NOνA Offaxis
Totally Active Detector

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NOνA Collaboration Meeting

Fermilab

May 13, 2004

Outline

- Parameters of the Detector
- Description of Analysis
- Detector Performance
- First Results from Simulations
- Possible Improvements in Analysis
- Future

Detector Parameters

- 2000 planes, alternating in x and y
- Each plane is 17.5 x 17.5 m
- Each plane has 14 extrusion
- Each extrusion has 32 cells, filled with liquid scintillator
- Cell dimensions are 3.8 x 4.5 cm
- Extrusion walls are 1 mm on the inside, 2mm on the outside

Detector (ctd)

- These parameters result in a detector of about 26 kt
- The non-active mass is about 13%
- A crude cost estimate give a total cost for such a detector that is roughly the same as baseline detector of 50 kt
- The simulations are based on a total mass of 25 kt

Outline of Analysis

- Initial reconstruction
  - Up to 4 tracks are found (>6 hits)
  - A quadratic fit is made, ph weighted in each plane
  - Each projection is treated independently
- A vertex is calculated (or defined)
- Assignment of particle identity is made based on a set of track parameters calculated
  - Particles are labeled as e, μ, p, or γ
  - Only 1 e, μ, or p are allowed
  - If 2 or more satisfy e criteria, the "best" one is chosen
- Ntuple file is written out with track parameters and converted to root format

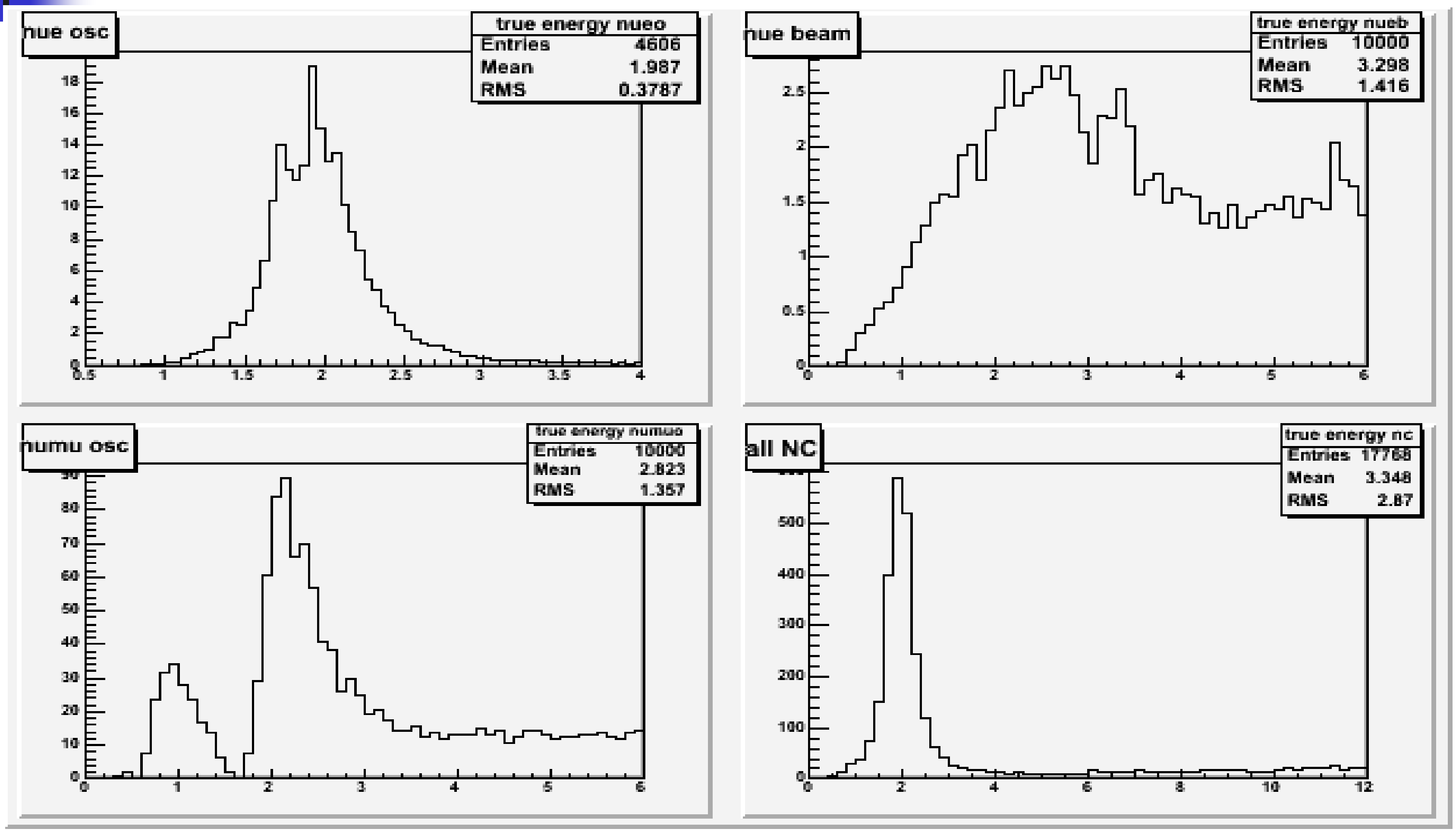
Analysis (2nd stage)

- Initial sample of e candidate events is selected, requiring:
  - Electron track in each view
  - Energy in right range
  - No μ or γ in event
  - No significant separation of “electron” from the vertex
  - No gaps near vertex
- Subsequent analysis is based on maximum likelihood method using about 9-14 different variables describing track and event “nature”
- So far only 1D distributions have been used in maximum likelihood calculation.
- In parallel there is also cuts-only analysis

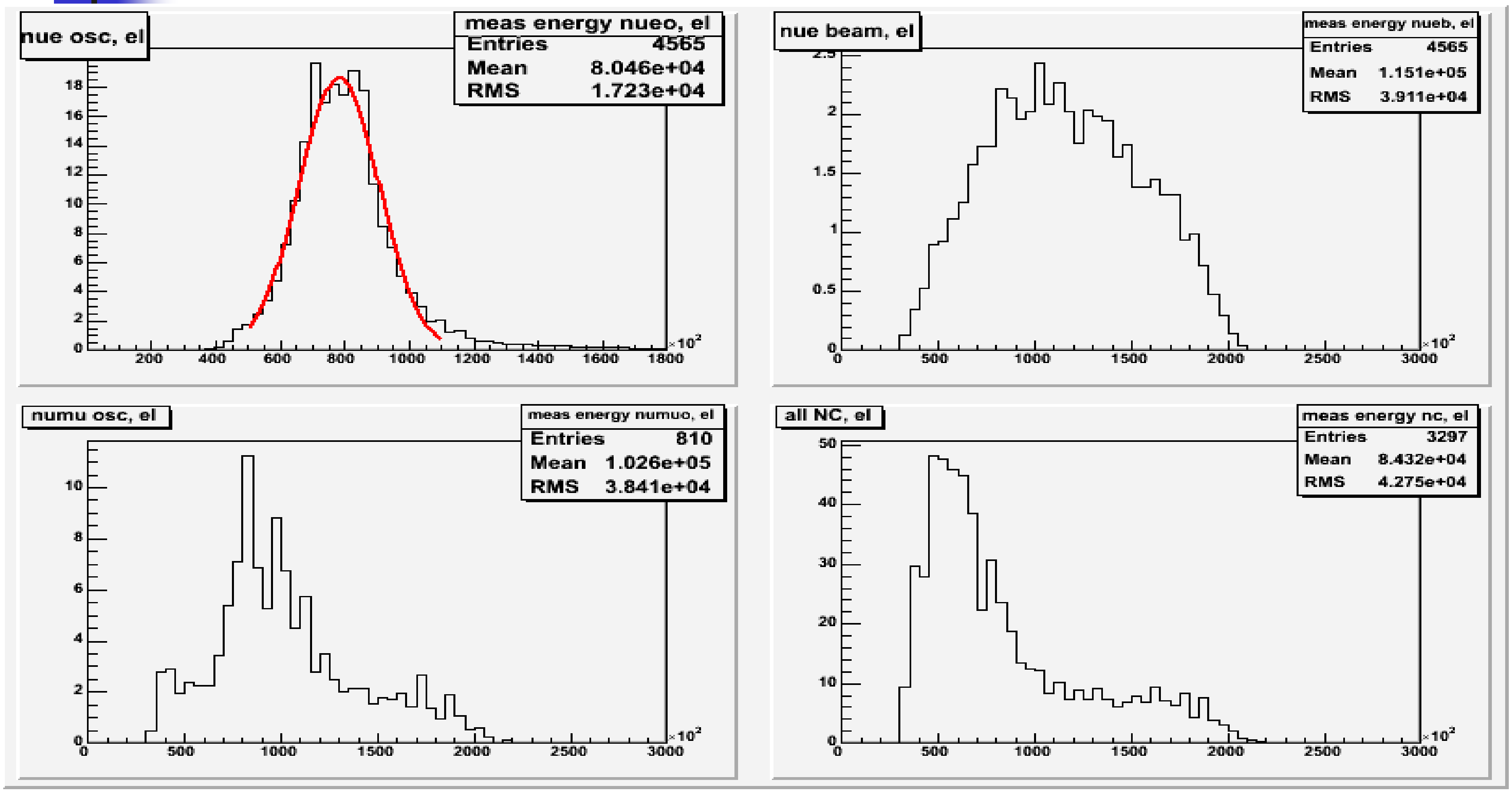
Detector Performance

- To give an idea of the performance of this detector we show next several relevant distributions:
  - Energy resolution for electron events
  - Electron/muon comparison for several variables used in ML calculation
  - Comparison of several distributions used in ML for both signal and background events (NC and CC only, except for energy)

