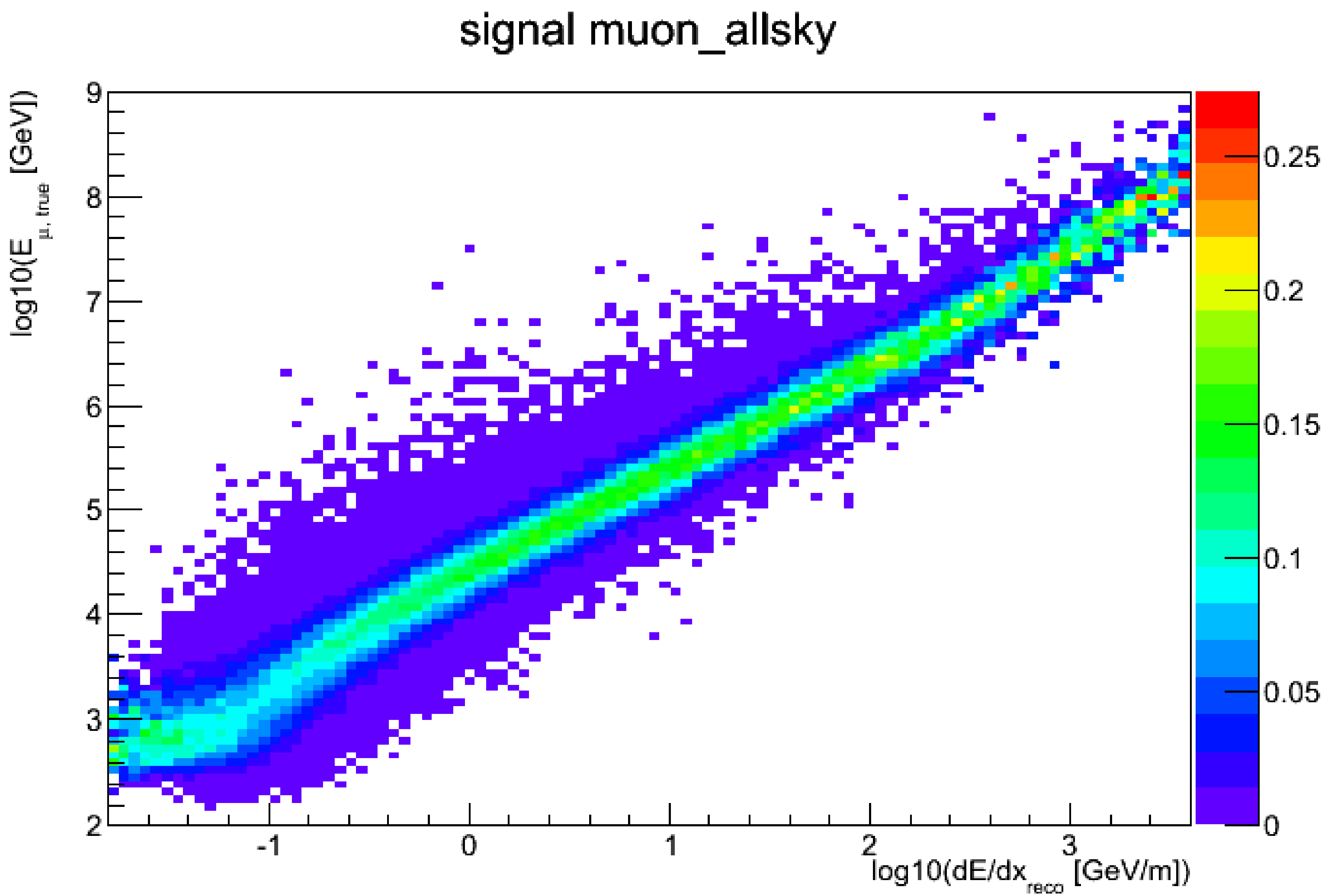
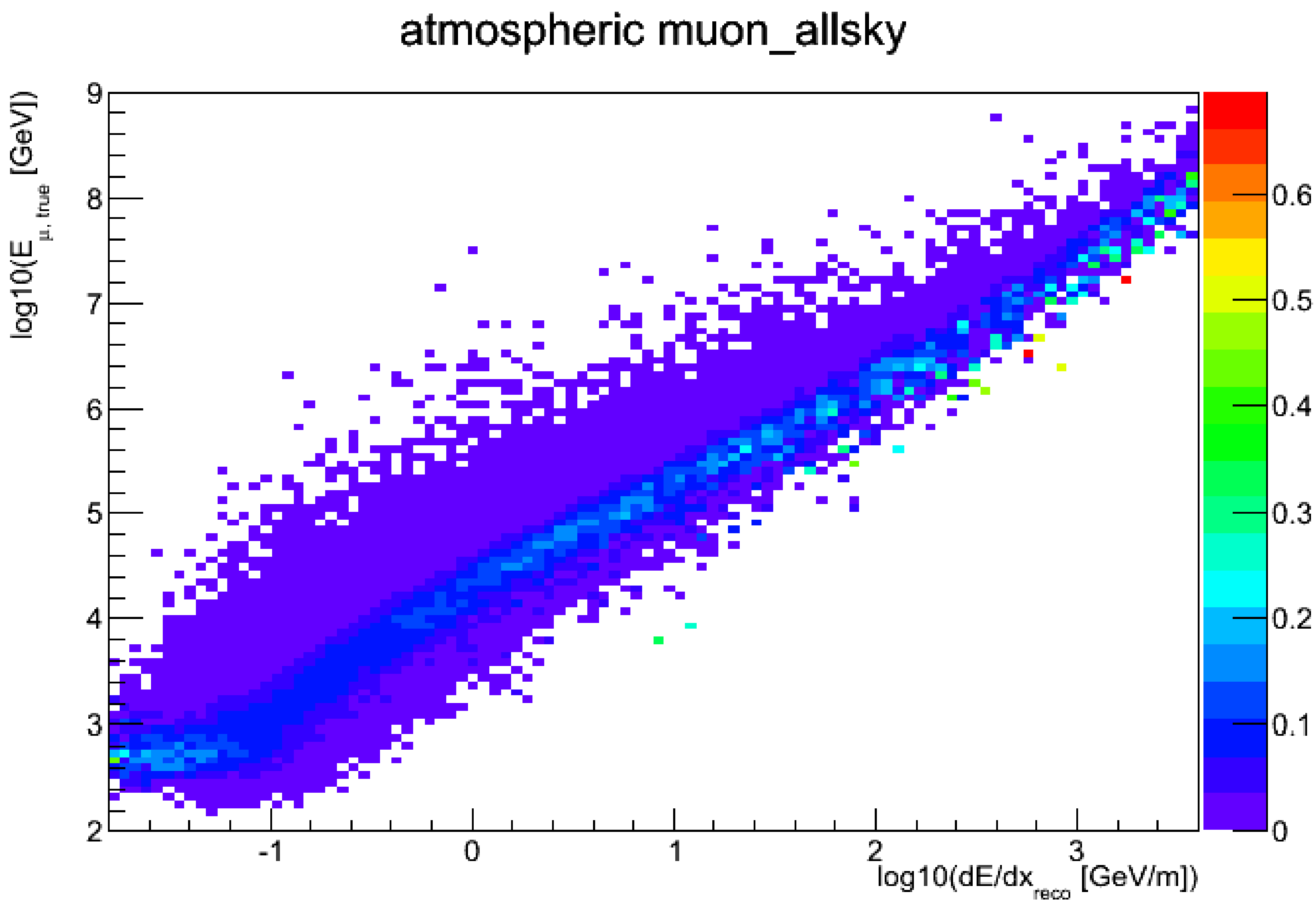
Apollon energy?

