

Bragg Peak Study

Progress Report

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ILLINOIS TECH

DUNE DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Introduction

- First year graduate student at IIT
- New to C++, ROOT, and DUNE
- Also working on scintillator extrusion studies with Alan Bross at Fermilab
- Worked on Mu2e tracker in the past

TMS Studies Spreadsheet

- Find the energy resolution of muons with Bragg peaks
- Find the rate of muons with Bragg peaks to compare with the rate of muons exiting TMS
- Determine if including Bragg peak information improves the measurement of momentum or energy

Getting Started

- Using data in `2024-04-19_bfield_1p0T.tmsreco.root`
- Made plots to get familiar with ROOT and datasets
- Physics “sanity checks” (such as using the momentum and energies in the data to correctly find the mass of the muon, muon energy vs neutrino energy, ...)
- 2D and 3D scatter plots from the BirthPosition of the muons in CC events seem to correctly show the geometry of LAr, TMS, and SAND.

Common Cuts

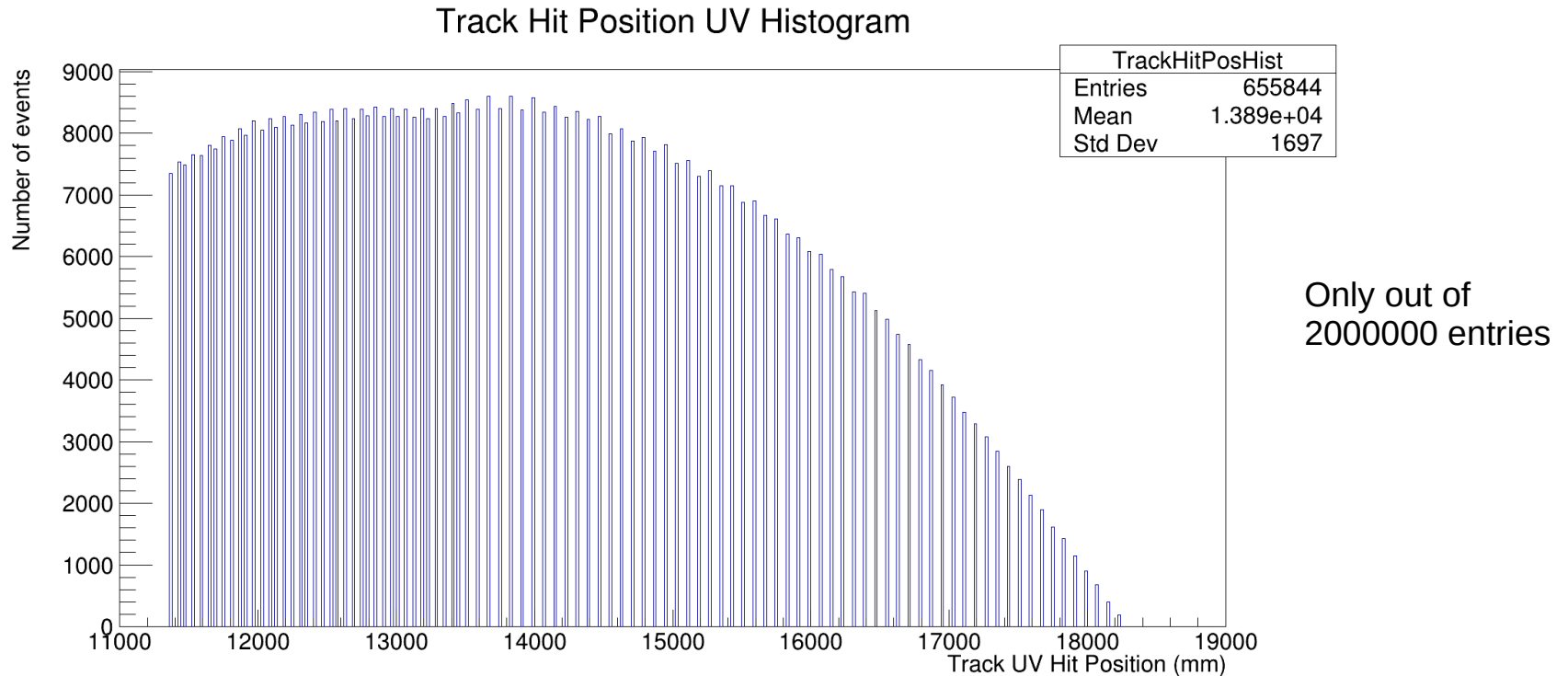
- $\text{Muon_Vertex}[2] \geq 0$; Muon born before absolute 0mm
- $\text{Muon_Death}[0]$ in $[-3520\text{mm}, 3520\text{mm}]$; Muon stops in TMS_x
- $\text{Muon_Death}[1]$ in $[-3864\text{mm}, 1159\text{mm}]$; Muon stops in TMS_y
- $\text{nLinesU} == 1$; One line in track U
- $\text{nLinesV} == 1$; One line in track V
- $(\text{nClustersU} \ \&\& \ \text{nClustersV}) == 0$; No clusters
- $(\text{nHitsInTrackU} \ \&\& \ \text{nHitsInTrackV}) \geq 5$; At least 5 hits per track
- $\text{Muon } p_T/p_z > 0.2$; Forward muons

Different Cuts

- Muon_Death[2] in [11362mm, 18294mm]; Muon stops in TMS
- Muon_Death[2] \geq 18294mm; Muon pass through TMS
- Muon_Death[2] \leq 13500mm; Muon stops in thin region
- Muon_Death[2] in [13500mm, 18294mm]; Muon stops in thick region

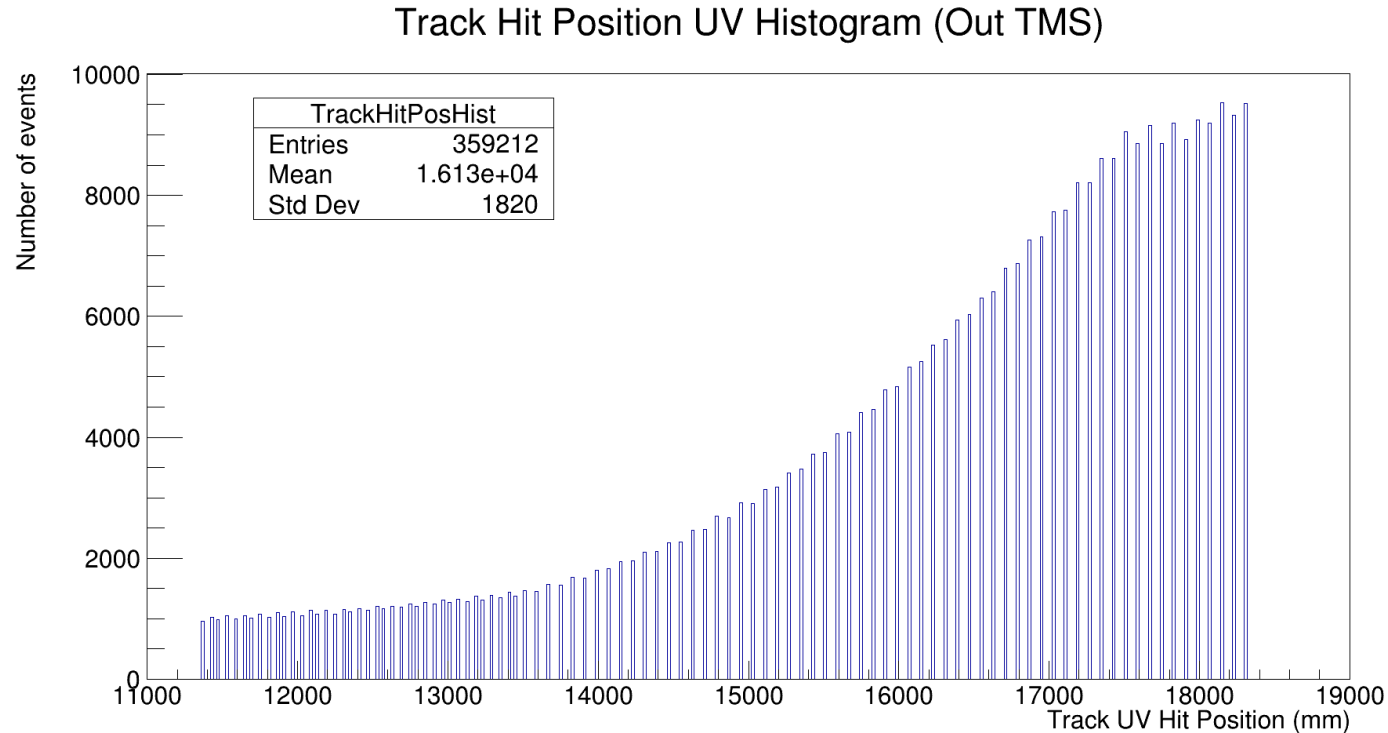
Stopped in TMS

- Thin region has denser hits
- Thick region starts at 13500mm
- Hits drop off near end of TMS
- No hits after TMS



Pass Through TMS

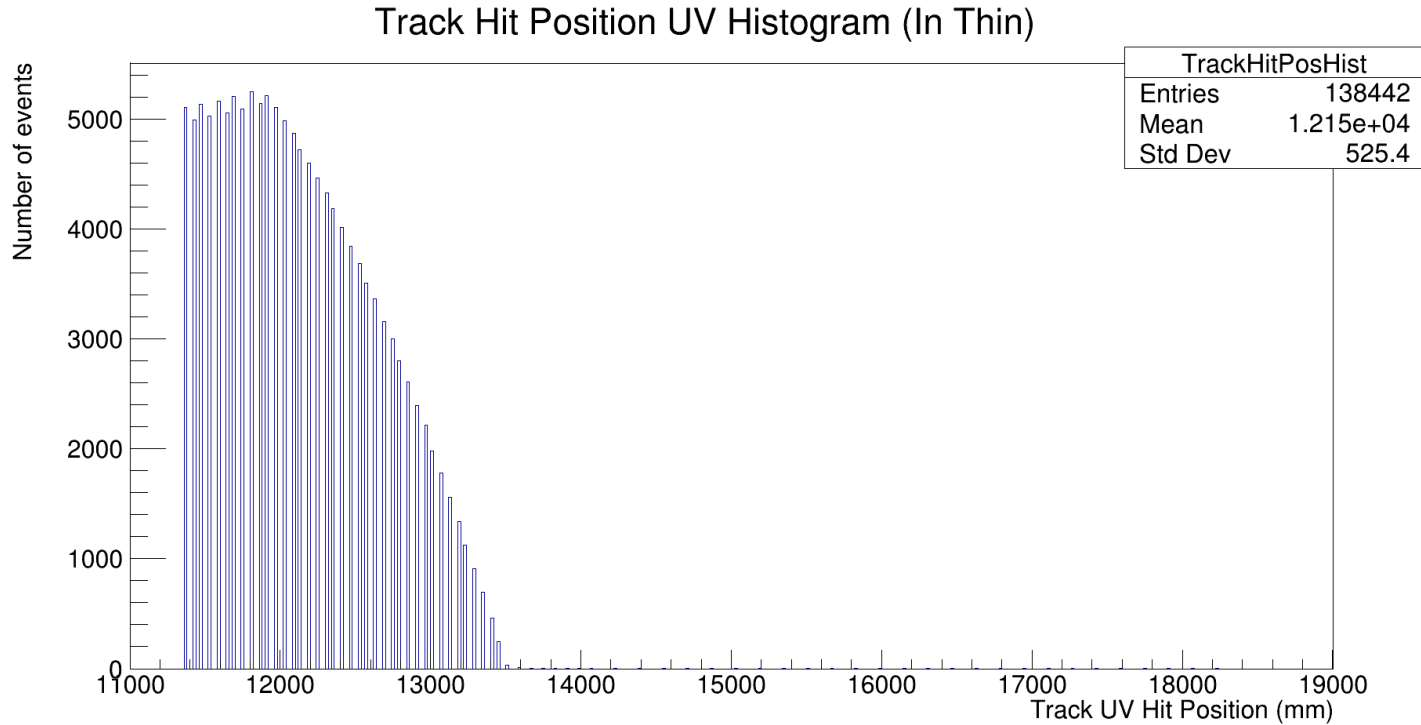
- Thin region has denser hits
- Thick region starts at 13500mm
- Hits start low and increase
- Max hits at end of TMS since muons pass through