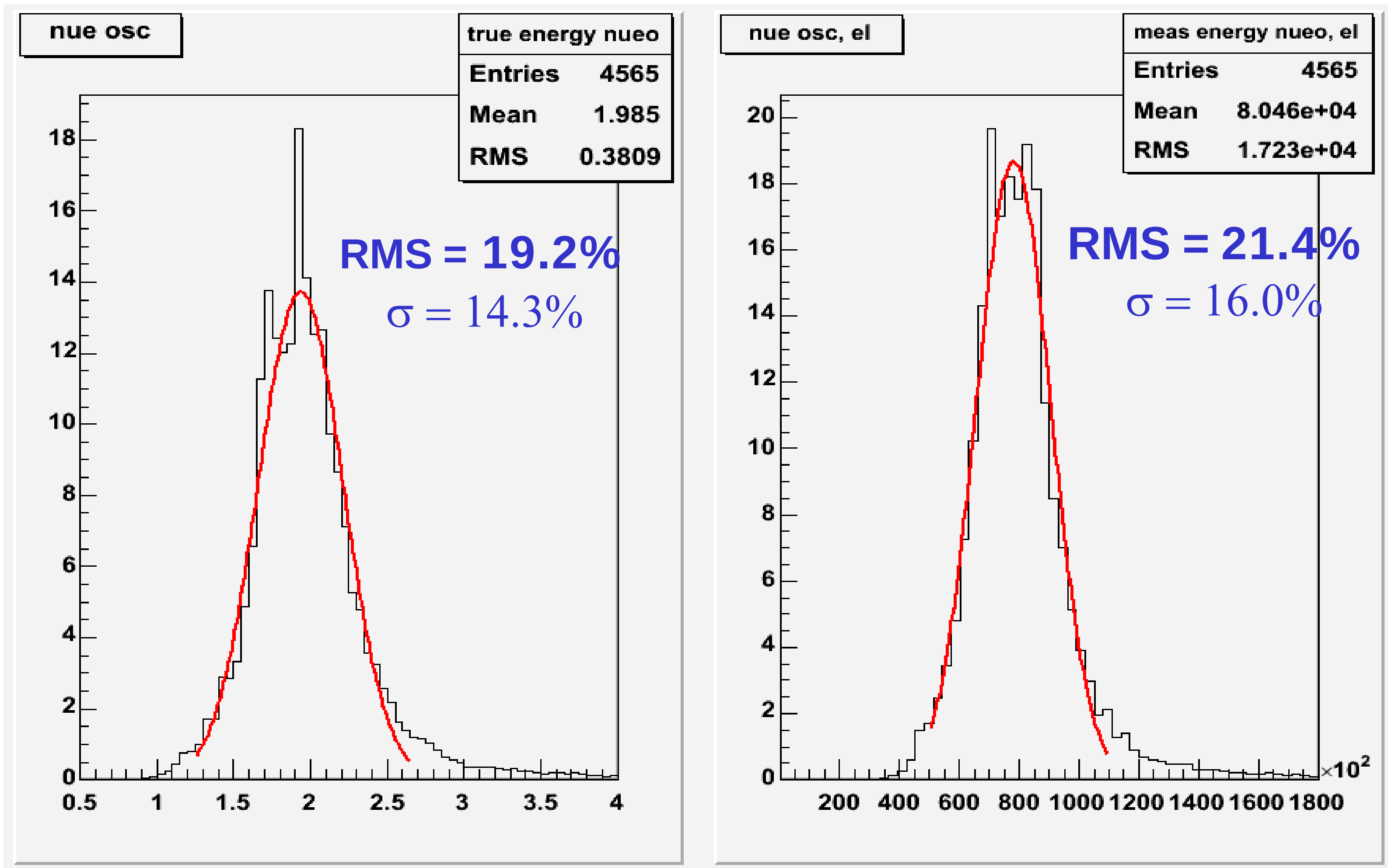
True Energy Distributions



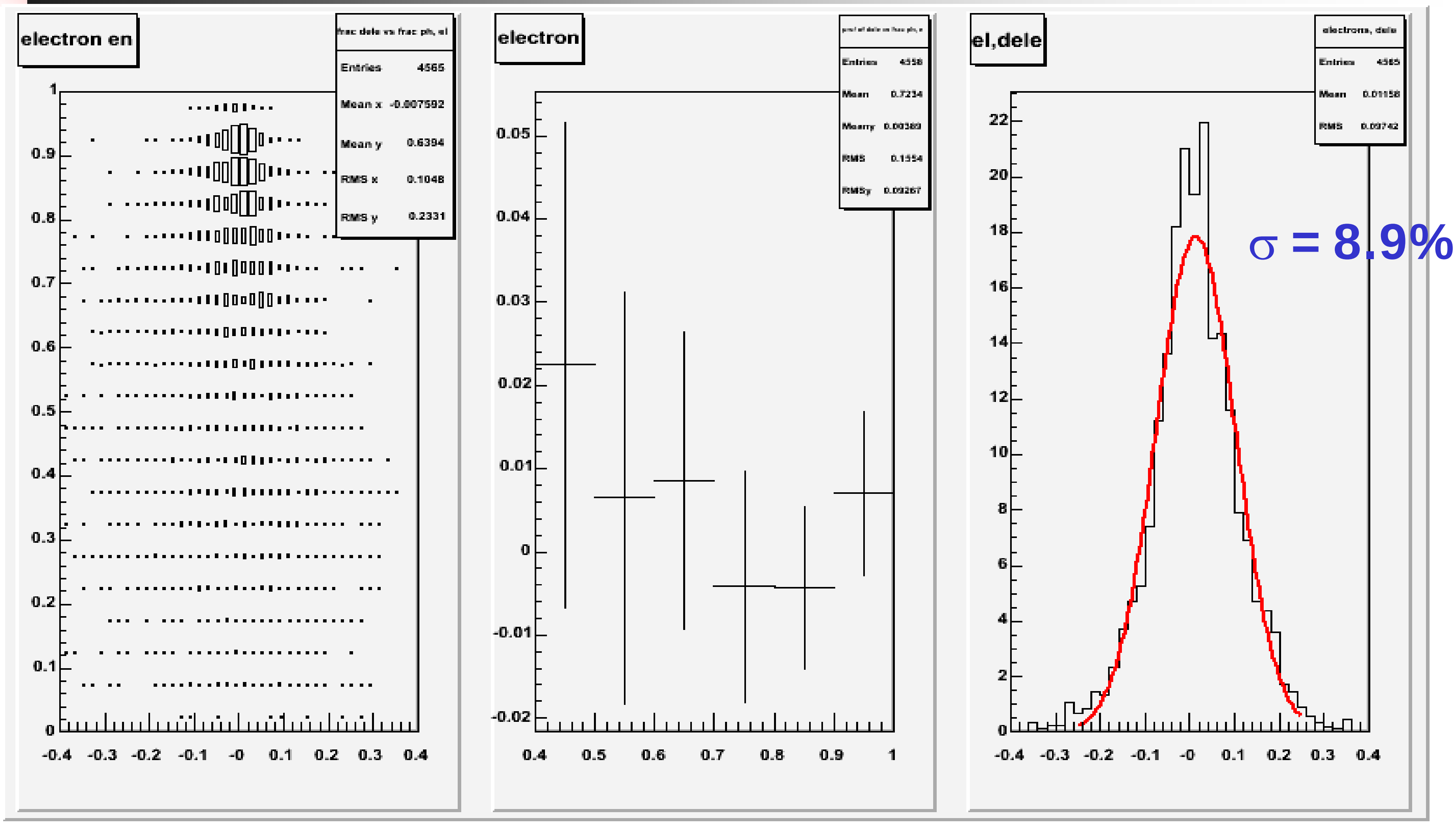
Measured Energy Distributions



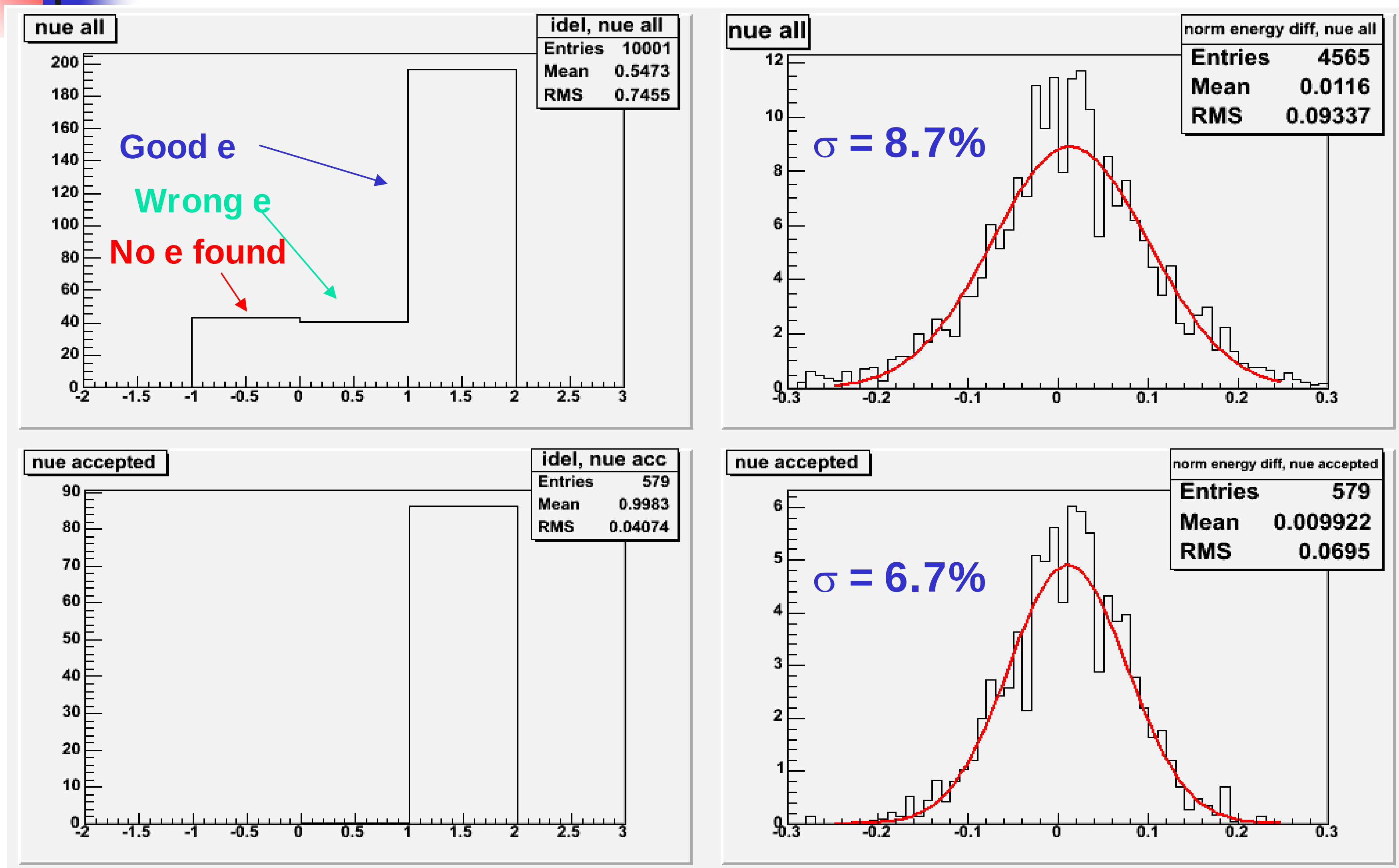
True and measured energies



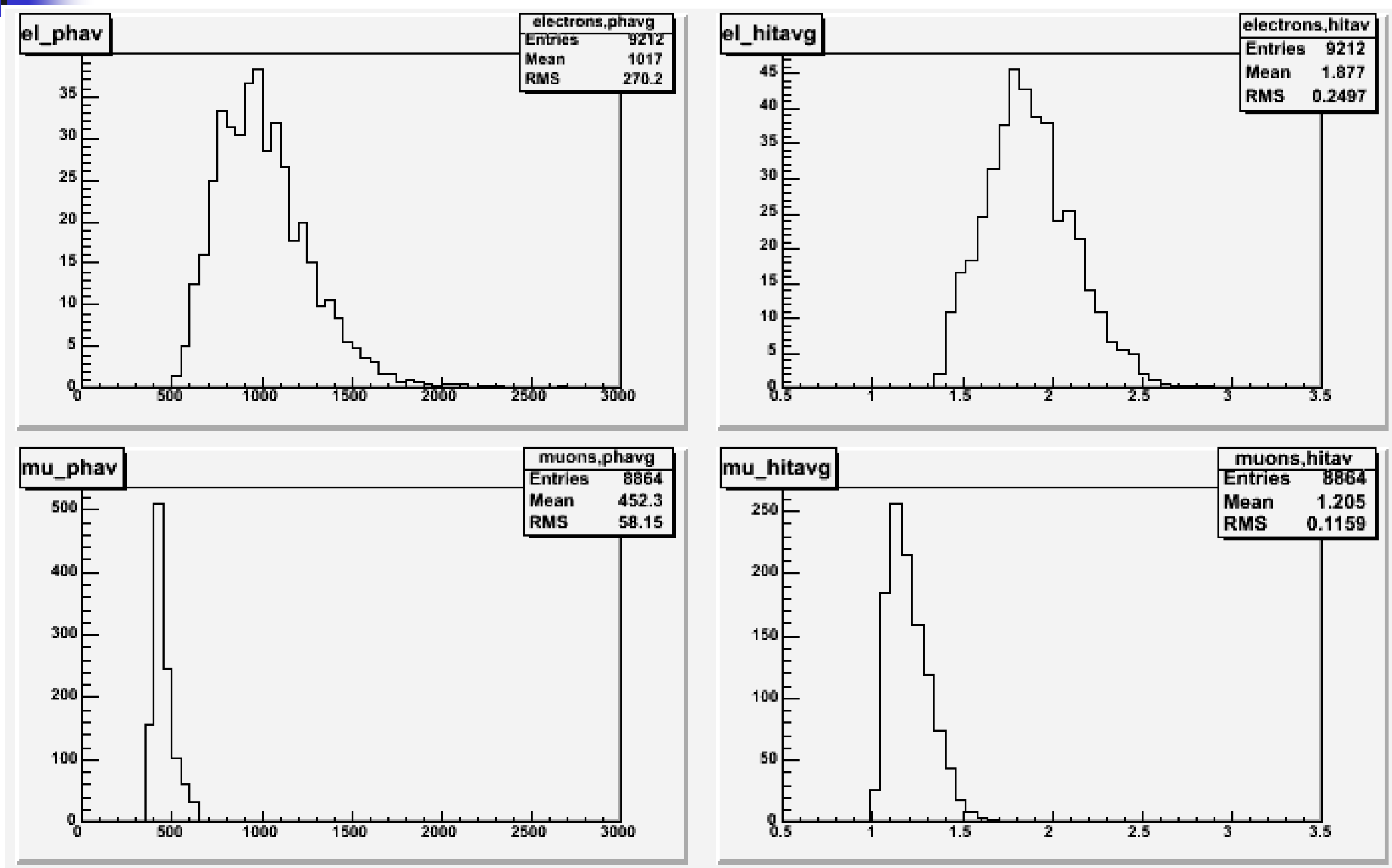
Energy Resolution - 2



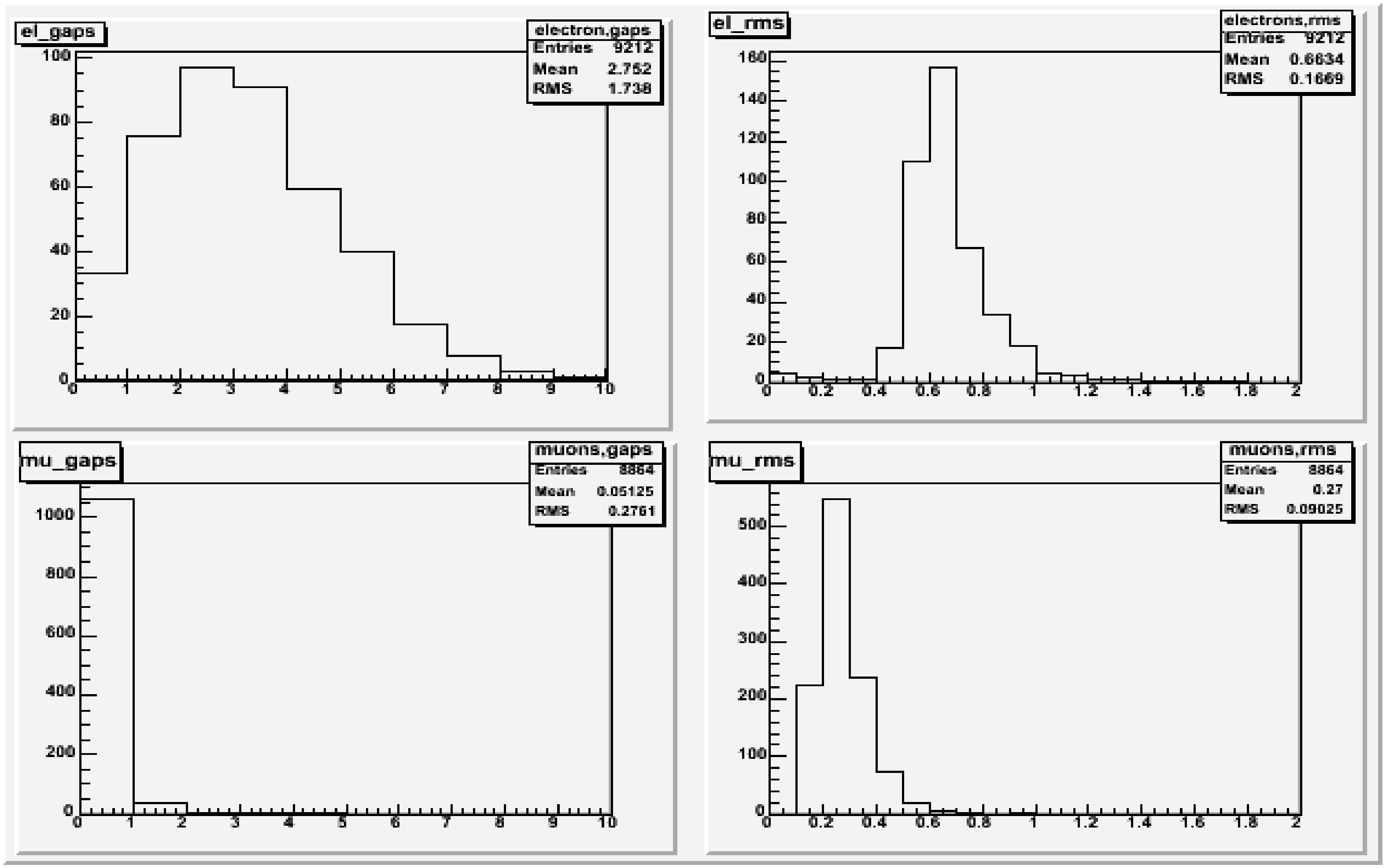
Summary Distributions



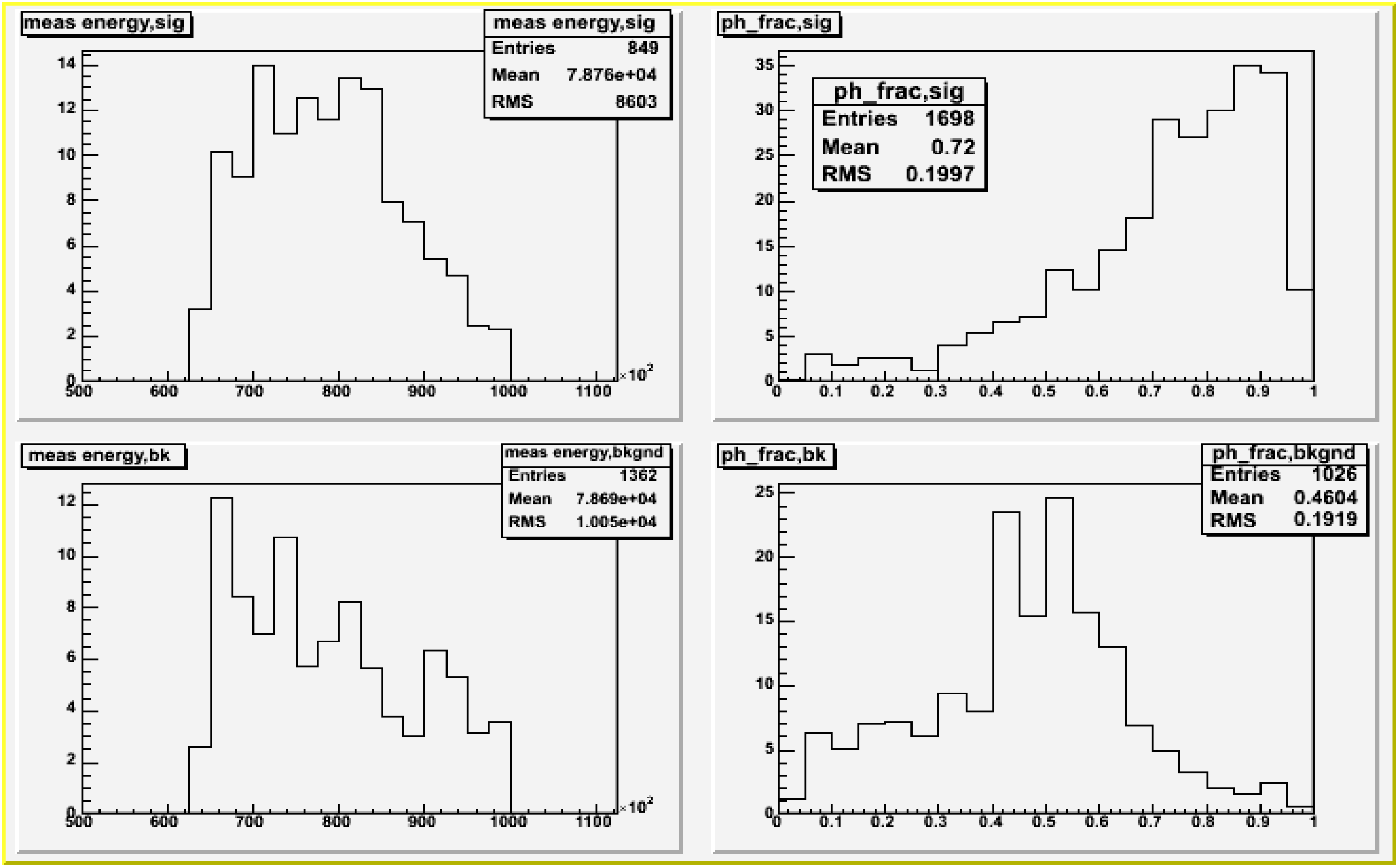
Electron / muon comparison (avg pulse height and no hits)



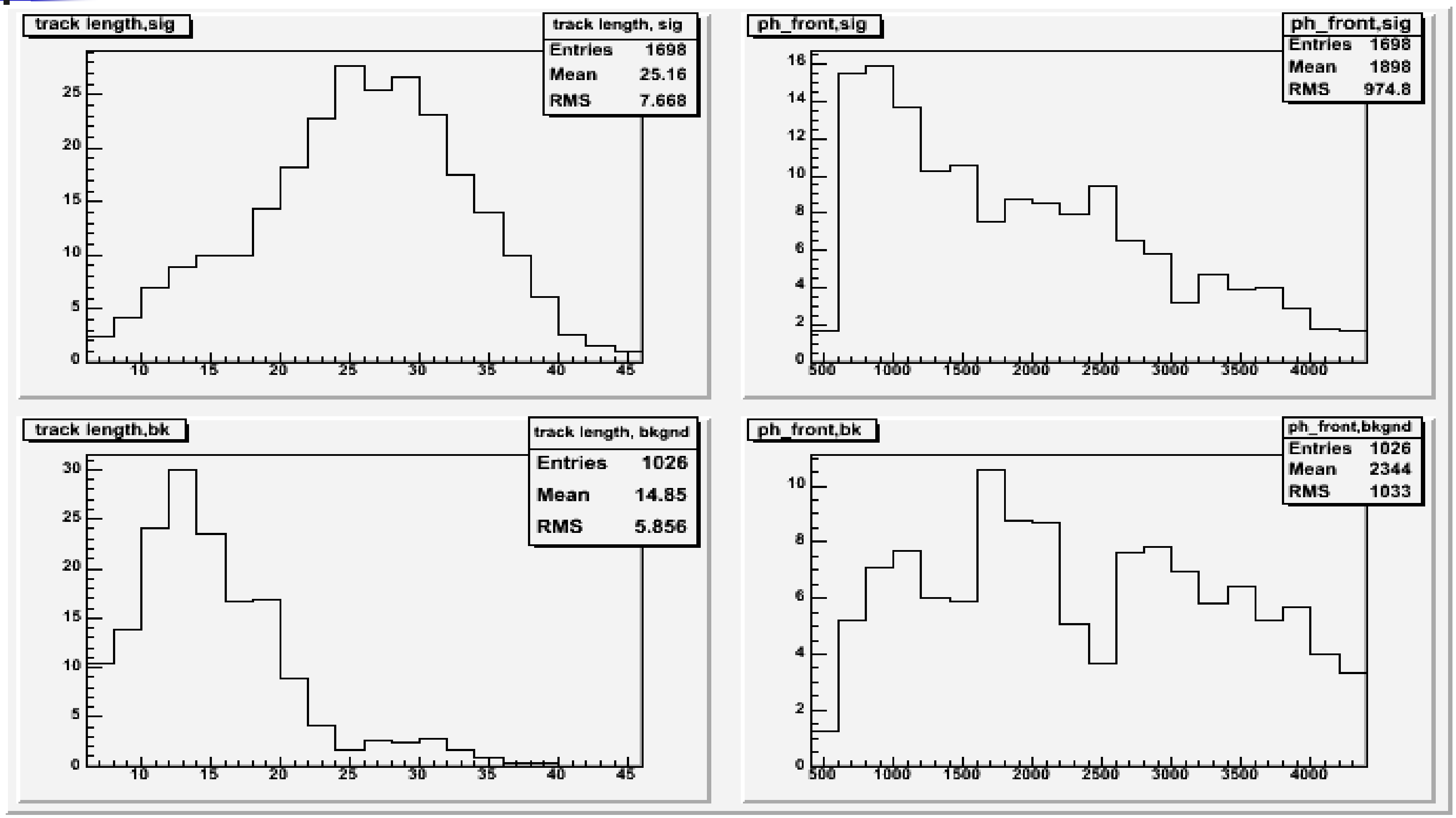
Electron/muon comparison
(no of gaps and average rms)



Signal/background (energy and measured "y")



Signal/background (track length and ph in front)



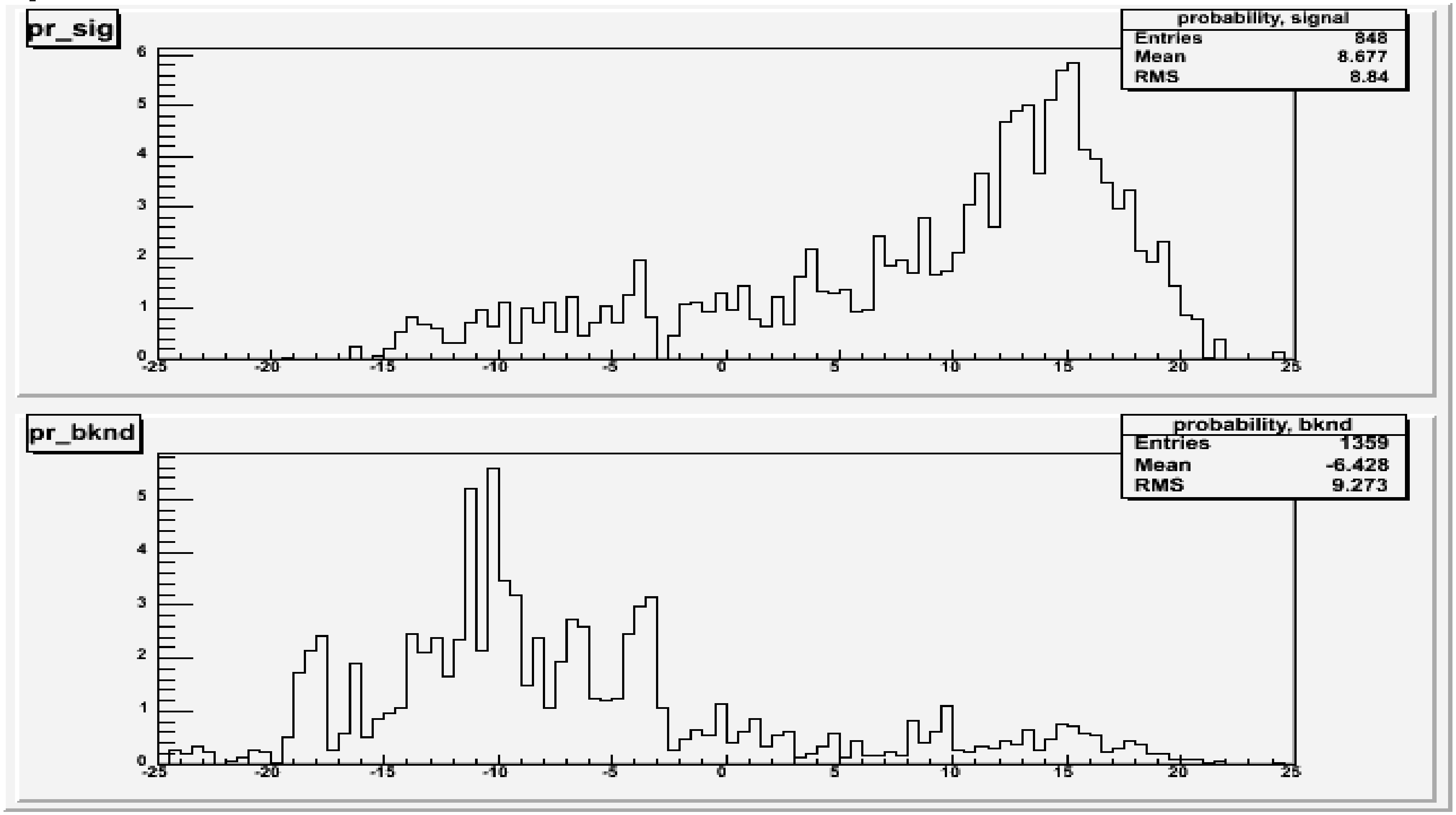
Simulation Results

- We show the results of the first simulation for this detector using the method described
- The results have to be considered quite preliminary at this time
- They are based on 10k events for ν_e CC (signal and beam ν_e background), and 10k each for NC (E_ν<6 GeV), NC (all) and ν_μ CC.

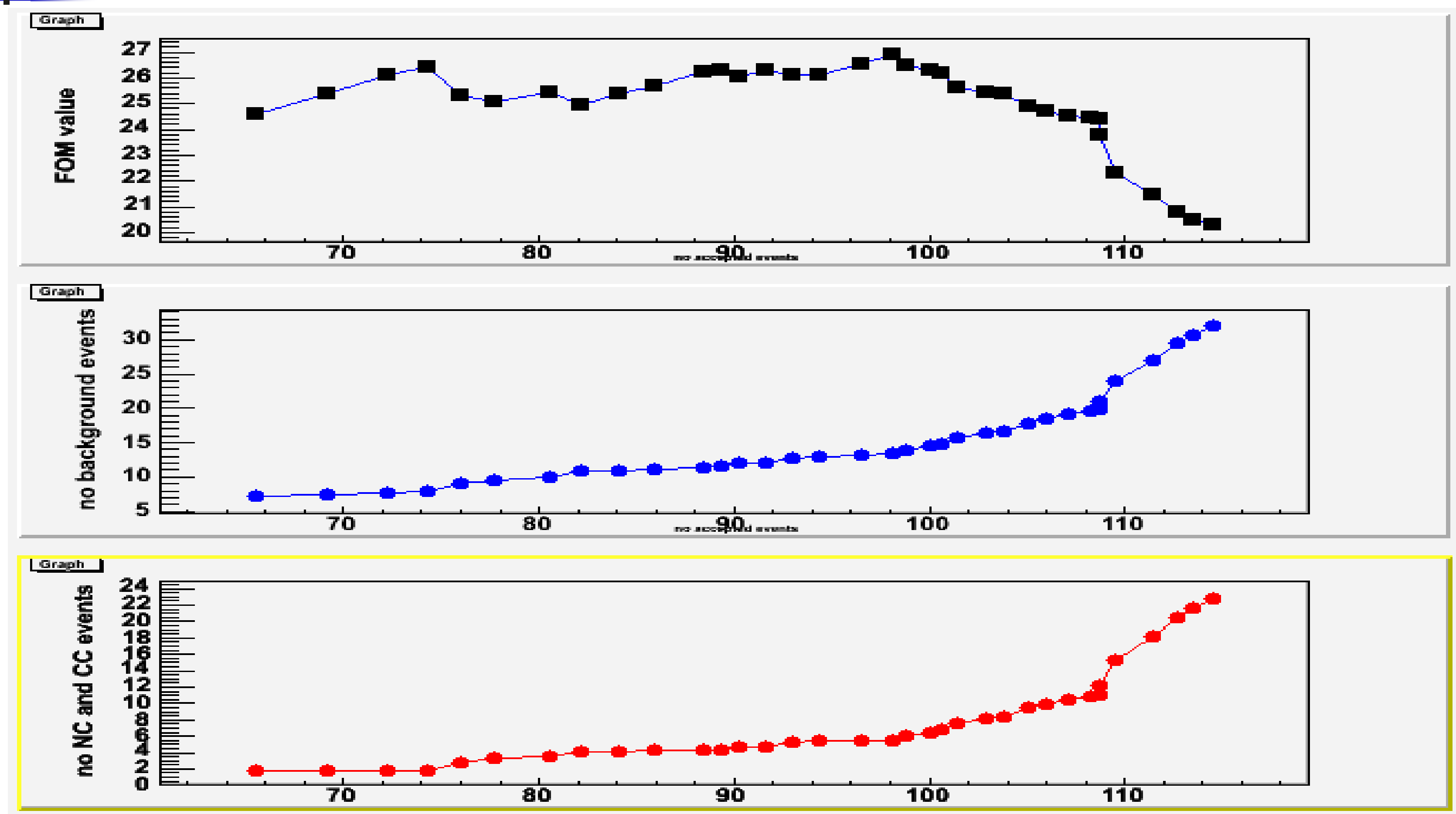
Input Conditions

- Detector 810 km away and at 12 km transverse distance
- Total mass is 25 kt
- Running time is 5 yrs, 3.7 x 10^{20} ppy
- Latest Messier spectra are used
- “Small” contributions (antineutrinos, NC from ν_e are not included)
- Δm^2_{23} = 2.5 x 10^{-3} eV^2, $P(\nu_\mu \text{->} \nu_e)$ = 0.05