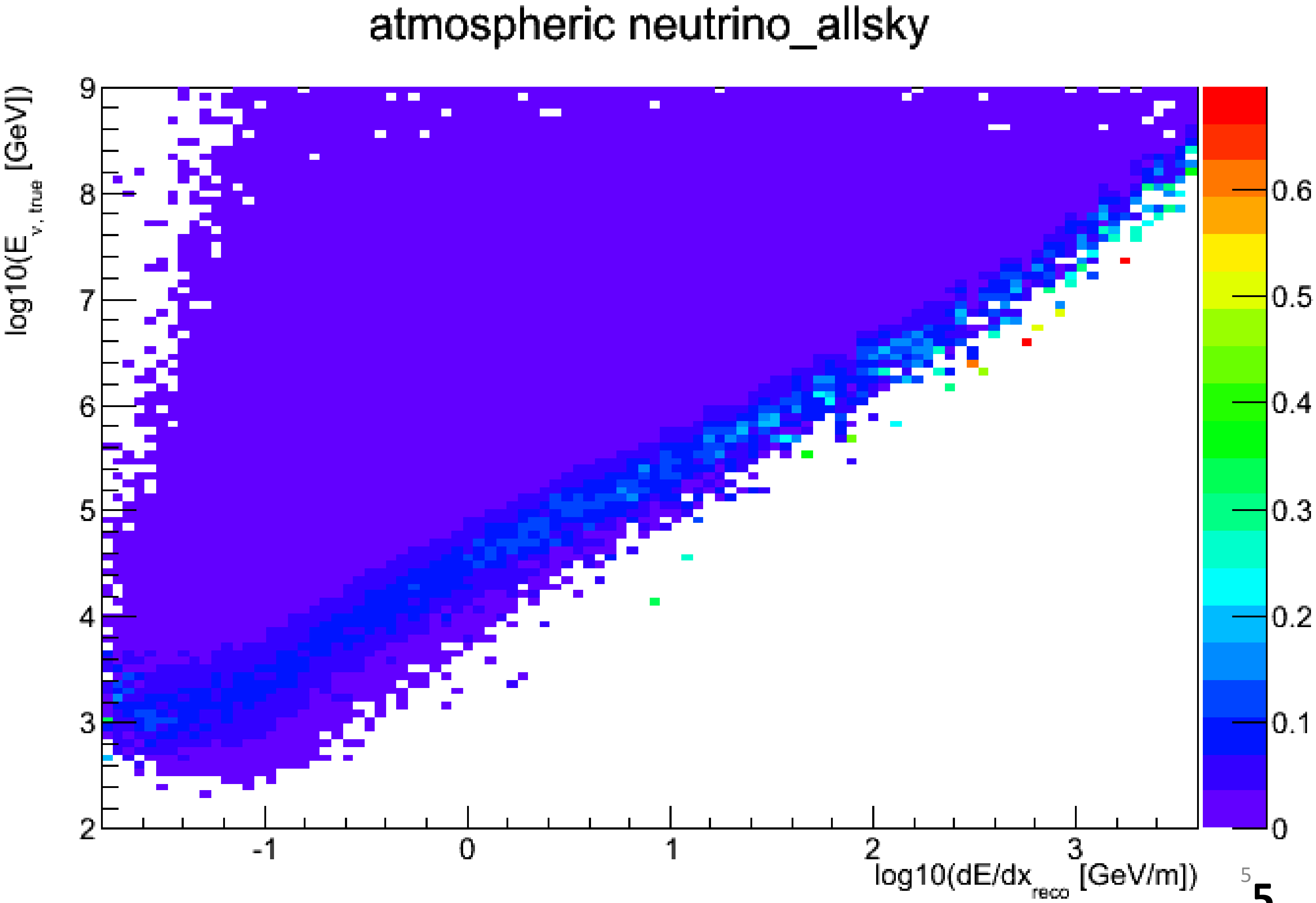
Anne Schukraft and Gary Hill

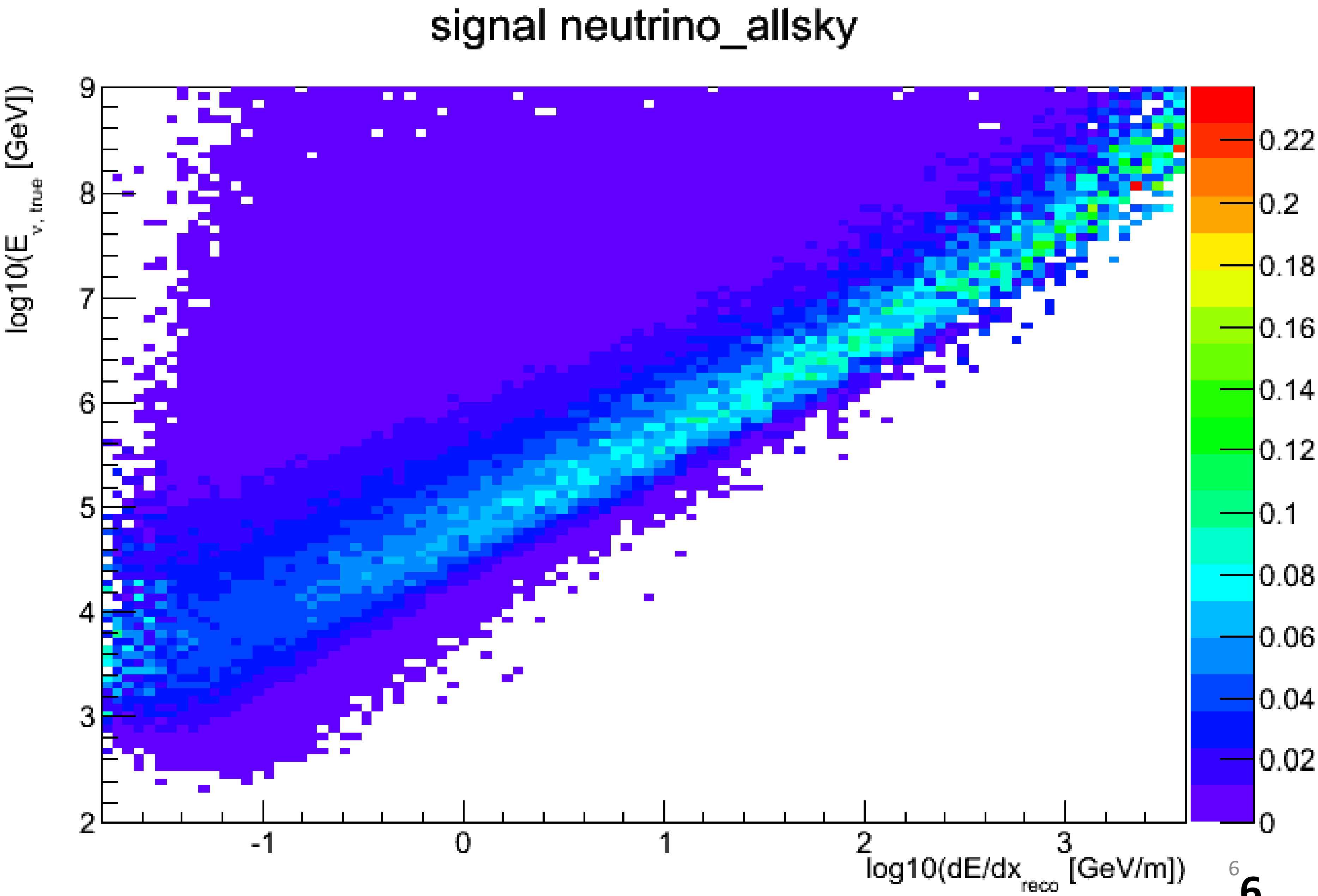
Note: all numbers are preliminary!

- How do we determine an energy?
- Know log10(dE/dx) = 1.37 for Apollon
- Look at a scatter plot of dE/dx vs true muon or neutrino energy
- Draw a vertical line at log10(dE/dx) = 1.37
- Integrate from bottom and top along curve to 16% to get a one-sigma central energy range
- However: this depends on how we weight the true energies… atmospheric, or E^{-2} ????


signal muon_allsky
log10(E_μ, true [GeV])
9
8
7
6
5
4
3
2
-1
0
1
2
3
log10(dE/dx_reco [GeV/m])
0.25
0.2
0.15
0.1
0.05
0


atmospheric muon_allsky
log10(E_{μ, true} [GeV])
log10(dE/dx_{reco} [GeV/m])
9
8
7
6
5
4
3
2
-1
0
1
2
3
0.6
0.5
0.4
0.3
0.2
0.1
0


atmospheric neutrino_allsky
log10(E_{ν, true} [GeV])
9
8
7
6
5
4
3
2
-1
0
1
2
3
log10(dE/dx_{reco} [GeV/m])
0.6
0.5
0.4
0.3
0.2
0.1
0
5

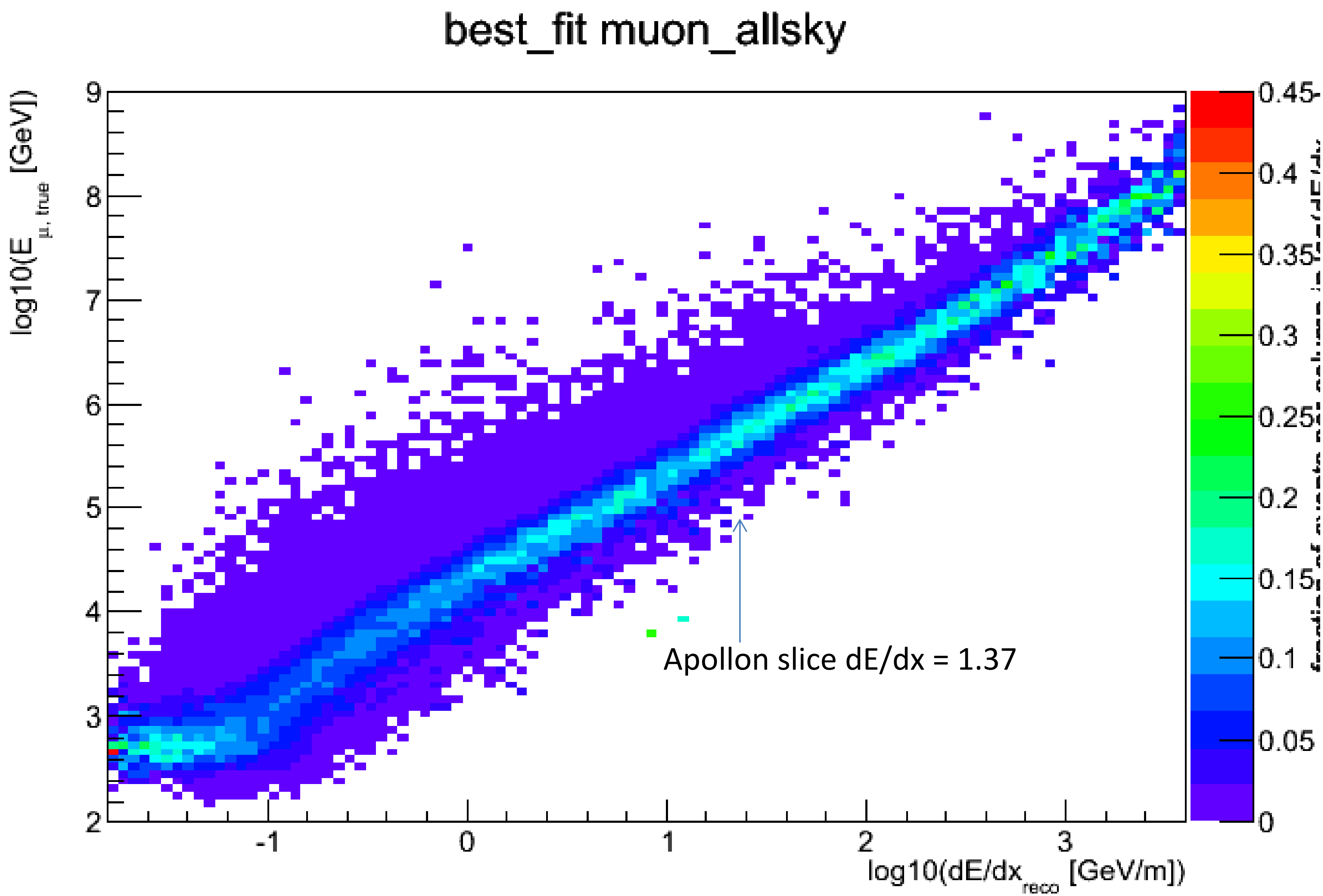

signal neutrino_allsky
log10(E_ν, true [GeV])
log10(dE/dx_reco [GeV/m])
9
8
7
6
5
4
3
2
-1
0
1
2
3
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0

- The choice of flux makes a difference:

- For Apollon:
- 420 vs 580 TeV muon energy (median)
- 600 TeV vs 2 PeV neutrino energy (median)
- How do we choose?

