Atmospheric ν_e Search

Pat Ward
University of Cambridge

- Motivation
- Selection cuts
- Muon shower simulation
- Neutron background
- Status / summary

Ntuples (code, expertise) from Caius

Signal MC: Battistoni solar max flux,

95k ν events $\equiv$ 330kty

Bg. MC: 2M cosmics $\equiv$ 30 days

Data: 2.52 kty total $\equiv$ 4088.4h

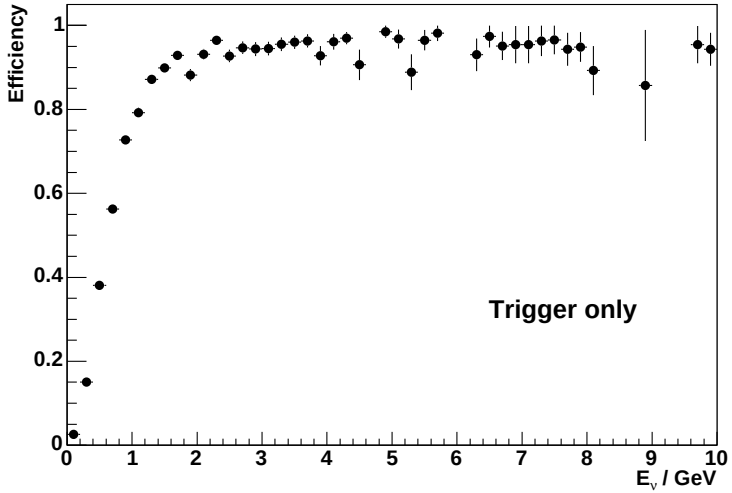
AtNu reconstruction

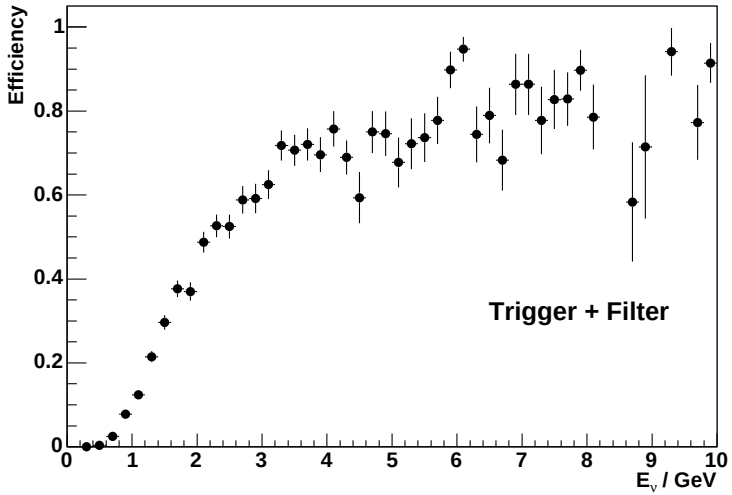
Atmospheric ν_e – Motivation

- Normalization of flux for ν_μ analysis
- Worthwhile if get normalization to $\sim$10%
- How many events do we expect?
- Using Battistoni solar max flux, expected ν_e CC events in 2.52kty:

Total ($E_\nu > 100$ MeV)	167
Vertex in fid. vol.	132
Pass trigger	69
Pass (7 planes) filter	22