Only out of
2000000 entries

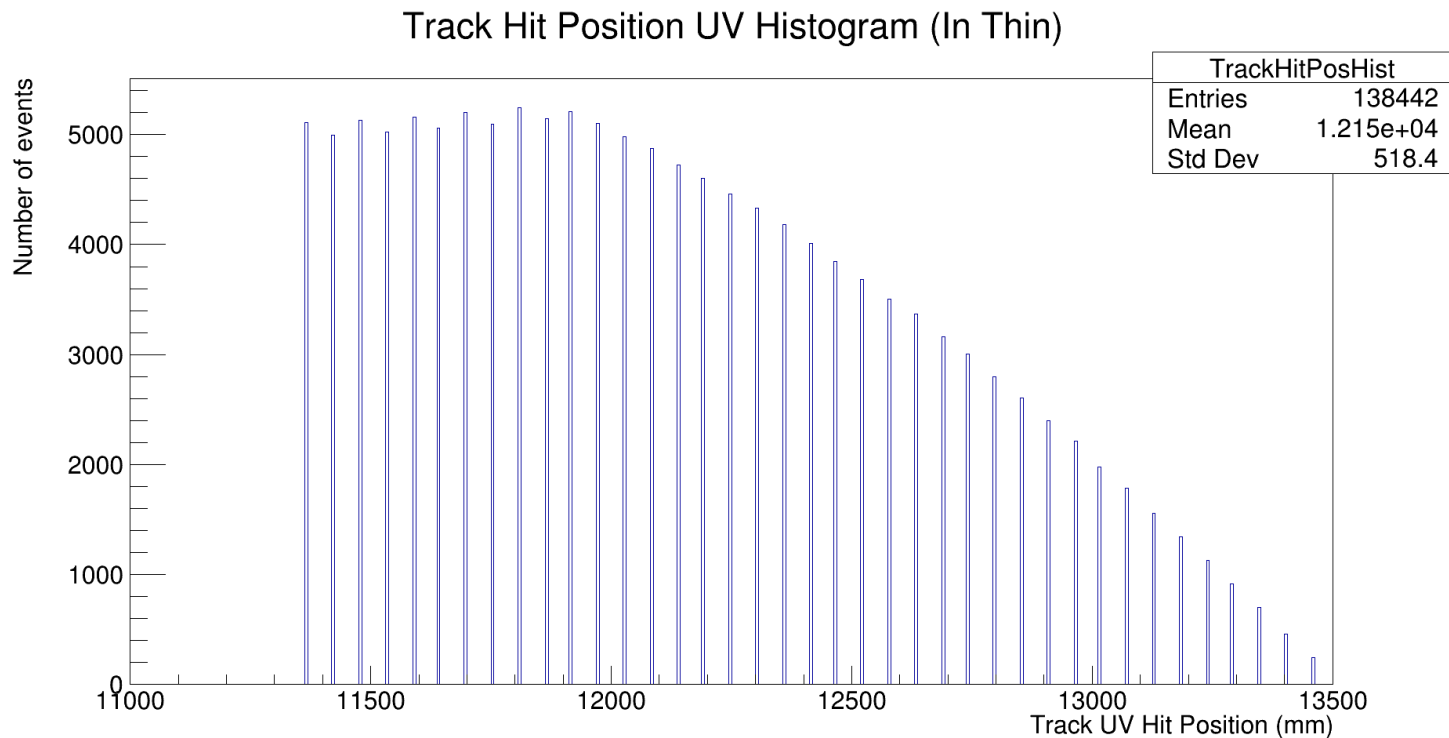
Stopped in Thin-Plate Region

- Hits end at 13500
- Full view



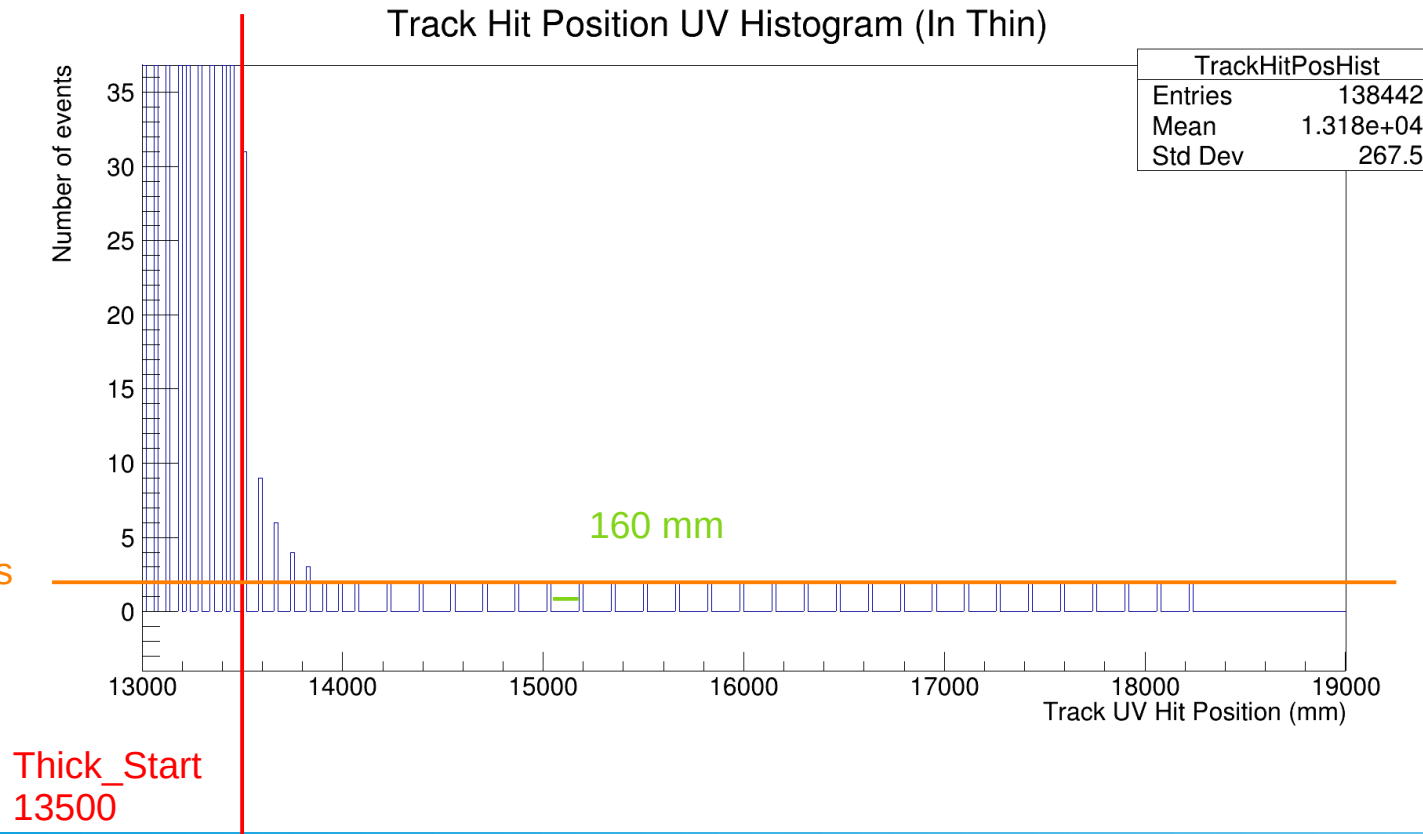
Stopped in Thin-Plate Region

- Zoomed in to thin region only
- 110mm spacing (x2 planes)
- Hits drop near zero at end of thin region



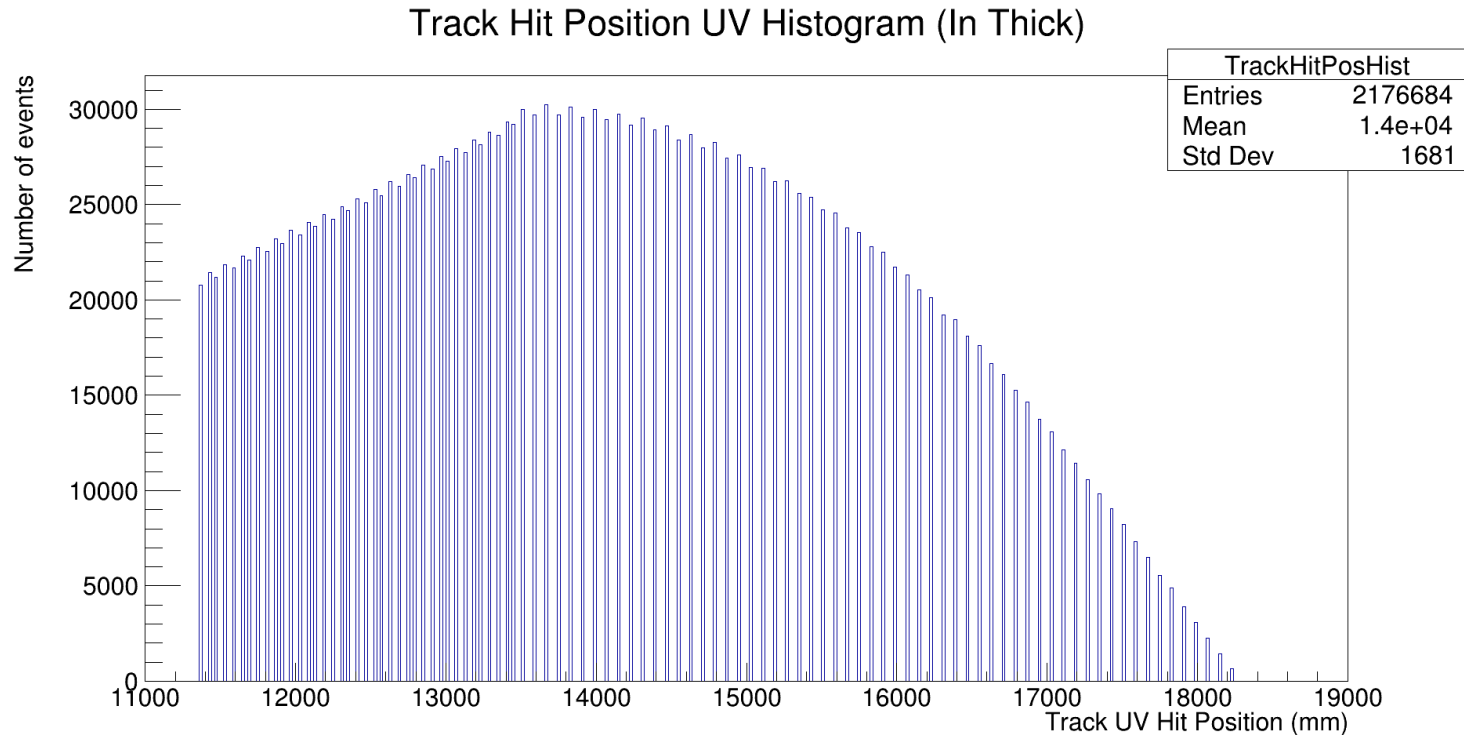
Stopped in Thin-Plate Region-Question 1

- Zoomed in to tail near end of thin region
- Why 2 hit pedestal in thick region, despite cutting on Truth_Info Muon_Death[2] ≤ 13500 ?
- Spacing is appropriate for x2 thick 2 hits planes



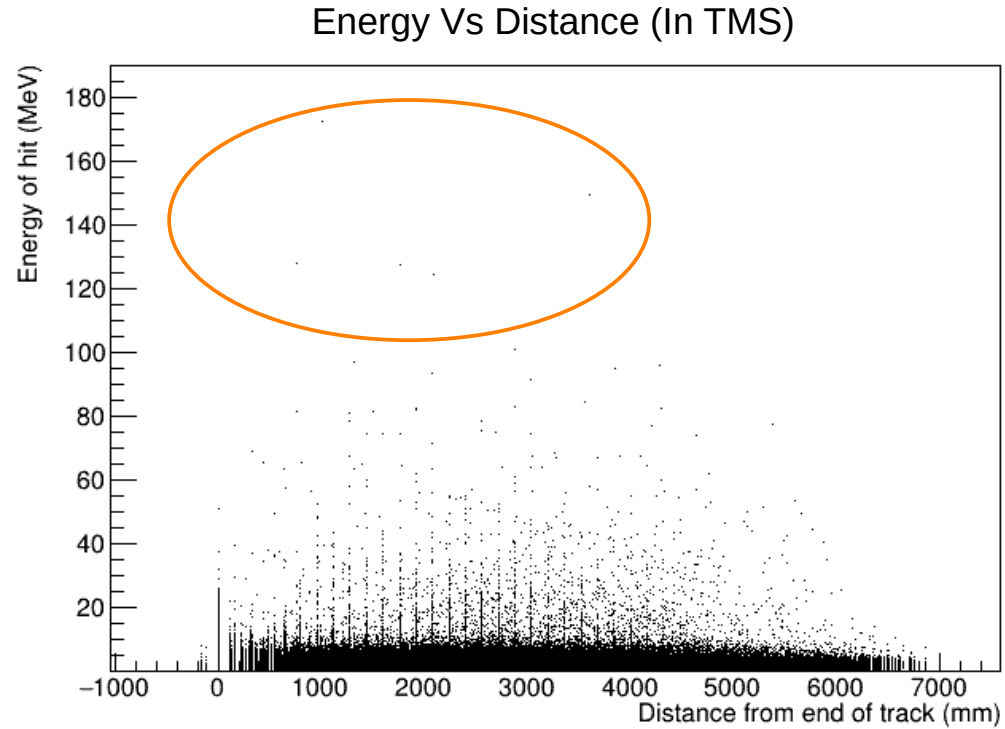
Stopped in Thick-Plate Region

- Thin region has denser hits
- Thick region starts at 13500mm
- Hits drop off near end of TMS
- No hits after TMS



Stopped in TMS-Question 2

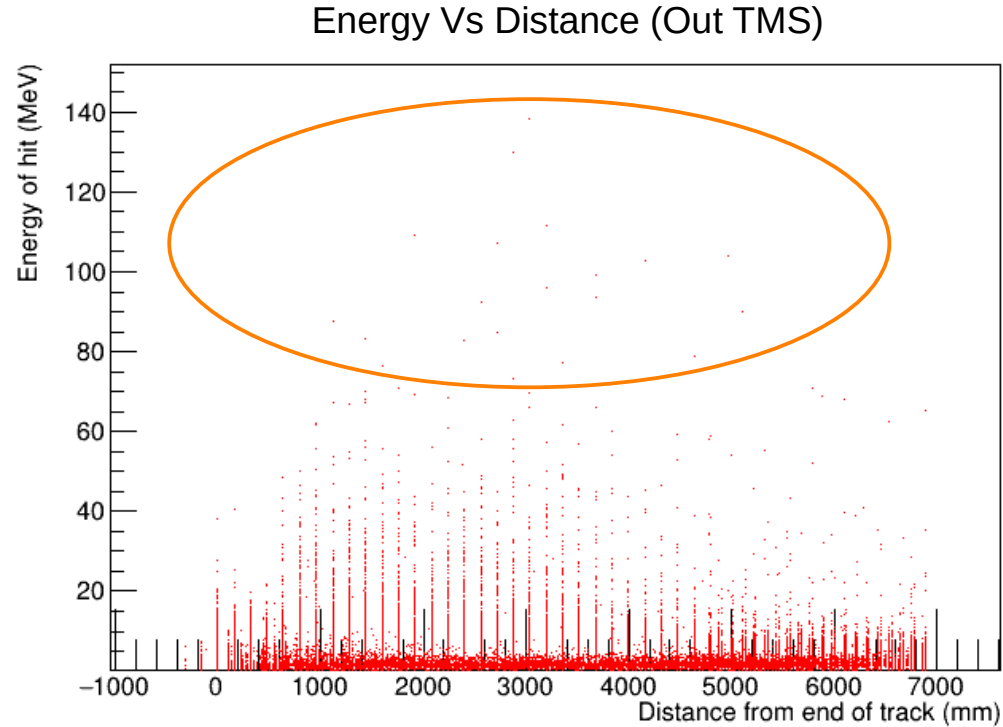
- What are these high energy/hit outliers?



Events: 2,314,934
Full sample (6,993,307)

Pass Through TMS-Question 2

- Still have these high energy/hit outliersj
- Darkest band closer to ~2MeV (MIP)?