Signal/background relative probabilities



FOM and backgrounds vs no of signal events



Cuts-only Analysis

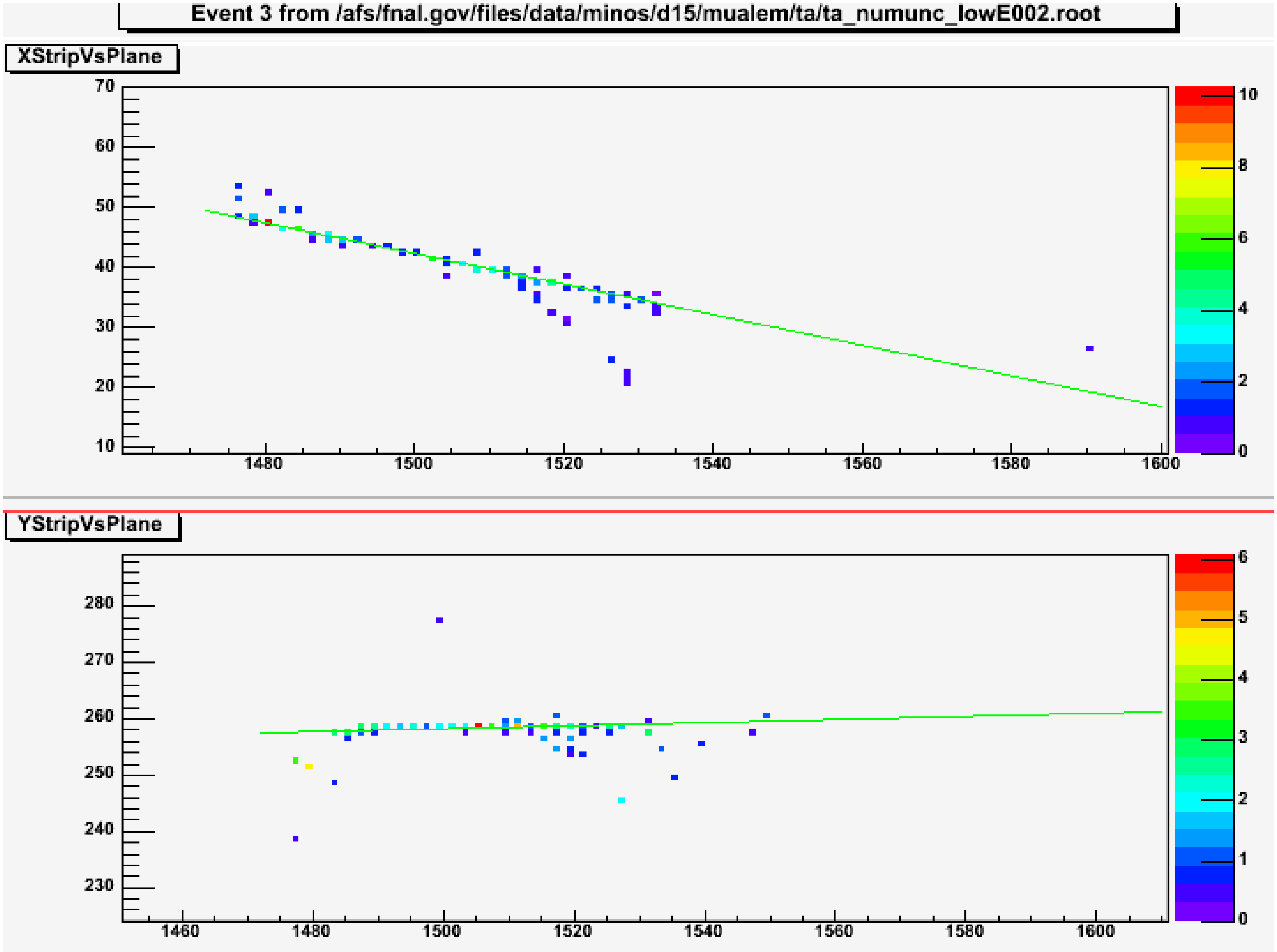
```
                         SUMMARY OF CUTS
 total count = 312.857  92.803  1232.33  3569.47  FOM= 4.47185
 early cuts, no leak = 176.786  72.305  866.483  3027.41  FOM= 2.80712
 electrons,no leak,early cuts = 176.786  49.0402  113.258  565.93  FOM= 6.5511
 electrons, + energy cut = 140.047  13.5834  48.8582  168.928  FOM= 9.20708
 no coherent = 140.047  13.5834  48.8582  168.928  FOM= 9.20708
 no muons = 139.491  13.3785  37.4855  166.584  FOM= 9.45952
 no gammas = 132.657  12.4862  32.2736  145.547  FOM= 9.61622
 + dist from vertx, gaps nr vrtx = 120.291  10.8391  20.1878  97.9566  FOM= 10.5
917
 + track length = 116.291  9.96149  13.2482  55.3218  FOM= 13.1227
 + avg ph = 114.464  9.77663  10.8854  49.18  FOM= 13.6966
  + ph frac = 101.967  8.16796  4.46897  14.9083  FOM= 19.4284
 + curvature, asymm = 90.6567  7.27035  2.35719  6.84207  FOM= 22.3387
 + ph_front, ph_unusd  = 86.3847  7.02798  0.945093  6.03828  FOM= 23.0779
 + quasielastics = 86.3847  7.02798  0.945093  6.21868  FOM= 22.9308
```

Possible Future Improvements

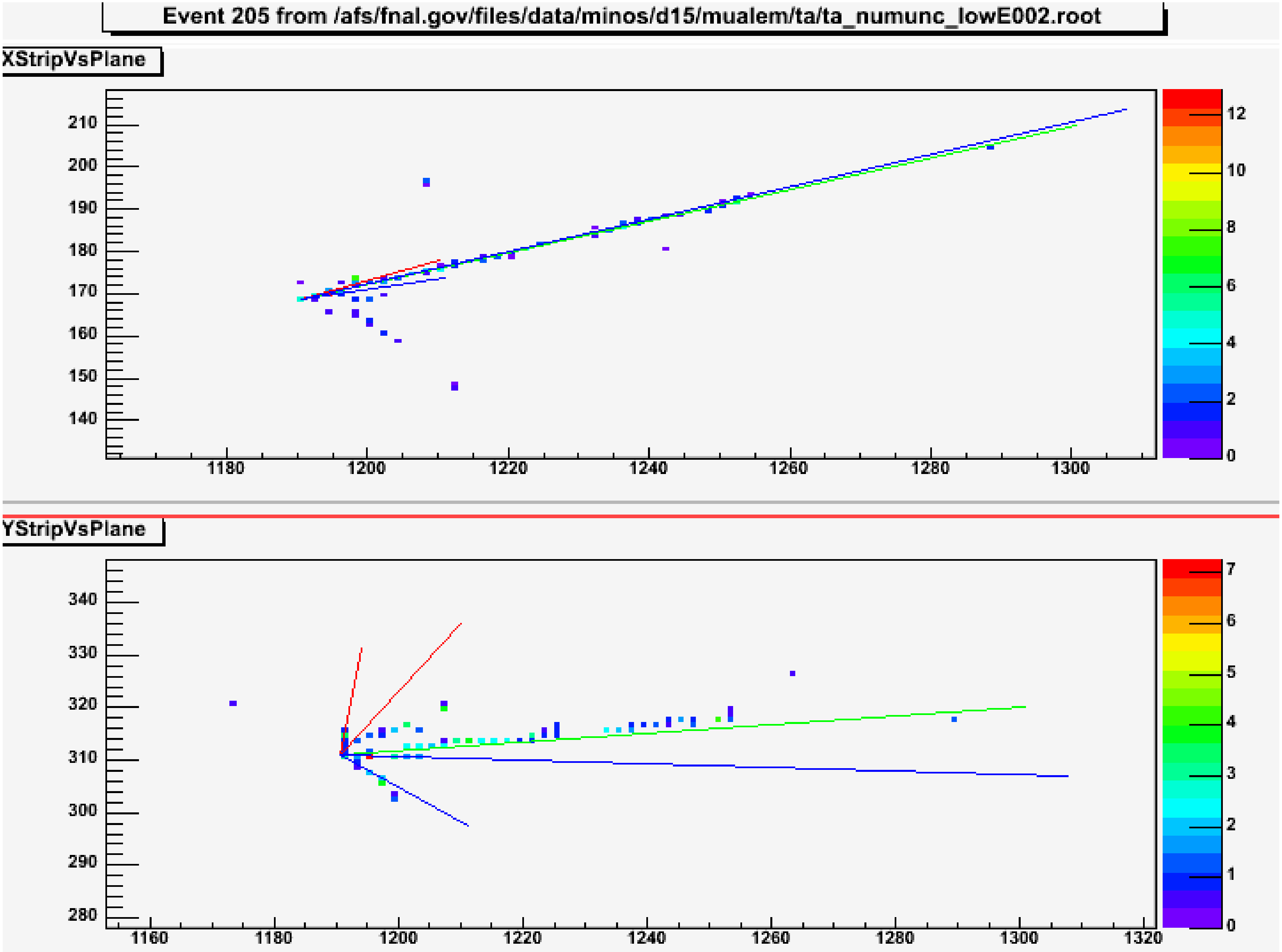
- Take account of inert material
- More sophisticated method of selecting electron (if >1 candidate)
- More sophisticated γ definition and its use
- Better track reconstruction (see sample of events to follow)
- Use of correlated distributions in ML and/or possibly neural network
- An alternative, more sophisticated, approach to pattern recognition

Examples of Events

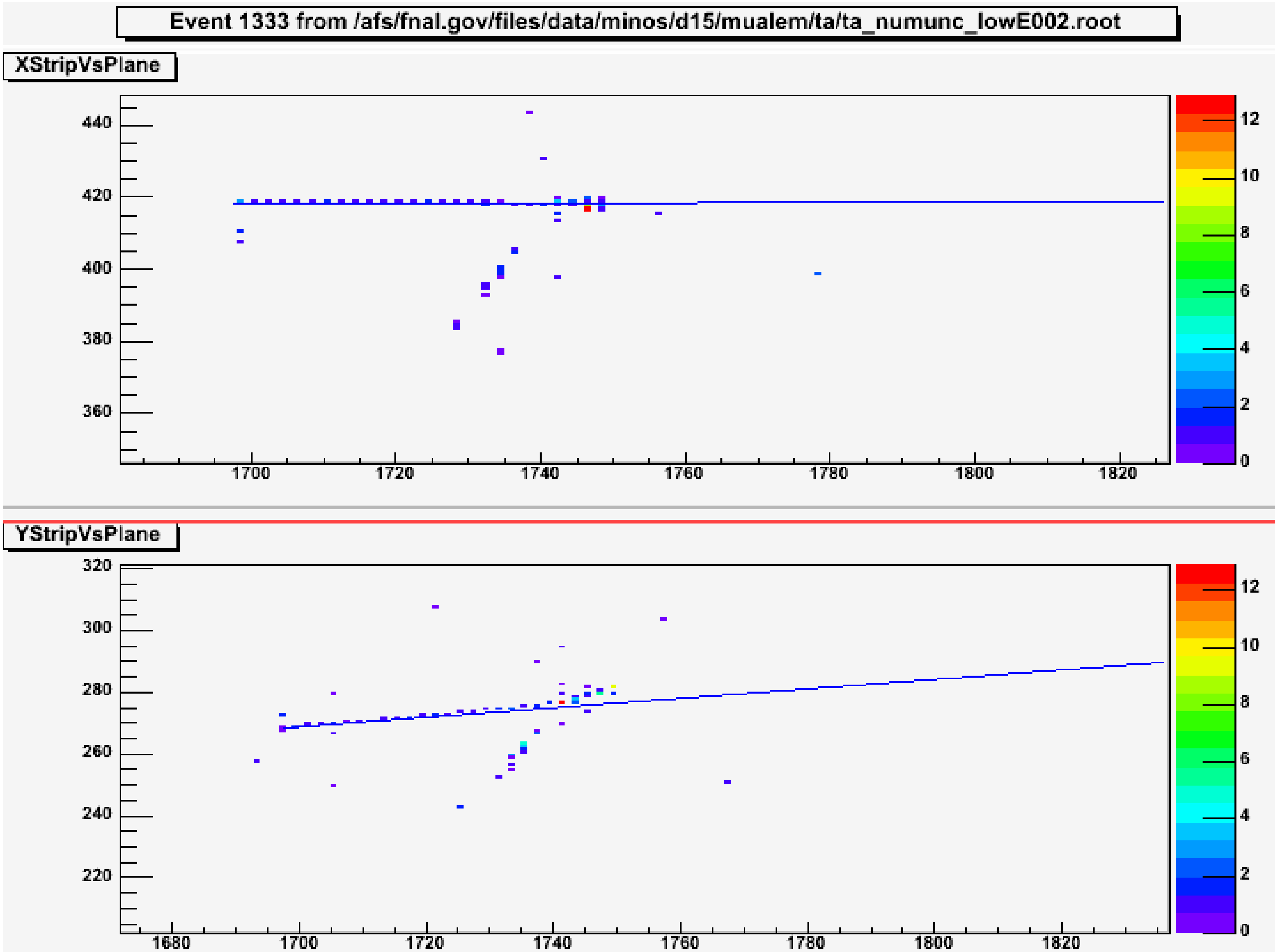
- We first show some NC and ν_μ CC events which pass our cuts
- Bear in mind that these are roughly 1 per mil
- Then we shall show ν_e CC events in the energy range of interest which fail in reconstruction (no electron found)
- These are relatively typical; chosen only to demonstrate different categories of failures



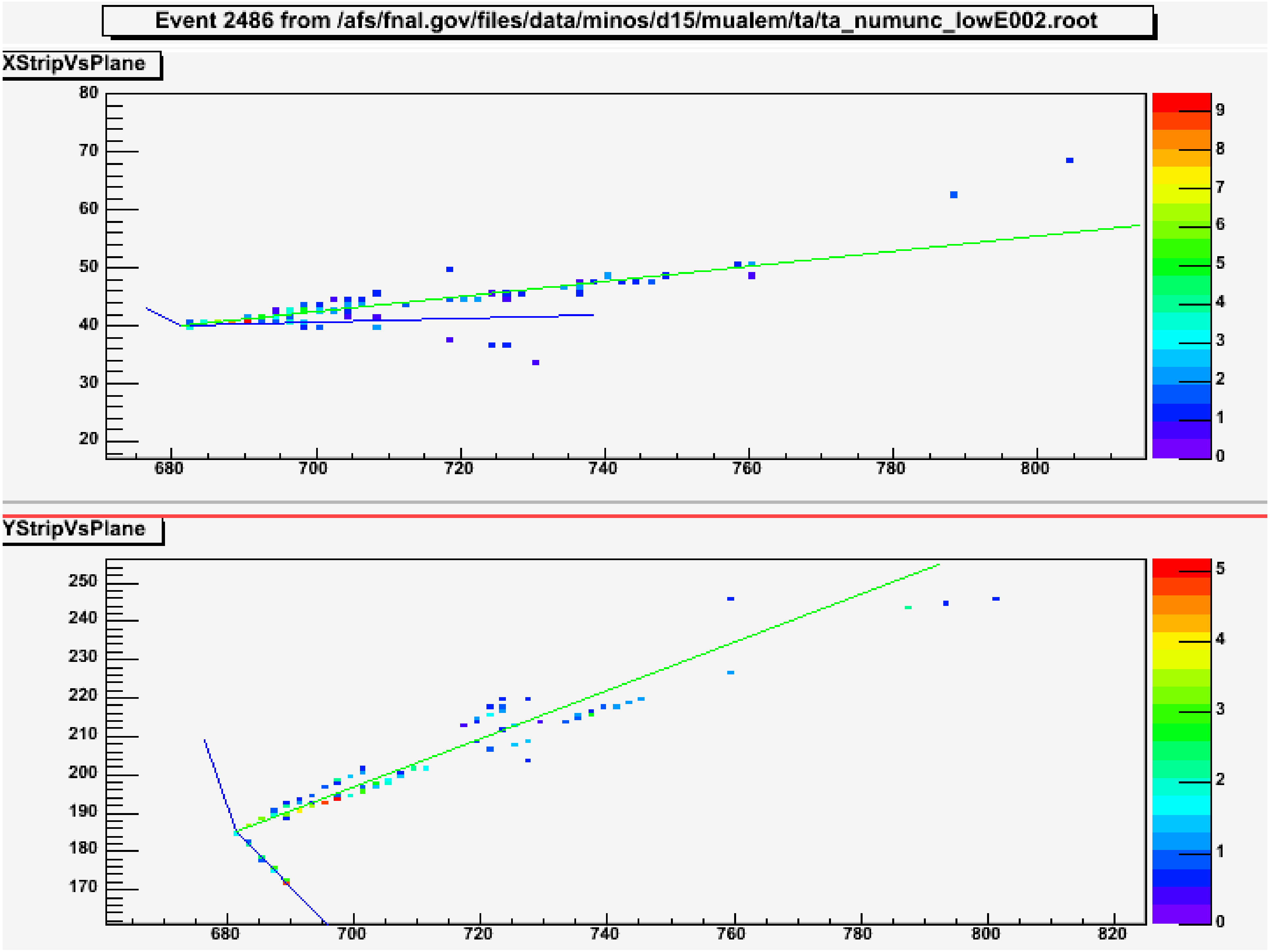
Event 3 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
70
60
50
40
30
20
10
1480
1500
1520
1540
1560
1580
1600
10
8
6
4
2
0
YStripVsPlane
280
270
260
250
240
230
1460
1480
1500
1520
1540
1560
1580
1600
6
5
4
3
2
1
0



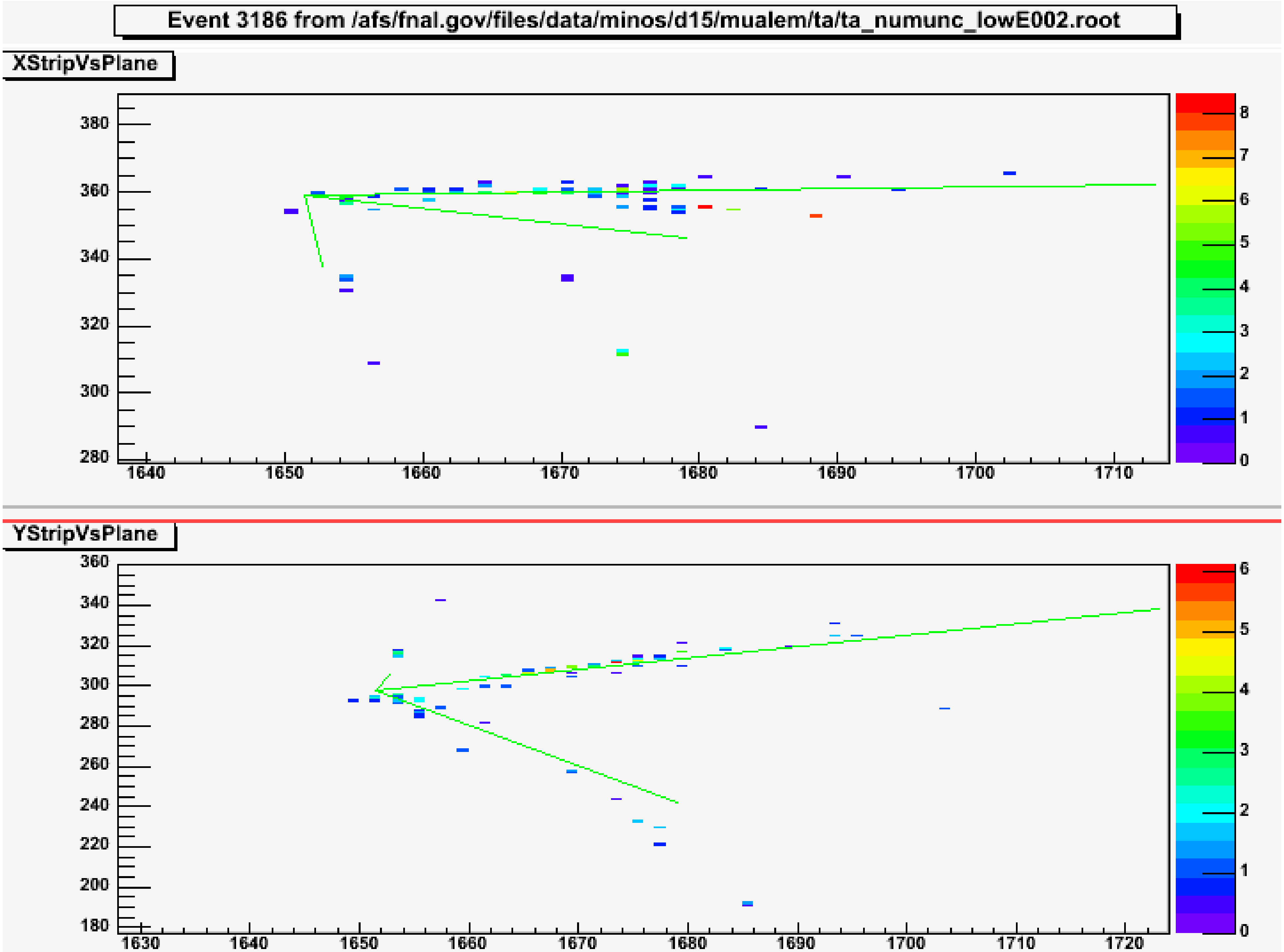
Event 205 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
YStripVsPlane



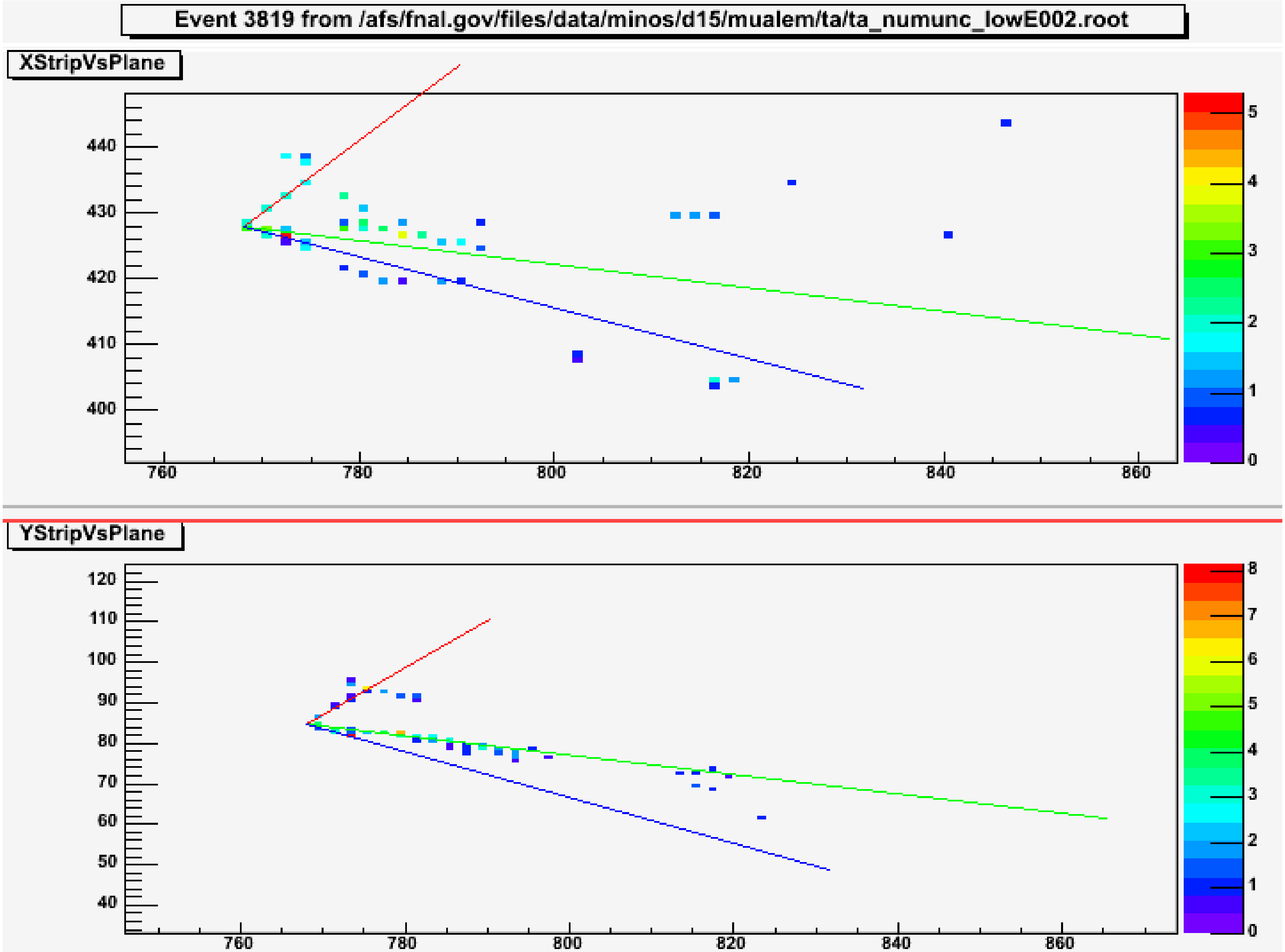
Event 1333 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
440
420
400
380
360
1700
1720
1740
1760
1780
1800
1820
12
10
8
6
4
2
0
YStripVsPlane
320
300
280
260
240
220
1680
1700
1720
1740
1760
1780
1800
1820
12
10
8
6
4
2
0