- $\Rightarrow$ in 4 years expect 200 events triggered and $\geq$ 7 planes





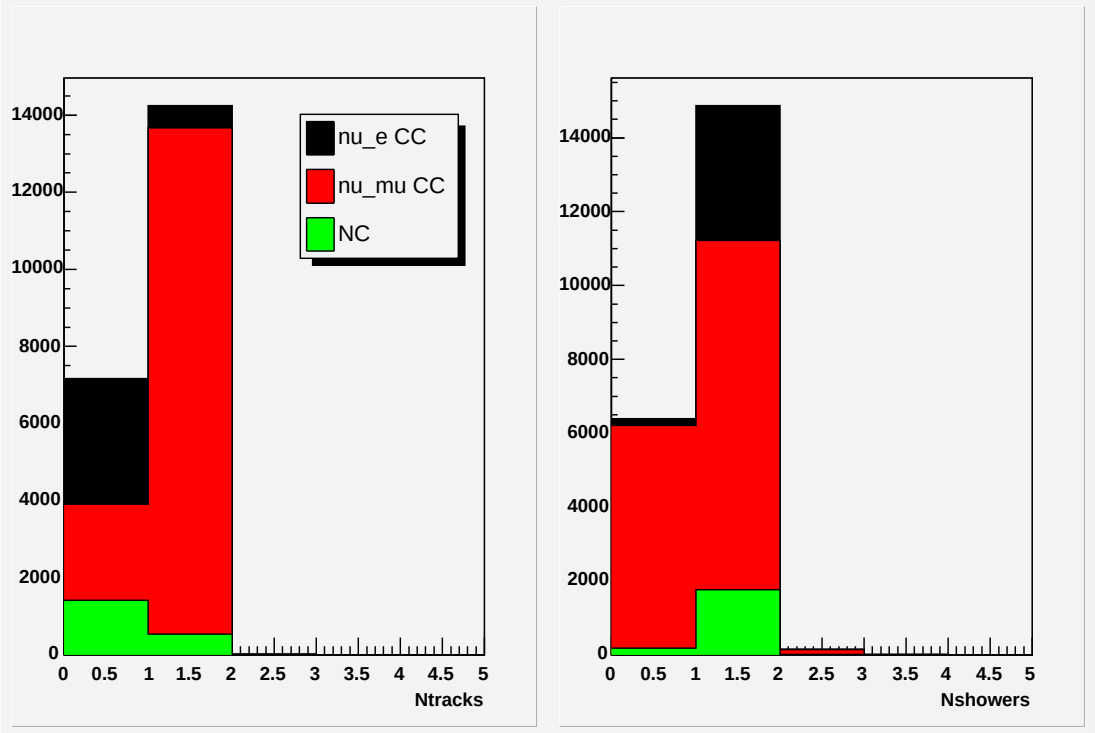
Atmospheric ν_e Selection Cuts 1

- Selection cuts need to

  (a) Remove cosmic background with high efficiency

  (b) Separate ν_e CC events from ν_μ CC and NC events

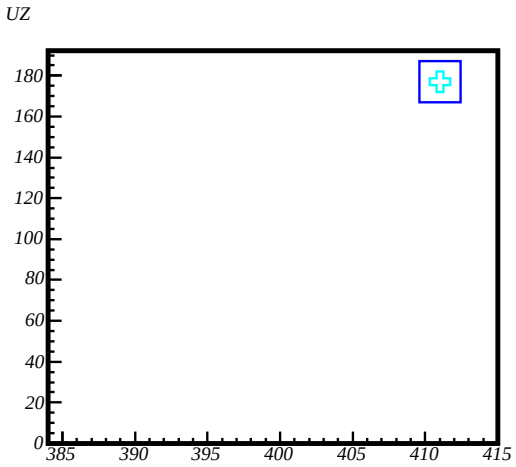
- Preselection
  - $<$5 PE outside fiducial volume
  - No reconstructed track
  - 1 reconstructed shower
- Reduces cosmic and ν_μ CC background, while retaining 84% of (contained) ν_e CC events

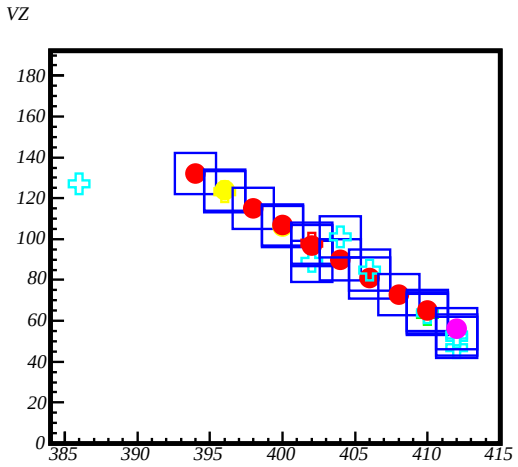


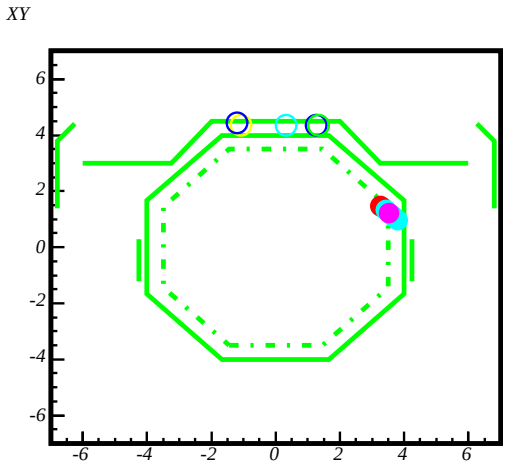
Atmospheric ν_e Selection Cuts 2

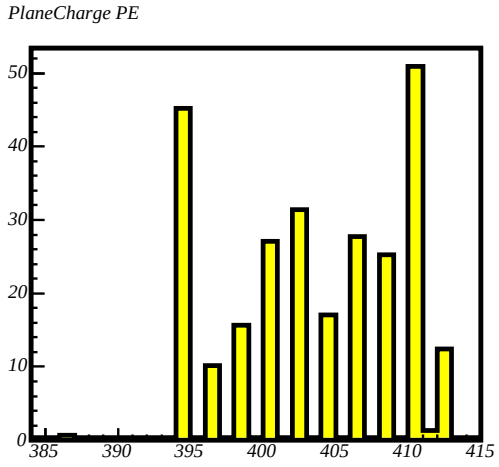
- Shower quality
  - Shower vertex in fiducial volume ($>$ 50cm from radial side, not first or last 4 planes of either SM)
  - At least 80% of energy of event associated to shower
  - Require shower to contain $\geq$ 2 planes in both U and V views with double-ended strip(s) with at least 5 PE
- Removes unsimulated background, e.g. light injection relics, which otherwise pass subsequent shower shape cuts

Event Rejected by Shower Quality









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Reseed: 1 VShw: 0 Plane:403 E:2.03

Q:4.73 0.00 T:9.99e+02 9.99e+02 S:4 P:-1.09 4.35
Q:0.43 0.00 T:9.99e+02 9.99e+02 S:4 P:0.32 4.35
Q:0.98 2.79 T:9.99e+02 9.99e+02 S:4 P:1.26 4.35
Q:1.46 5.63 T:9.99e+02 9.99e+02 S:4 P:1.34 4.37
Q:3.89 0.00 T:9.99e+02 9.99e+02 S:1 P:-1.19 4.43

0/0/2/0/1 11 -1 M:D
15/2/1/0/1 448 -1 M:D
15/2/4/1/0 459 -1 M:D
15/2/4/1/2 461 459 M:D
2/2/1/0/0 113 -1 M:B
3/2/2/0/2 75 73 M:B
14/0/5/0/0 -1 -1 M:B
15/2/1/0/0 446 -1 M:D
15/2/1/0/2 448 446 M:D
15/2/4/1/1 461 -1 M:D
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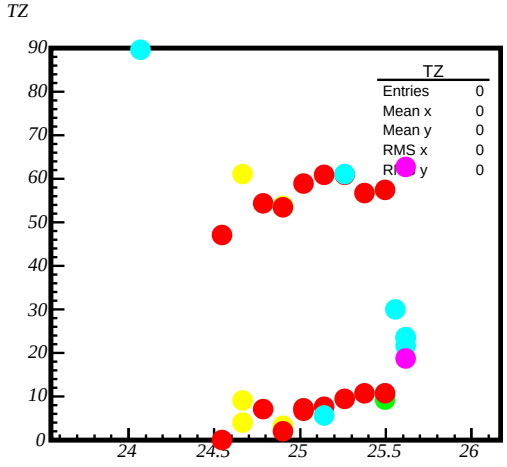
3/2/0/1/1 68 -1 M:B
4/2/5/1/0 -1 -1 M:B