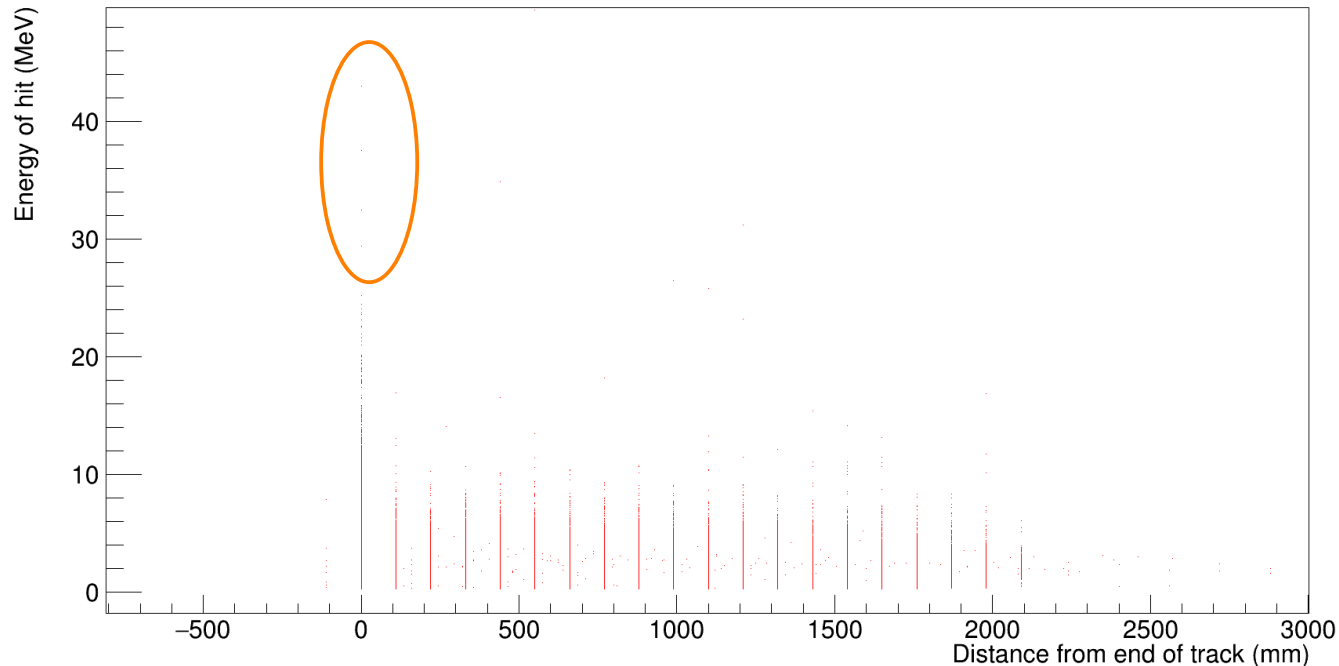


Events: 1,242,573
Full sample (6,993,307)

Stopped in Thin-Plate Region-Question 2

Events:
138442

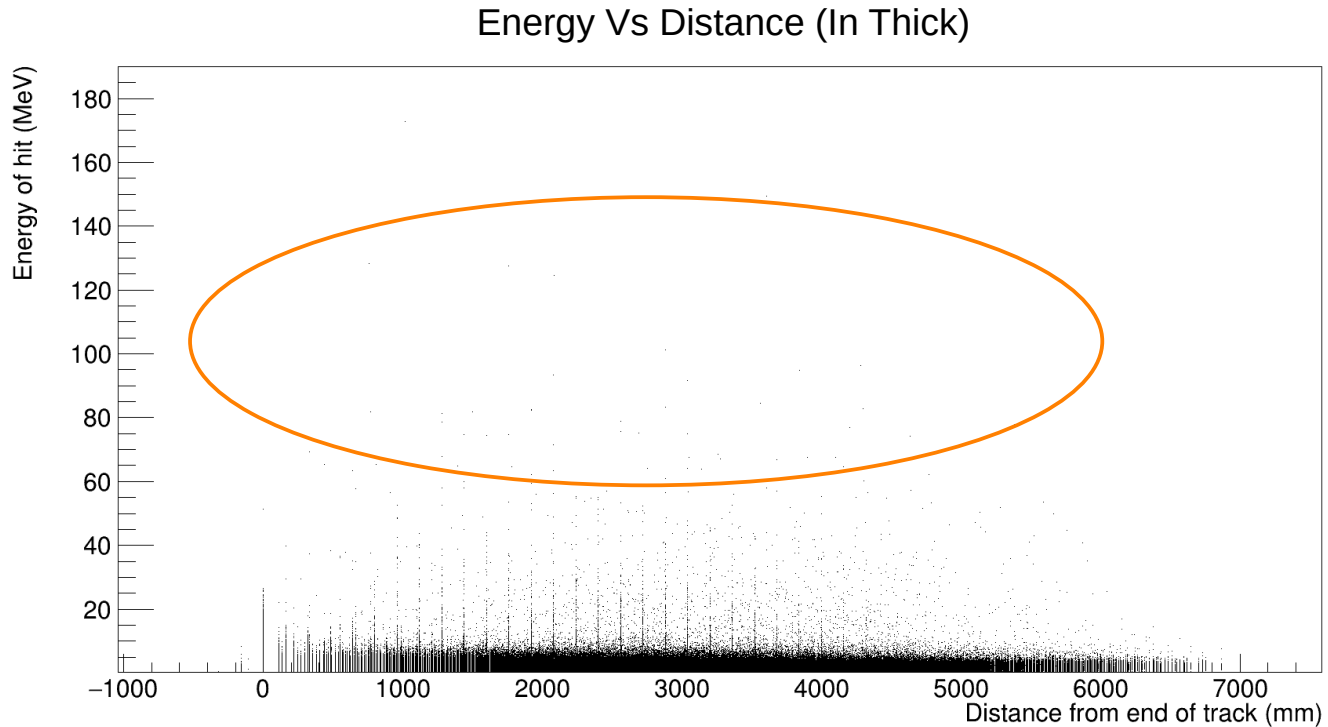
Energy Vs Distance (In Thin)



- Hardly any high energy outliers
- Scale much smaller (max 50 MeV vs 190 MeV before)
- Spacing is 110mm (x2 thin planes)
- Peak at 0mm from end of track → Bragg?

Stopped in Thick-Plate Region-Question 2

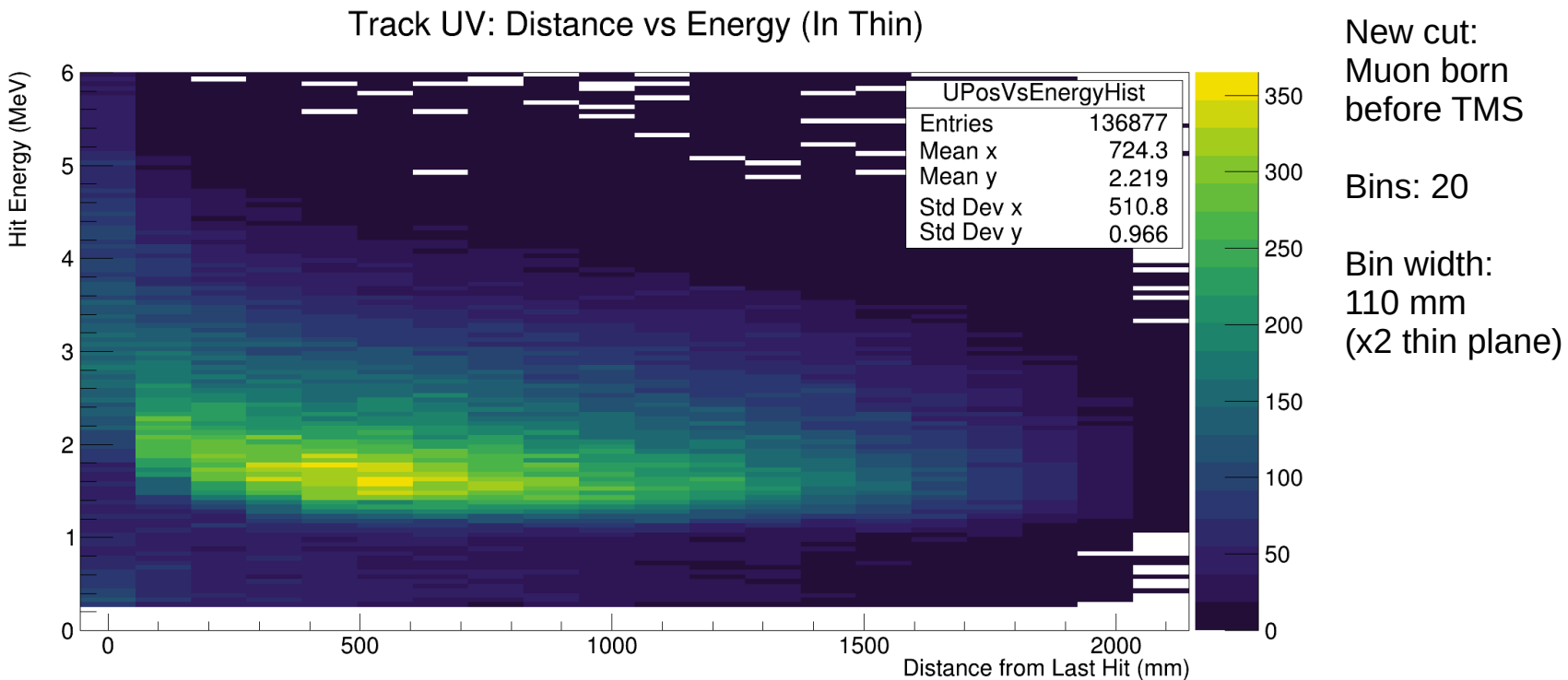
- High energy/hit outliers are back
- High energy/hit come from muons that stop in thick region?



Events:
2176684

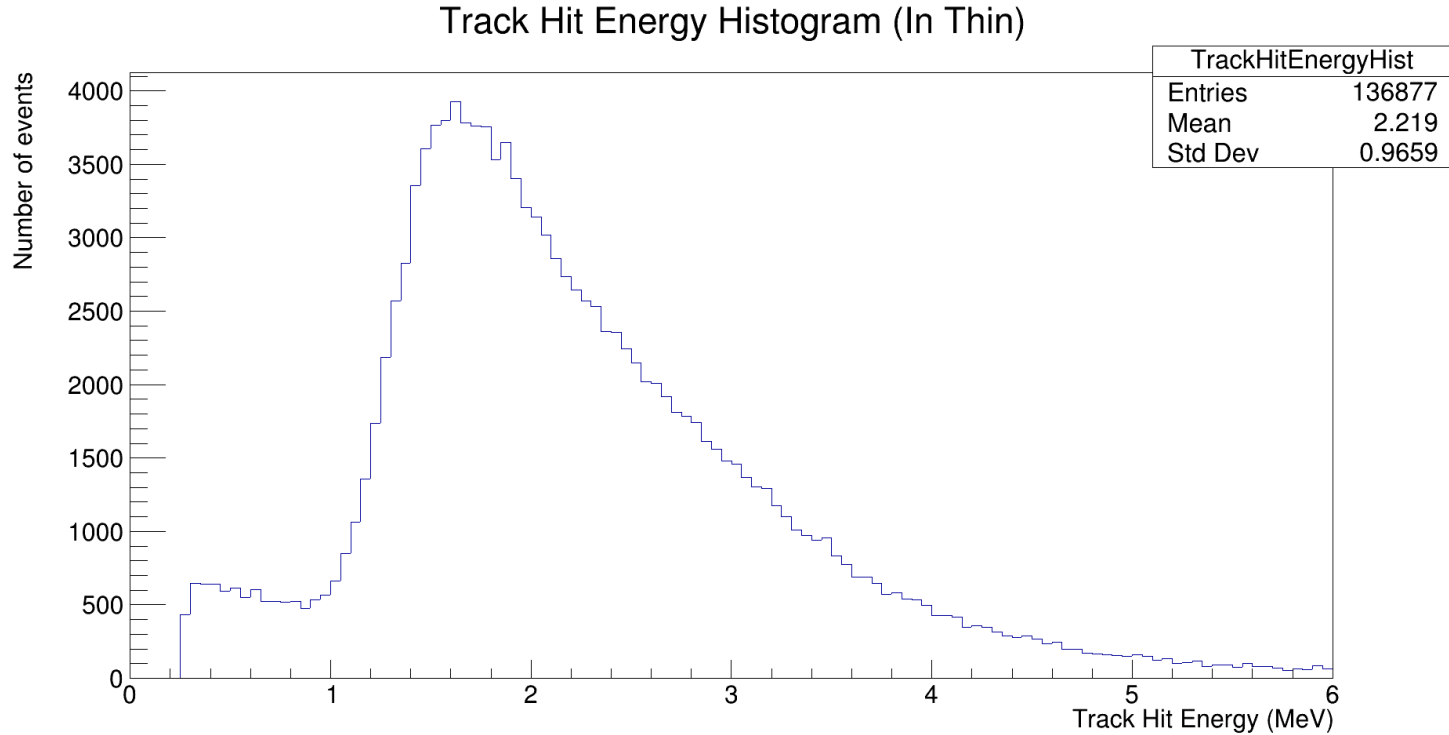
Stopped in Thin-Plate Region

- MIP around 1.6-1.8 MeV?
- Upward curve near 0mm from end of track → Bragg?



Stopped in Thin-Plate Region (y-Projection)

- MIP around 1.6-1.8 MeV?



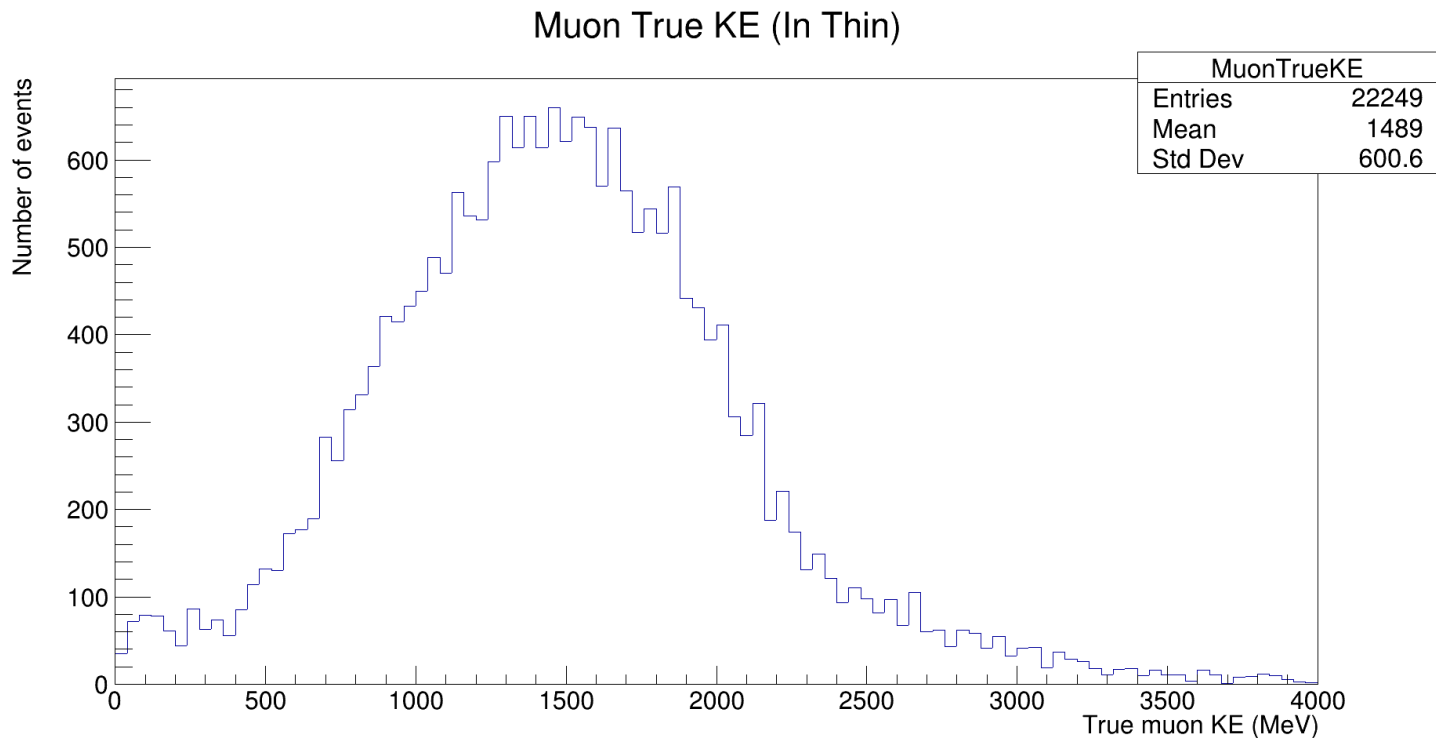
New cut:
Muon born
before TMS

Bins: 120

Bin width:
50 keV

Stopped in Thin-Plate Region

- Truth info
- Doesn't account for energy loss between birth position and first hit in TMS