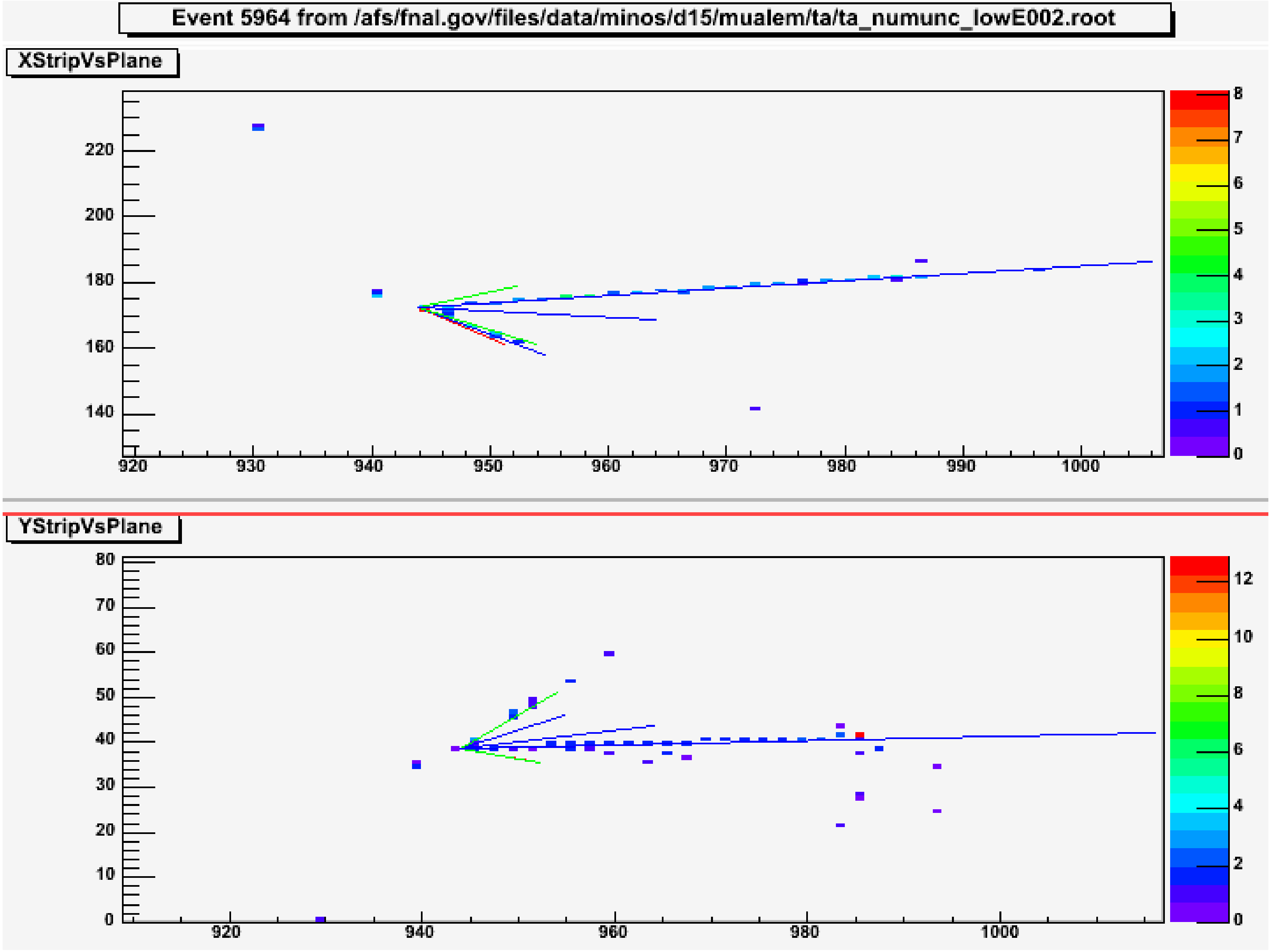
Event 2486 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
80
70
60
50
40
30
20
680
700
720
740
760
780
800
9
8
7
6
5
4
3
2
1
0
YStripVsPlane
250
240
230
220
210
200
190
180
170
680
700
720
740
760
780
800
820
5
4
3
2
1
0

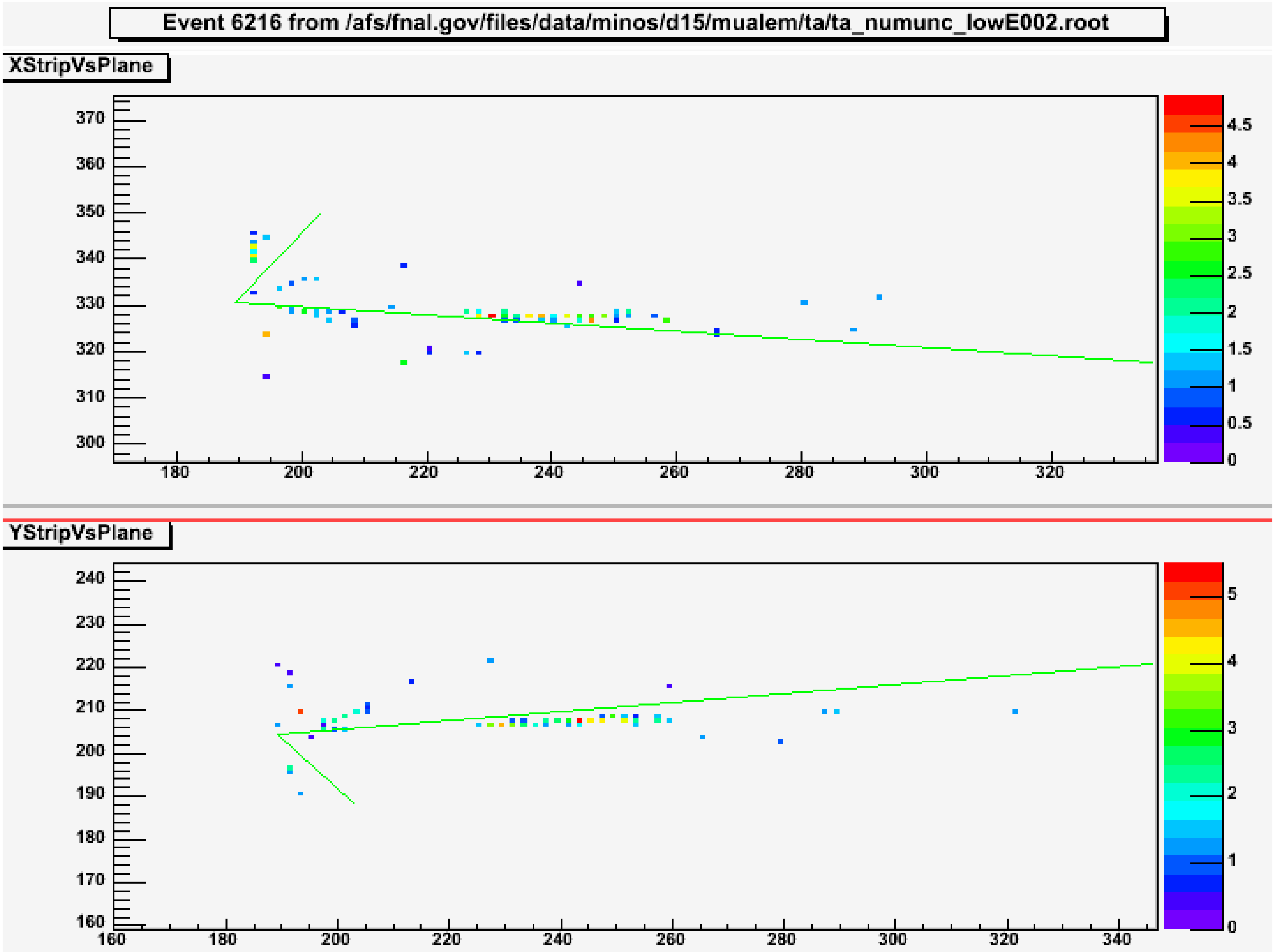


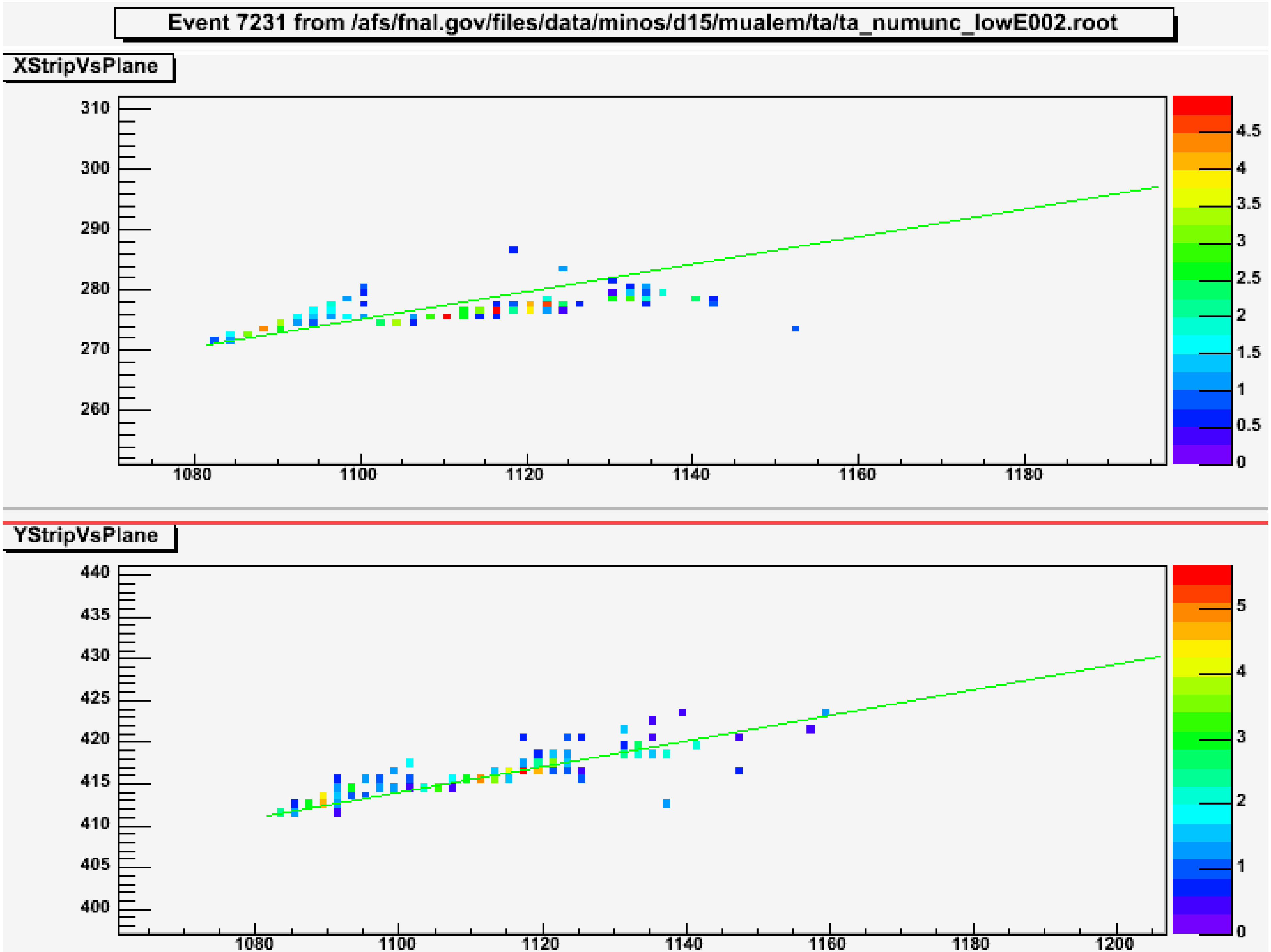
Event 3186 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
YStripVsPlane

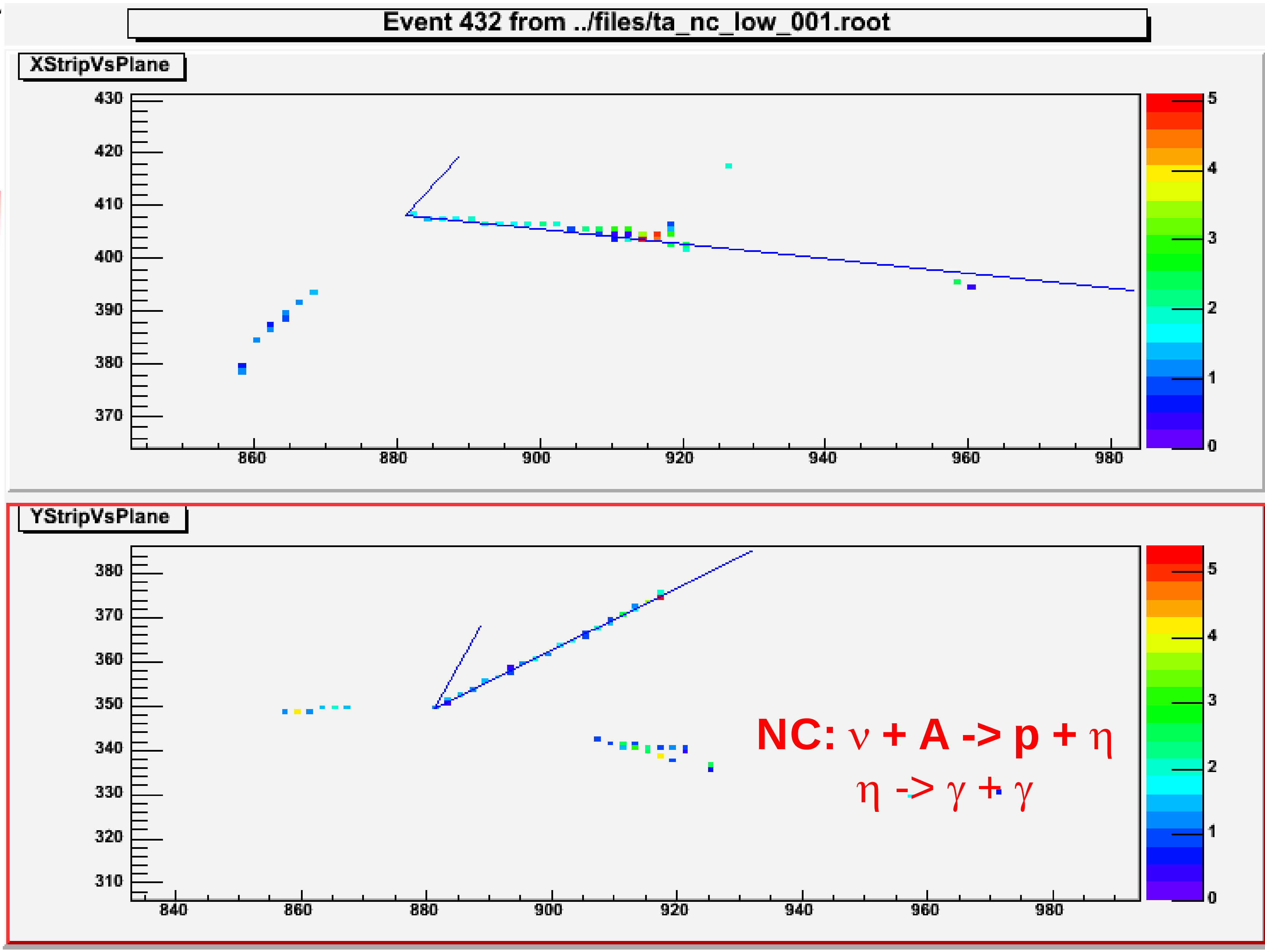


Event 3819 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
440
430
420
410
400
760
780
800
820
840
860
5
4
3
2
1
0
YStripVsPlane
120
110
100
90
80
70
60
50
40
760
780
800
820
840
860
8
7
6
5
4
3
2
1
0

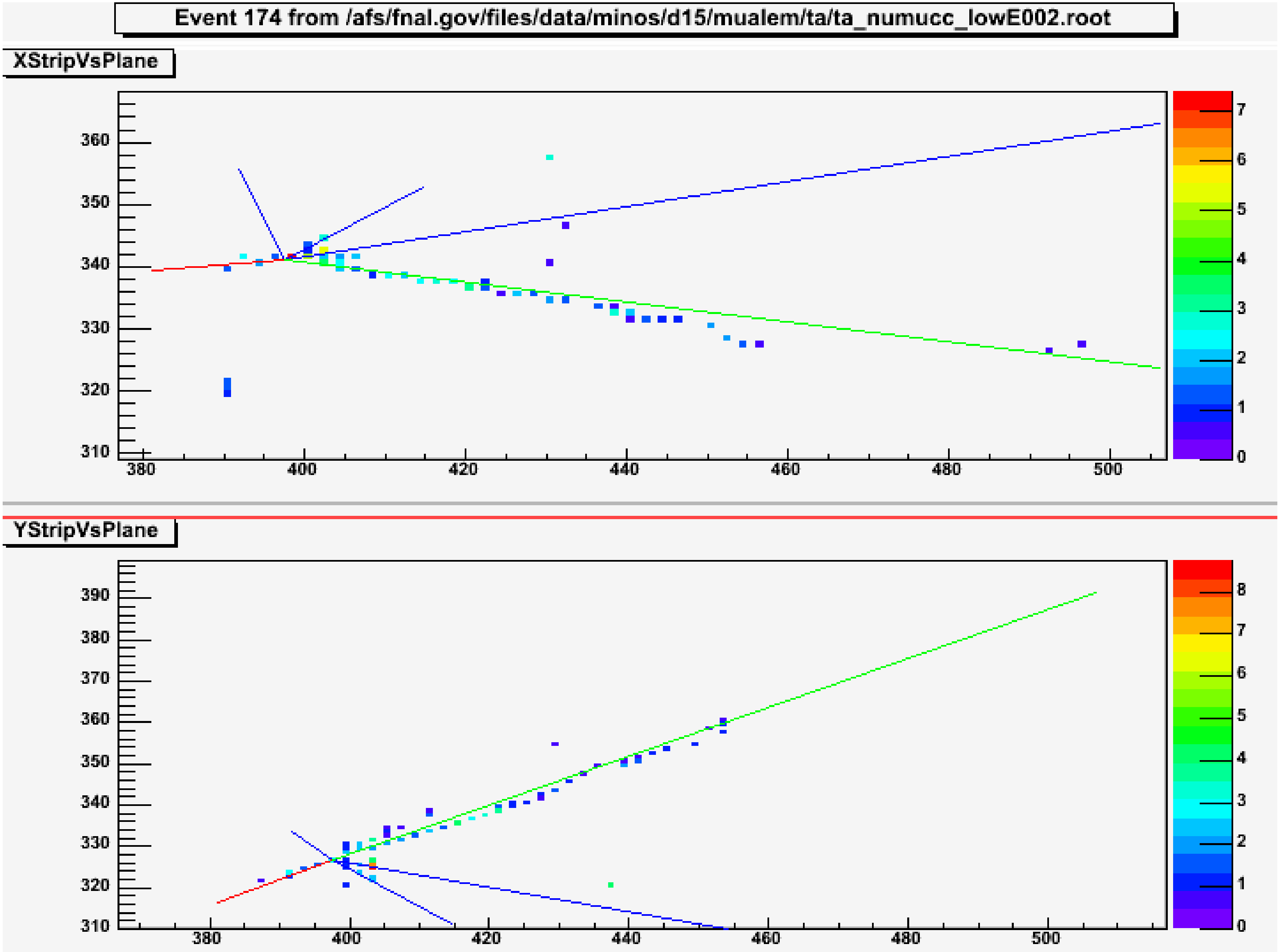

Event 5964 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
YStripVsPlane


Event 6216 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
YStripVsPlane

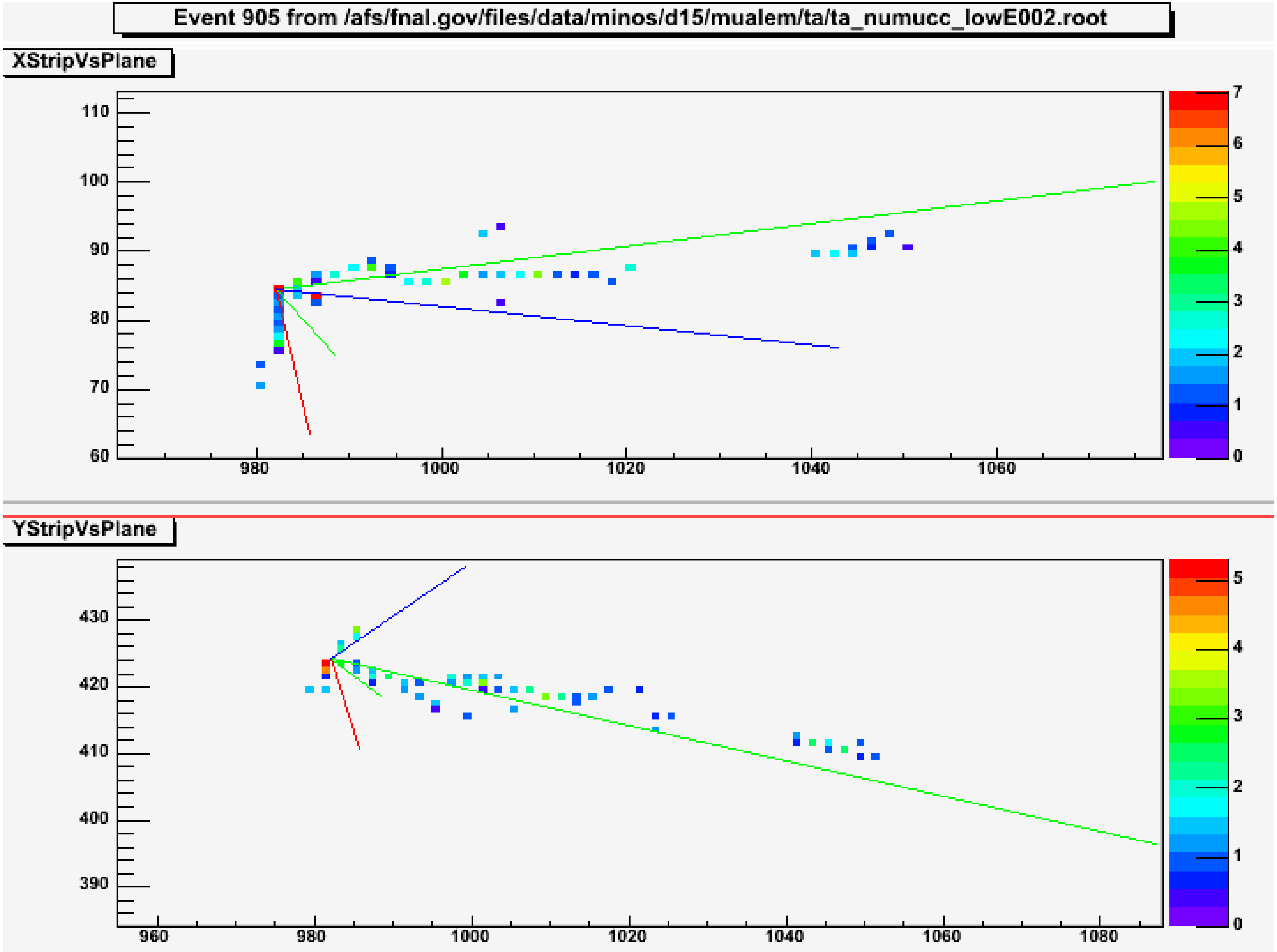

Event 7231 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numunc_lowE002.root
XStripVsPlane
310
300
290
280
270
260
1080
1100
1120
1140
1160
1180
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
YStripVsPlane
440
435
430
425
420
415
410
405
400
1080
1100
1120
1140
1160
1180
1200
5
4
3
2
1
0