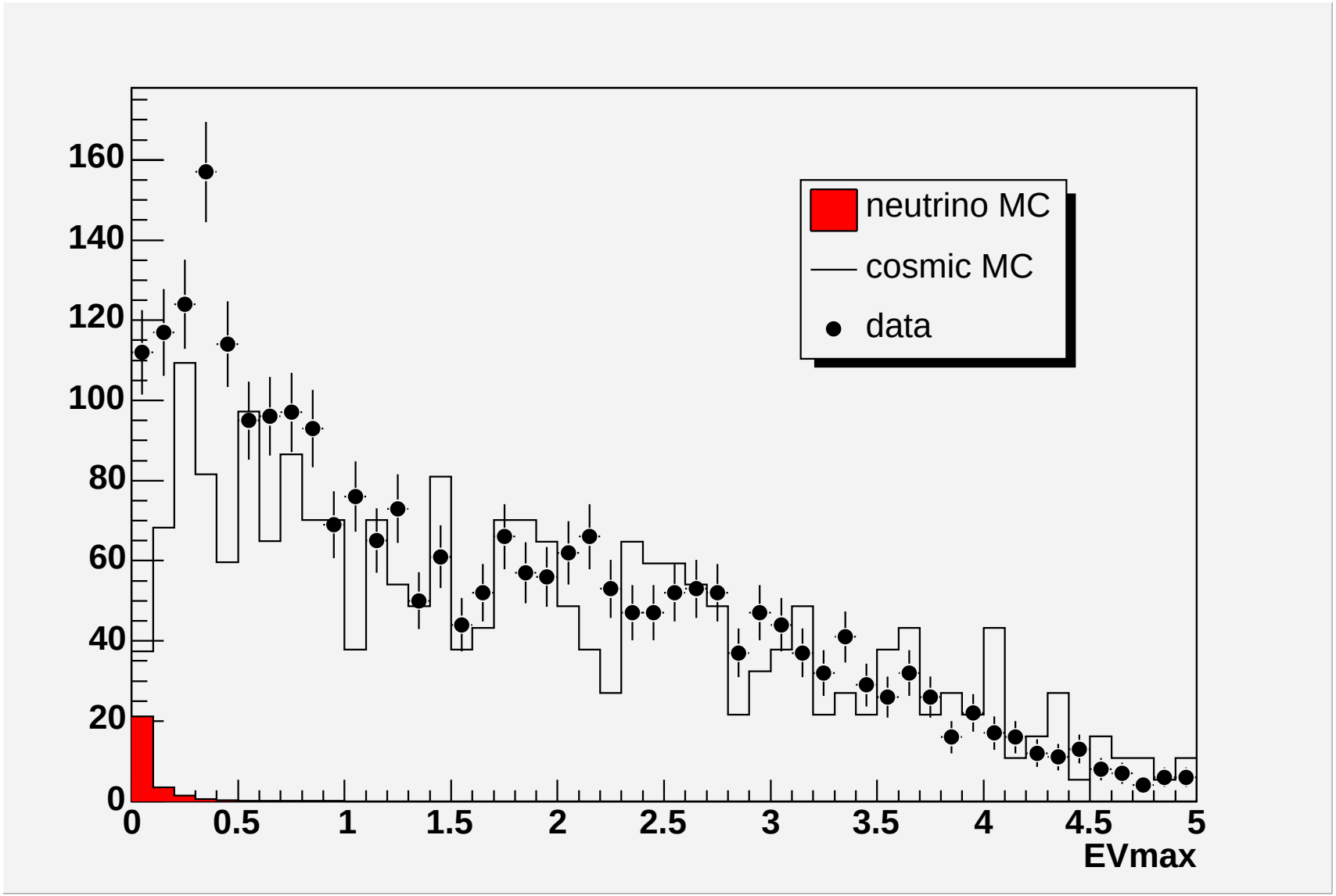
Possibly skims end of U strips beyond last V strip

Atmospheric ν_e Selection Cuts 3

- Shower Shape
  - Shower Length. Using 3D reconstruction of strips in shower, form 'moment of inertia' tensor, normalized to total energy, and find eigenvalues and eigenvectors; require largest eigenvalue <0.1
  - Max strips. Reject event if any plane has more than 12 hit strips
  - Max Energy fraction. Reject event if $>$ 70% of energy in one plane
  - Mean strips. Require mean strips/plane <5
- These reject cosmics which are track-like (long showers) or nearly parallel to planes (large number of strips in a plane)
- Shower length cut also removes $\sim$40% of remaining ν_μ CC events
- Finally, veto events with shield hits (as Caius contained ν_μ analysis)