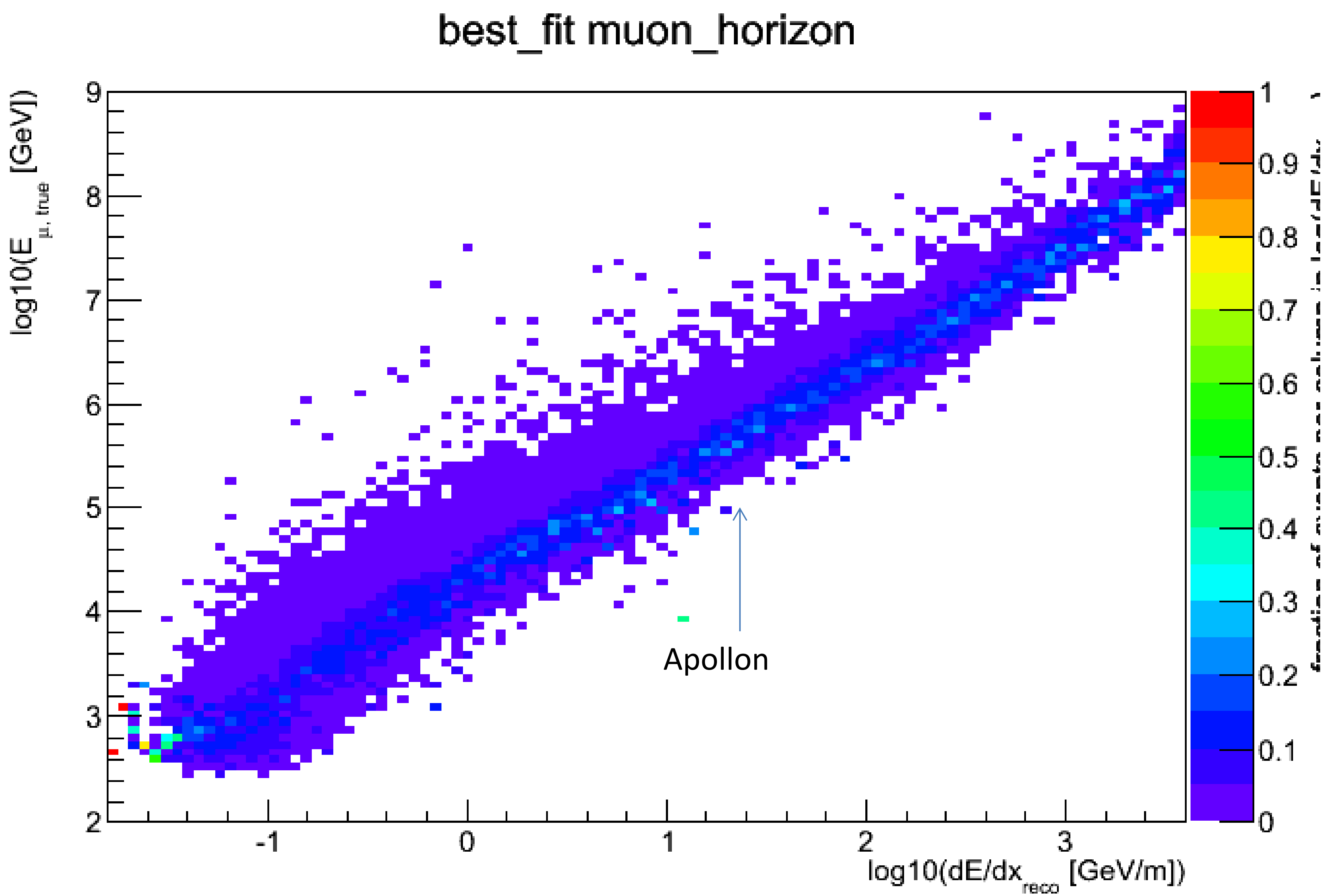
- We don’t have to choose:

- We know more: we fitted for both fluxes, so use the final best fit mixture as the weighting
- Weight to the best fit mixture from IC59 analysis



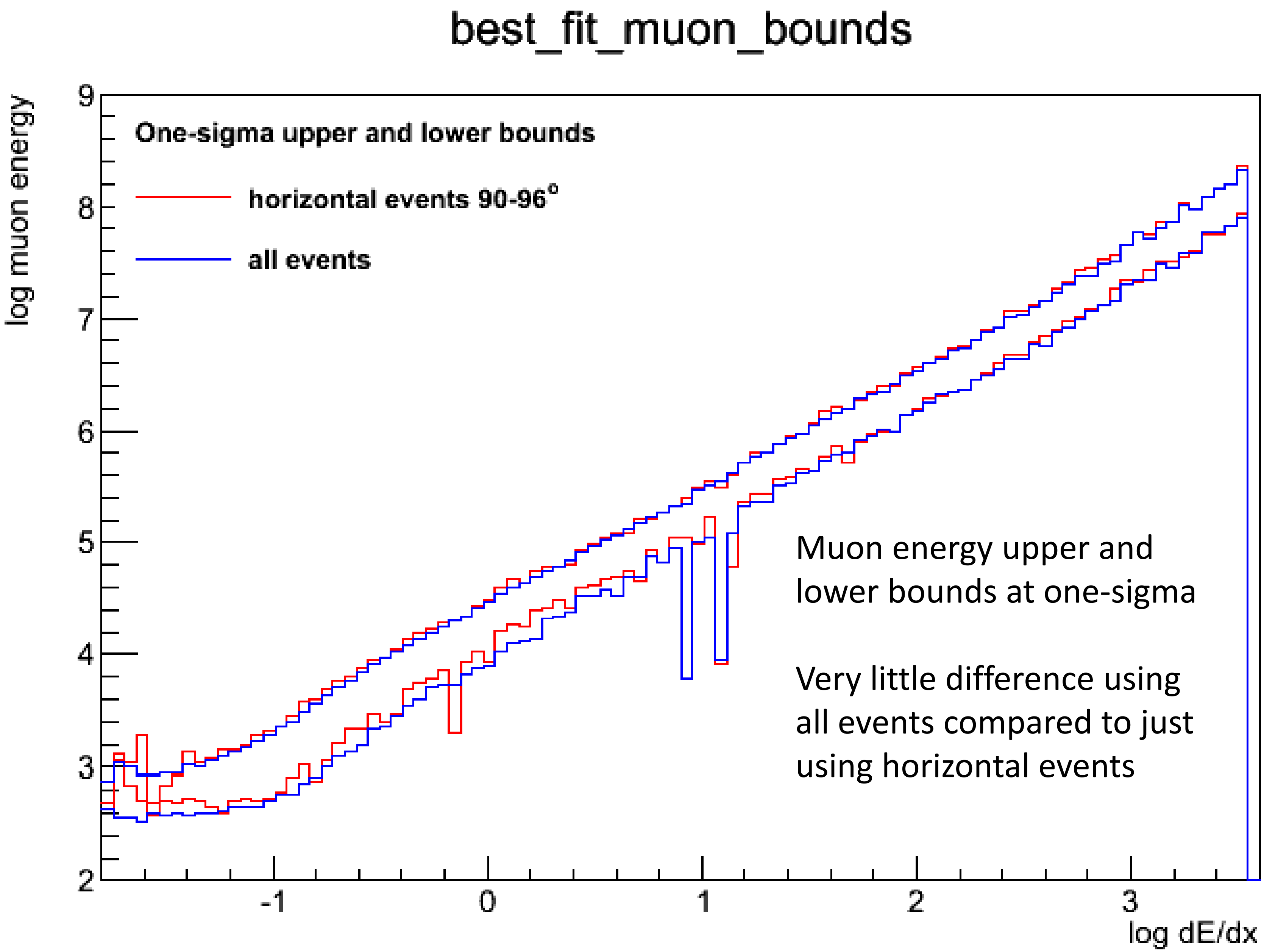
Scatter plot for muons, weighted to best fit mixture of atmospheric and signal from the IC59 analysis