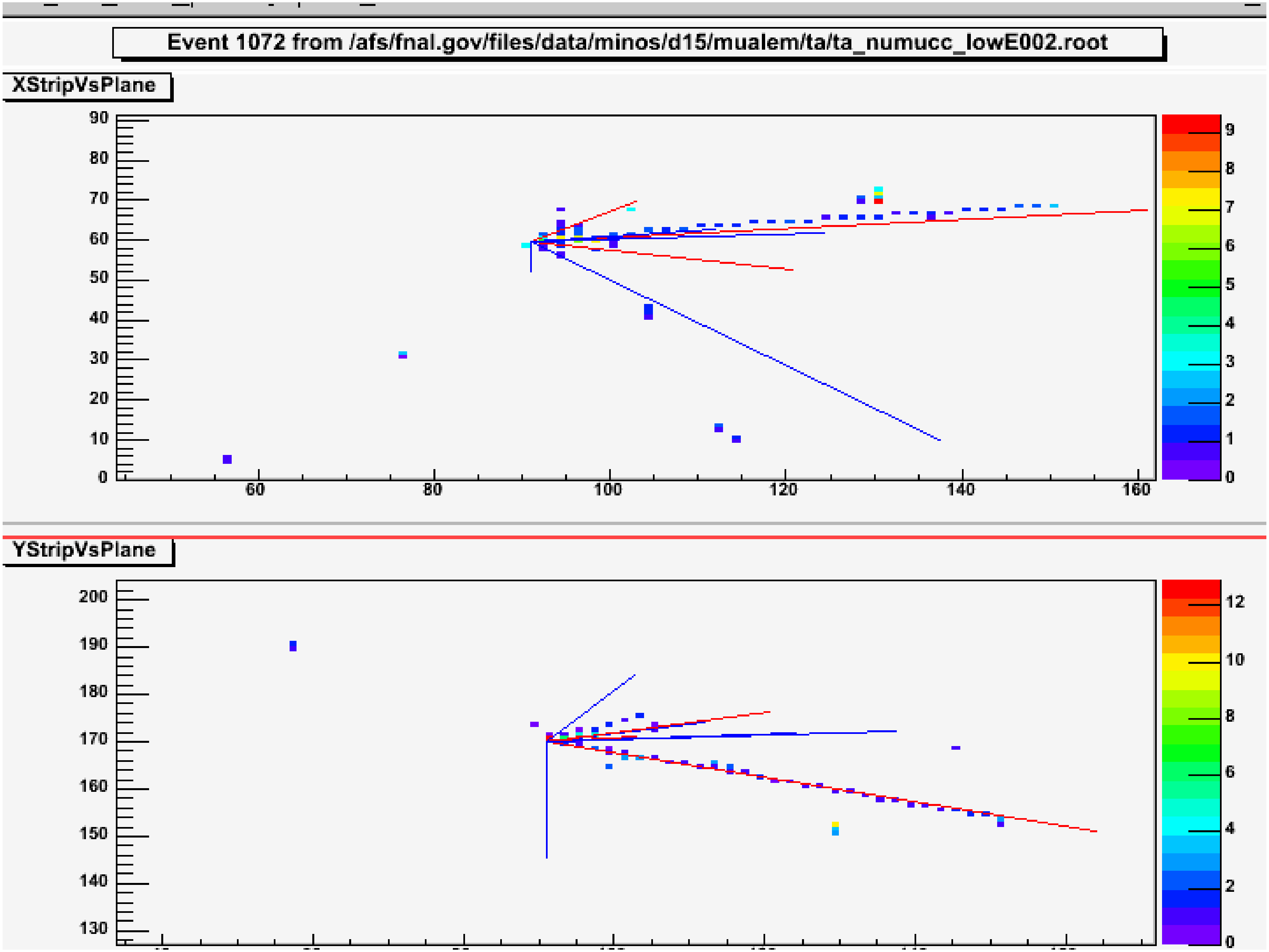


Event 432 from ../files/ta_nc_low_001.root
XStripVsPlane
YStripVsPlane
NC: ν + A -> p + η
η -> γ + γ

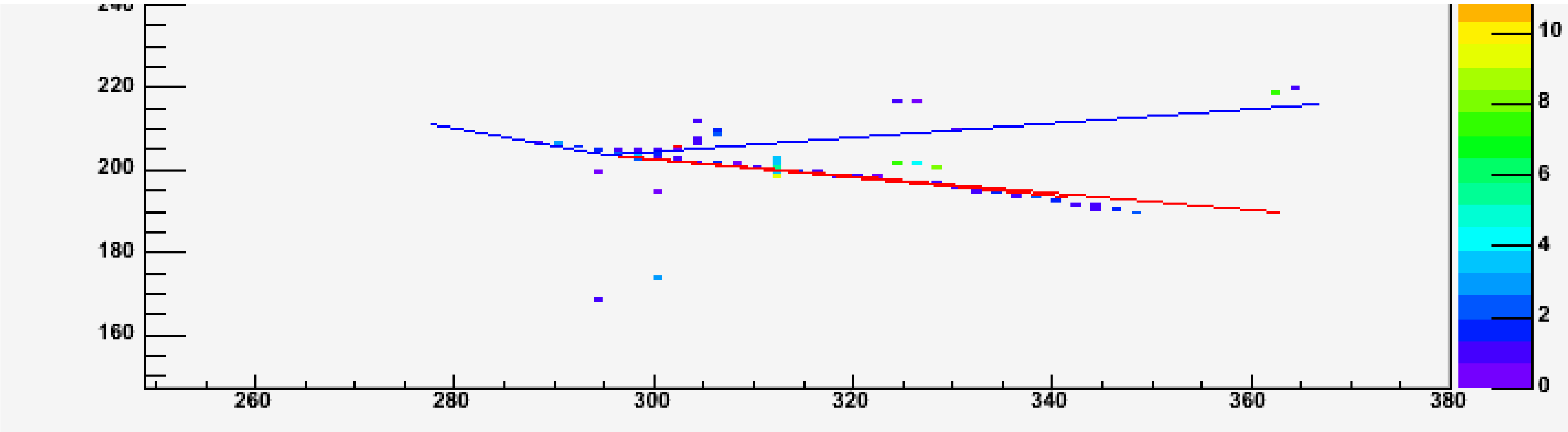


Event 174 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
360
350
340
330
320
310
380
400
420
440
460
480
500
7
6
5
4
3
2
1
0
YStripVsPlane
390
380
370
360
350
340
330
320
310
380
400
420
440
460
480
500
8
7
6
5
4
3
2
1
0

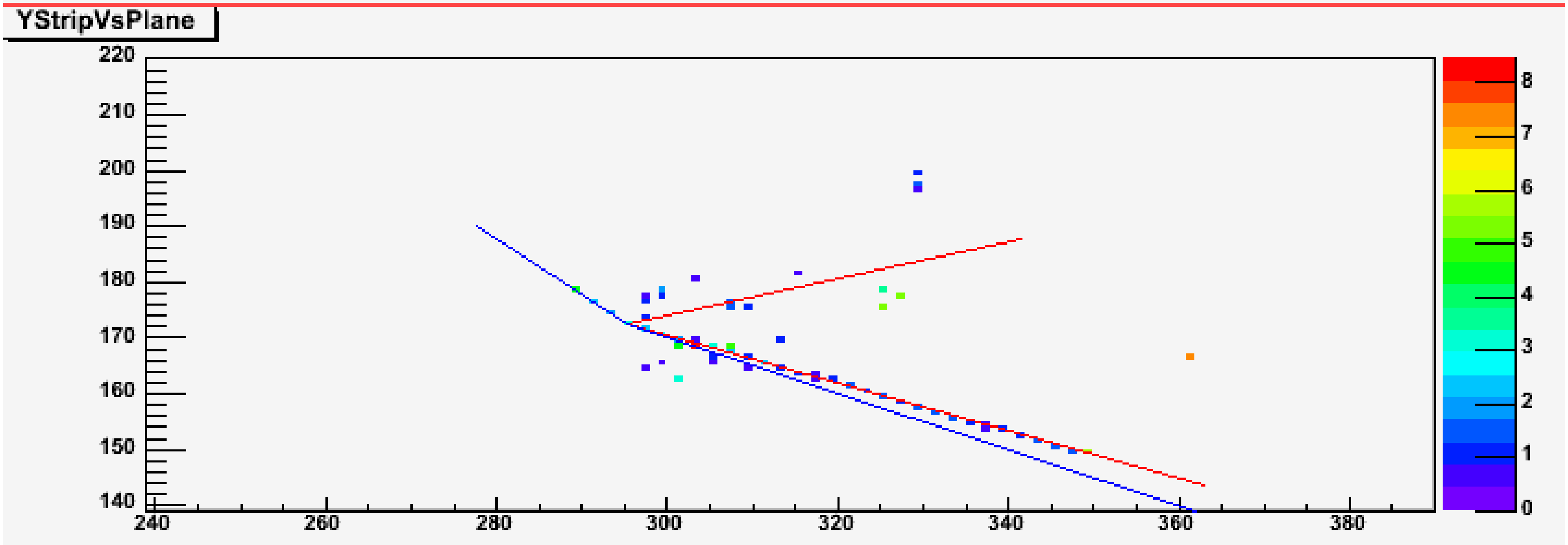

Event 905 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
110
100
90
80
70
60
980
1000
1020
1040
1060
7
6
5
4
3
2
1
0
YStripVsPlane
430
420
410
400
390
960
980
1000
1020
1040
1060
1080
5
4
3
2
1
0



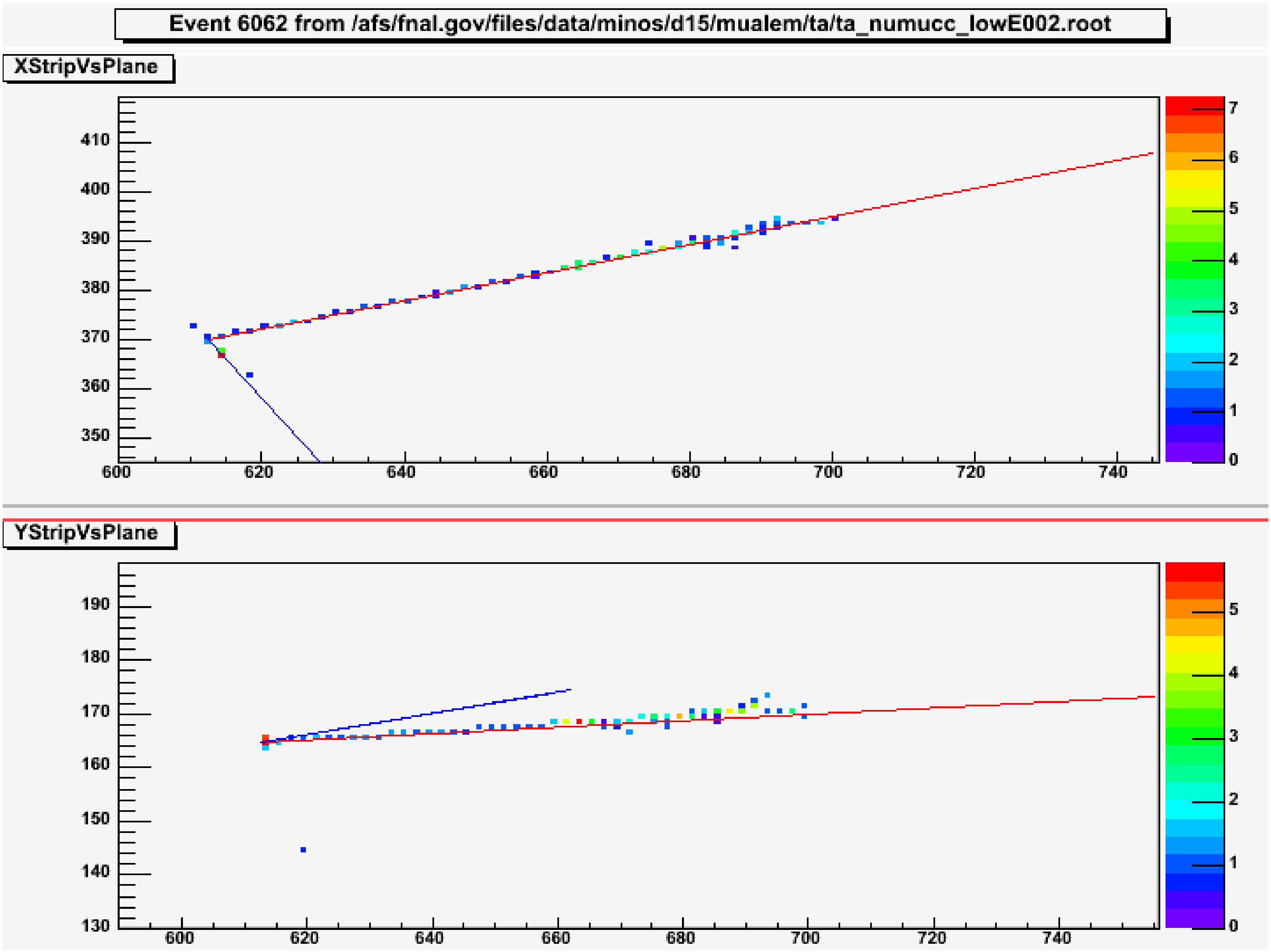
Event 1072 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
90
80
70
60
50
40
30
20
10
0
60
80
100
120
140
160
9
8
7
6
5
4
3
2
1
0
YStripVsPlane
200
190
180
170
160
150
140
130
12
10
8
6
4
2
0



220
200
180
160
260
280
300
320
340
360
380
10
8
6
4
2
0

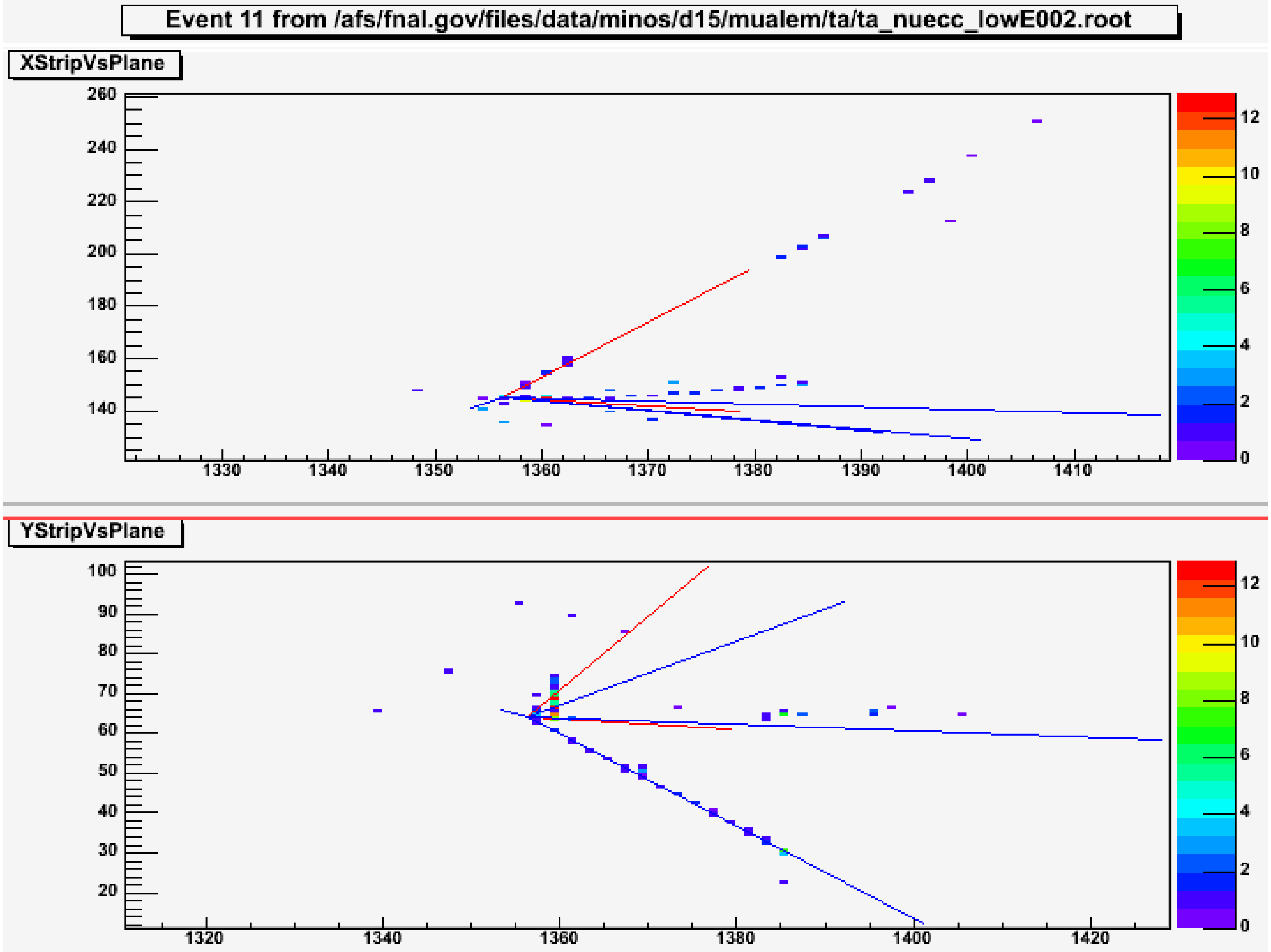


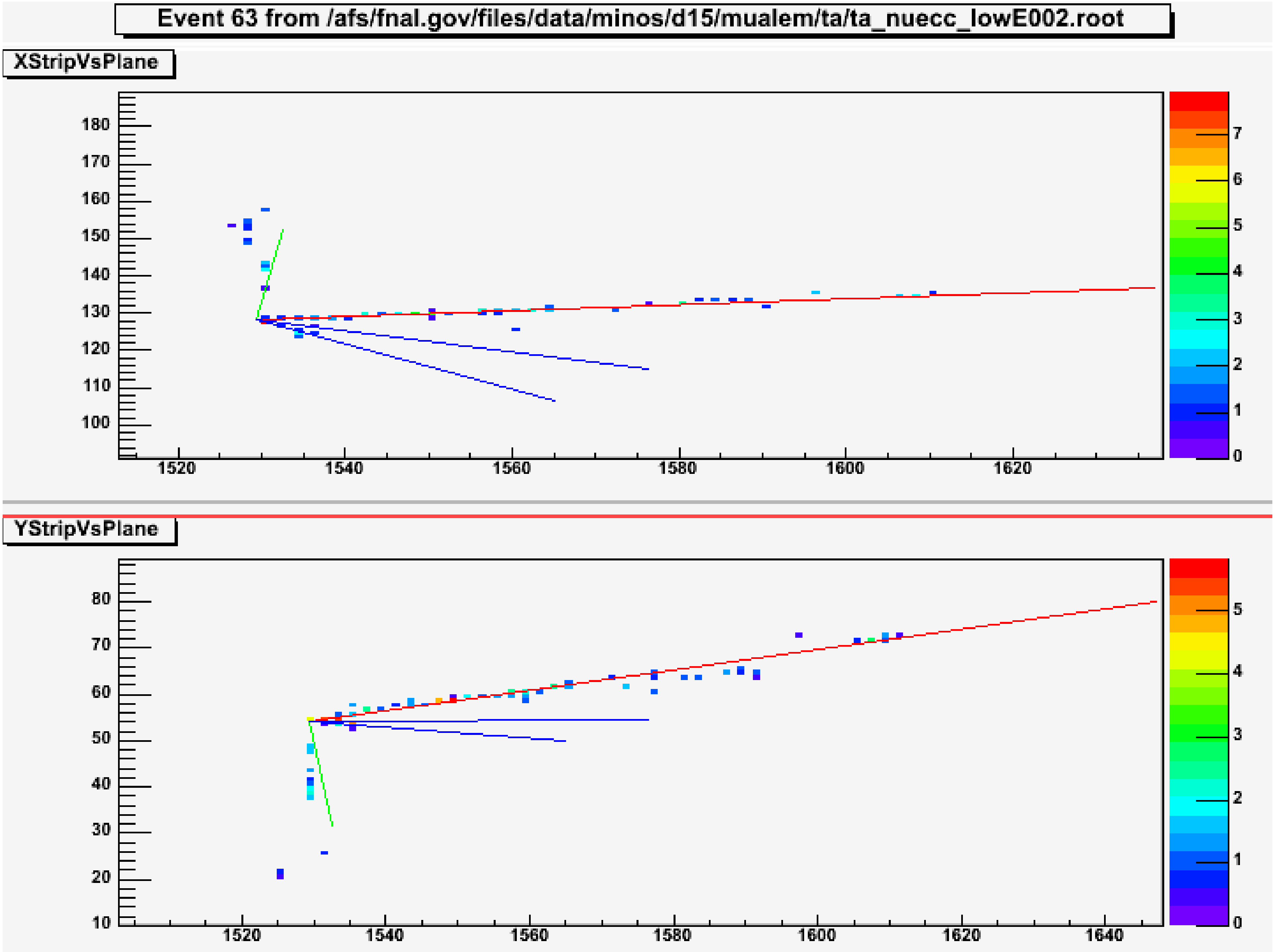
YStripVsPlane
220
210
200
190
180
170
160
150
140
240
260
280
300
320
340
360
380
8
7
6
5
4
3
2
1
0