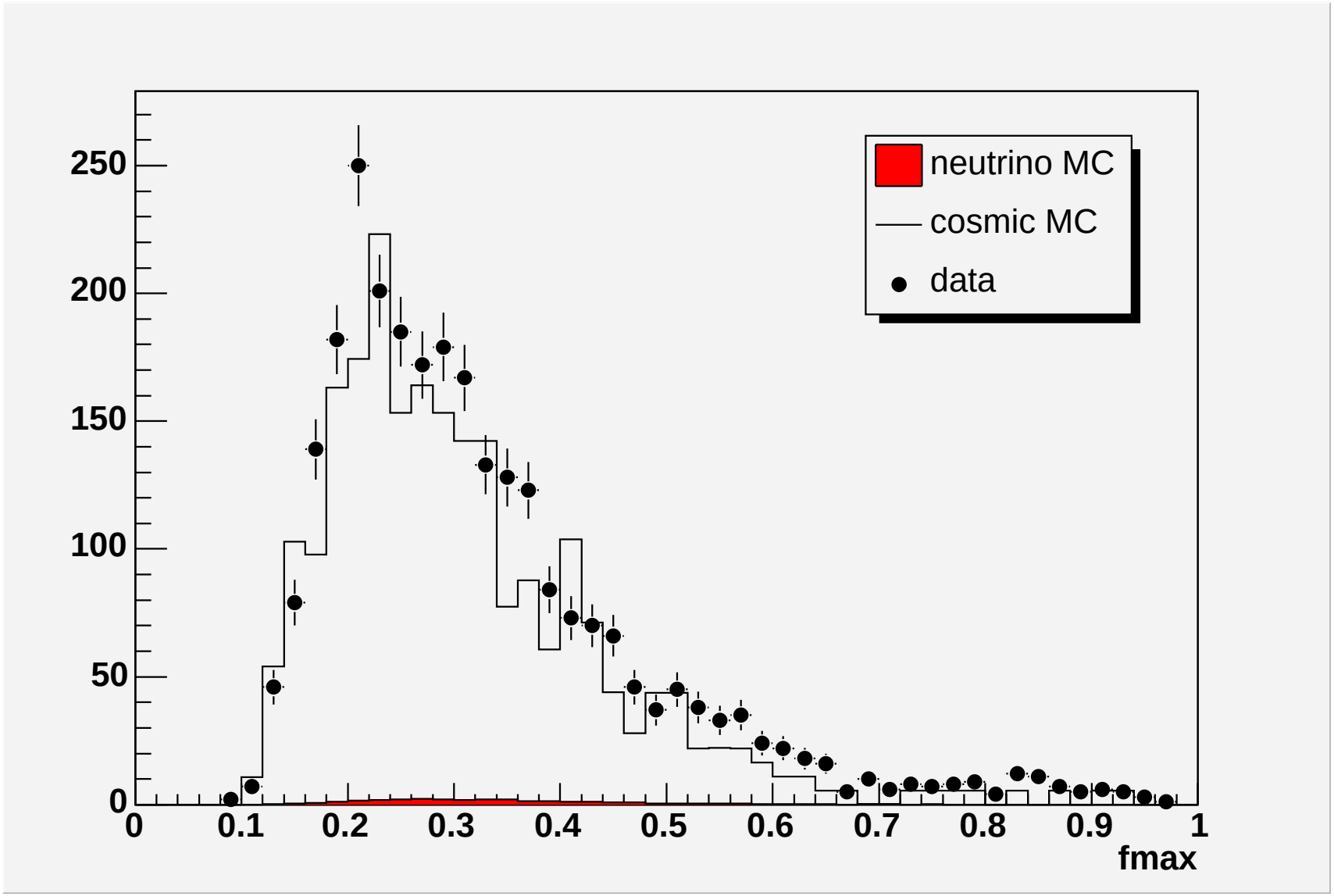
Shower length

Largest eigenvalue of ‘MoI’ tensor after all cuts except shower length and shield.



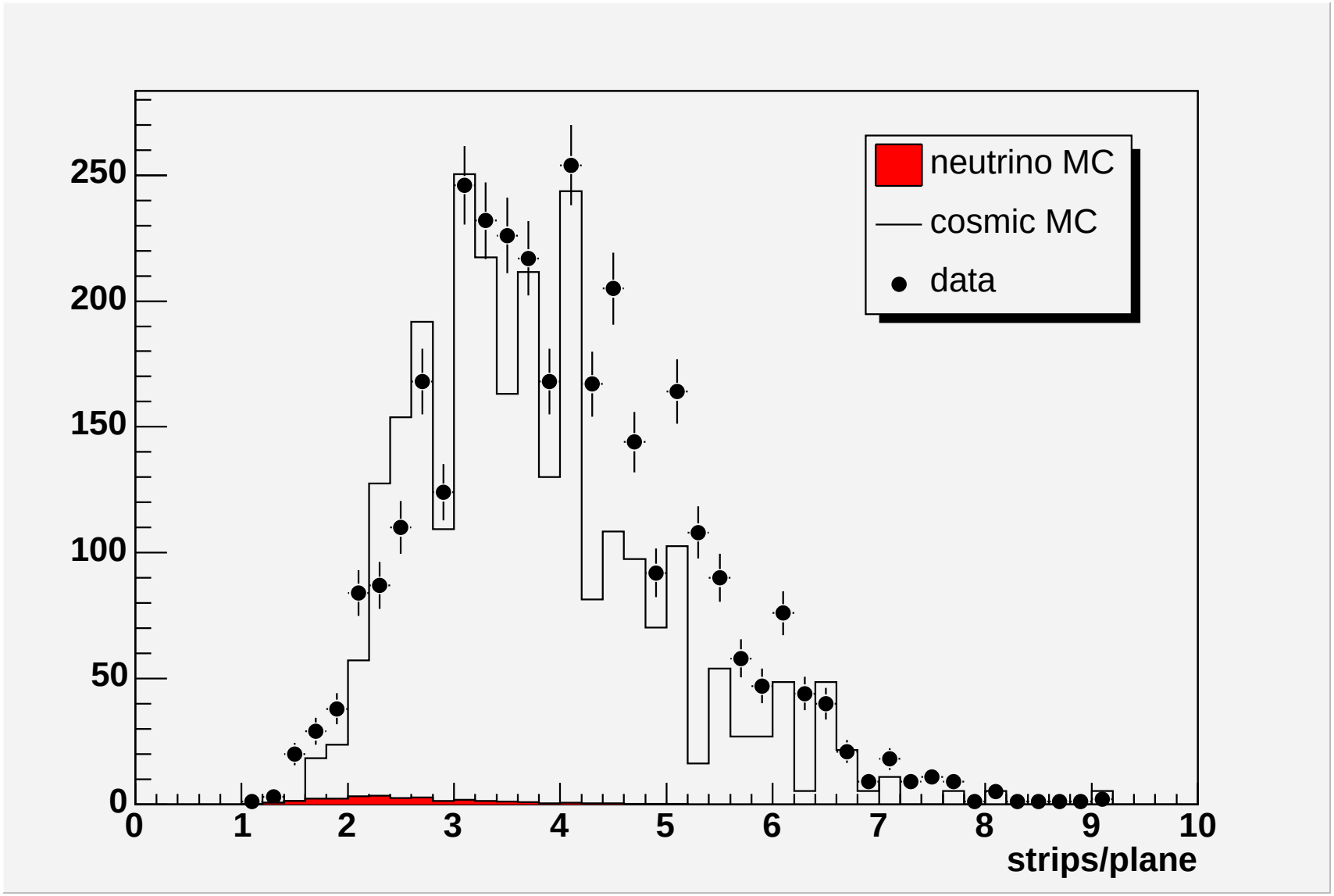
Max energy fraction

Maximium fraction of energy in a plane after all cuts except shower length, max energy fraction and shield



Mean strips

Mean number of hit strips per plane after all cuts except shower length, mean strips and shield