Muon energy



Better: we know Apollon is near-horizontal, so take MC 90-96 degrees

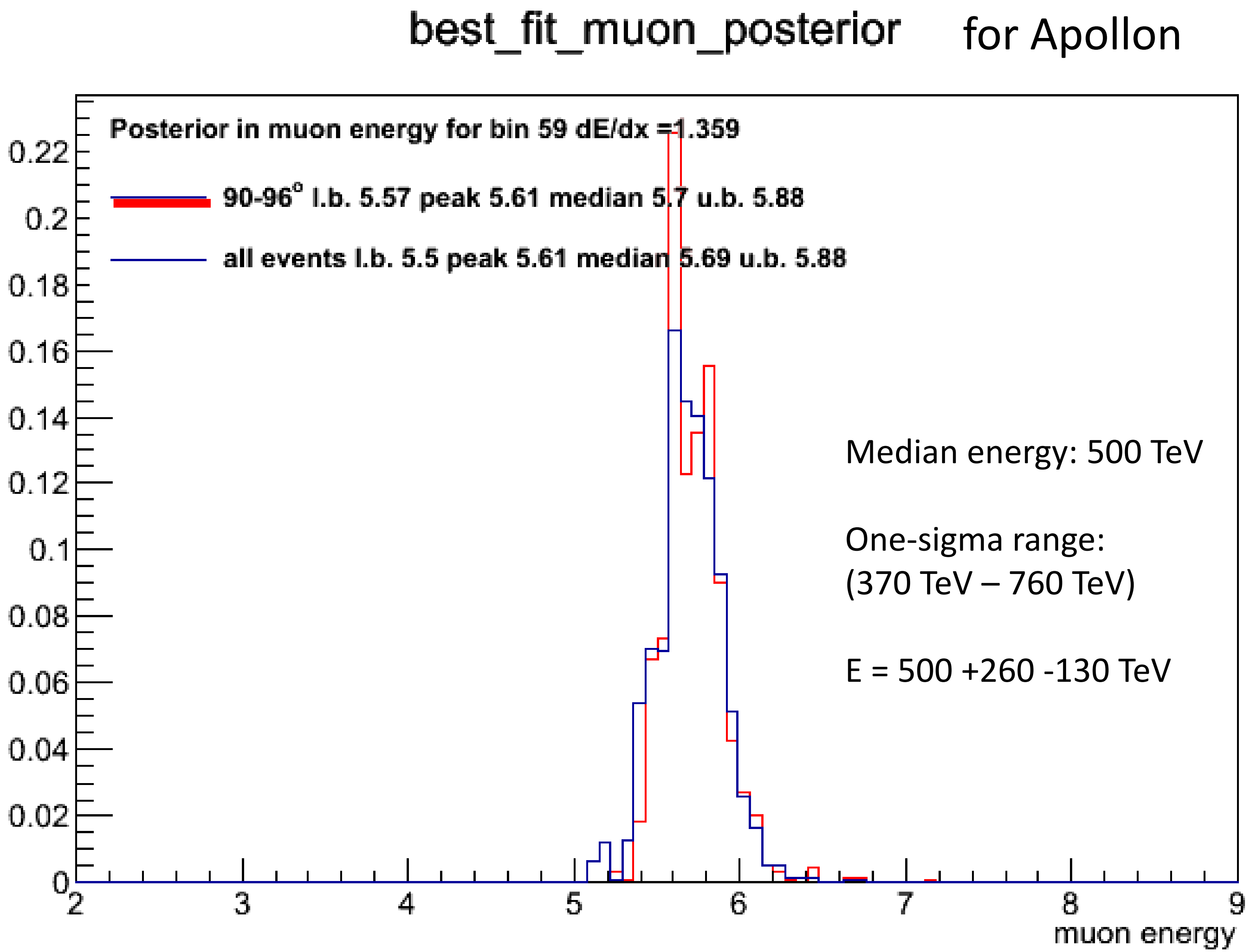
Muon energy



Muon energy upper and lower bounds at one-sigma

Very little difference using all events compared to just using horizontal events

Muon energy



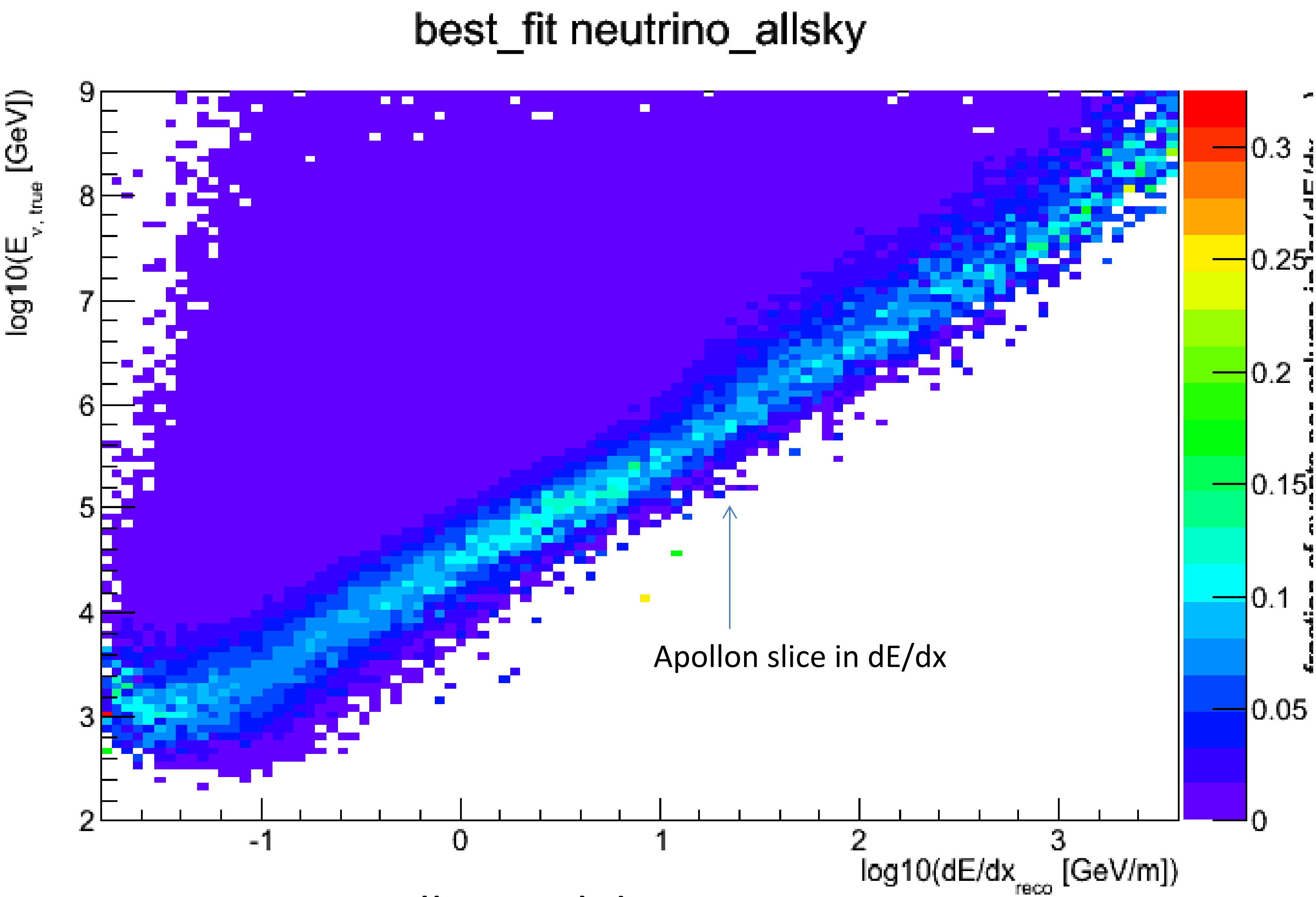
for Apollon

Median energy: 500 TeV

One-sigma range:
(370 TeV – 760 TeV)

