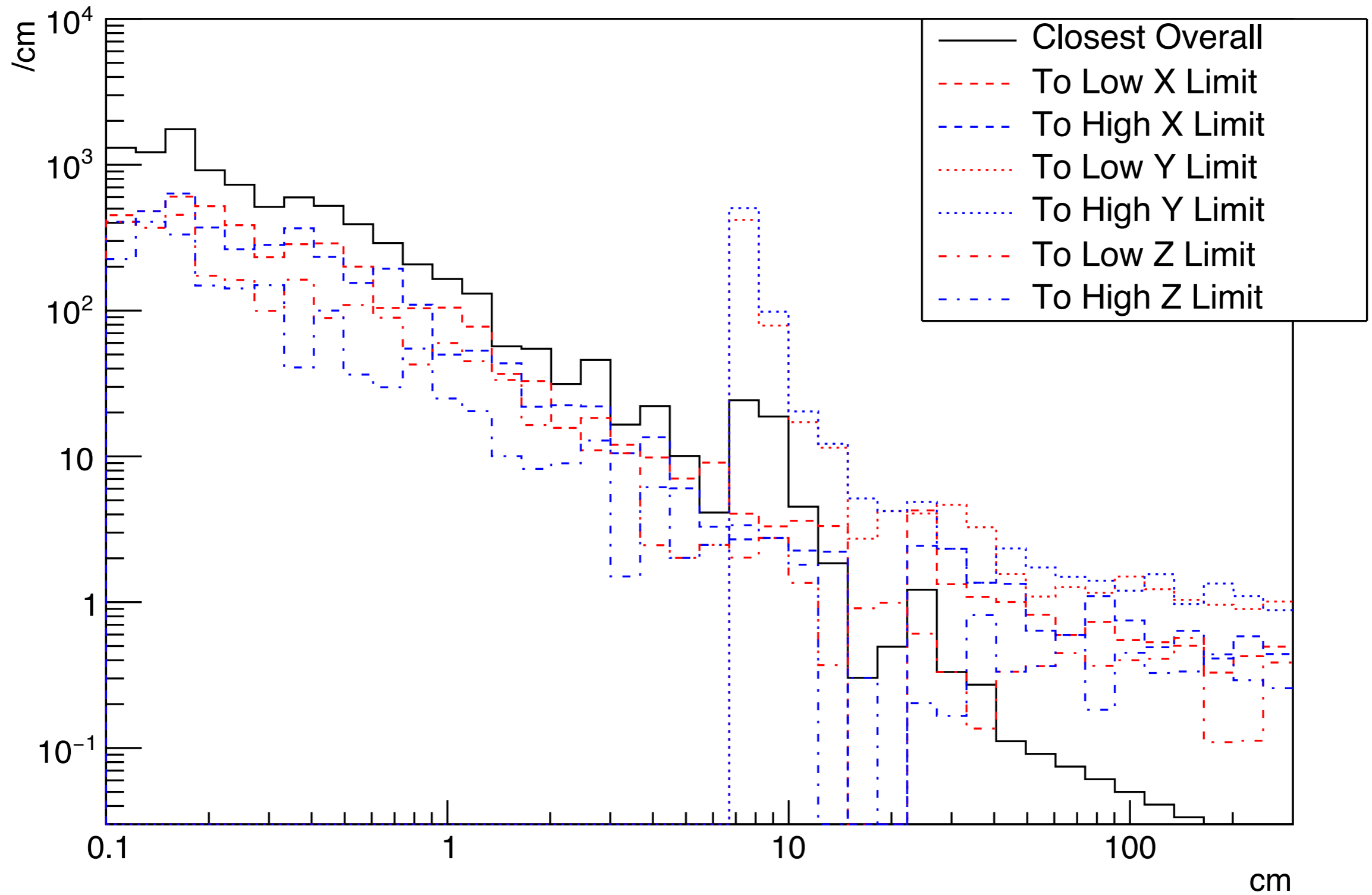
Charged Kaon Spectrum, 10^8 filtered muons