Atmospheric ν_e

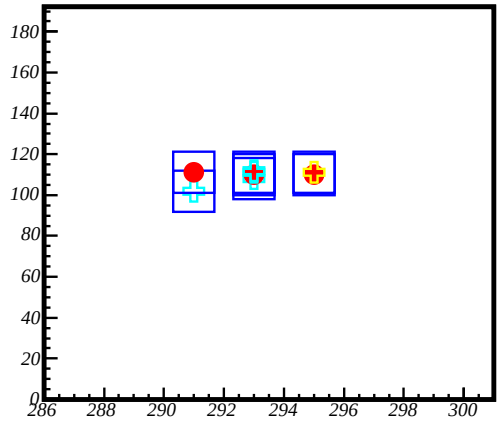
Expected/observed numbers for 2.52kty after each cut:

	ν_e CC	ν_μ CC	NC	MC cosmics	Data
Preselection	16.2	9.0	6.5	25496	38415
Shower Quality	15.2	8.0	5.7	6430	11756
Shower Length	13.3	4.9	4.2	1020	2271
Max strips	13.1	4.8	4.1	63	231
Max energy fraction	12.8	4.7	4.1	29	143
Mean strips	12.6	4.7	4.0	17 ± 10	112
No Shield hits					27

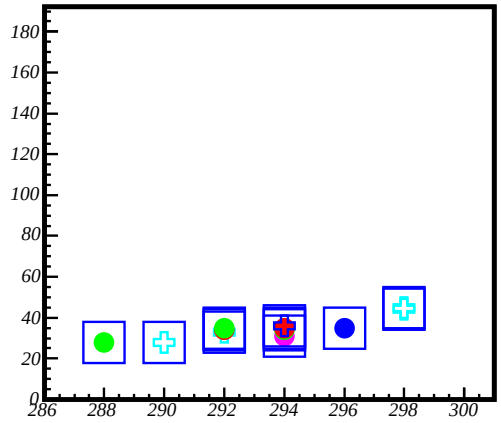
- Cosmic MC underestimates background at all stages

Selected Data Event

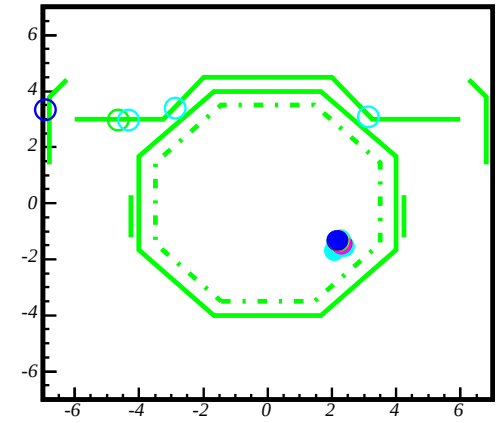
UZ



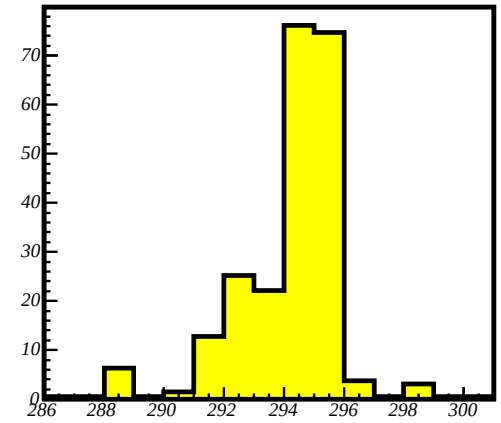
VZ



XY



PlaneCharge PE



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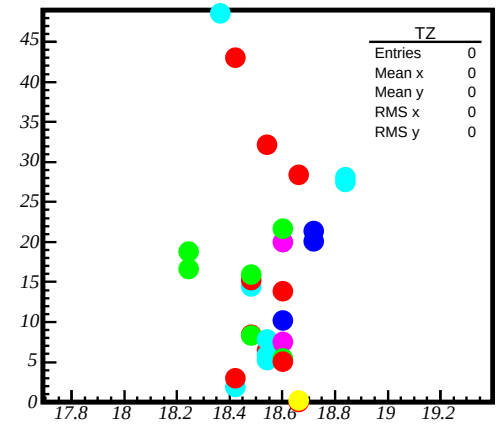
Reseed: 0 VShw: 0 Plane:293 E:1.78

Q:3.26 2.77 T:-1.87e-06 -1.58e-06 S:2 P:-4.65 2.97
Q:1.52 0.00 T:-1.87e-06 -5.45e-01 S:2 P:-4.32 2.97
Q:1.82 0.00 T:-2.30e-06 -5.45e-01 S:2 P:3.14 3.08
Q:3.12 0.00 T:-4.31e-06 -5.45e-01 S:4 P:-6.92 3.33
Q:0.00 1.50 T:-5.45e-01 -4.08e-06 S:3 P:-2.87 3.38

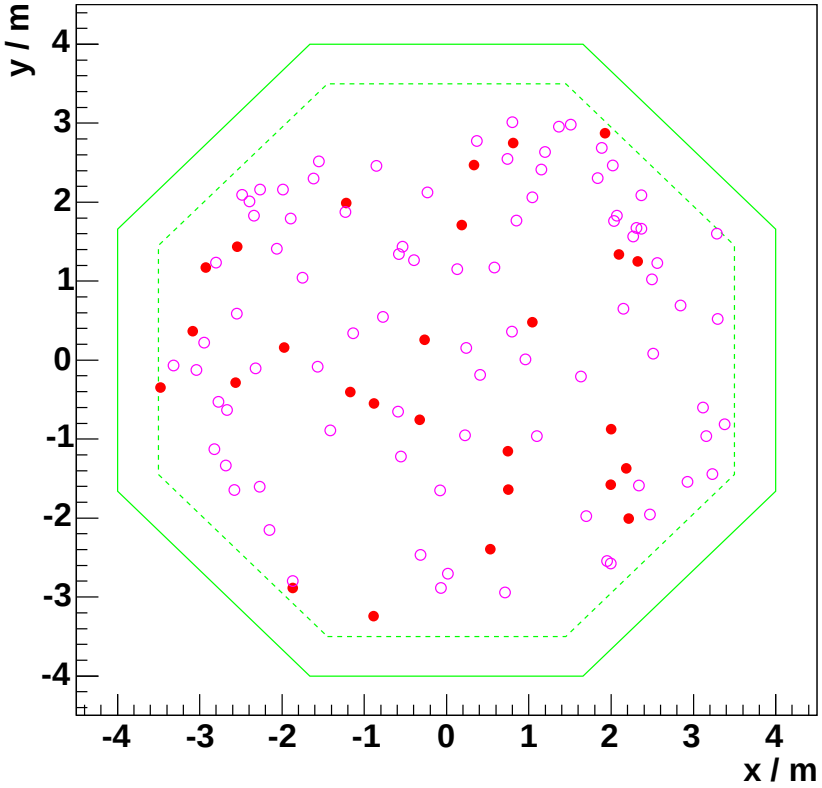
0/0/2/0/1 11 -1 M:D
2/2/5/1/1 -1 -1 M:B
5/1/1/0/0 153 -1 M:B
7/0/5/1/1 -1 -1 M:B
11/1/4/1/2 353 351 M:B