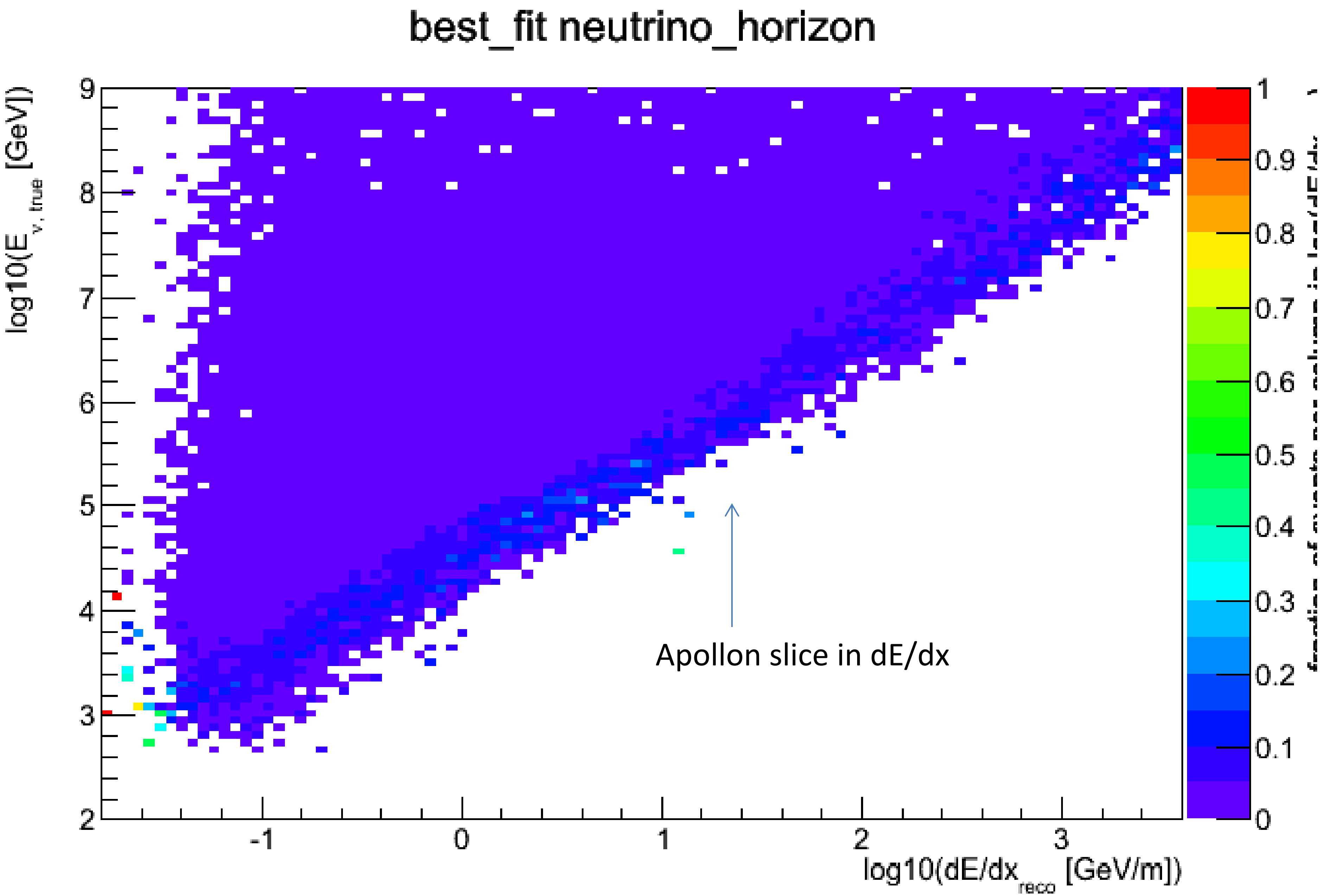
E = 500 +260 -130 TeV

Muon energy



Neutrino energy, all arrival directions

Exclude muon-less events



Neutrino energy, horizontal directions

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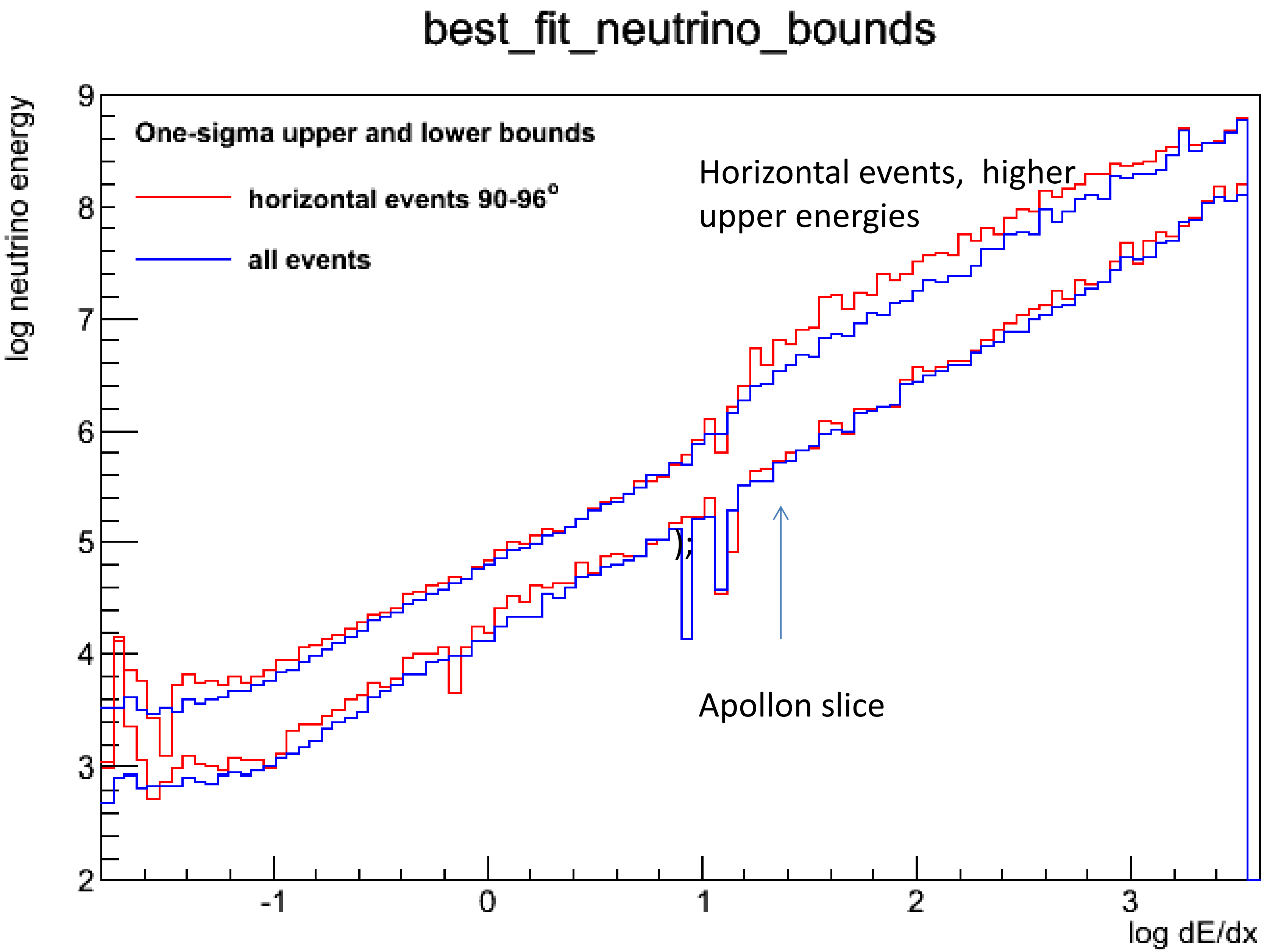
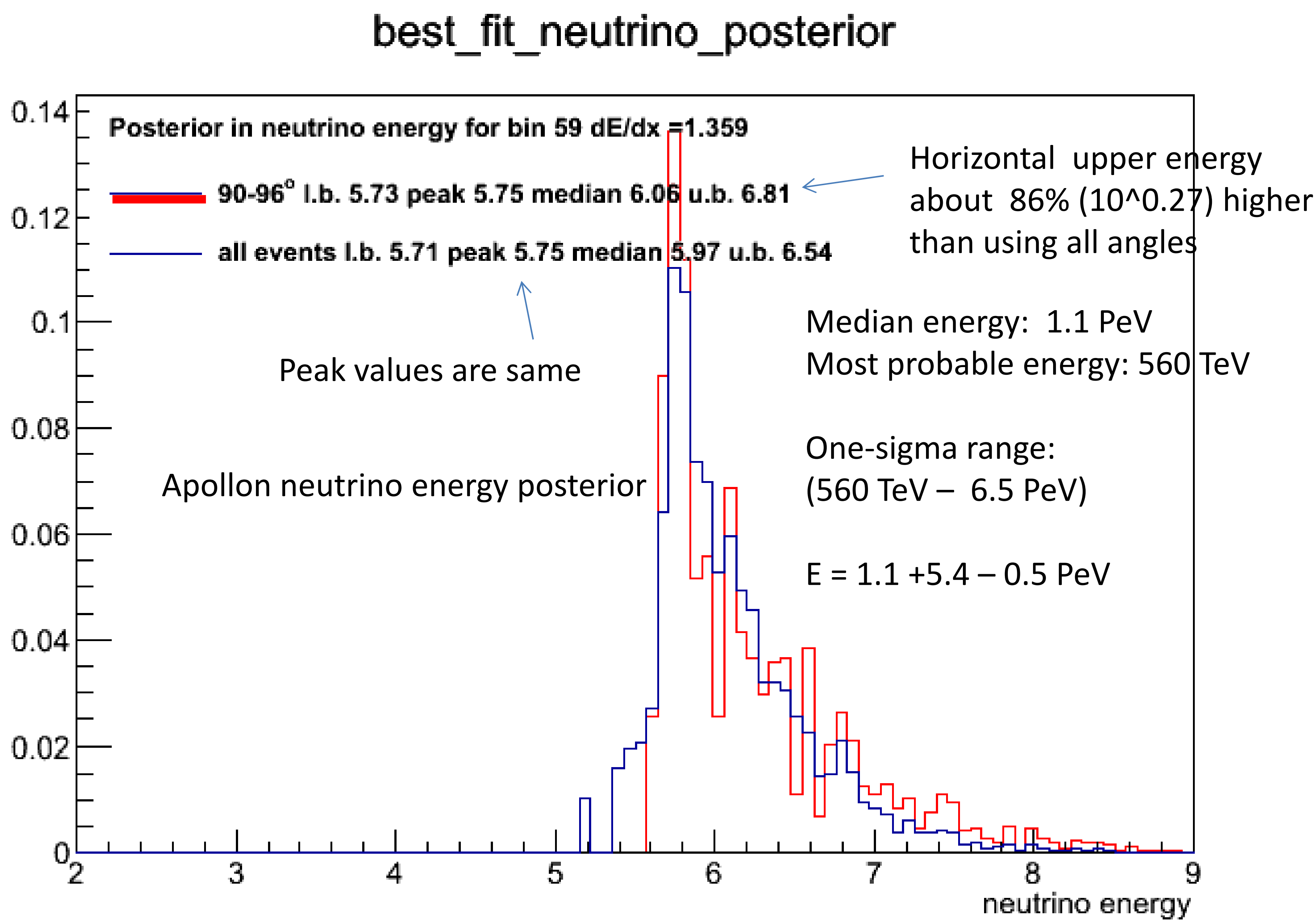


See slightly higher neutrino energies for horizontal vs all directions – earth absorption



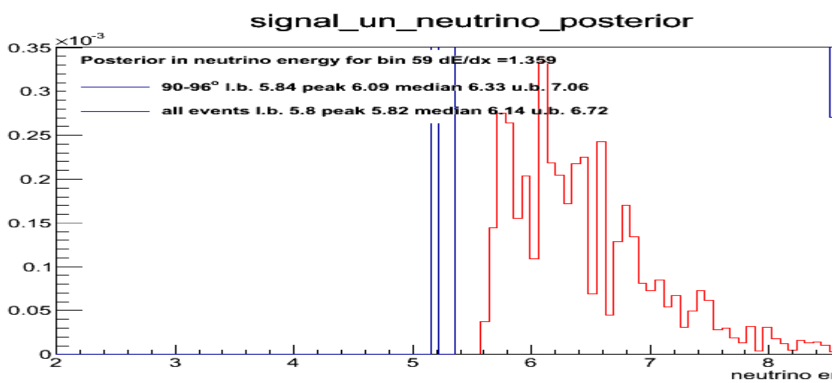
Neutrino energy

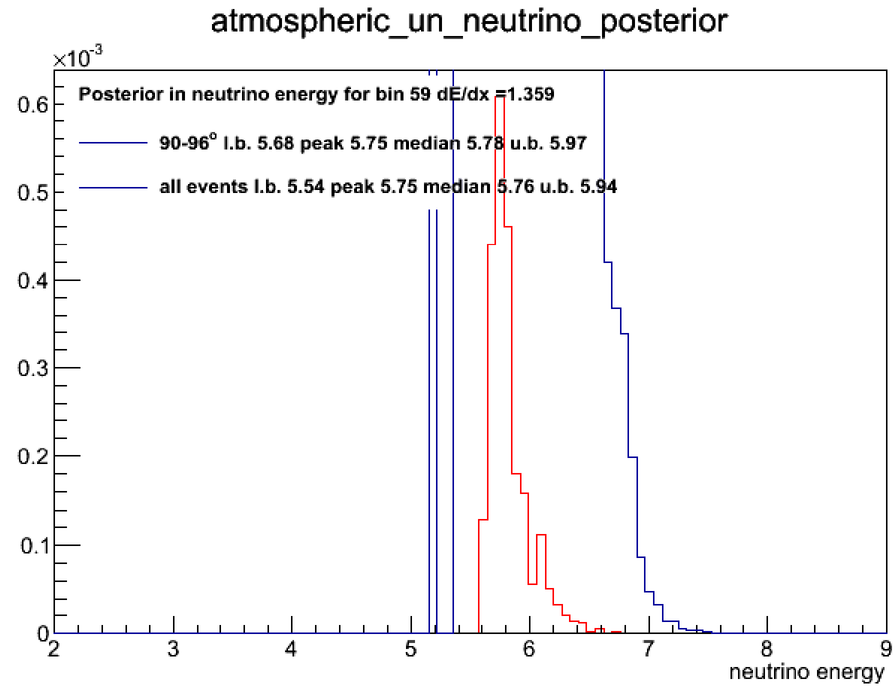
However…

- Apollon is either an atmospheric neutrino, or it is a signal neutrino
- The fit tells us the odds of each, for the observed dE/dx, and knowing it is horizontal

Look at the posteriors for each case

Areas are in the ratio 2:1 favouring a signal origin





If it’s signal (2/3), it’s likely more than 1 PeV.

If it’s atmospheric (1/3), it’s likely less than 1 PeV.

Conclusions

- Apollon is likely higher energy than we have previously thought… sometimes quoting 100-300 TeV neutrino energy…

- 500 TeV muon energy
- 1 PeV neutrino energy

- All numbers are preliminary

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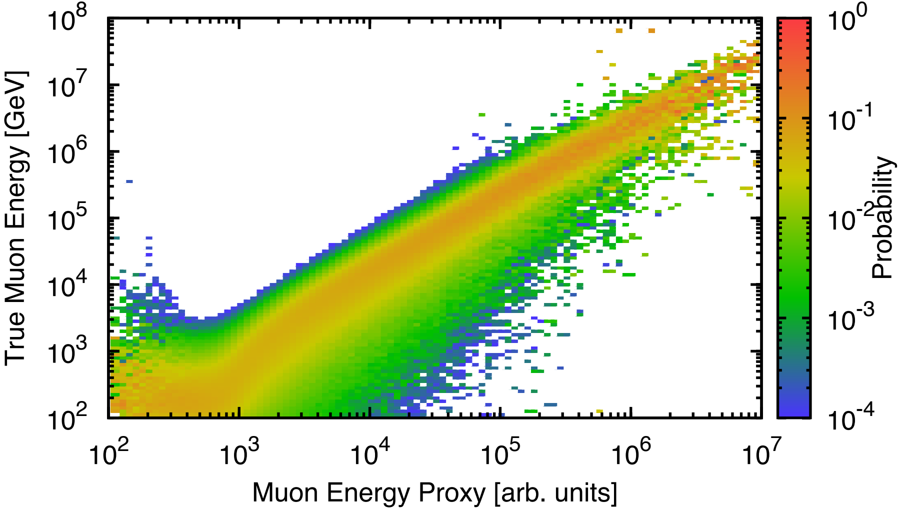
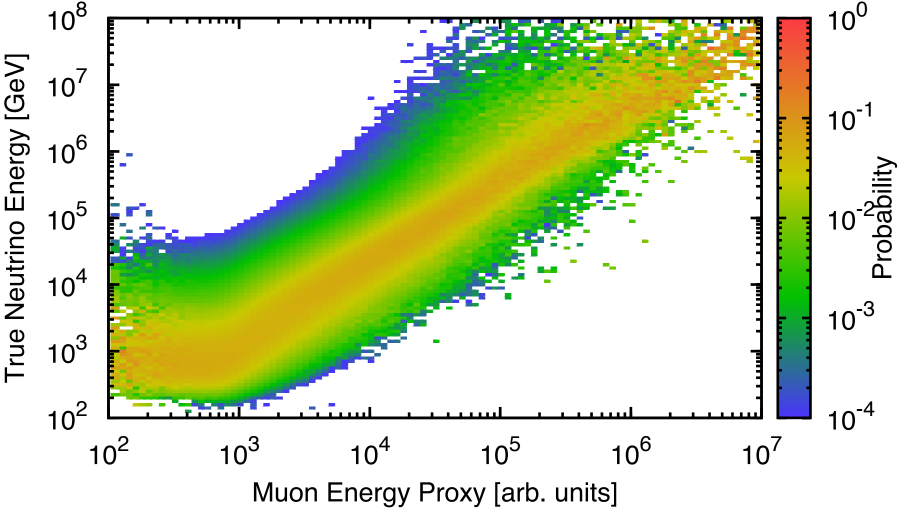