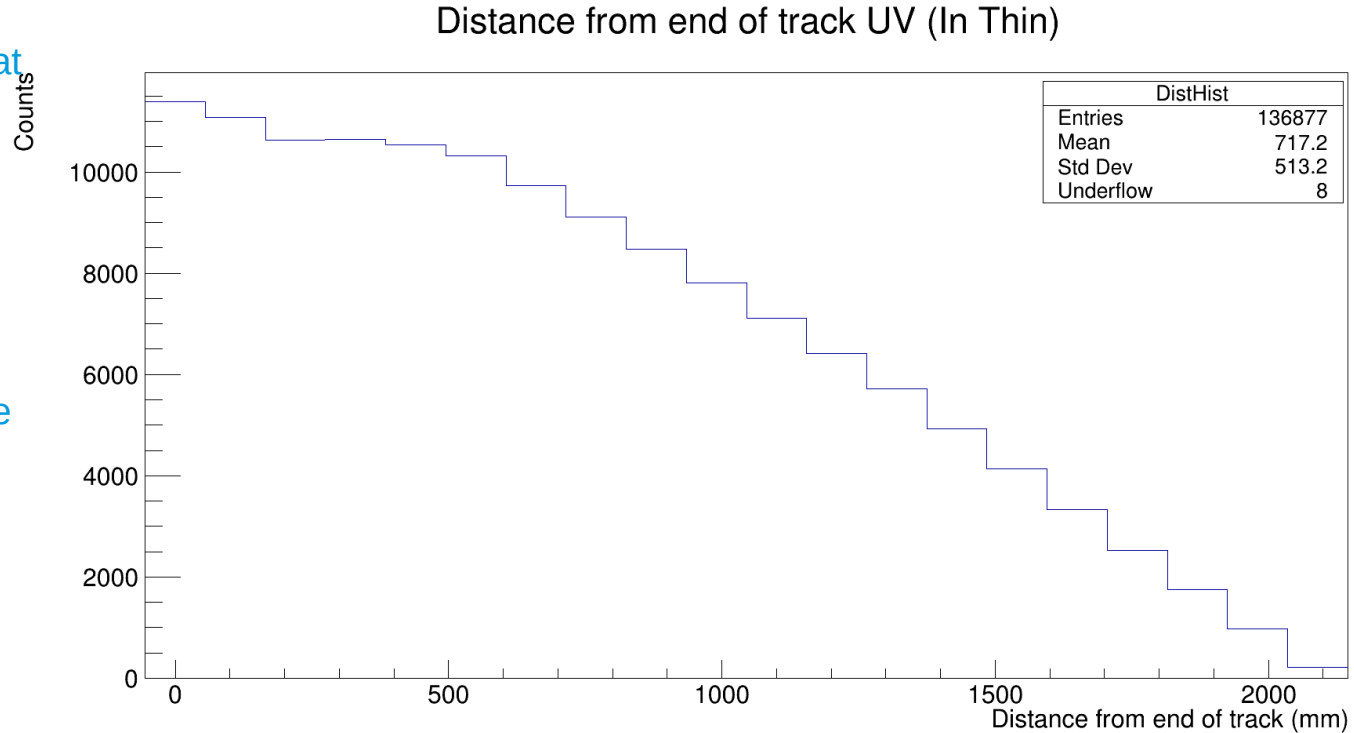
New Cut:
Muon born
before TMS

Bins: 100

Bin width:
40 MeV

Stopped in Thin-Plate Region (x-Projection)

- As expected, most counts at 0 distance from end of track
- Flat region ~150mm-500mm ?
- Unsure where the 8 underflow (-distance) counts come from



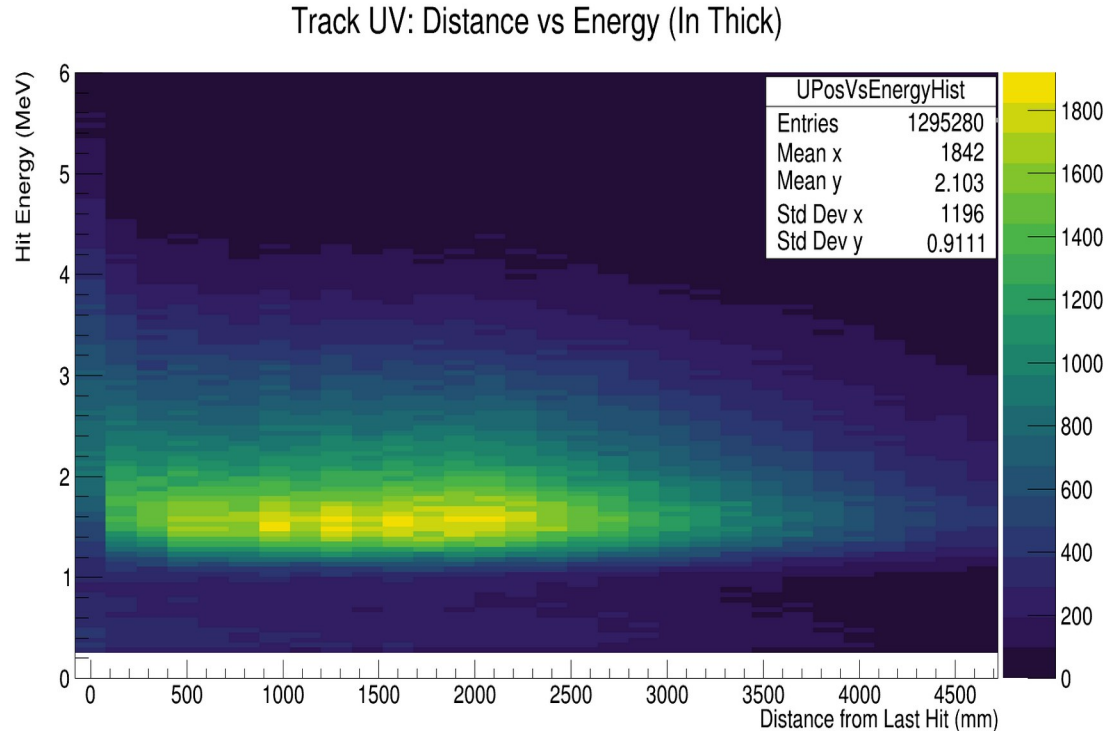
New Cut:
Muon born
before TMS

Bins: 20

Bin width:
110 mm
(x2 thin plane)

Stopped in Thick-Plate Region

- MIP around 1.6 MeV?
- Upward curve near 0mm from end of track → Bragg?



New cut:
Muon born
before TMS

Bins: 30

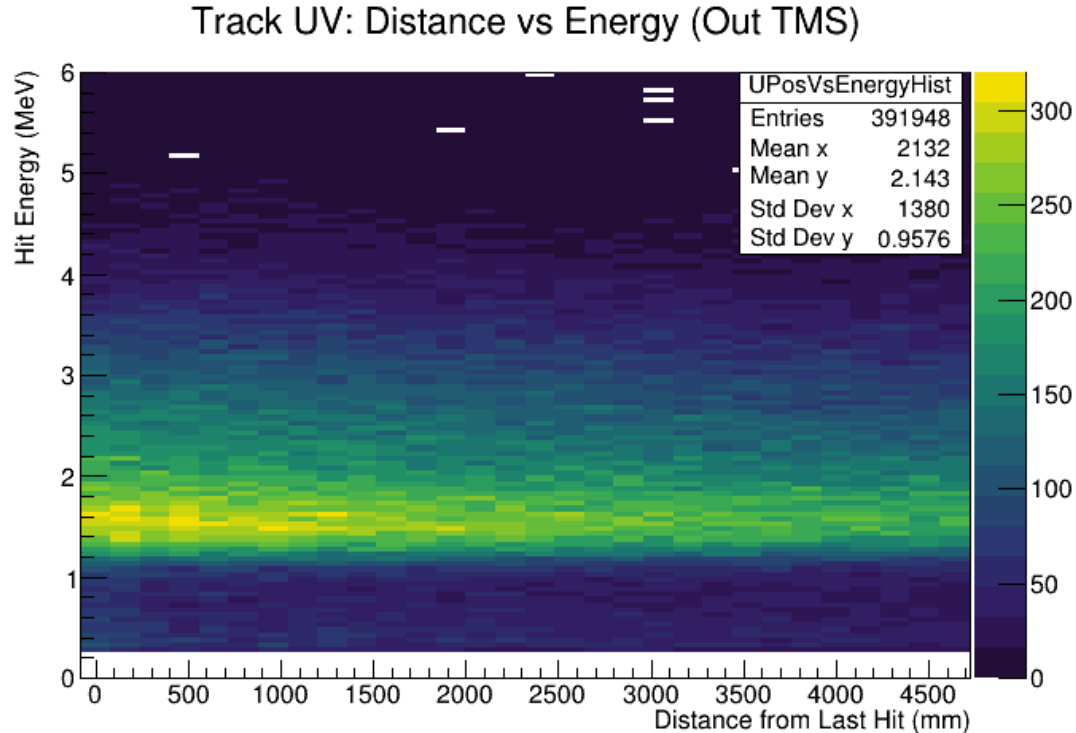
Bin X Width:
160 mm
(x2 thick plane width)

Bin Y Width:
50 keV

Min x: -80
Max x: 4720
Range: 4800

Pass Through TMS

- MIP around 1.6MeV?
- No upward curve near 0mm from end of track → muons pass through TMS



New Cut:
Muon born
Before TMS

Bins: 30

Bin X Width:
160 mm
(x2 thick plane width)

Bin Y Width:
50 keV

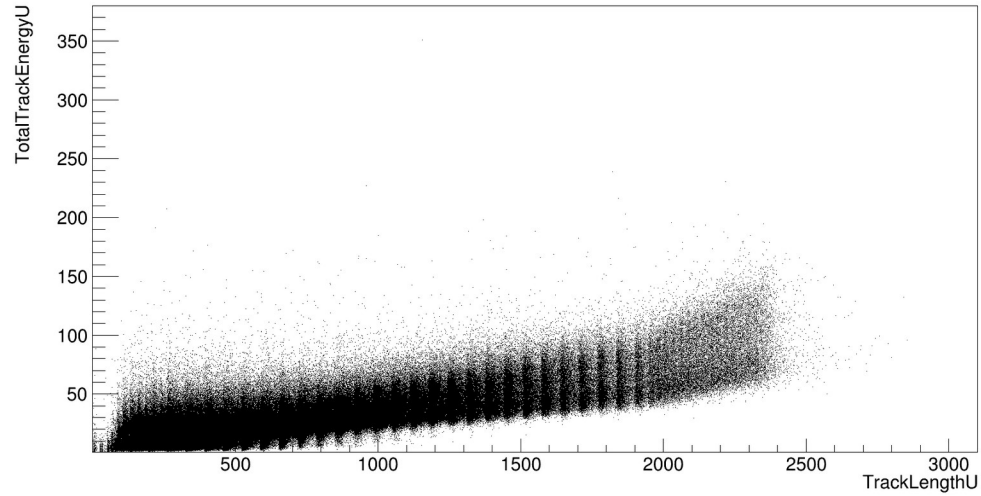
Min x: -80
Max x: 4720
Range: 4800

Thank You!

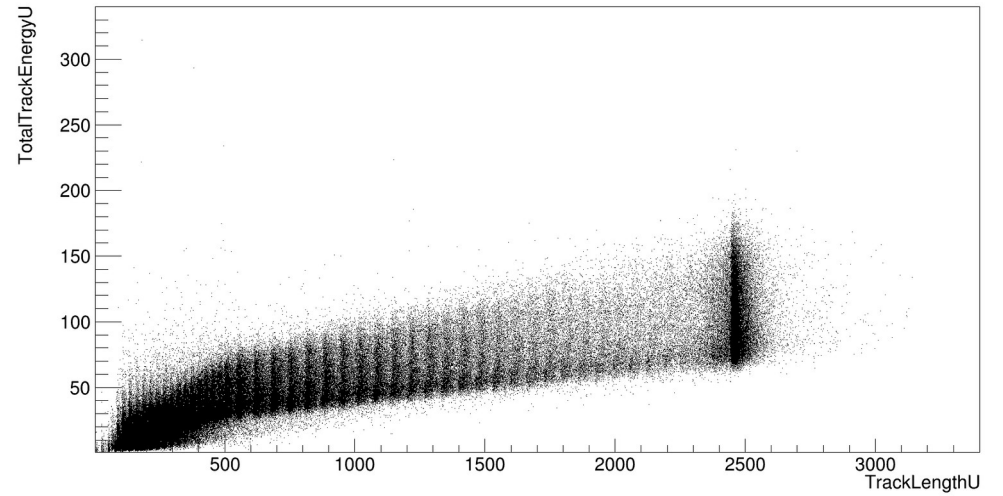
Questions

Plots

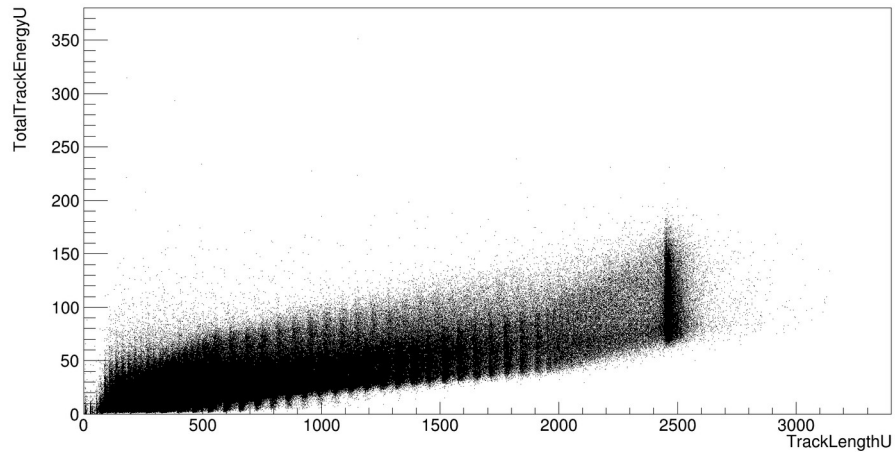
TotalTrackEnergyU:TrackLengthU {TMSStart==1}



TotalTrackEnergyU:TrackLengthU {TMSStart==0}



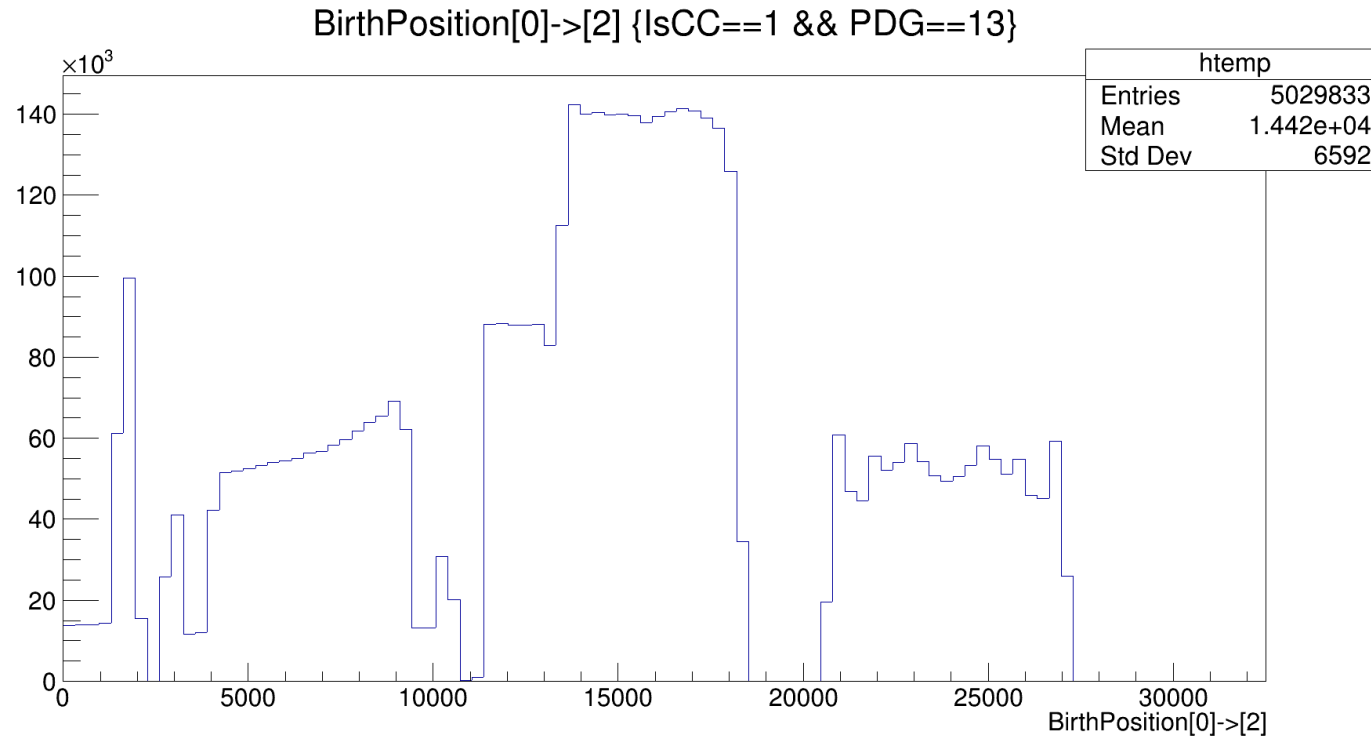
TotalTrackEnergyU:TrackLengthU



Why is this dark region > 2138 mm?