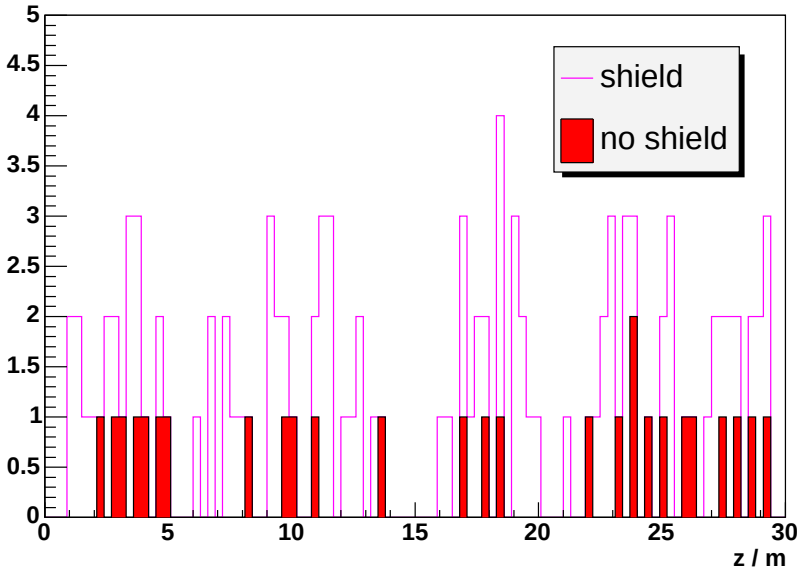
9/2/0/0/1 252 -1 M:D
5/1/1/0/2 155 153 M:B
6/2/5/1/1 -1 -1 M:B
8/0/5/1/1 -1 -1 M:B
14/0/5/1/0 -1 -1 M:B