True Muon Energy [GeV]
Muon Energy Proxy [arb. units]
Probability
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}

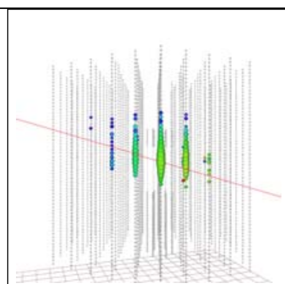
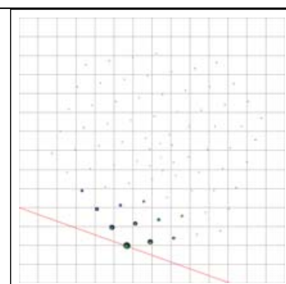
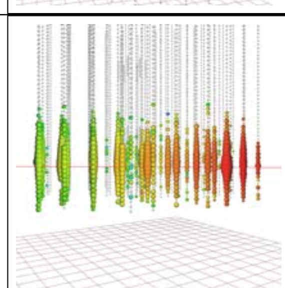
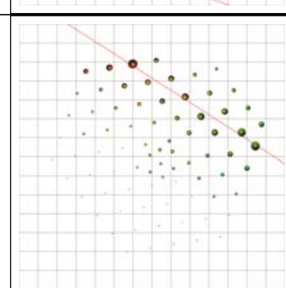
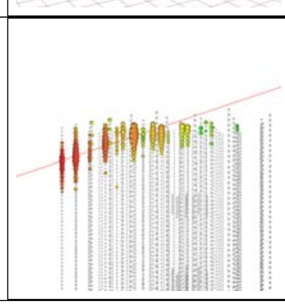
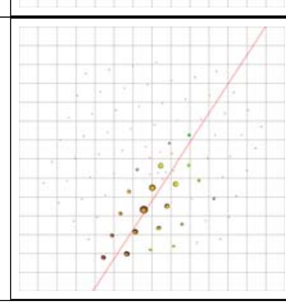


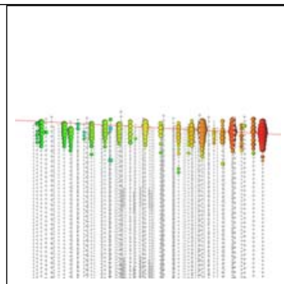
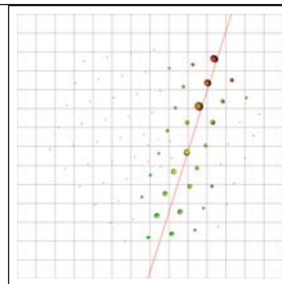
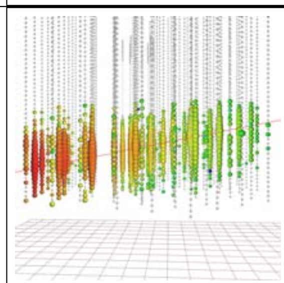
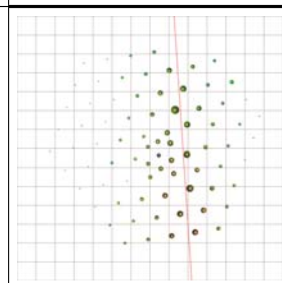
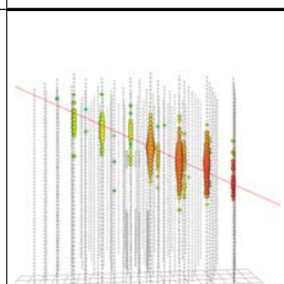
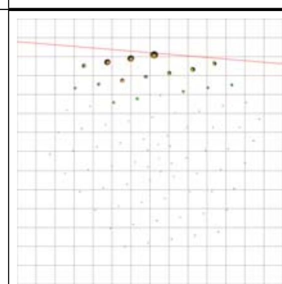
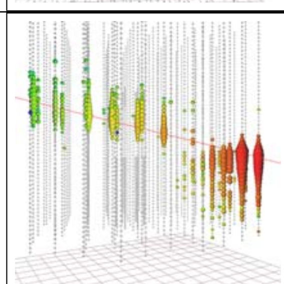
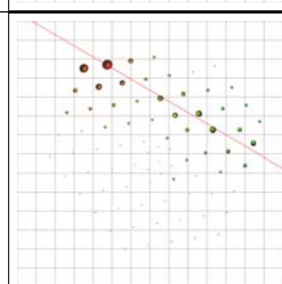
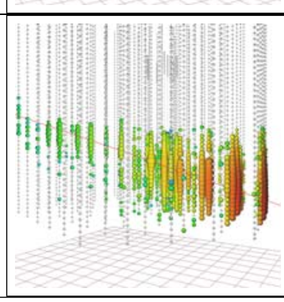
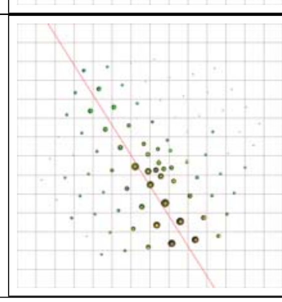
True Neutrino Energy [GeV]
Muon Energy Proxy [arb. units]
Probability
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}

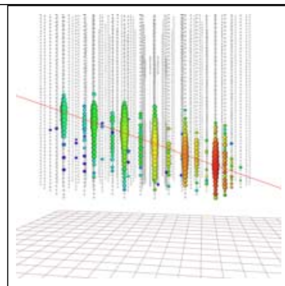
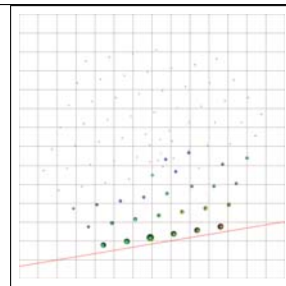
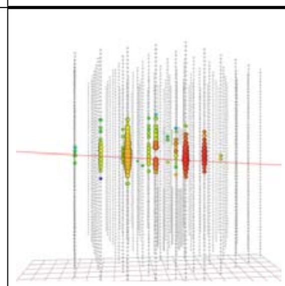
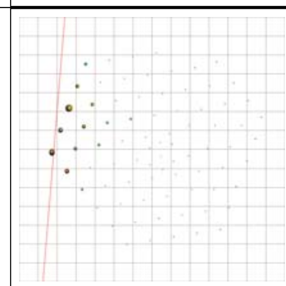
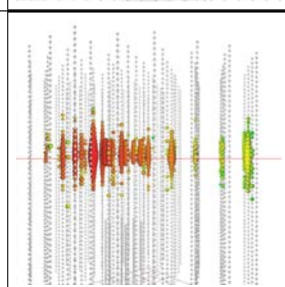
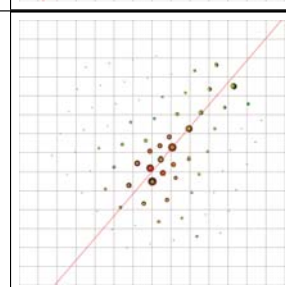
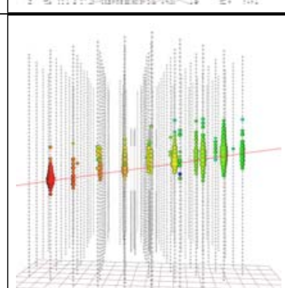
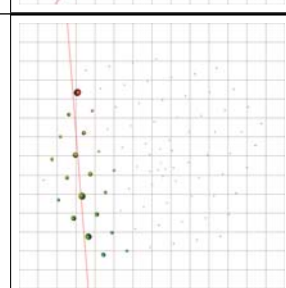
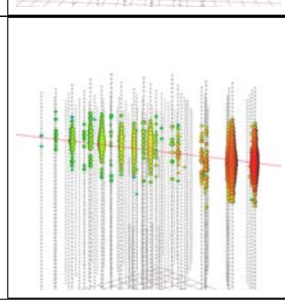
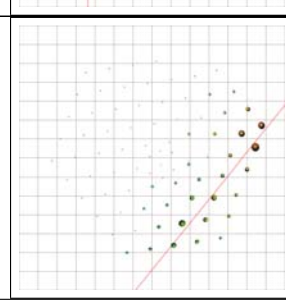
APPENDIX
Details of Observed Events

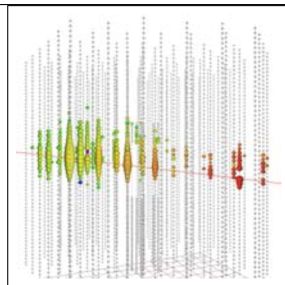
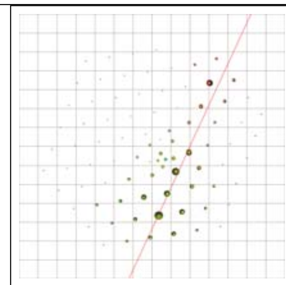
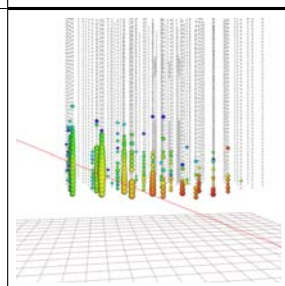
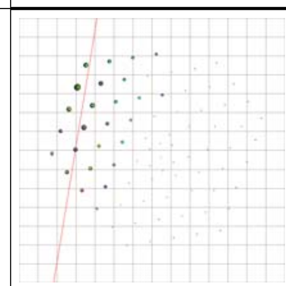
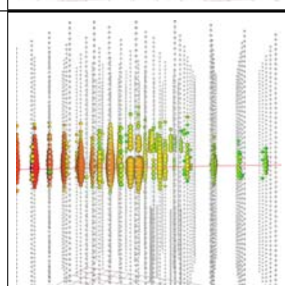
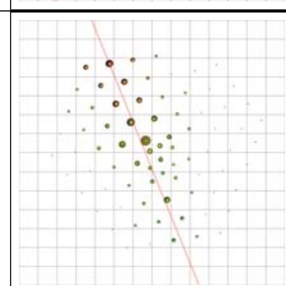
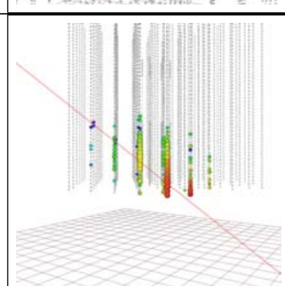
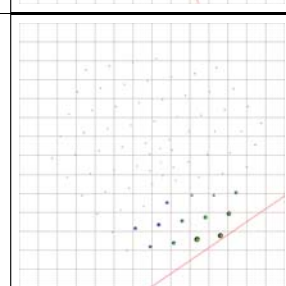
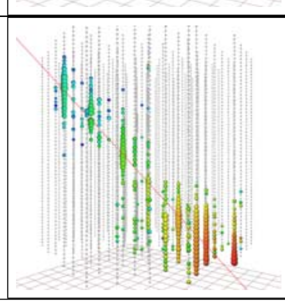
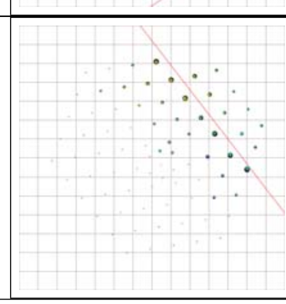
Table A.1 lists the 20 events which were found in the final data sample, which are those with energy proxy values greater than 50 TeV. The grid shown in the top view of the events has a spacing of 100 meters.