Muon z Birth Position

Should there be more muons being born from neutrino interactions in TMS than in the LAr?



NeutrinoP4

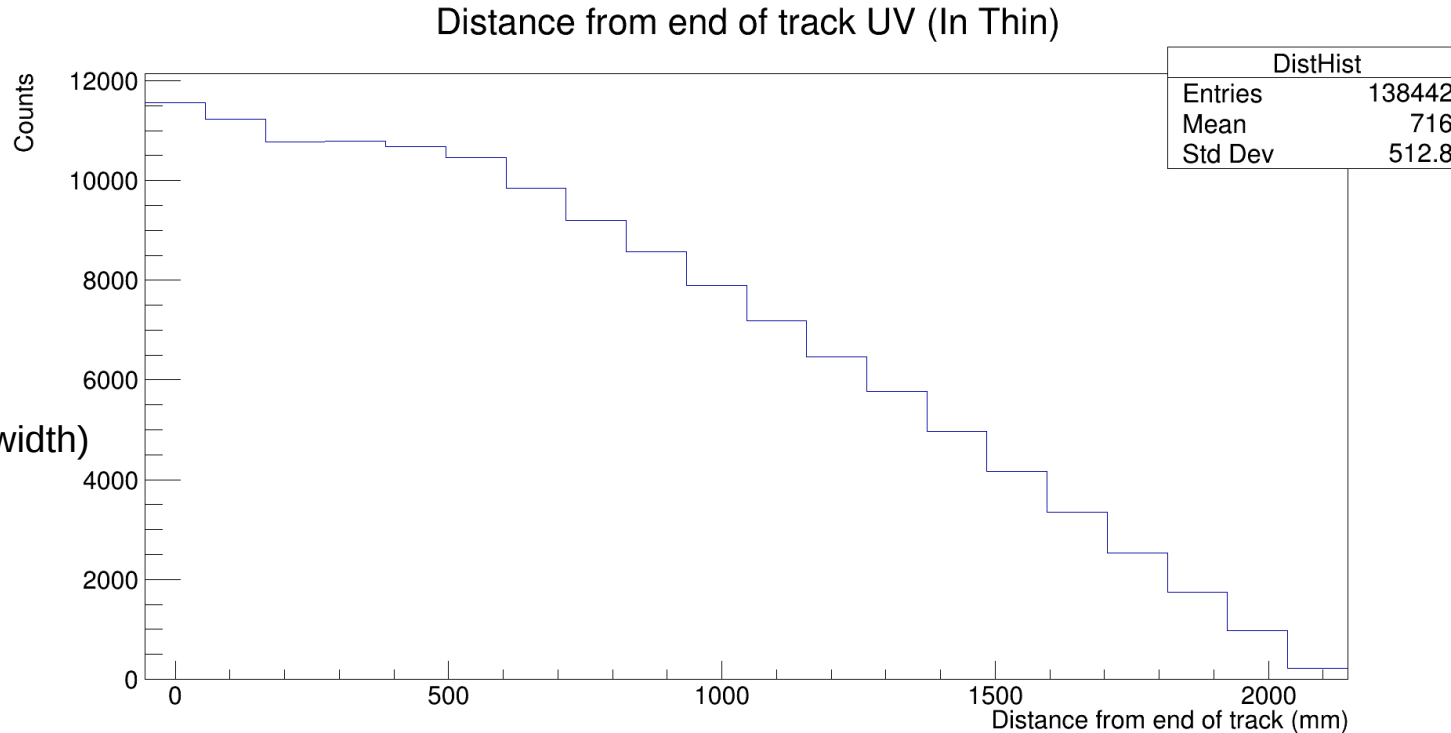
- NeutrinoP4 has an unusually small energy. Is this in GeV, or is there a bug? Check other events, maybe make a histogram to investigate.
- Seems that this is in GeV rather than MeV

Stopped in Thin-Plate Region (x-Projection)

Cuts 12.3

Bins: 20

Bin X Width:
110 mm
(x2 thin plane width)



Min x: -55
Max x: 2145
Range: 2200

Canvas size
changed?

Spacing between planes

Likely a binning problem

This is for thin region only

Cuts:

- Muon_Vertex[2] >= 0
- Muon_Death[0] in (-3520, 3520)
- Muon_Death[1] in (-3864, 1159)
- Muon_Death[2] <= 13500
- MuonP4: (p_T / p_z) < 0.2 forward muons
- nLinesU = 1
- nClustersU = 0
- nHitsInTrackU >= 5

TMS_Thin_Gap = 55

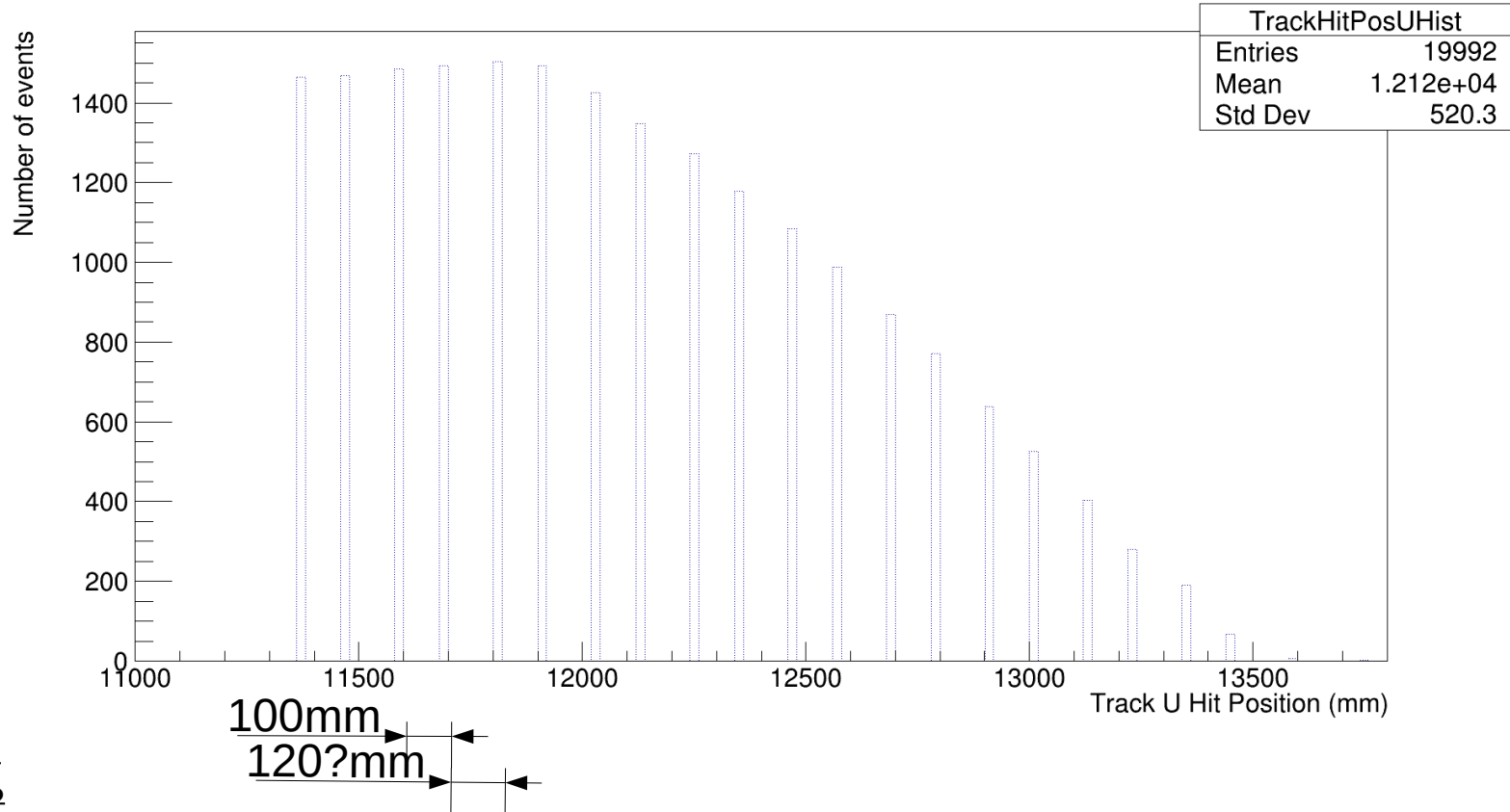
TMS_Thin_Steel_Width = 15

TMS_Scint_Width = 10

So spacing should be 80 mm

Here appears to be 100 mm?

Track Hit Position U Histogram



Every two bars seem to have extra spacing? I expected same spacing for all bars in thin region

Track UV: Distance vs Energy (In TMS)

Cuts 12.1

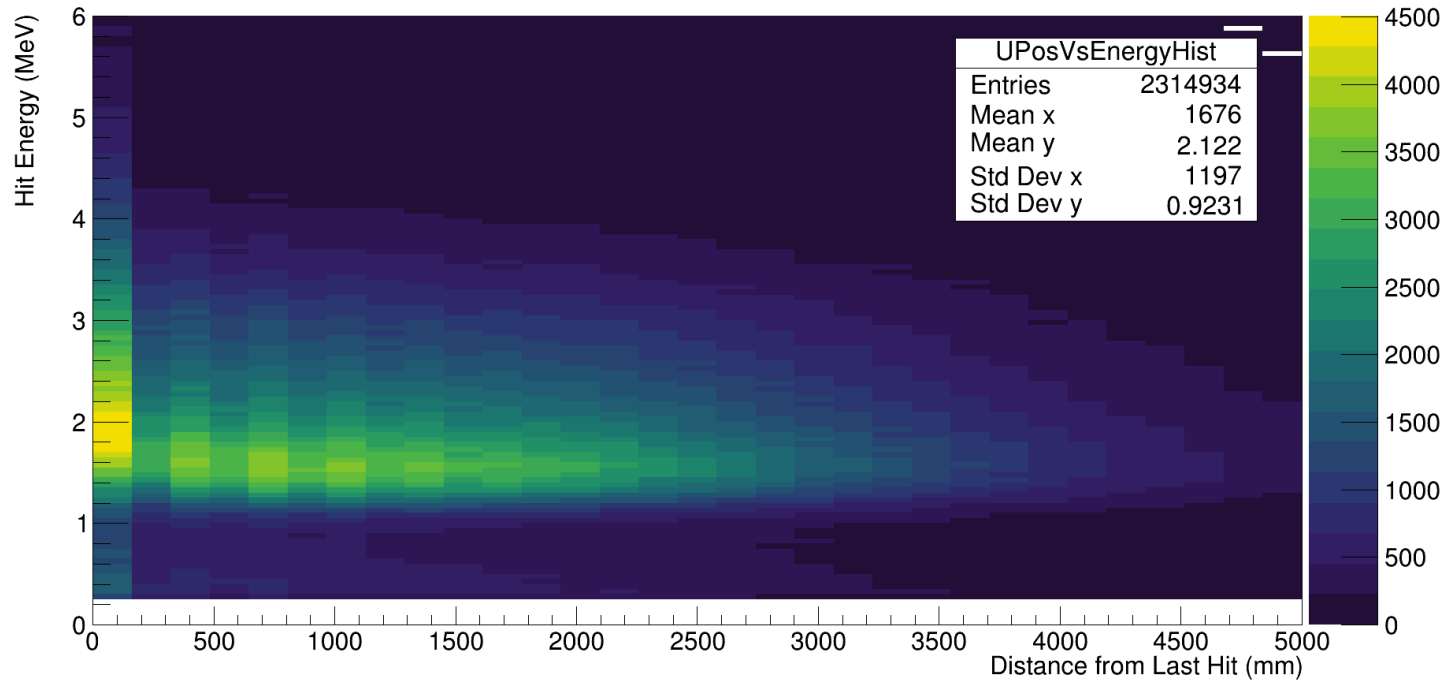
Bins: 31

Bin X Width:
161.3 mm
(x2 planes)

Bin Y Width:
50 keV

New color:
kViridis

Instead of:
kBird



Track UV: Distance vs Energy (Out TMS)

Cuts 12.2

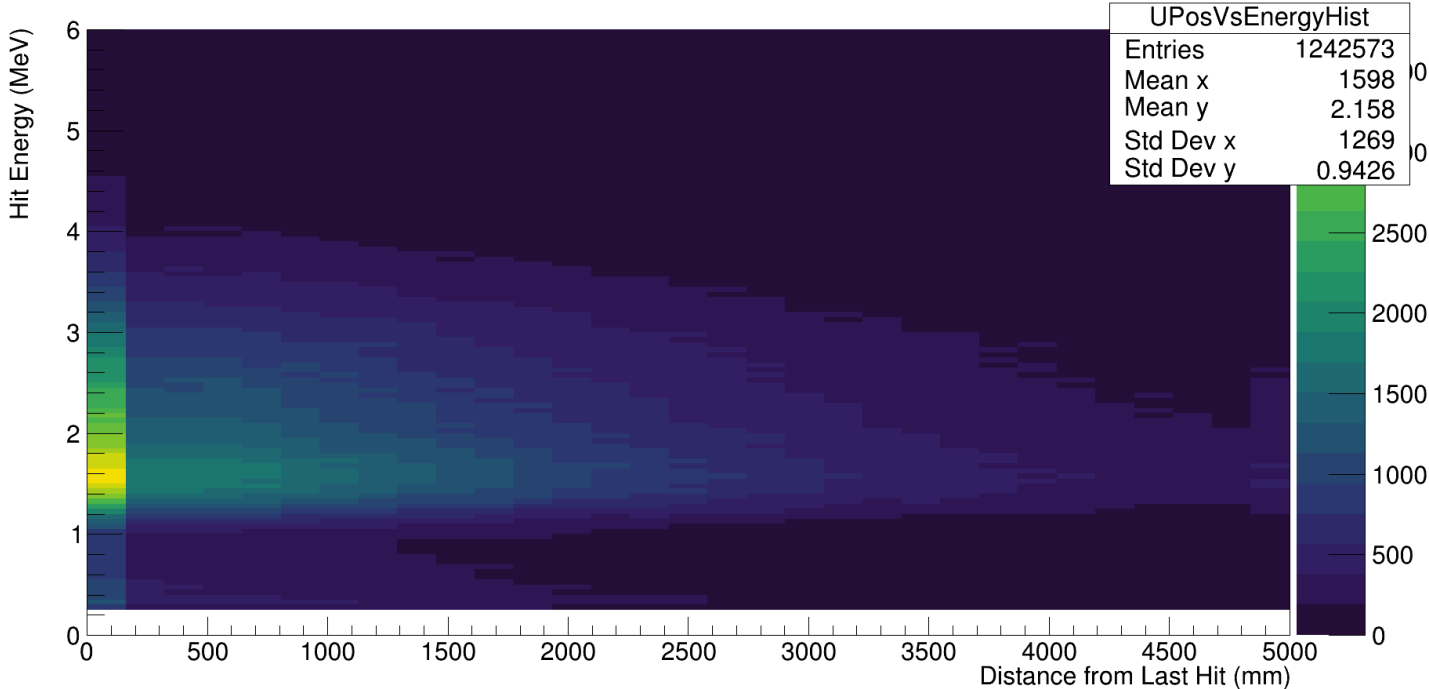
Bins: 31

Bin X Width:
161.3 mm
(x2 planes)