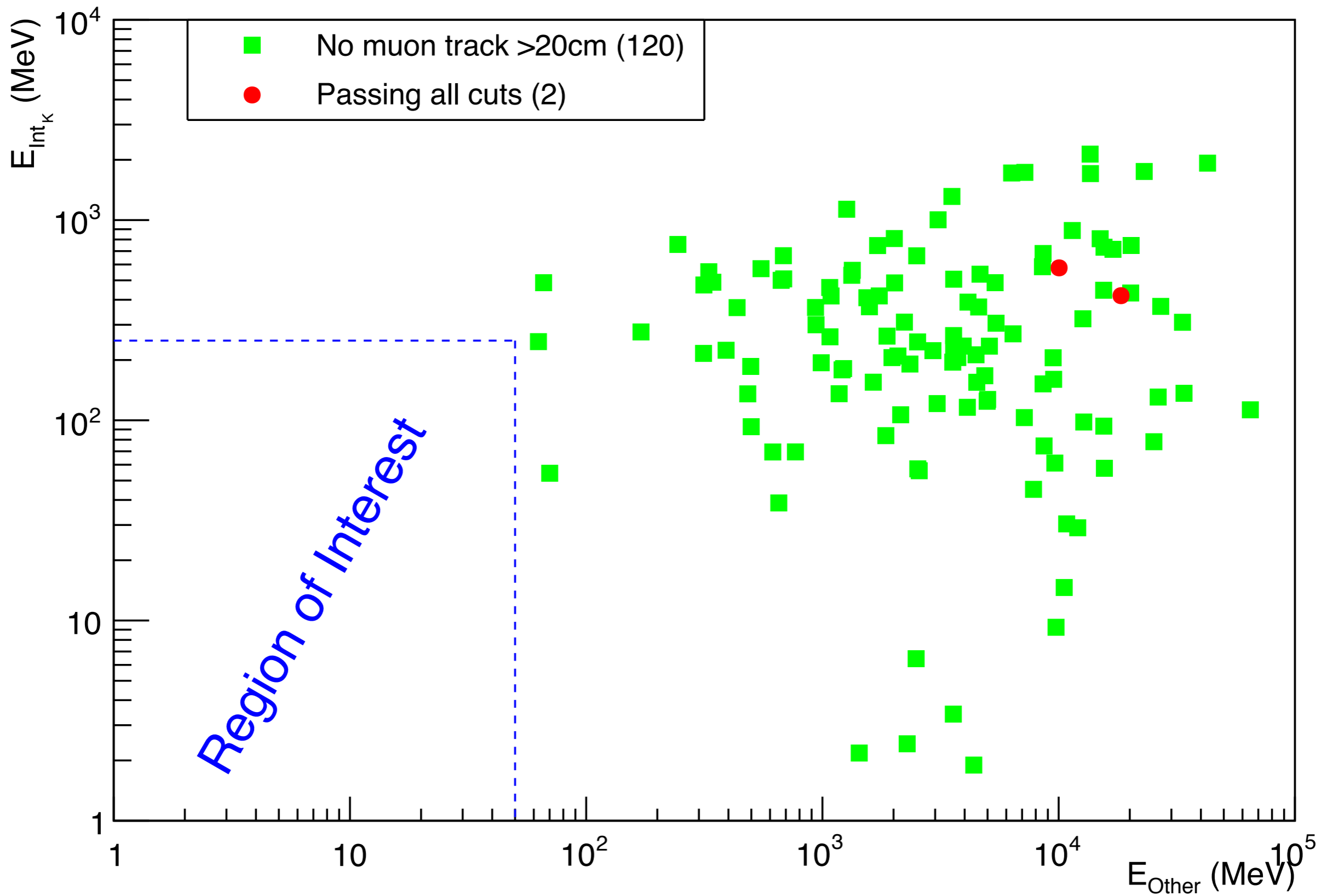
Charged Kaon Spectrum, 10^8 filtered muons



Closest hit to wall (edge of cryostat active)



Background Candidates



Higher statistics

- With a rate 0.05 Hz background studies will require around a billion events.
- 10^8 events simulated and analysed so far. More on the way.
- Filter used to reject long muon tracks as these are an unlikely source of background.

Conclusions and Plans

- MUSUN module checks out. Everything looks reasonable.
- As of larsoft version v04_29_02 MUSUN module can safely be selected as an event generator in larsoft from fhicl.
- We predict a trigger rate from cosmic muons in the current far detector geometry of 0.05 Hz.
- Analysis shows zero background so far.
- Attempt reconstruction on events without long Muon tracks. Should be far less affected by Muon-Bremsstrahlung reconstruction issue.

Kaon Parentage

- 2 events passing all cuts:
 - $\mu^+ \rightarrow \pi^- \rightarrow K^+$
 - $\mu^- \rightarrow \pi^+ \rightarrow K^+$
- 120 events passing most cuts:
 - 30 from K0L directly
 - 9 from K0L indirectly
 - 4 from K0S directly
 - 6 from K0S indirectly (4 of these from K0L)
 - Full list on indico page “parentage.pdf”

Event Display

- Working on it. Sorry, not used it before.
- 2 events passing all cuts have been reconstructed (reconstruction output on indico page)
- Got data on the plots, but can't find them in the display window