Table A.1: Images of observed events with highest estimated energies

Name	Side view	Top View	Energy Proxy Zenith Angle (Comments)
Dr. Heinrich Faust			290.1 TeV 106.3°
Dr. Hari Seldon			199.8 TeV 90.2°
Dr. Susan Calvin			160.2 TeV 108.7°

Captain Nemo			147.4 TeV 93.1°
Dr. Richard Seaton			141.9 TeV 101.1°
Dr. Henry Jekyll			133.2 TeV 114.1°
Dr. Emmet Brown			132.1 TeV 103.8°
Dr. Henry Walton Jones, Jr.			131.8 TeV 108.9°

Dr. Victor Frankenstein			109.3 TeV 106.3°
Dr. Strangelove			66.7 TeV 92.8°
Dr. Strangepork			65.1 TeV 90.0° (This is a clear starting event, also found by [103] and [104])
Impey Barbicane			64.0 TeV 97.9°
Professor Joseph Cavor			60.9 TeV 96.7°

Professor Abraham Van Helsing			60.2 TeV 96.8°
Dr. Moreau			55.2 TeV 112.0°
Buckaroo Banzai			53.4 TeV 91.0°
Dr. David Bowman			52.0 TeV 128.6°
Angus MacGyver			51.1 TeV 137.6°

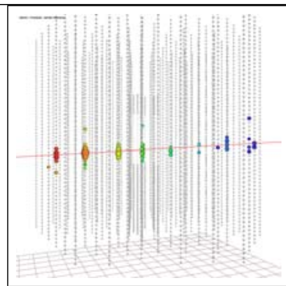
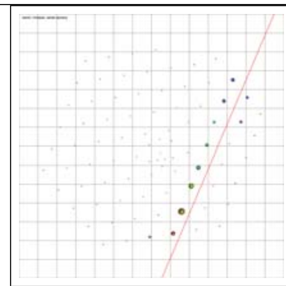
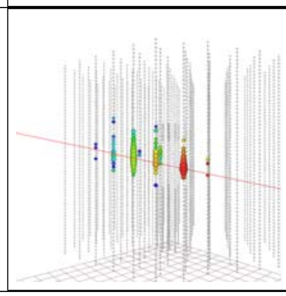
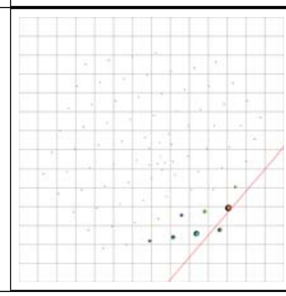
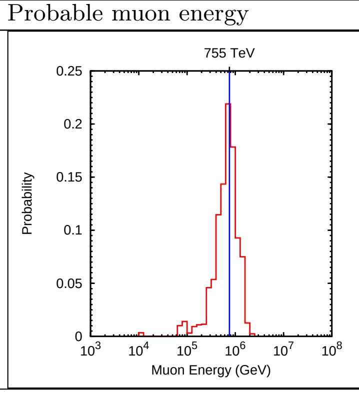
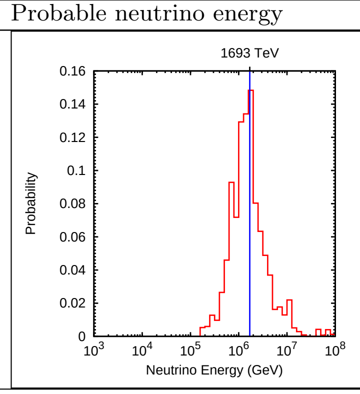
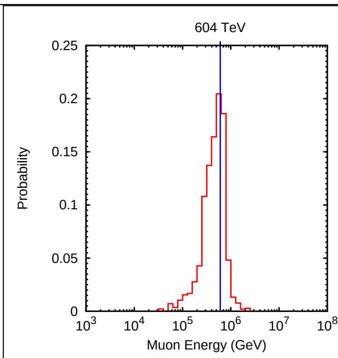
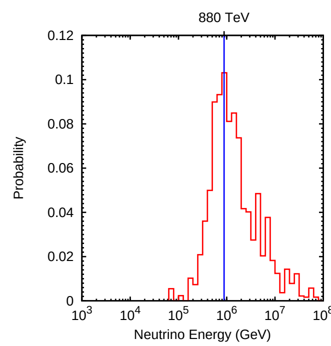
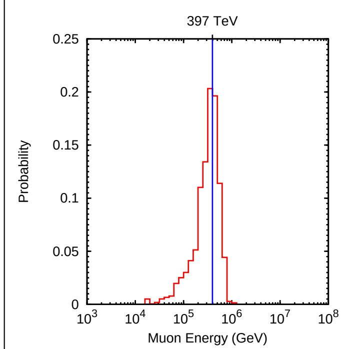
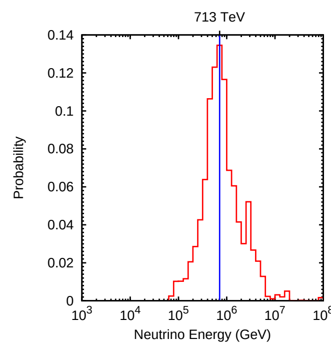
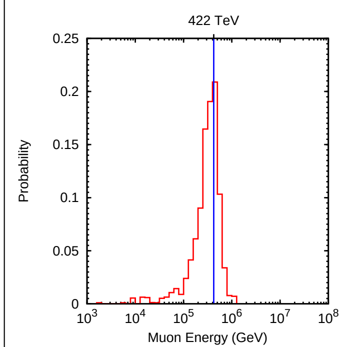
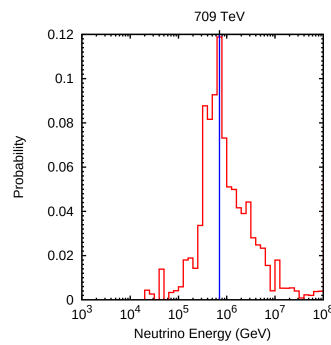
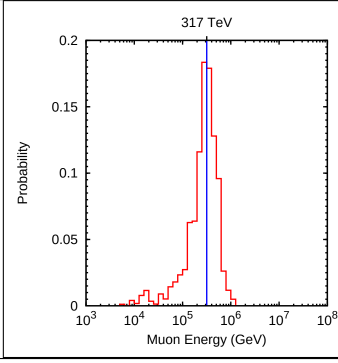
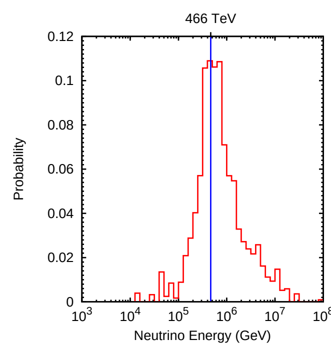
Professor James Moriarty			50.7 TeV 93.2° (This event looks quite dim due to being entirely in the dust layer.)
Dr. Giacomo Rappaccini			50.3 TeV 101.9°

Table A.2 lists the same 20 events with their true muon and neutrino energy PDFs computed assuming the spectrum fitted in Section 6.3. Each PDF is constructed from the true properties of all simulated events which have energy proxies within 5% of the observed event's value, and reconstructed zenith angles within 5° for events with energy proxies less than 100 TeV and 10° for those with larger energy proxies. Unfortunately, due to limited simulation statistics, many of these distributions still contain large fluctuations, particularly those with the highest energies. As a result, the estimated energies are rather imprecise and should be treated as 'ballpark' numbers only.

Table A.2: Inferred event energies

Name	Probable muon energy	Probable neutrino energy
Dr. Heinrich Faust		

Dr. Hari Seldon		
Dr. Susan Calvin		
Captain Nemo		
Dr. Richard Seaton		

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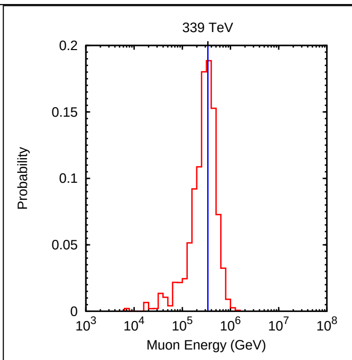

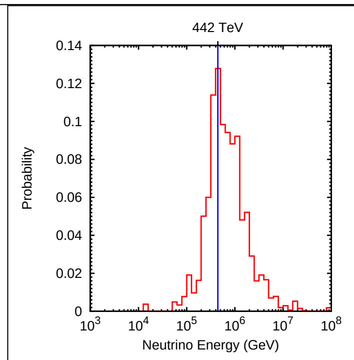

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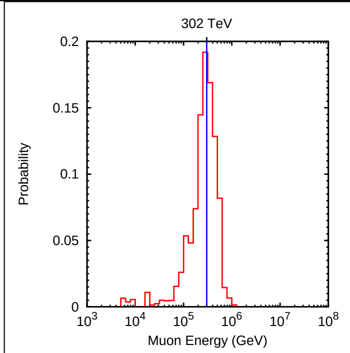

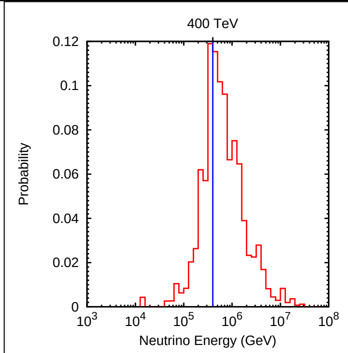

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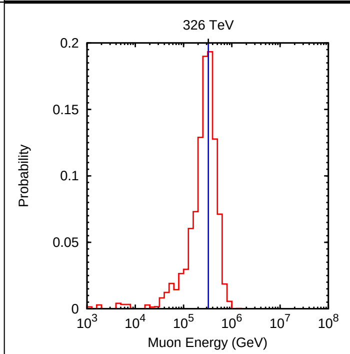