Bin Y Width:
50 keV

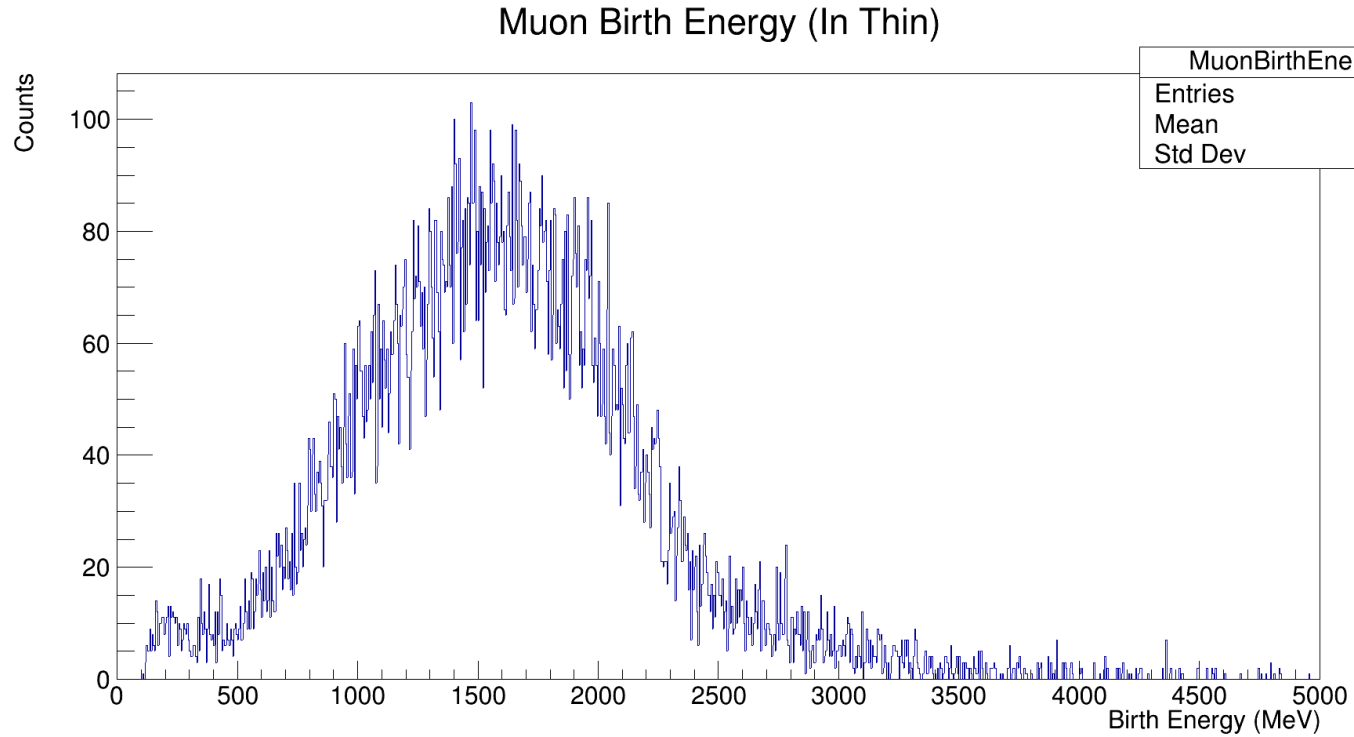
New color:
kViridis

Instead of:
kBird



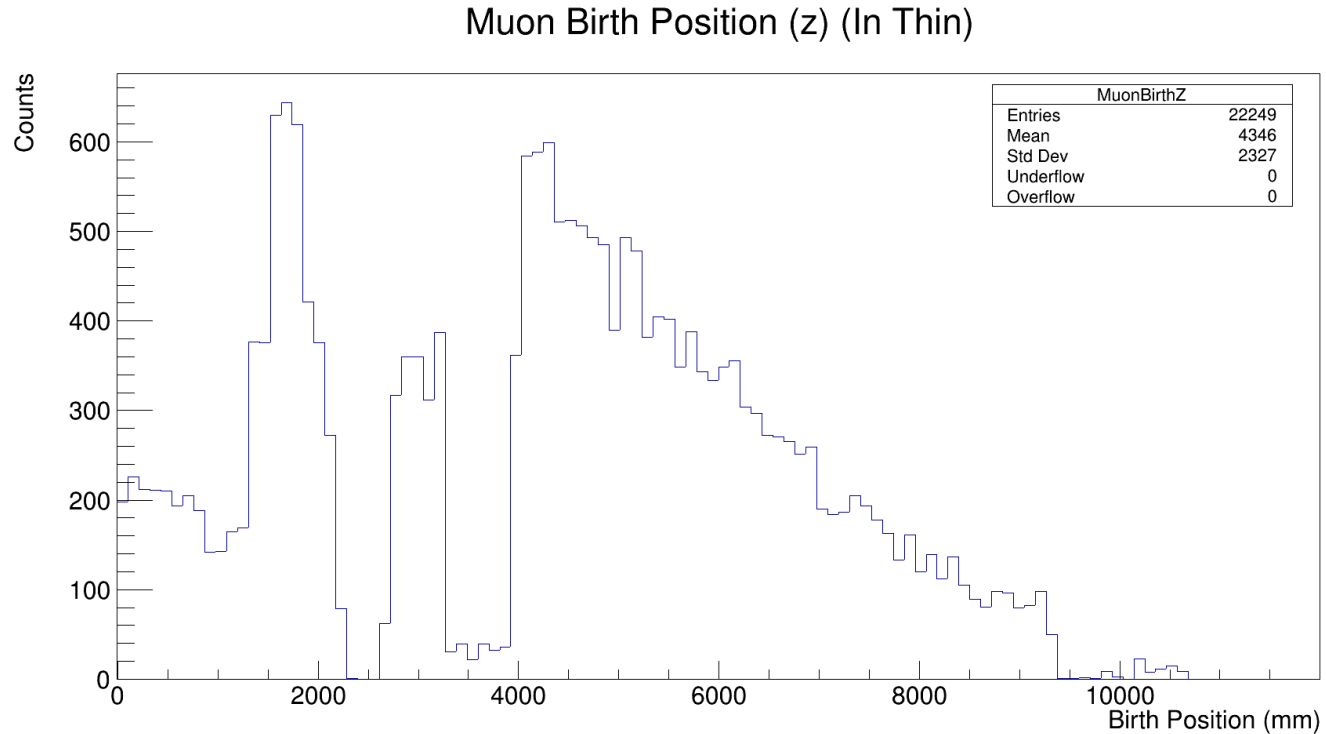
Appendix

Stopped in Thin-Plate Region



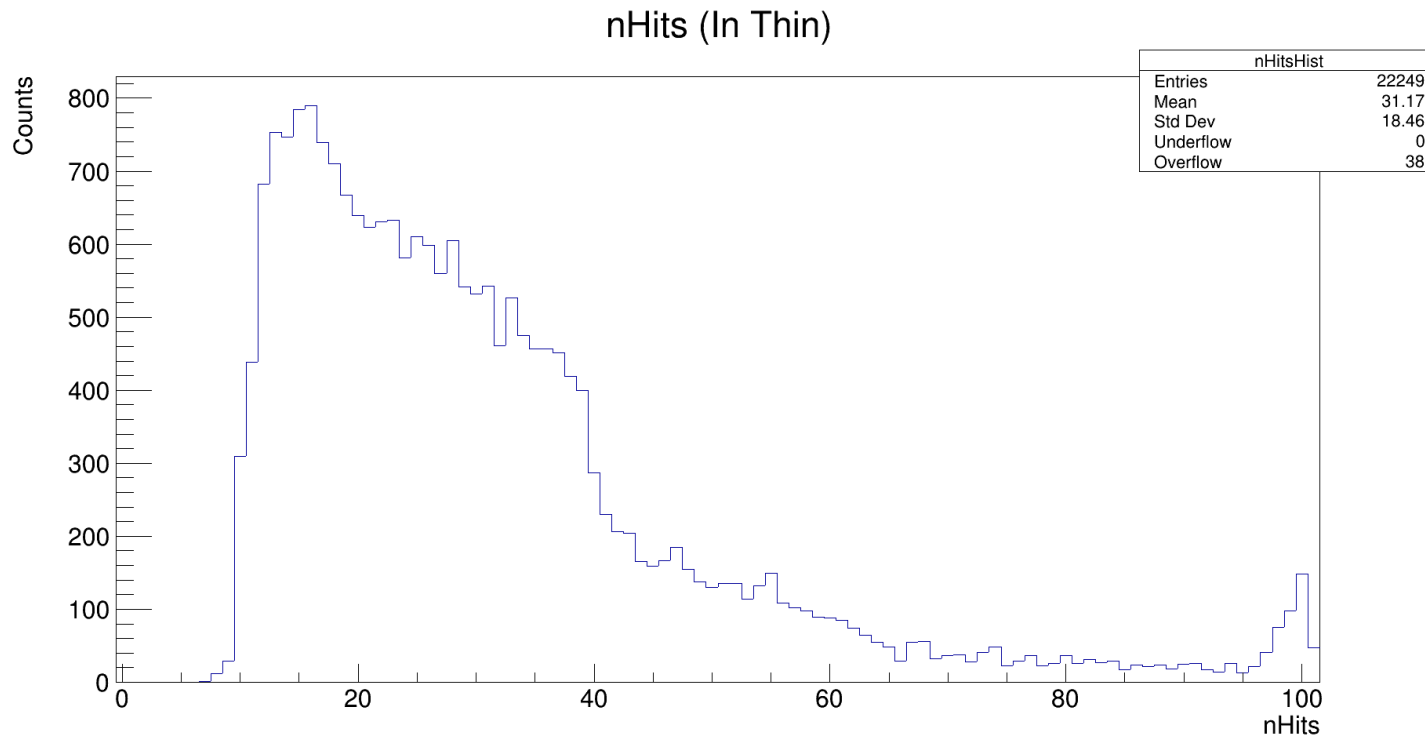
New Cut:
Muon born
before TMS

Stopped in Thin-Plate Region

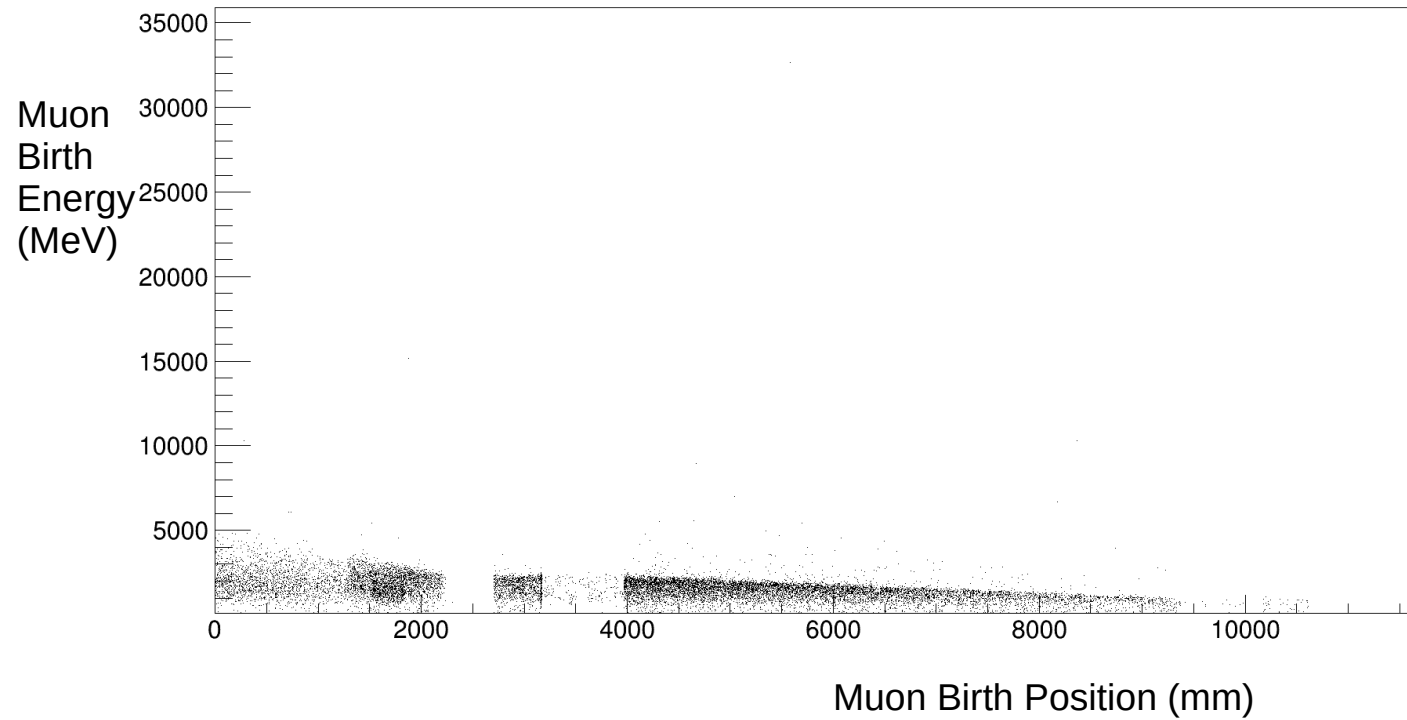


New Cut:
Muon born
before TMS

Stopped in Thin-Plate Region



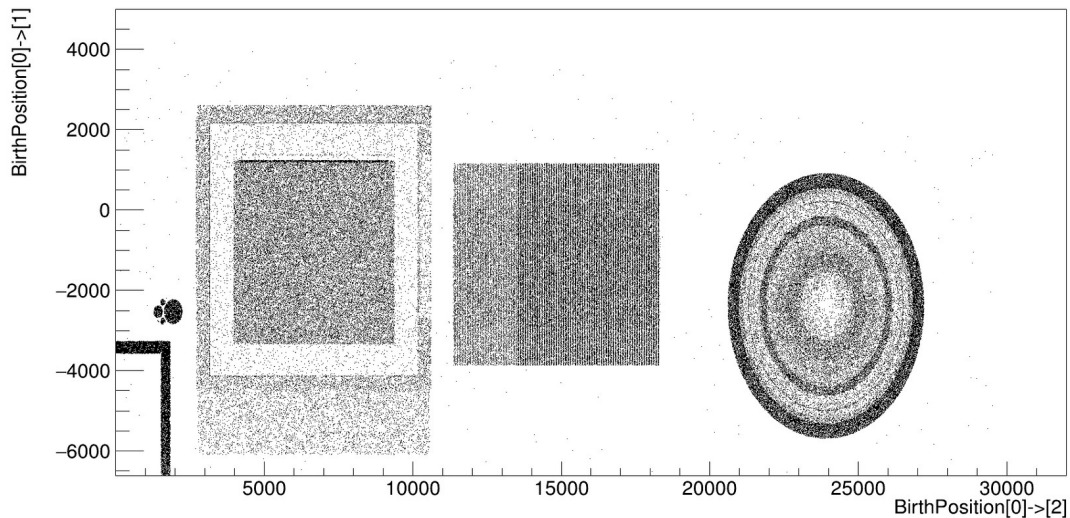
Muon Birth Position vs Muon Birth Energy