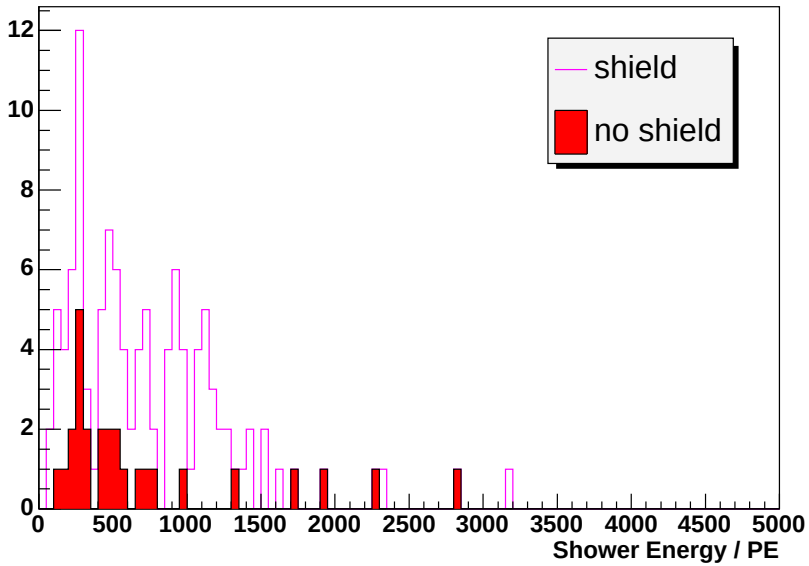
TZ



Selected Events







- Data fairly uniformly distributed in detector volume

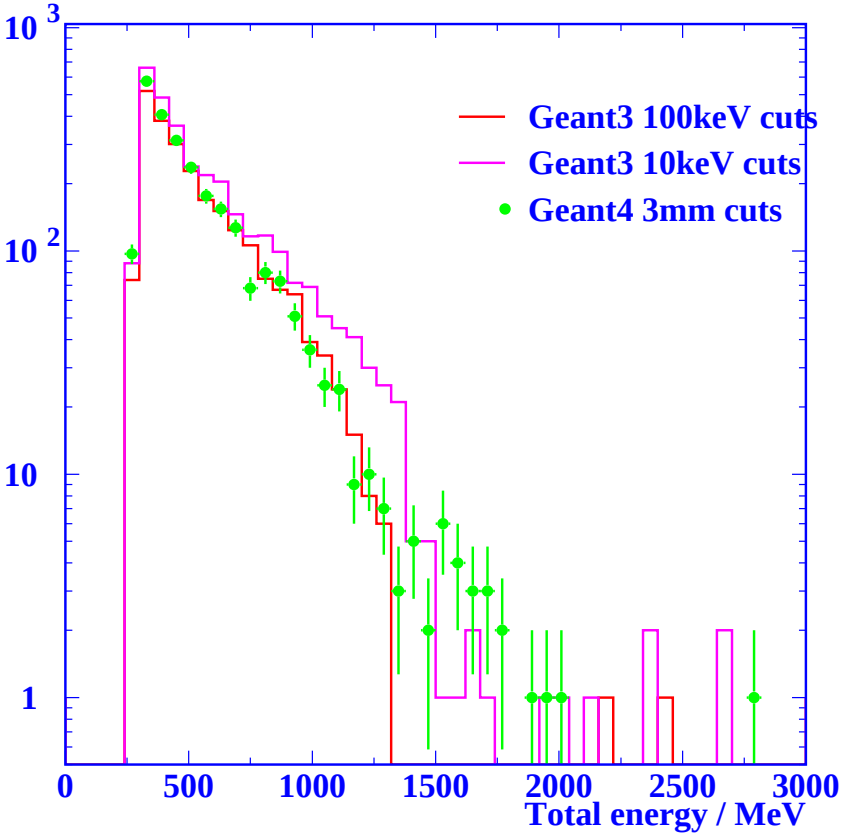
Muon Shower Simulation

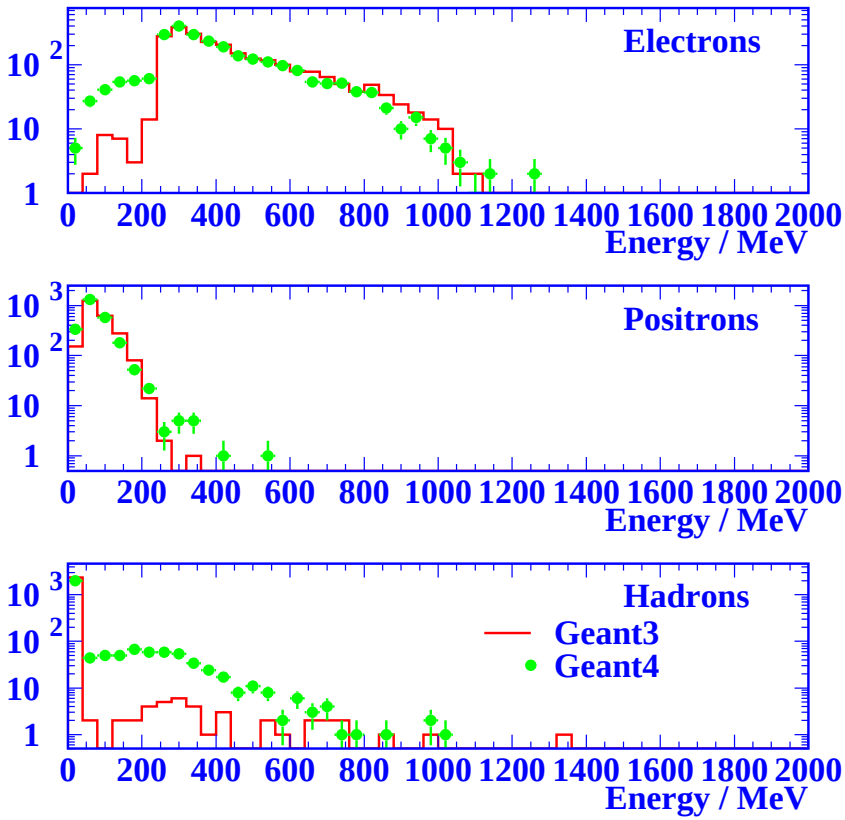
- Cosmic MC predicts fewer events than observed at all stages

  Underestimates background in selected events by factor ~ 5
- Possible problem with simulation of showers from high energy muons?
- Compare Geant3 and Geant4 using CALDET simulation
- Generate 1M 100 GeV μ^-, either 'horizontal' (along detector axis) or 'vertical' (parallel to planes, entering centre of middle steel plane)
- Record true energy deposited in each strip
- Only consider high energy tail – more than 300 MeV deposited energy
- In general, Geant3 and Geant4 distributions fairly similar

Vertical Muons

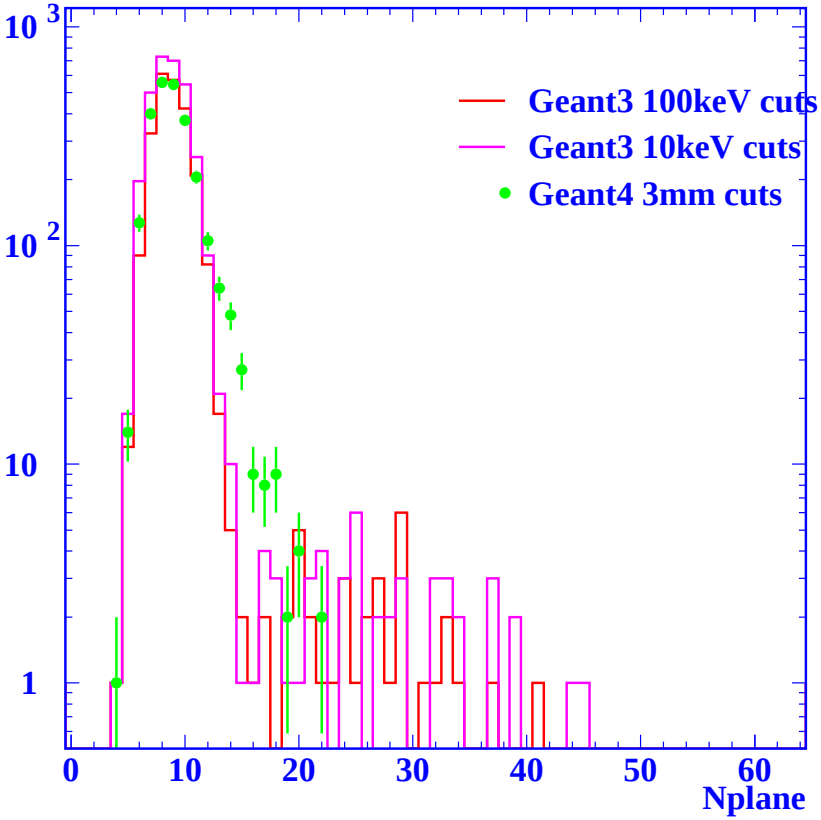
- In Geant3, total energy deposited increases as tracking cuts lowered
- But distributions similar in Geant3 and Geant4
- Main difference is larger number of hadronic showers in Geant4