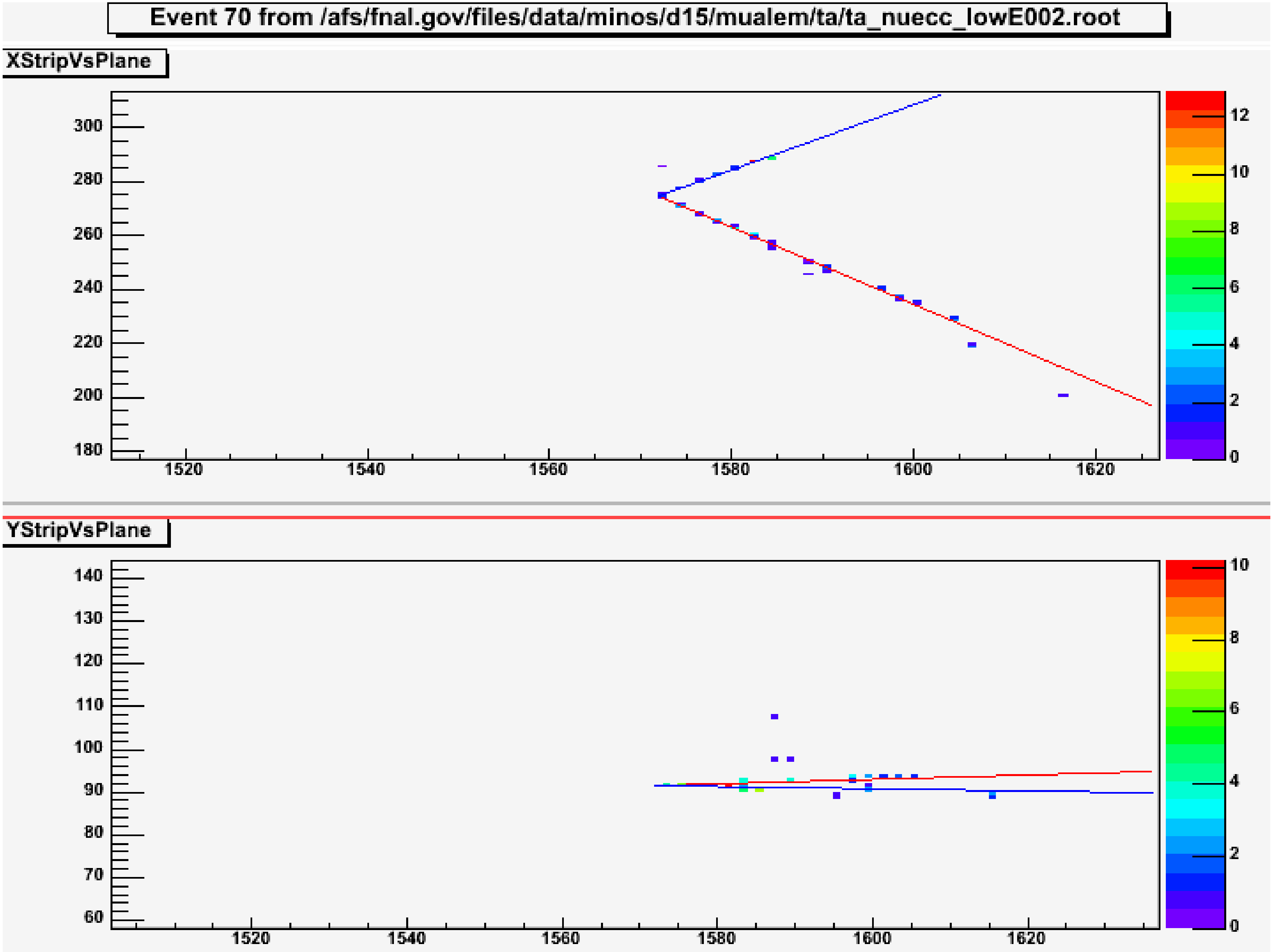


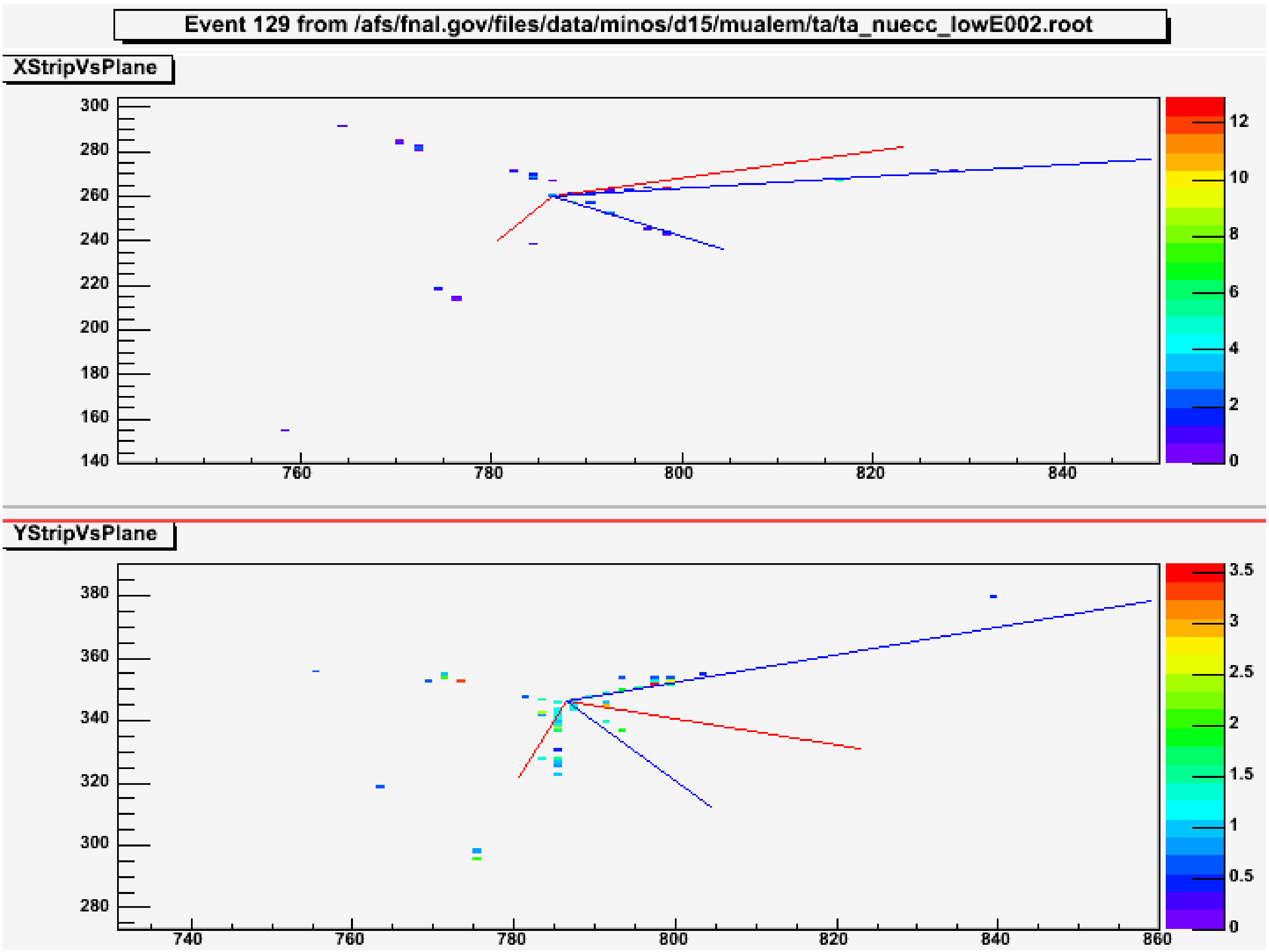
Event 6062 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
YStripVsPlane

And now some failing ν_e CC events

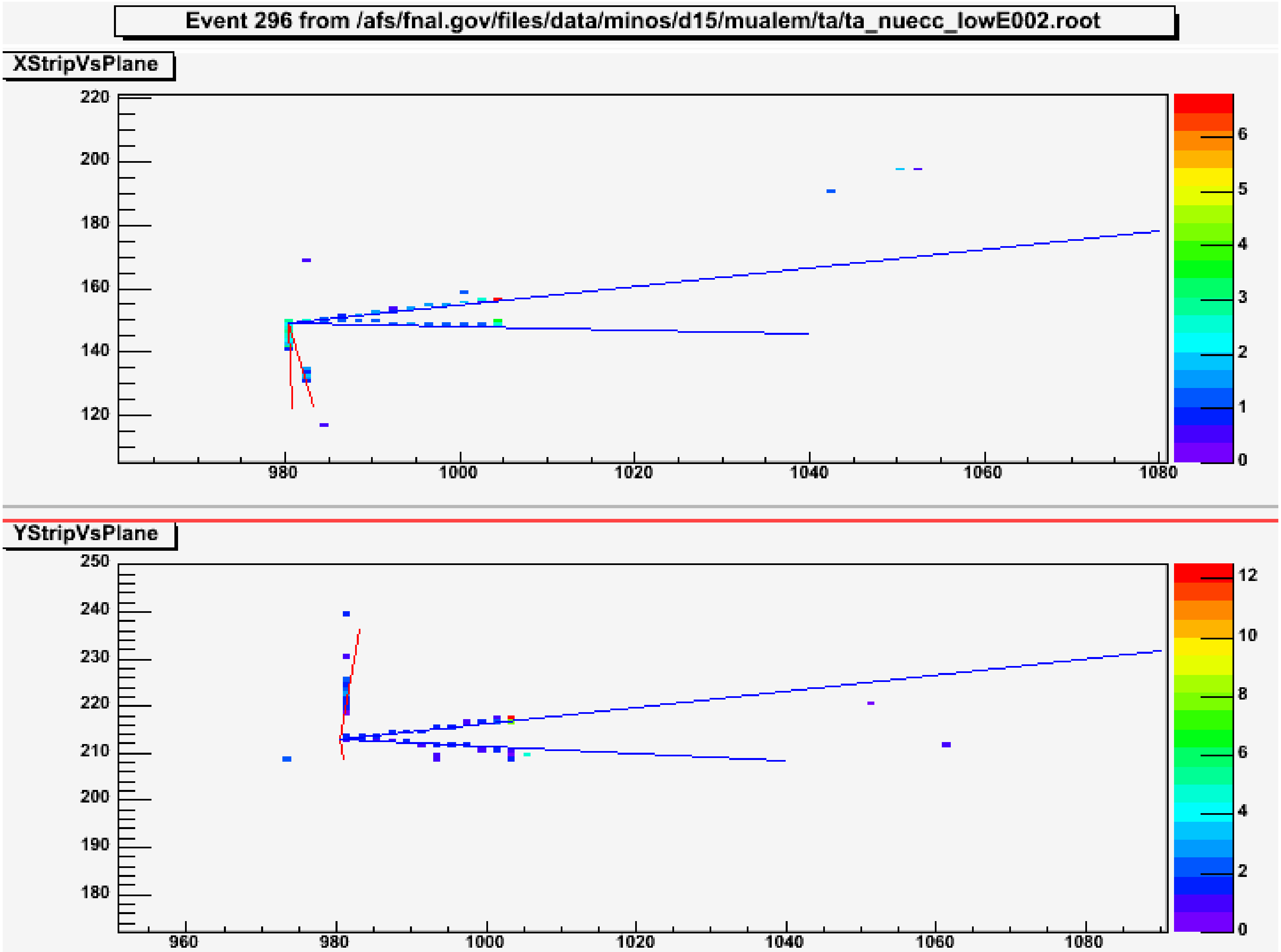

Event 11 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
260
240
220
200
180
160
140
1330
1340
1350
1360
1370
1380
1390
1400
1410
12
10
8
6
4
2
0
YStripVsPlane
100
90
80
70
60
50
40
30
20
1320
1340
1360
1380
1400
1420


Event 63 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
180
170
160
150
140
130
120
110
100
1520
1540
1560
1580
1600
1620
0
1
2
3
4
5
6
7
YStripVsPlane
80
70
60
50
40
30
20
10
1520
1540
1560
1580
1600
1620
1640
0
1
2
3
4
5

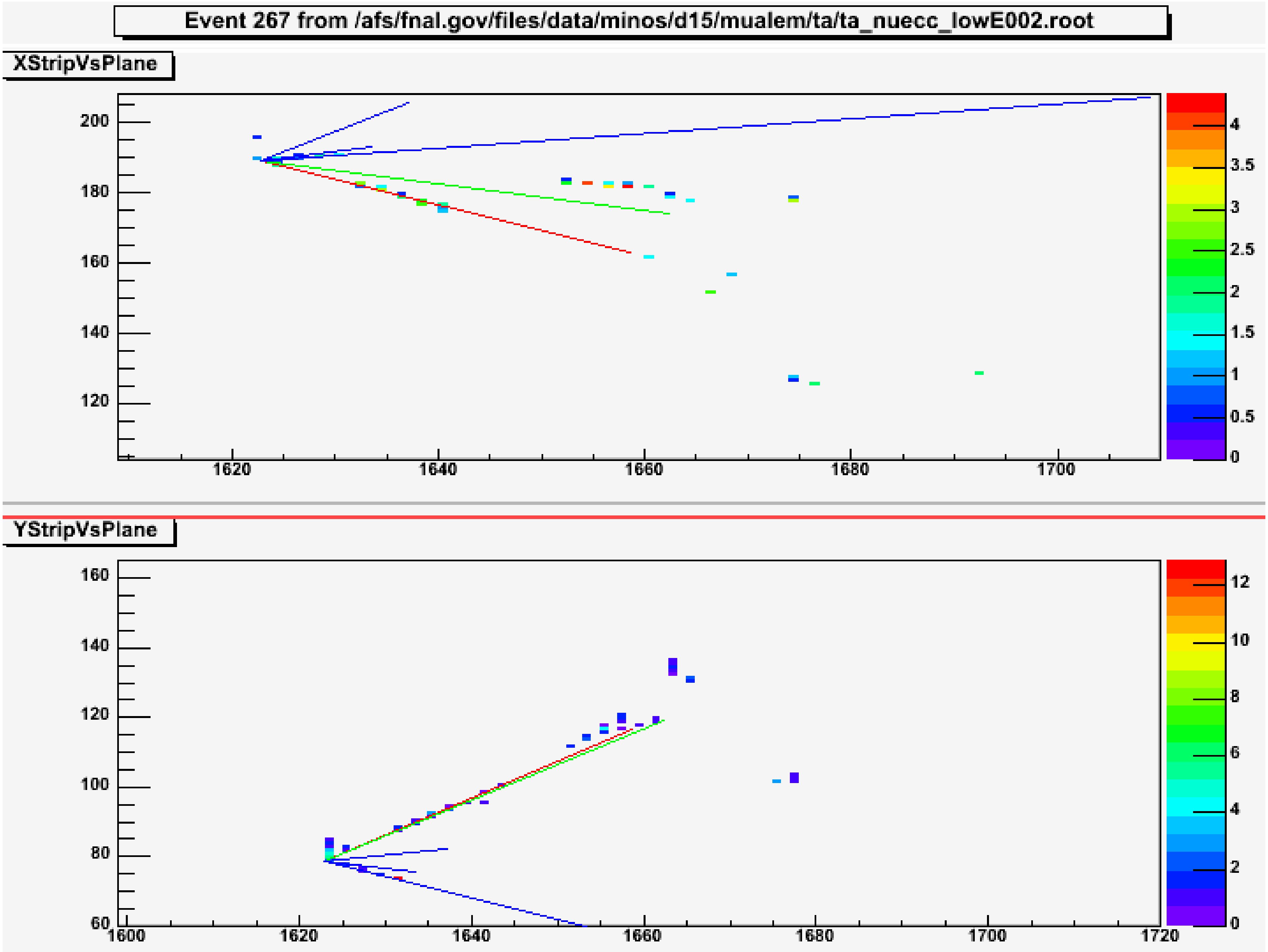

Event 70 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
300
280
260
240
220
200
180
1520
1540
1560
1580
1600
1620
12
10
8
6
4
2
0
YStripVsPlane
140
130
120
110
100
90
80
70
60
1520
1540
1560
1580
1600
1620
10
8
6
4
2
0

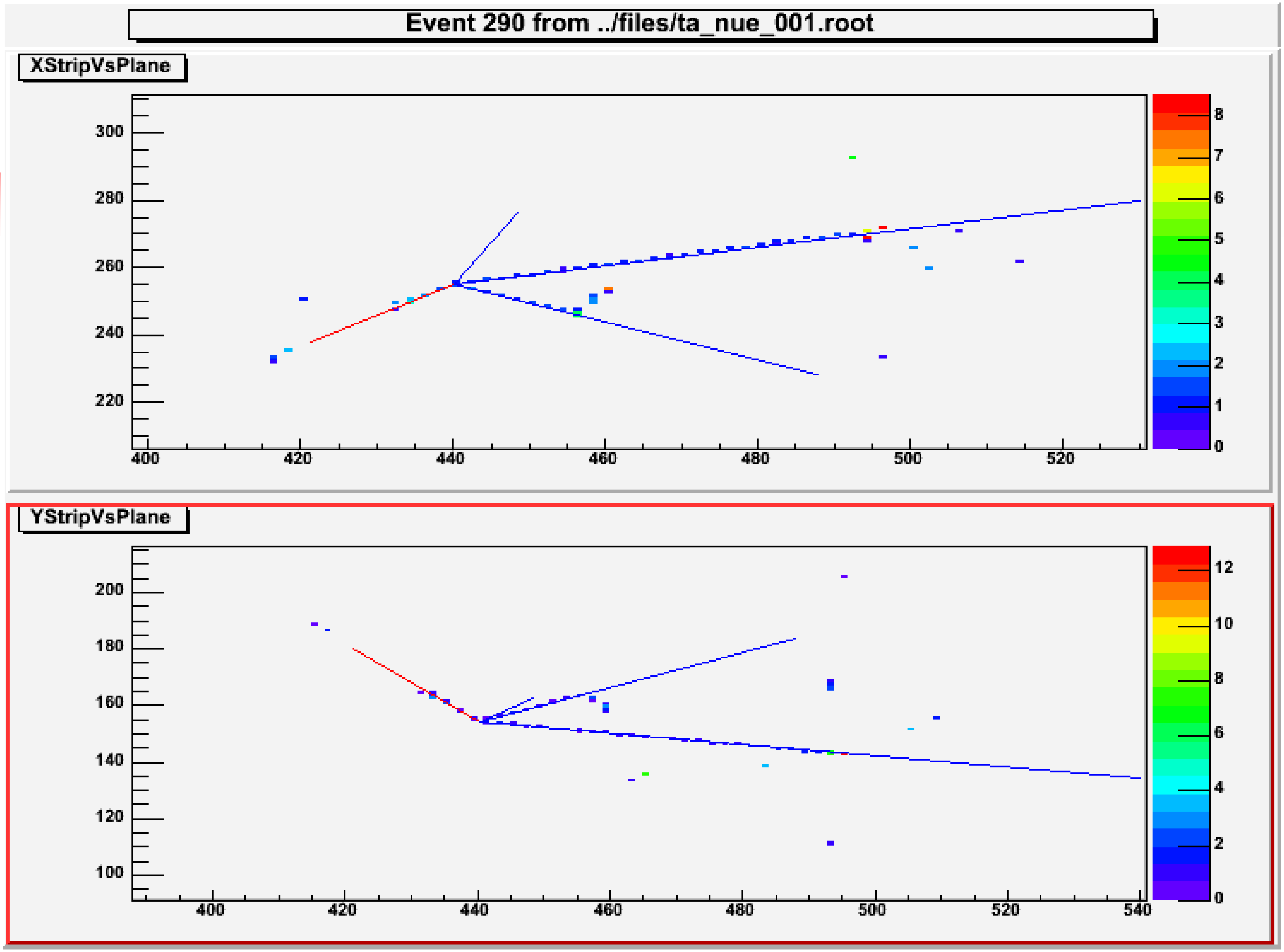


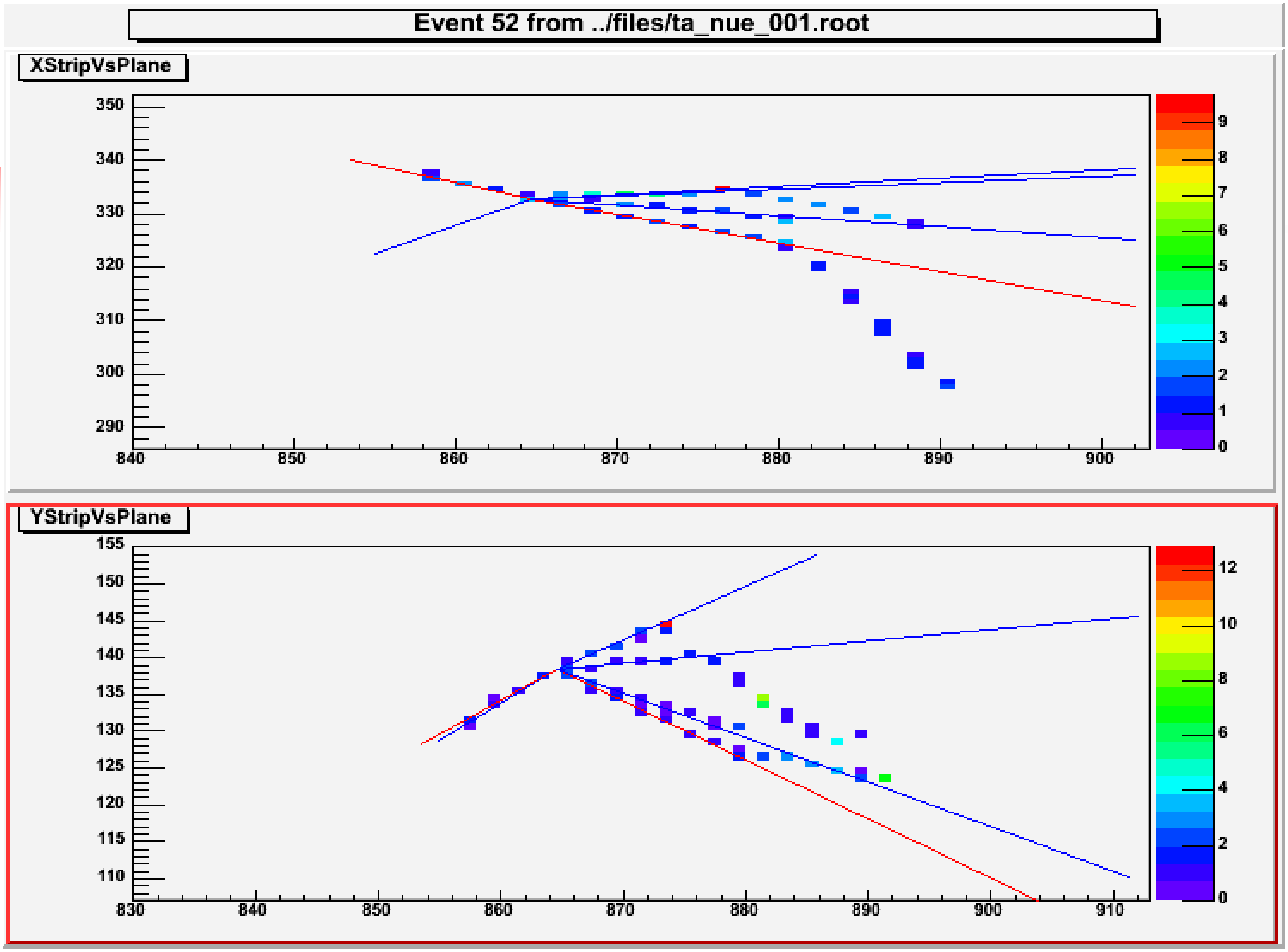
Event 129 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
300
280
260
240
220
200
180
160
140
760
780
800
820
840
12
10
8
6
4
2
0
YStripVsPlane
380
360
340
320
300
280
740
760
780
800
820
840
860
3.5
3
2.5
2
1.5
1
0.5
0