New Cut:
Muon born
before TMS

TMS Geometry

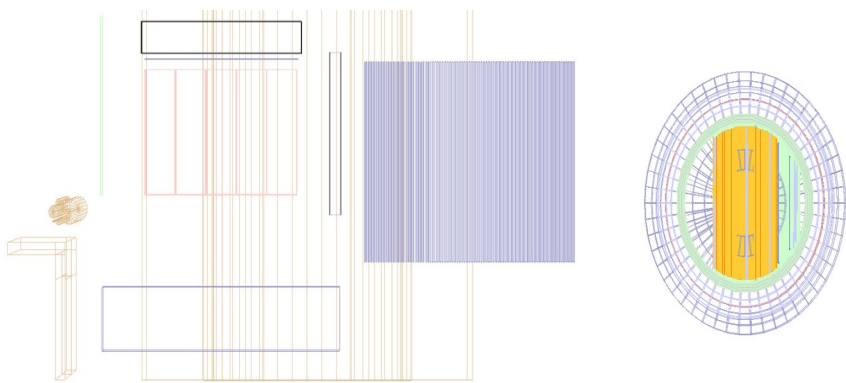
BirthPosition[0]->[1]:BirthPosition[0]->[2] {IsCC==1 && PDG==13}



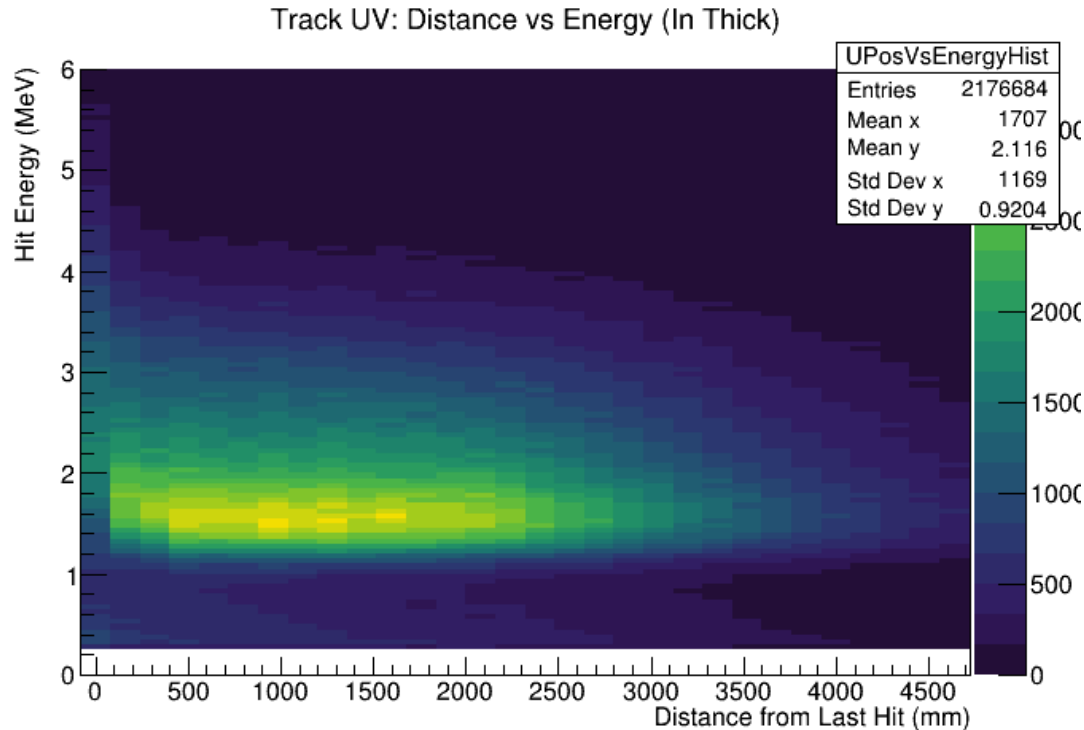
Scatter plot of muon birth positions involved in CC events

Geometry from:

nd_hall_with_lar_tms_sand_TDR_Production_geometry_v_1.0.3.gdml



Stopped in Thick-Plate Region



Bins: 30

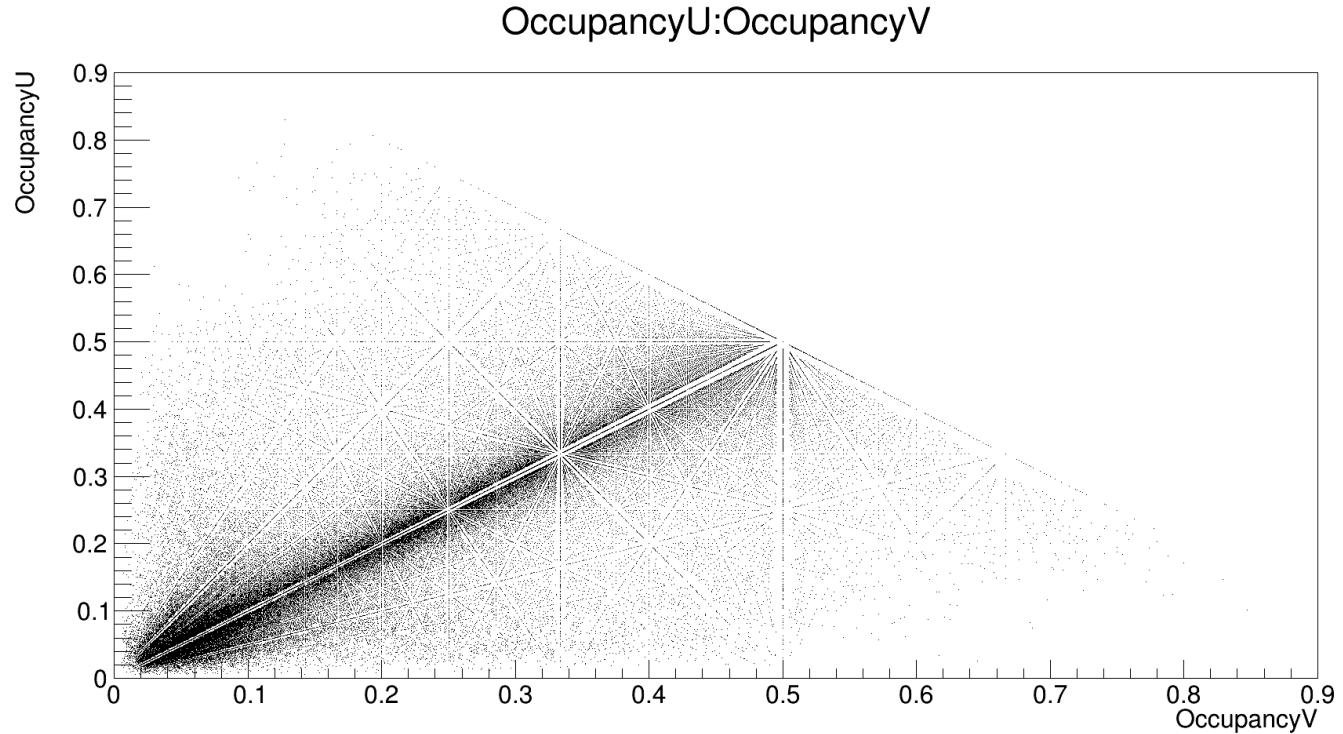
Bin X Width:
160 mm
(x2 thick plane width)

Bin Y Width:
50 keV

Min x: -80
Max x: 4720
Range: 4800

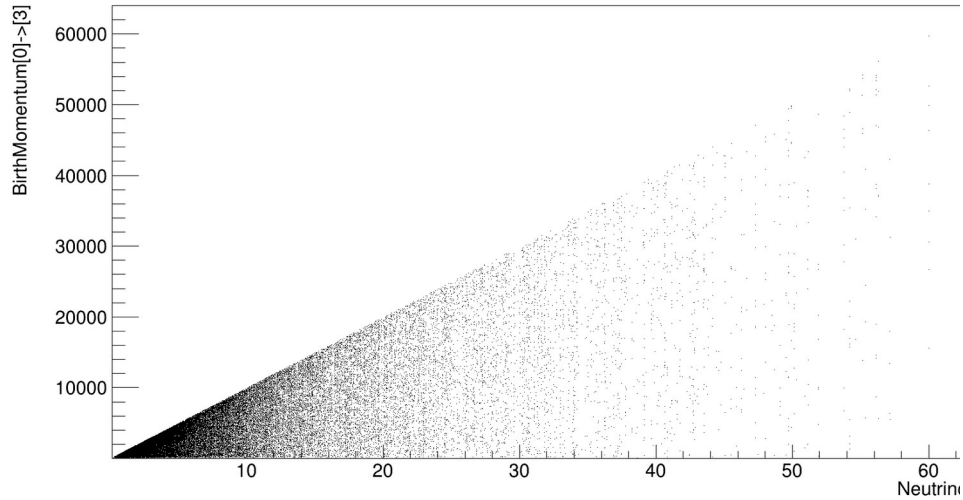
Wow!

Looks cool!
Not sure what these
features are.



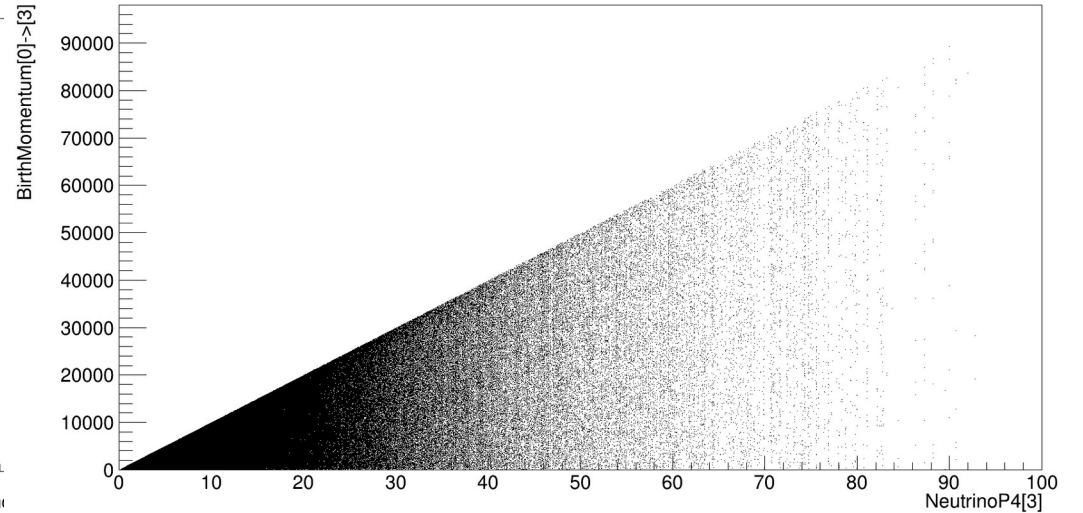
Sanity Checks

BirthMomentum[0]->[3]:NeutrinoP4[3] {IsCC==1 && NeutrinoPDG==12}



Electron energy vs Neutrino energy

BirthMomentum[0]->[3]:NeutrinoP4[3] {IsCC==1 && NeutrinoPDG==14}

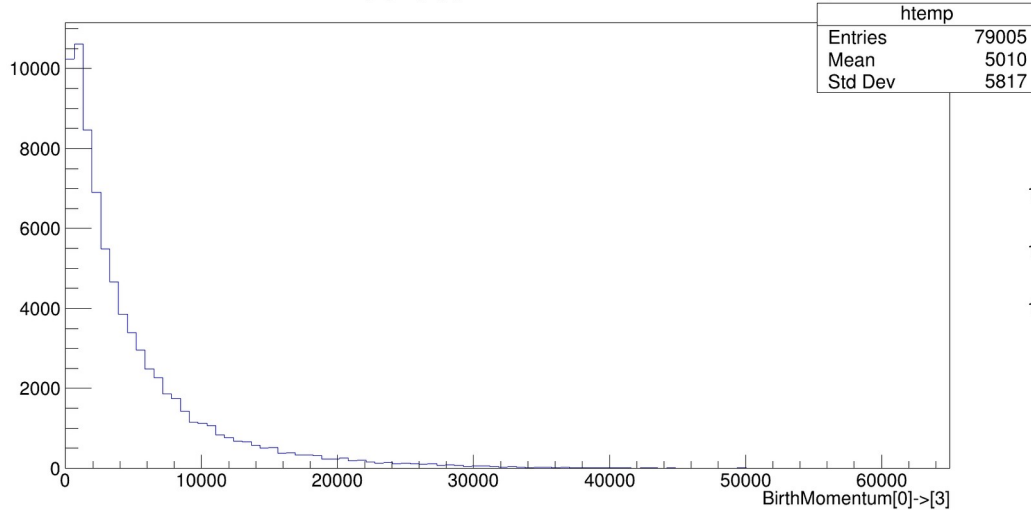


Muon energy vs Neutrino energy

Bfield data

Sanity Checks

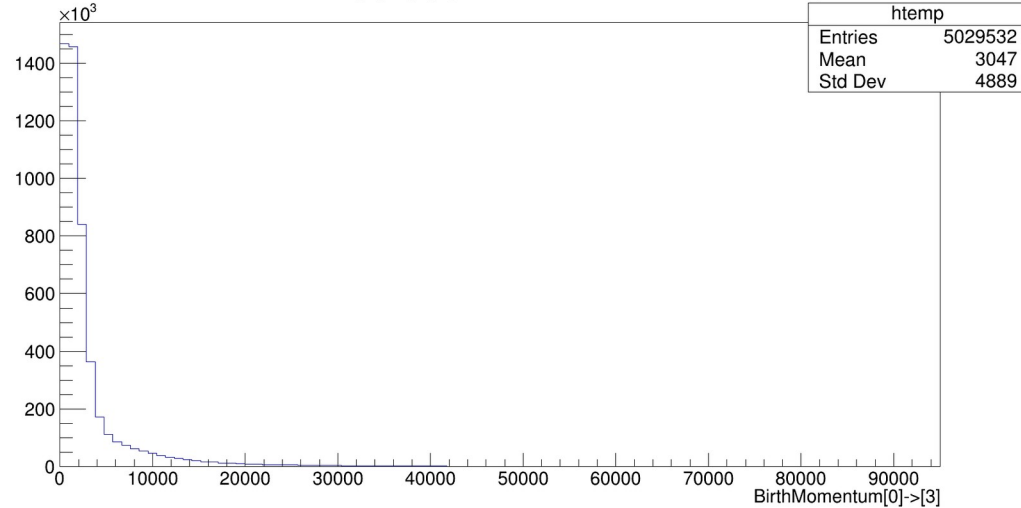
BirthMomentum[0]->[3] {IsCC==1 && NeutrinoPDG==12}