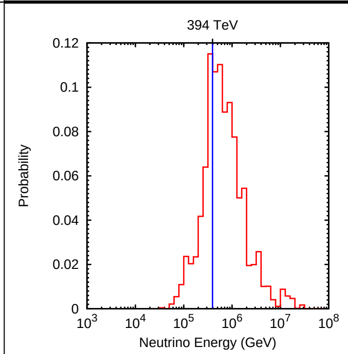

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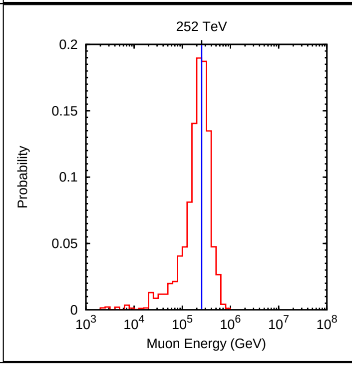
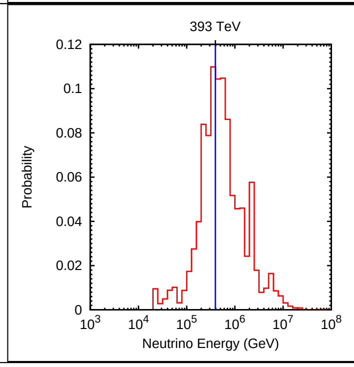
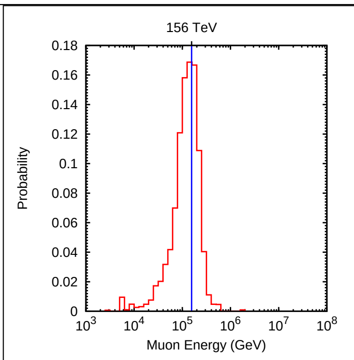
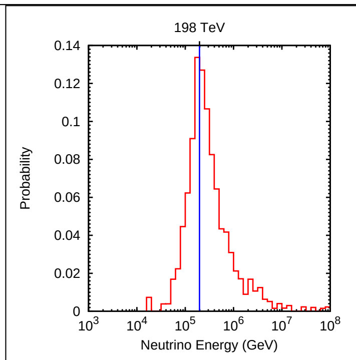
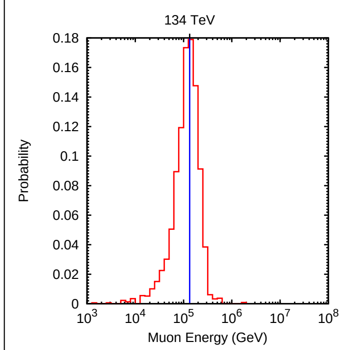
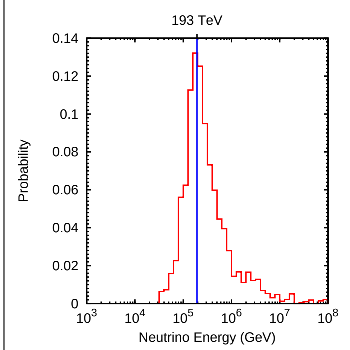
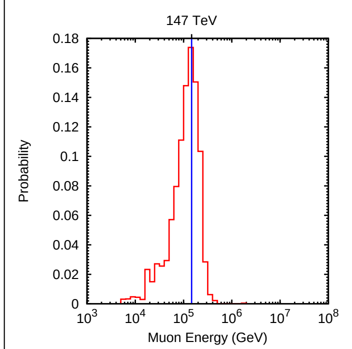
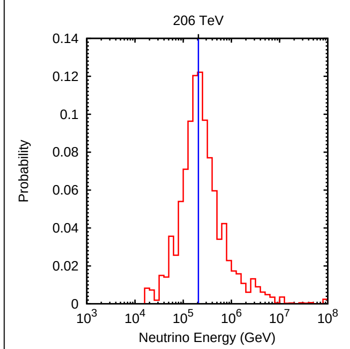
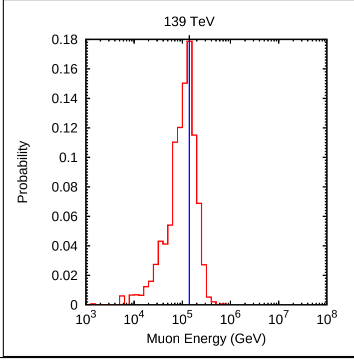
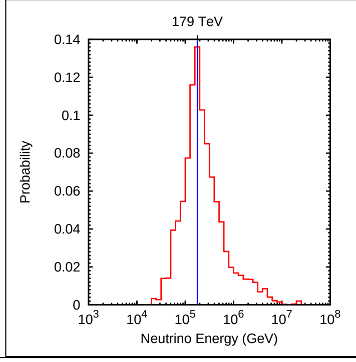




Dr. Strangelove		
Dr. Strangepork		
Impey Barbicane		
Professor Joseph Cavor		

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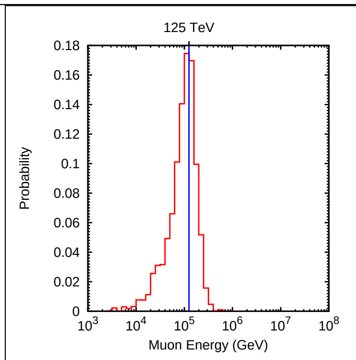
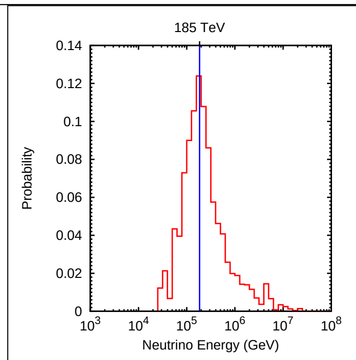
<tr><td>Professor Abraham Van Helsing</td><td>
</td><td>
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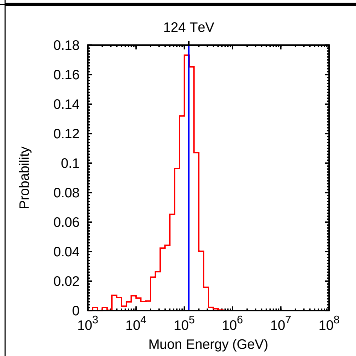
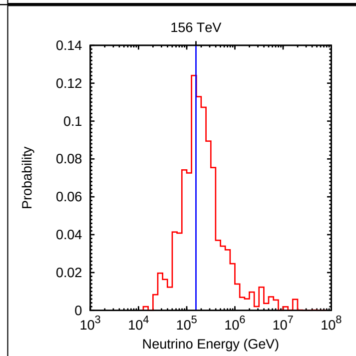
<tr><td>Dr. Moreau</td><td>
</td><td>
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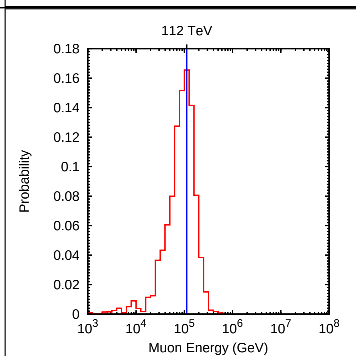
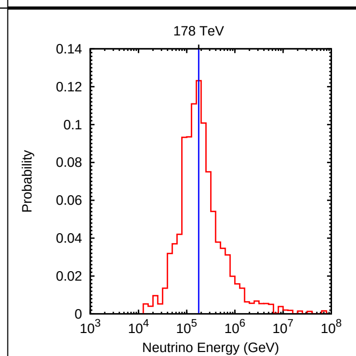
<tr><td>Buckaroo Banzai</td><td>
</td><td>
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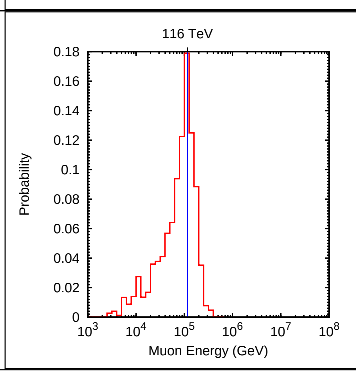
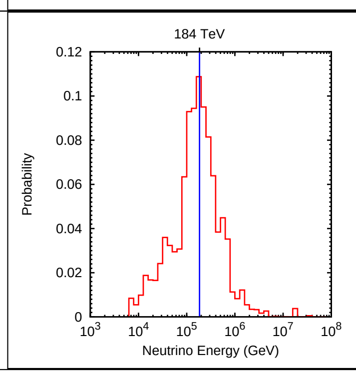
<tr><td>Dr. David Bowman</td><td>
</td><td>
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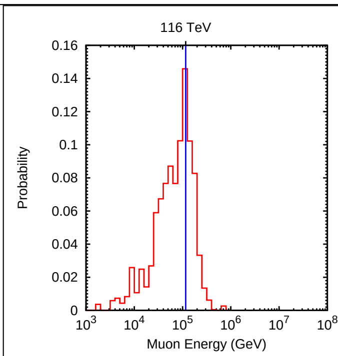
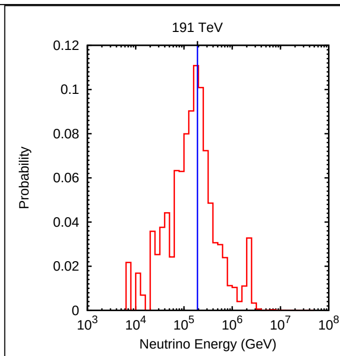
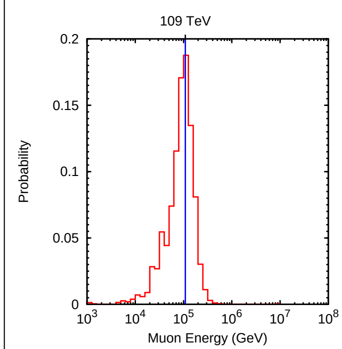
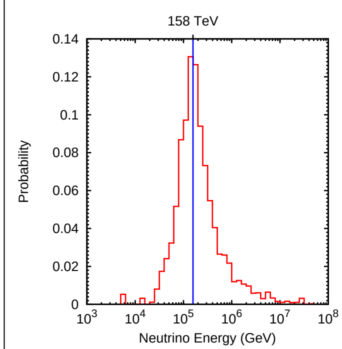
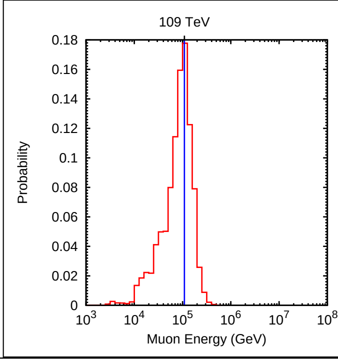
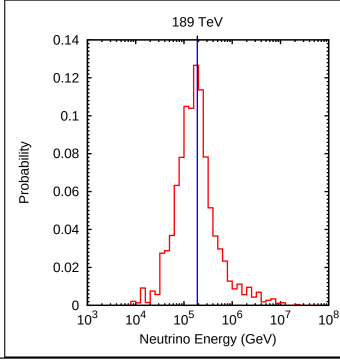
Angus MacGyver		
Professor James Moriarty		
Dr. Giacomo Rappaccini		

APPENDIX
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