Event 296 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
220
200
180
160
140
120
980
1000
1020
1040
1060
1080
6
5
4
3
2
1
0
YStripVsPlane
250
240
230
220
210
200
190
180
960
980
1000
1020
1040
1060
1080
12
10
8
6
4
2
0


Event 267 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_nuecc_lowE002.root
XStripVsPlane
200
180
160
140
120
1620
1640
1660
1680
1700
4
3.5
3
2.5
2
1.5
1
0.5
0
YStripVsPlane
160
140
120
100
80
60
1600
1620
1640
1660
1680
1700
1720
12
10
8
6
4
2
0

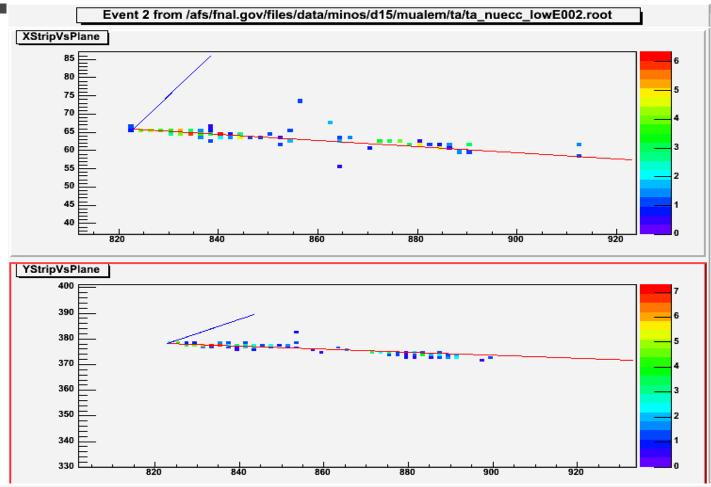

Event 290 from ../files/ta_nue_001.root
XStripVsPlane
300
280
260
240
220
400
420
440
460
480
500
520
8
7
6
5
4
3
2
1
0
YStripVsPlane
200
180
160
140
120
100
400
420
440
460
480
500
520
540
12
10
8
6
4
2
0

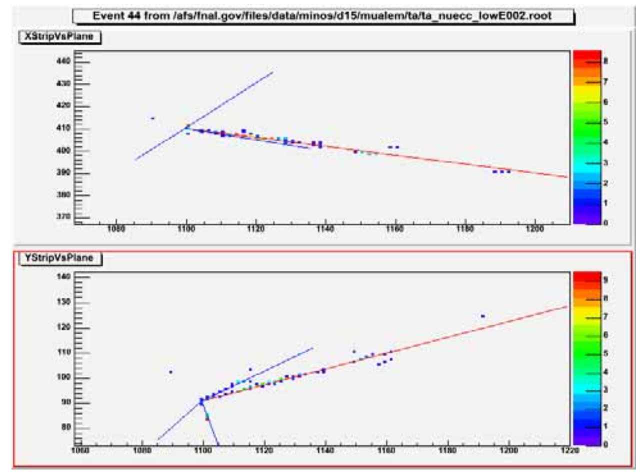

Event 52 from ../files/ta_nue_001.root
XStripVsPlane
350
340
330
320
310
300
290
840
850
860
870
880
890
900
9
8
7
6
5
4
3
2
1
0
YStripVsPlane
155
150
145
140
135
130
125
120
115
110
830
840
850
860
870
880
890
900
910
12
10
8
6
4
2
0

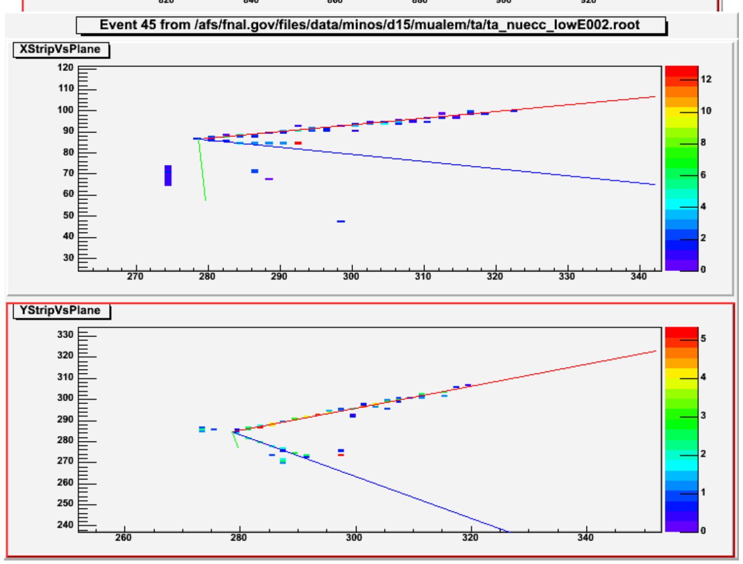
And now as antidote:

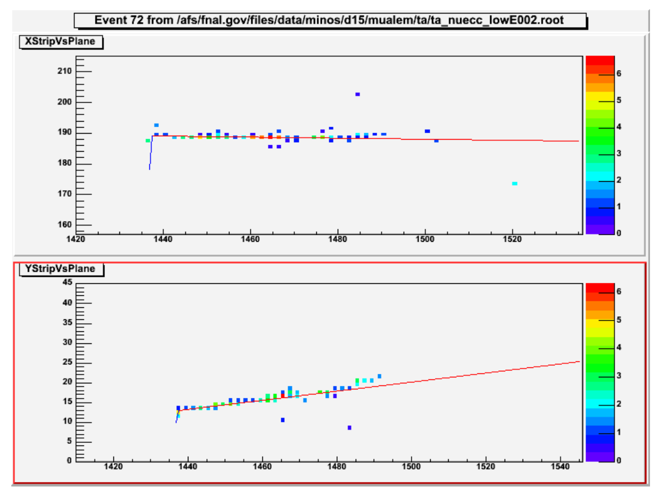
First 20 passing ν_e CC events

Good ν_e CC events (1)

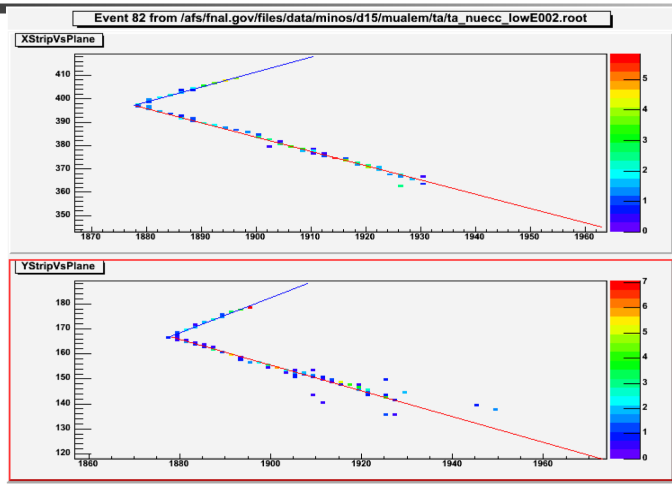


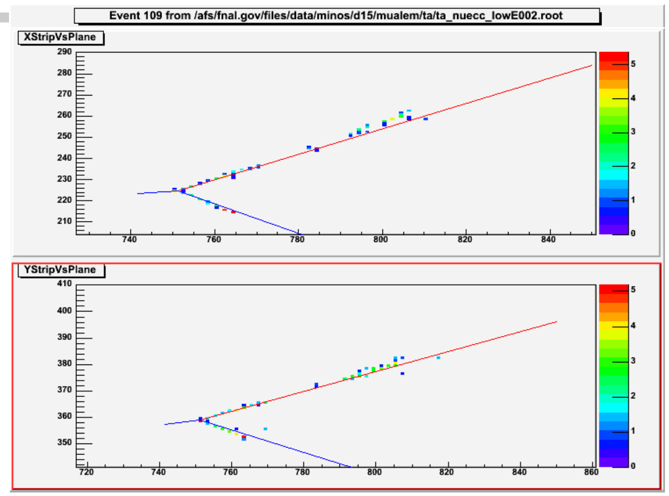


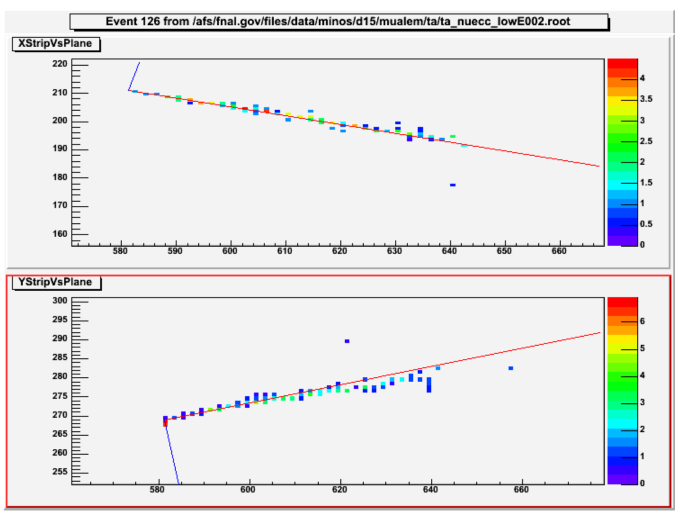


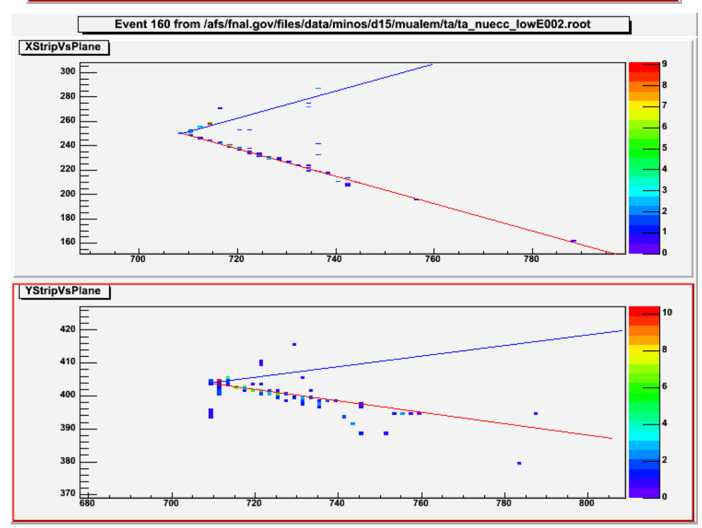


Good ν_e CC events (2)

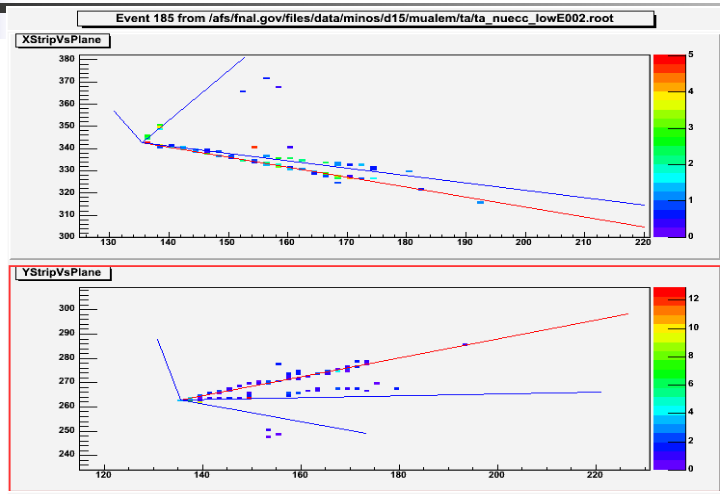


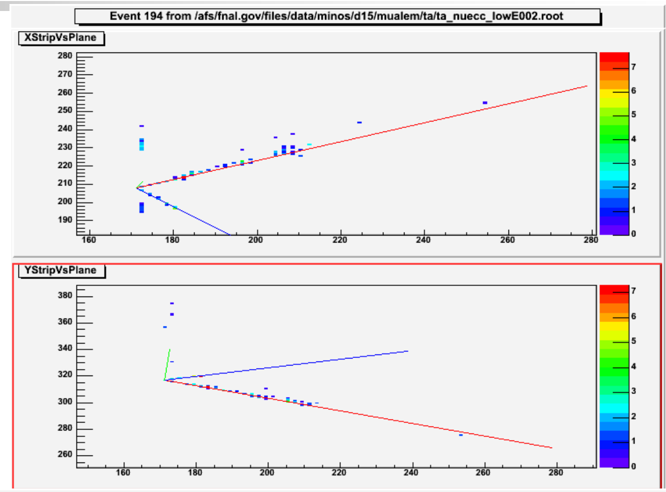


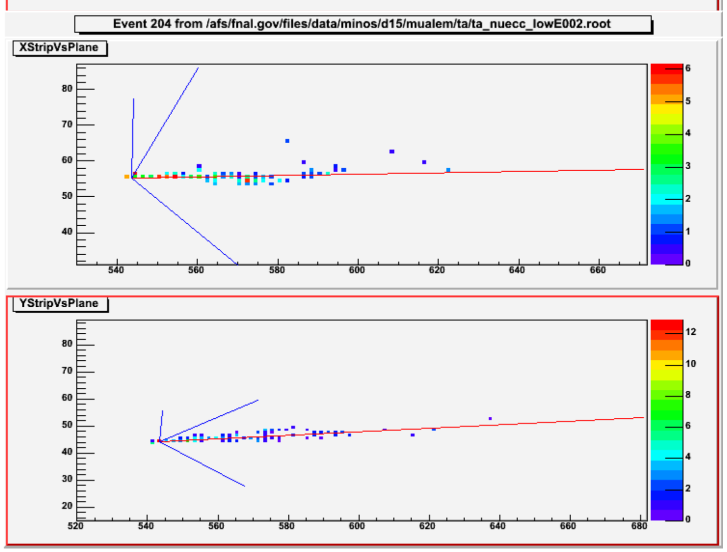


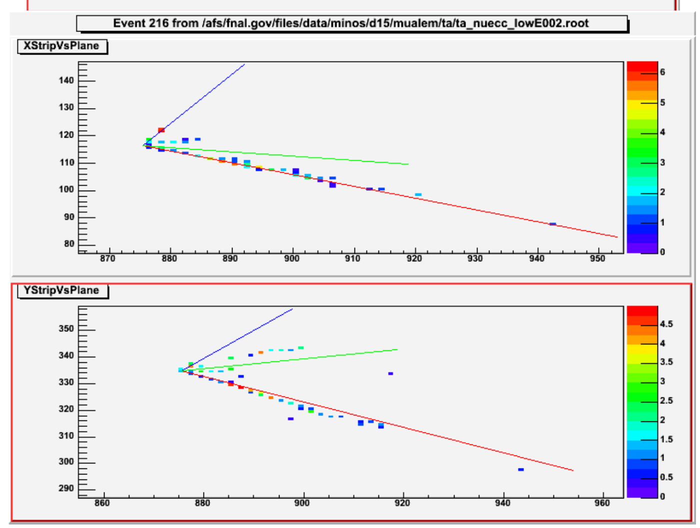


Good ν_e CC events (3)

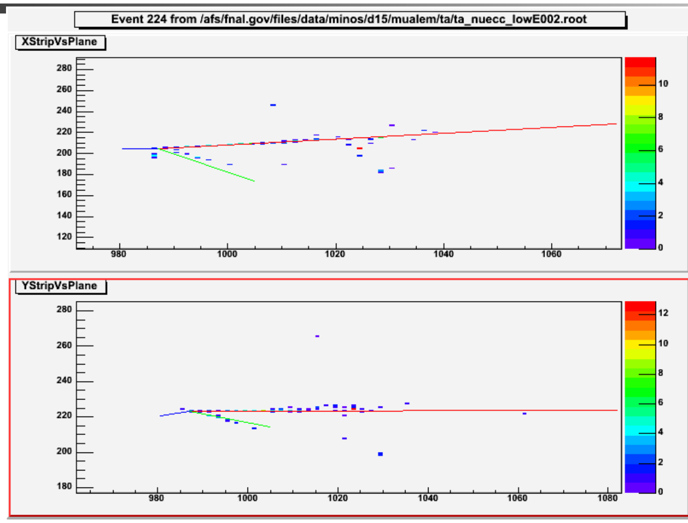


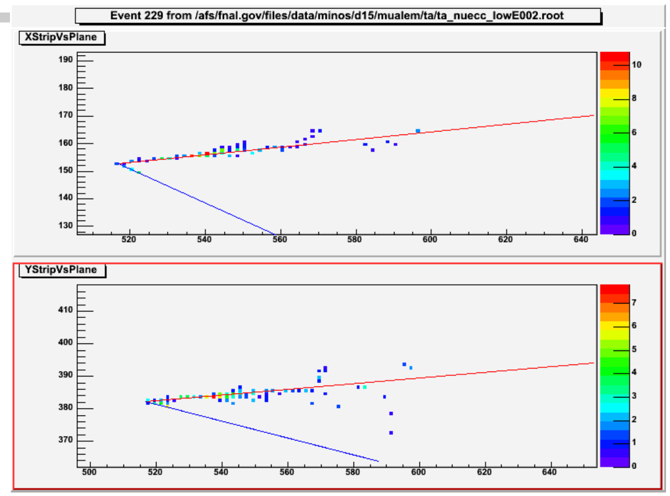


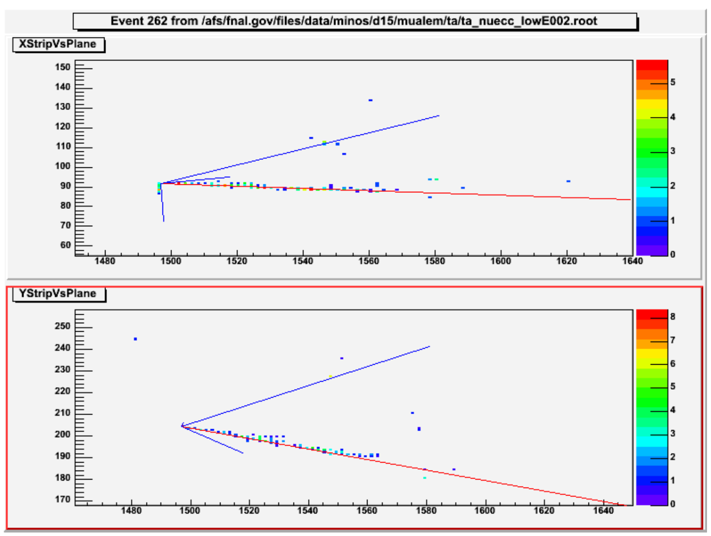


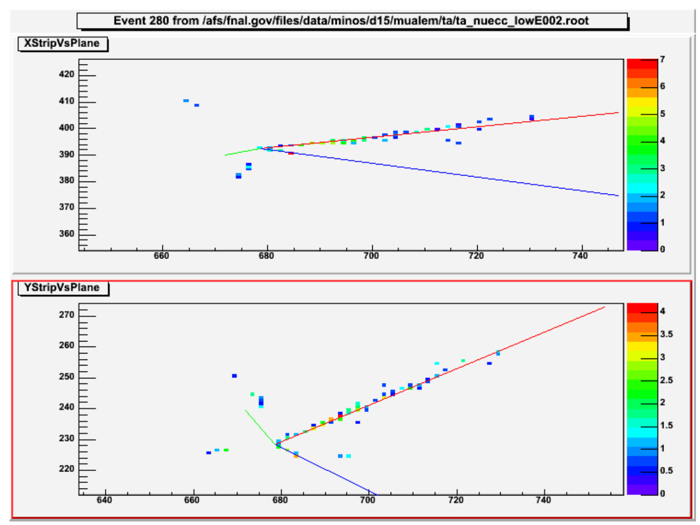


Good ν_e CC events (4)

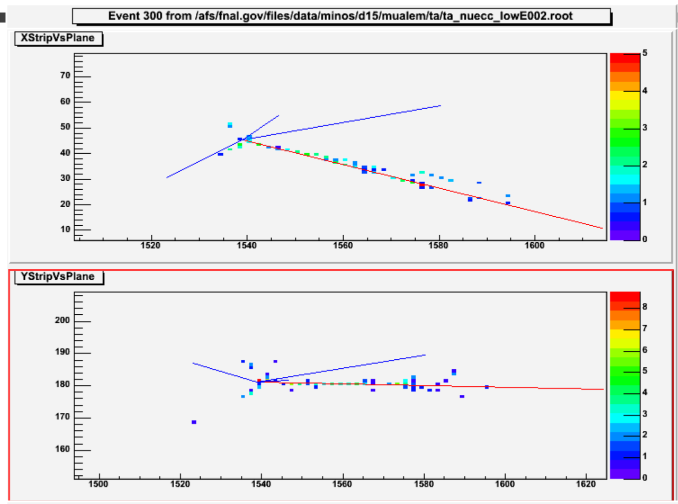


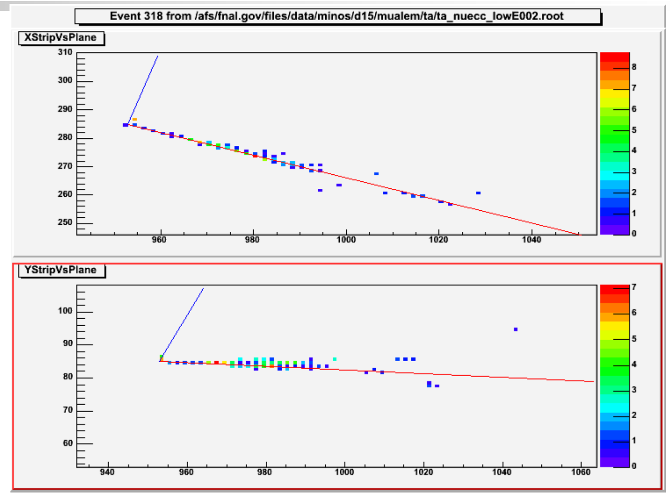


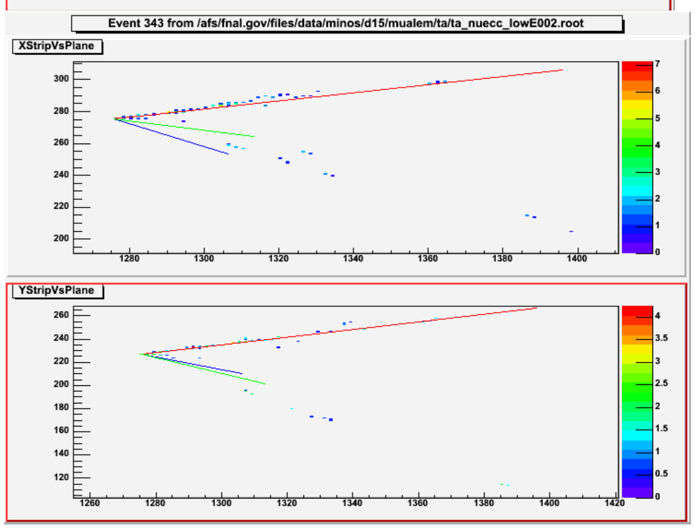


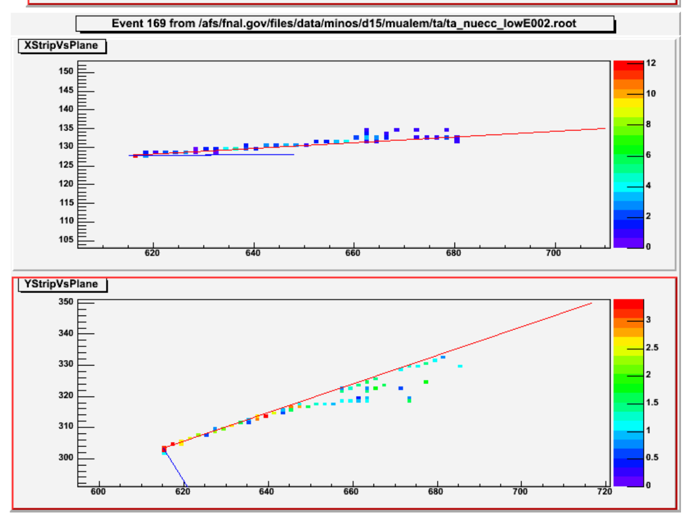


Good ν_e CC events (5)