Electron CC event
Energy hist

Bfield

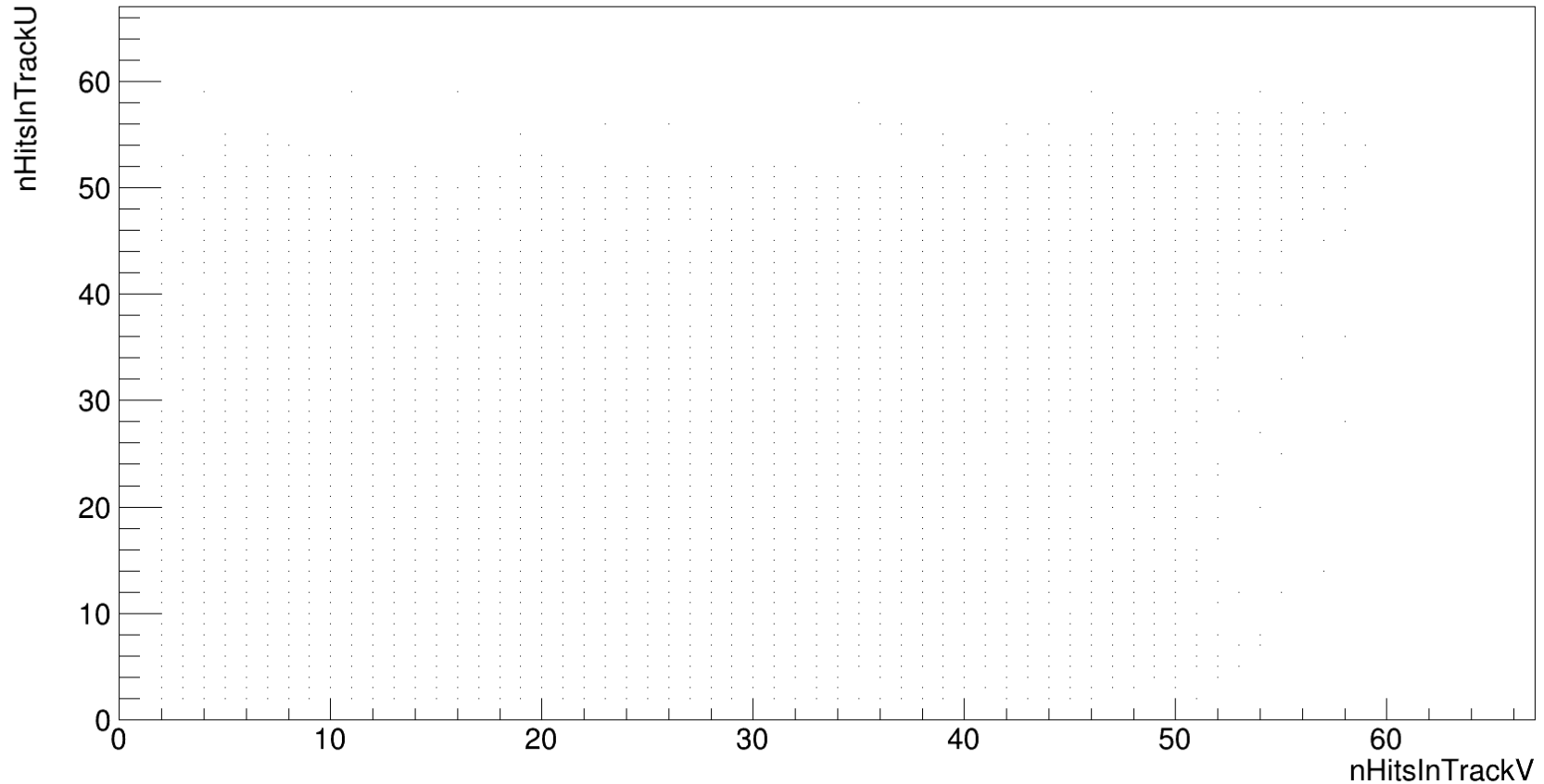
BirthMomentum[0]->[3] {IsCC==1 && NeutrinoPDG==14}



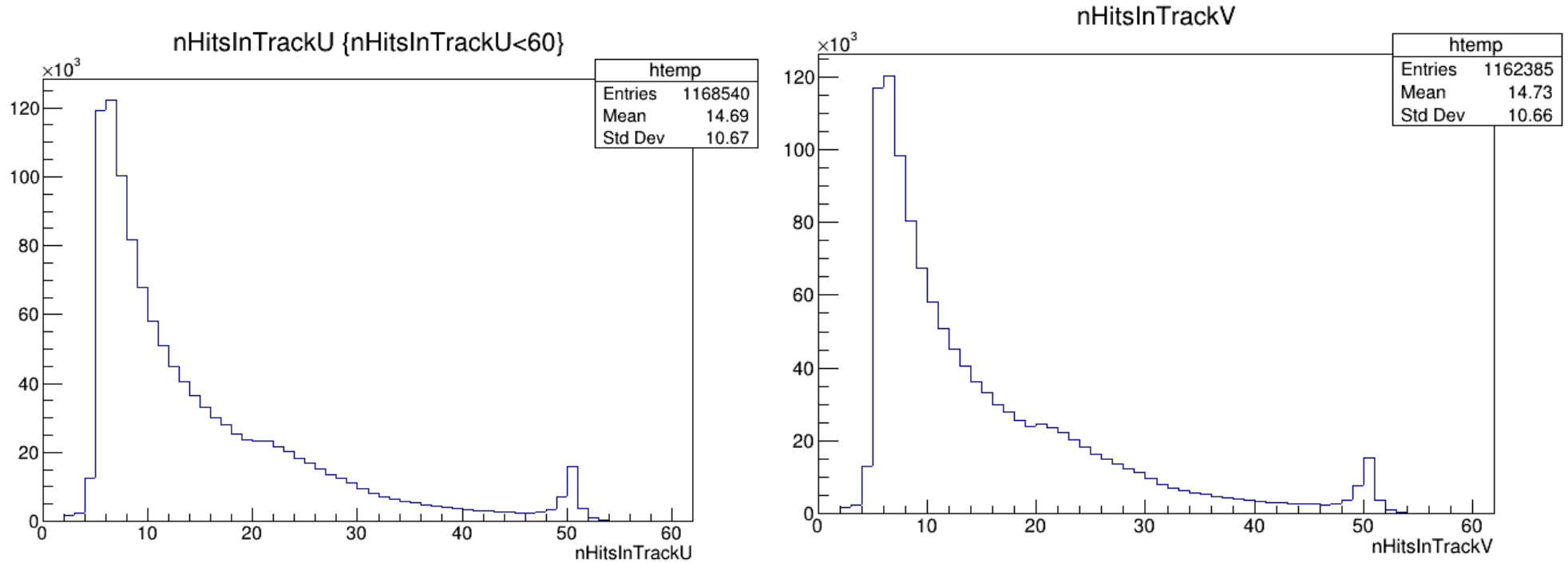
Muon CC event
Energy hist

Sanity Checks

$n\text{HitsInTrackU}:n\text{HitsInTrackV} \{n\text{HitsInTrackU}<60 \ \&\& \ n\text{HitsInTrackV}<60\}$



Why I cut on > 5 hits



Cuts

12.1

In TMS

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z in (11362, 18294)

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

12.2

Out TMS

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z > 18294

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

12.3

In Thin

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z < 13500

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

12.4

In Thick

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z in (13500, 182964)

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

Cuts

31.1

In TMS

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z in (11362, 18294)

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

31.2

Out TMS

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z > 18294

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

31.3

In Thin

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z < 13500

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

31.4

In Thick

Muon_Vertex[2] >= 0

Muon_Death_X in TMS

Muon_Death_Y in TMS

Muon_Death_Z in (13500, 182964)

n LinesU = 1

n LinesV = 1

n ClustersU = 0

n ClustersV = 0

n HitsInTrackU >= 5

n HitsInTrackV >= 5

p_T / p_z <= 0.2

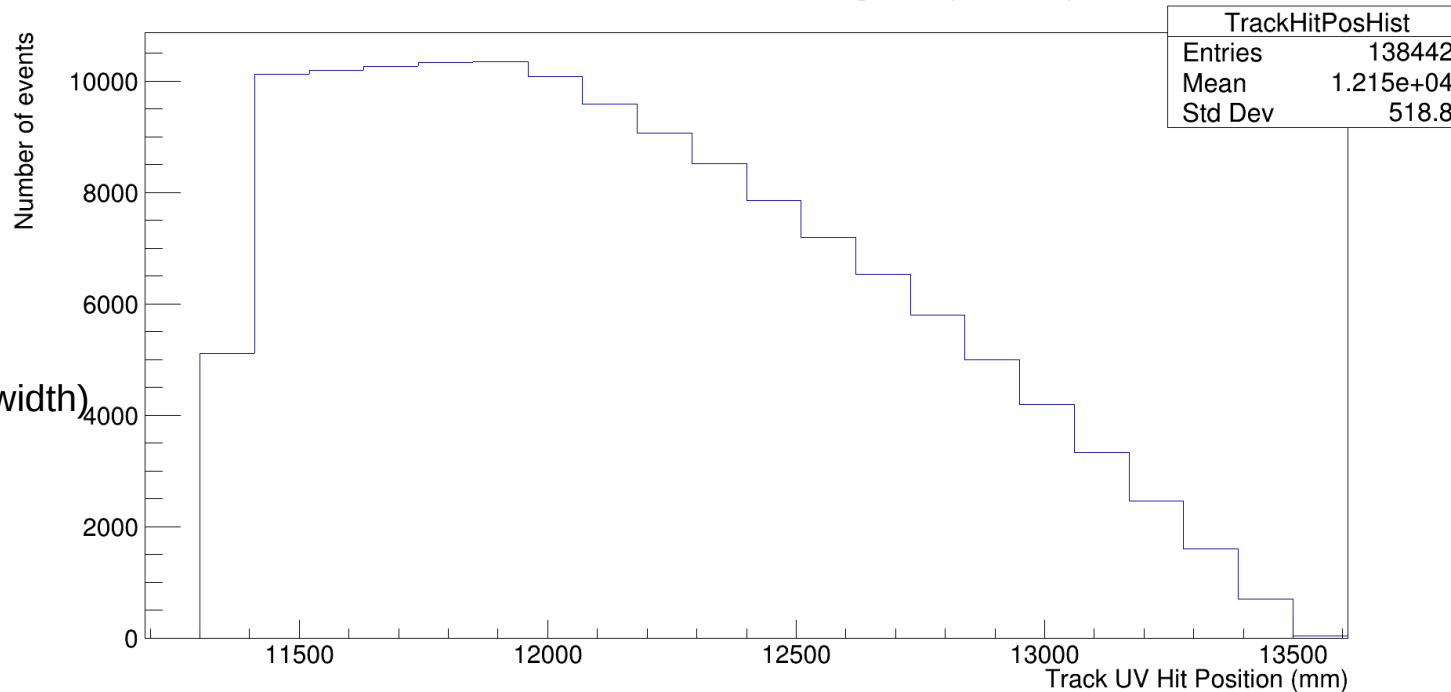
Added Muon_Vertex[2] <= 11000 (Only muons born before TMS) to all cuts

Track Hit Position UV Histogram (In Thin)

Cuts 12.3

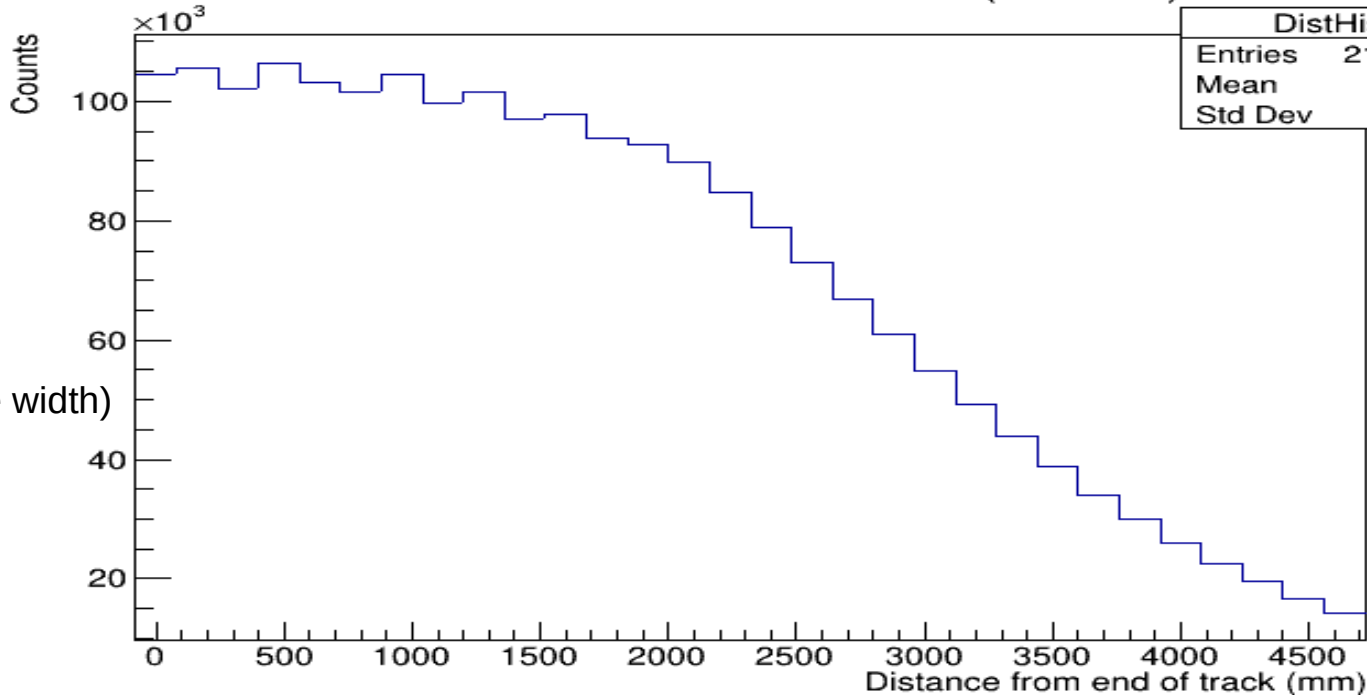
Bins: 22

Bin X Width:
110 mm
(x2 thin plane width)



Min x: 11190
Max x: 13610
Range: 2420

Distance from end of track UV (In Thick)



Cuts 12.4

Bins: 30

Bin X Width:
160 mm
(x2 thick plane width)

Min x: -80
Max x: 4720
Range: 4800

Canvas size
changed?

- Muon birth energy
- Muon birth position
- 2D plot of above
- nhits
-