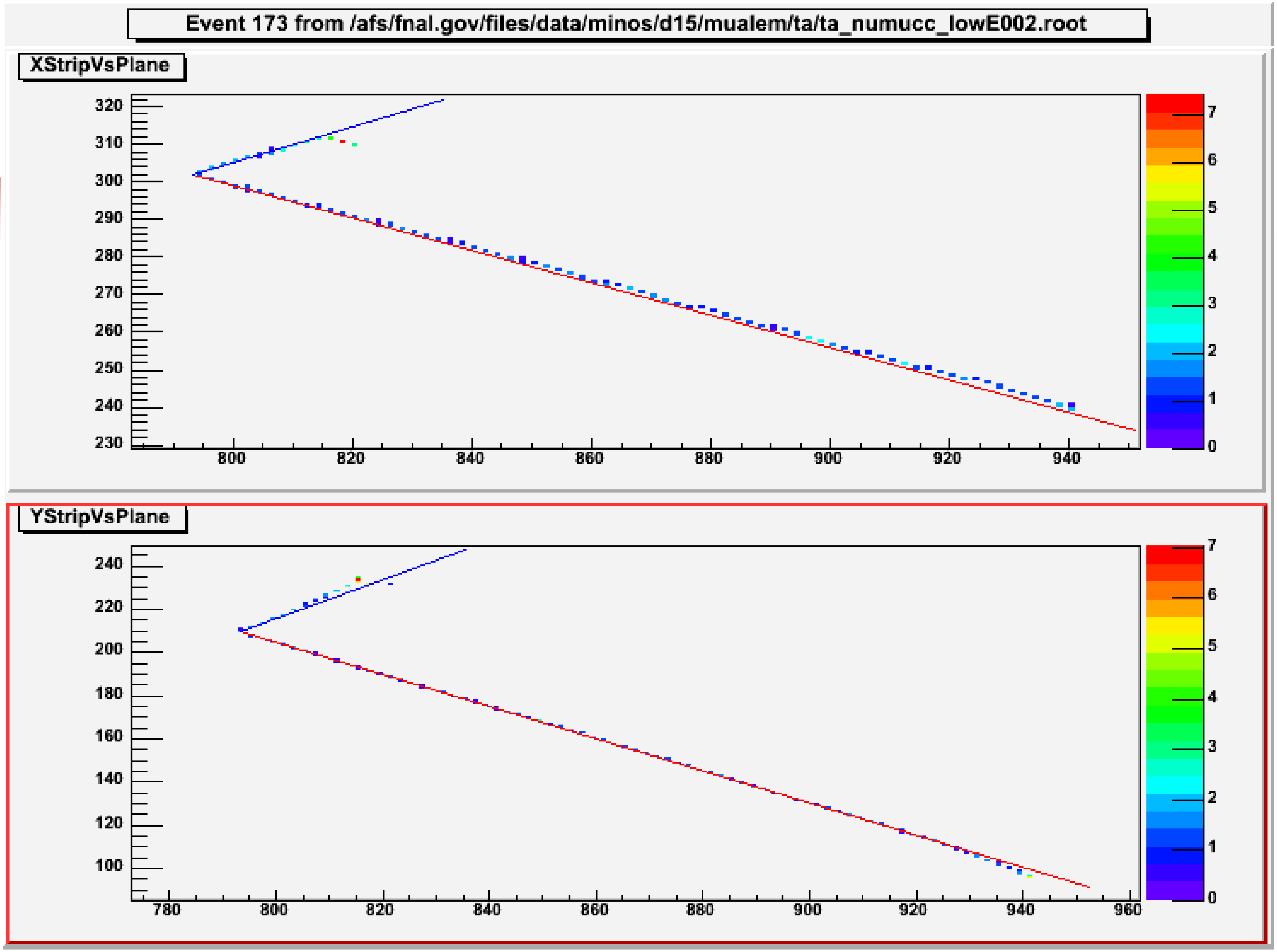


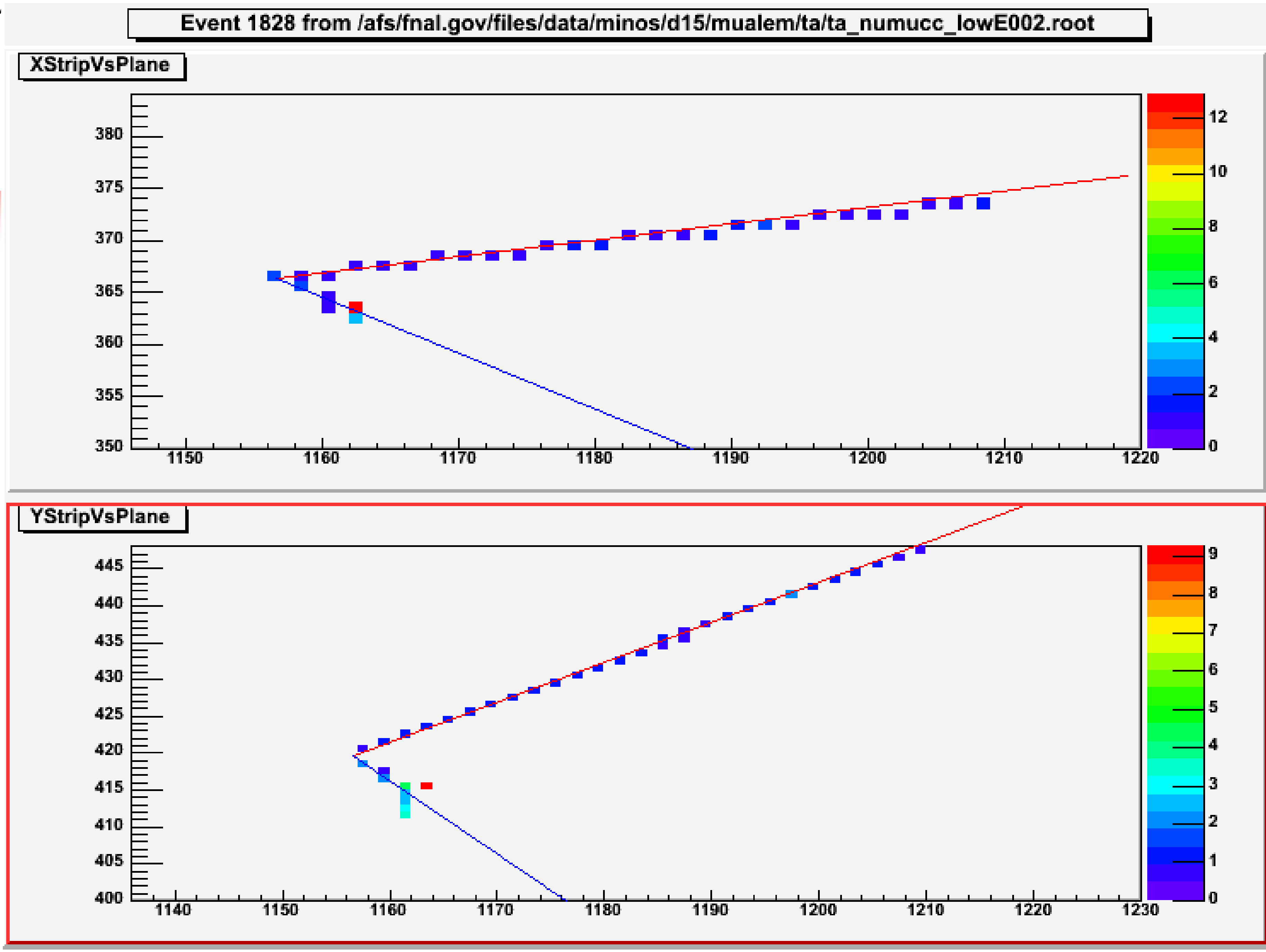




Other Possible Physics Measurements

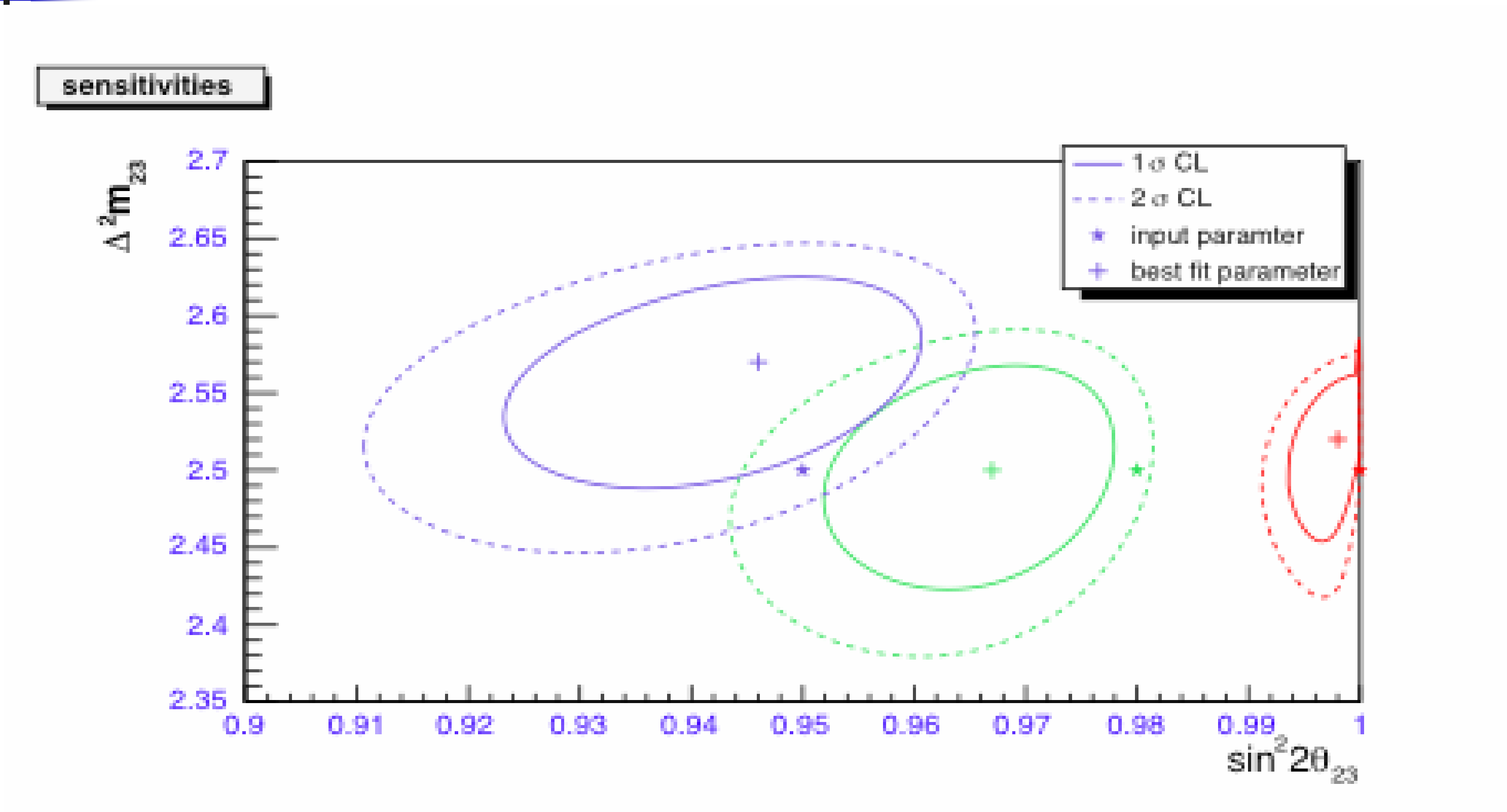
- Could measure θ_{23} much better - quasielastics are well measured and constrained
- Δm^2_{23} could be also measured better, less uncertainty on energy scale
- Could set better limits on sterile ν contribution - should have subset of very clean NC events
- Quasielastic ν_μ's are very clean - two examples follow


Event 173 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
320
310
300
290
280
270
260
250
240
230
800
820
840
860
880
900
920
940
0
1
2
3
4
5
6
7
YStripVsPlane
240
220
200
180
160
140
120
100
780
800
820
840
860
880
900
920
940
960
0
1
2
3
4
5
6
7



Event 1828 from /afs/fnal.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root
XStripVsPlane
380
375
370
365
360
355
350
1150
1160
1170
1180
1190
1200
1210
1220
12
10
8
6
4
2
0
YStripVsPlane
445
440
435
430
425
420
415
410
405
400
1140
1150
1160
1170
1180
1190
1200
1210
1220
1230
9
8
7
6
5
4
3
2
1
0

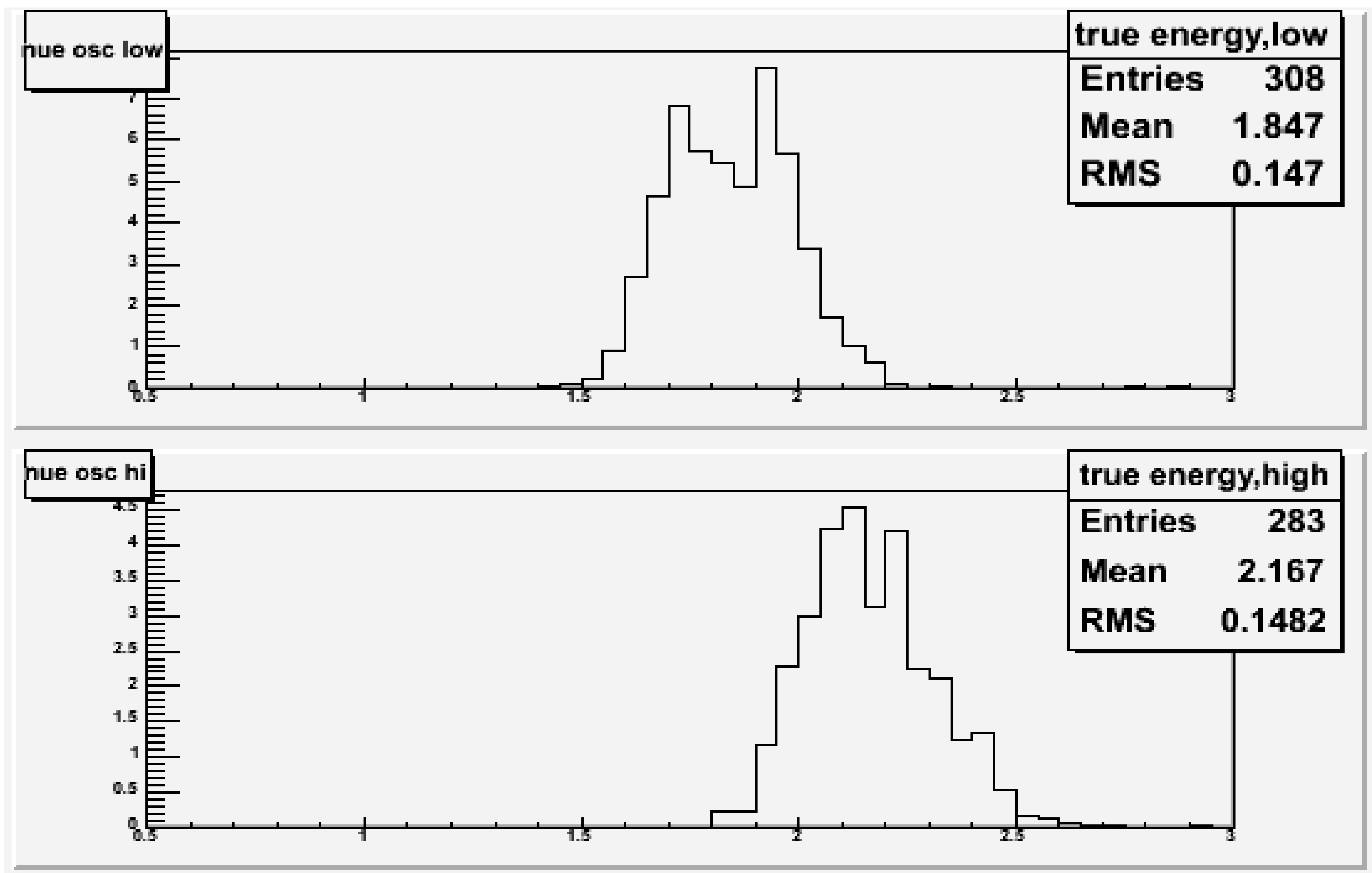
Measurement of θ_{23} and Δm^2_{23}



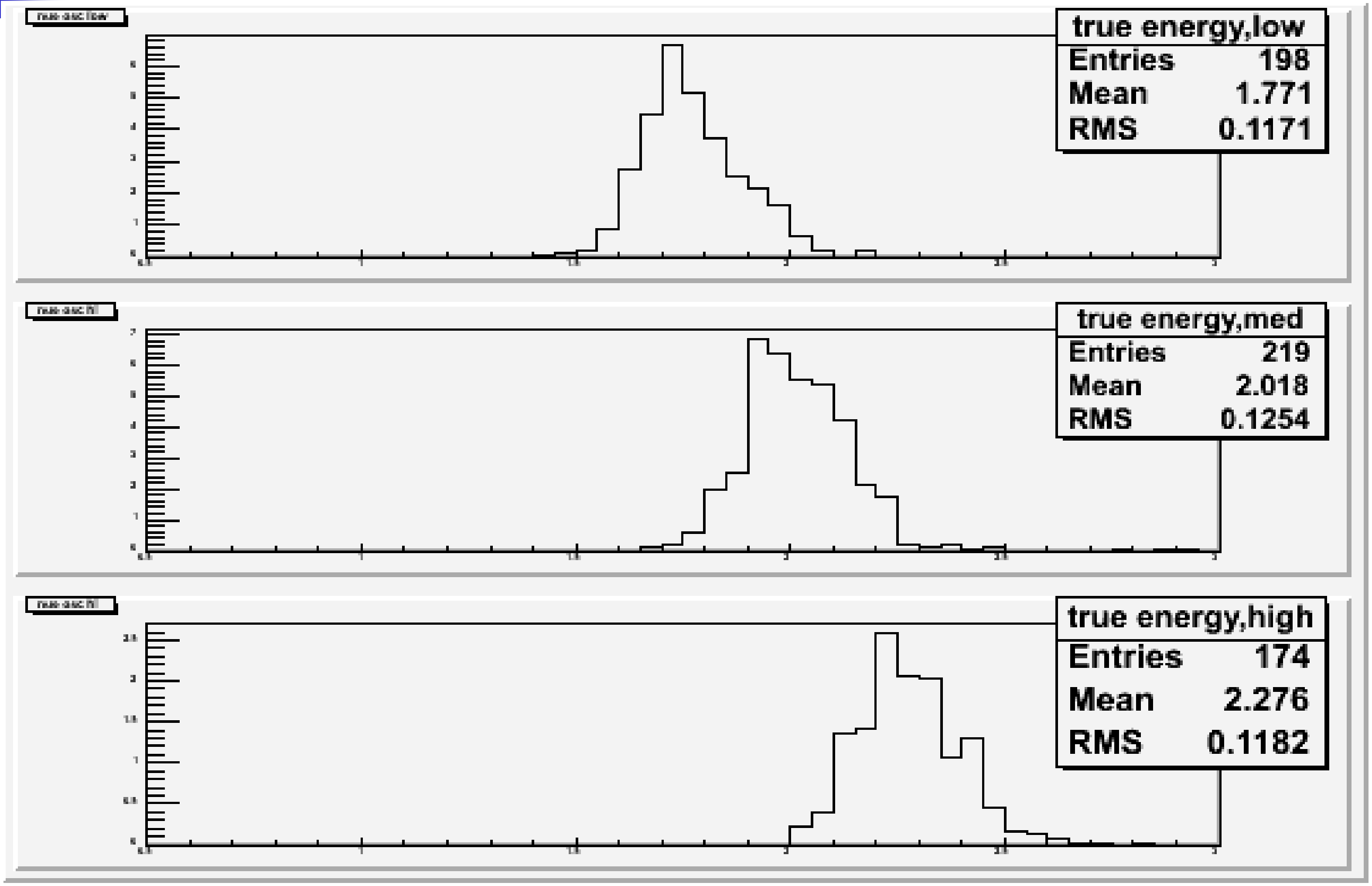
Other advantages

- Cosmic ray background drastically reduced; hence need for overburden is less likely
- Because of good energy resolution data can be divided by energy
- Not restricted by particle board sizes; more freedom in choice of detector dimensions
- Fiber, electronics cost inversely proportional to area of cell -> more freedom in choice of cell dimensions. Maybe other dimensions are better than 3.9x2.8 (more light/cell, better transverse segmentation)
- Near Detector becomes simpler and more like far detector; less need to measure NC and CC

Dividing data into 2 energy bins



Dividing data into 3 energy bins



Conclusions

- The initial round of simulations shows that this approach could have significant advantages over the current baseline design
- There is still a lot of room for improvement in analysis, probably also in choice of hardware parameters
- Additional steps that should be taken next are:
  - Understanding of construction and installation issues
  - Optimizing the design, eg packaging of electronics
  - Obtaining reliable cost estimate