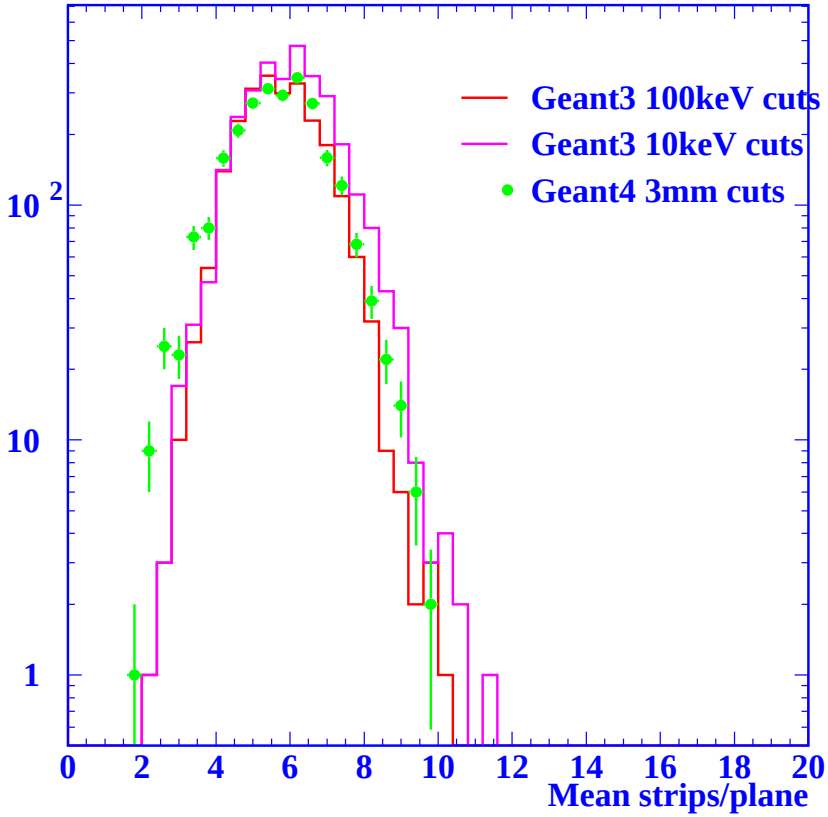




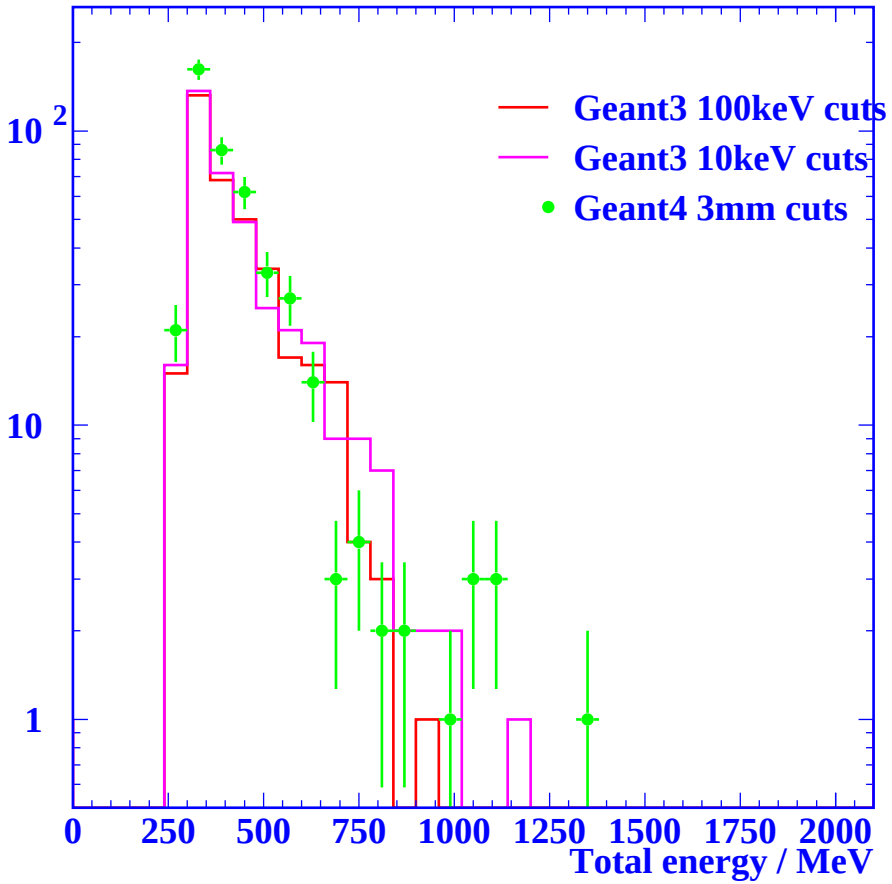
Vertical muons

- Shower shapes (using strips with $>$0.5 MeV ($\sim$0.3 mip)) broadly similar; differences arise from hadronic events





Vertical muons



- Applying ν_e shower shape cuts, slightly more Geant4 events are selected:

  G3: 354

  G4: 424

- But absolute numbers depend strongly on threshold applied to strip energies
- Appears unlikely that using Geant4 simulation would significantly improve agreement with data

Neutrons

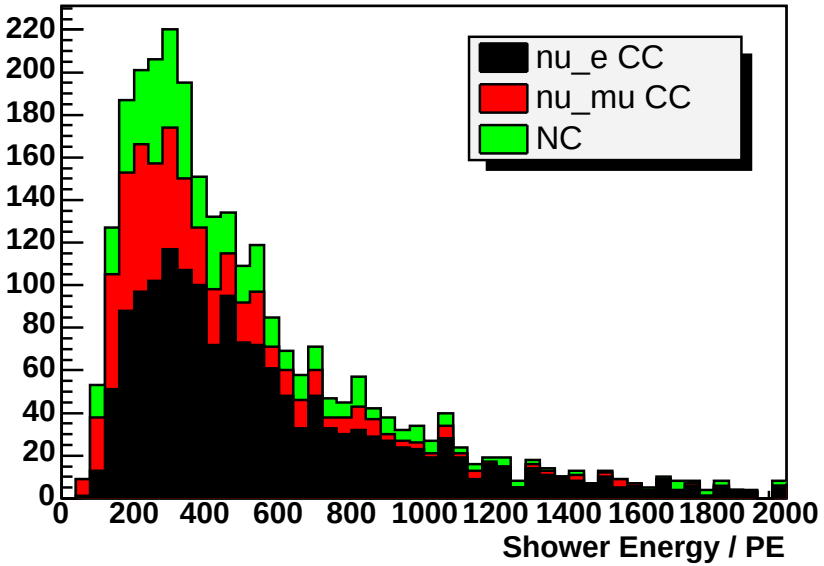
- A possible source of background events is neutrons from cosmic muon interactions in rock
- Neutron flux is unknown

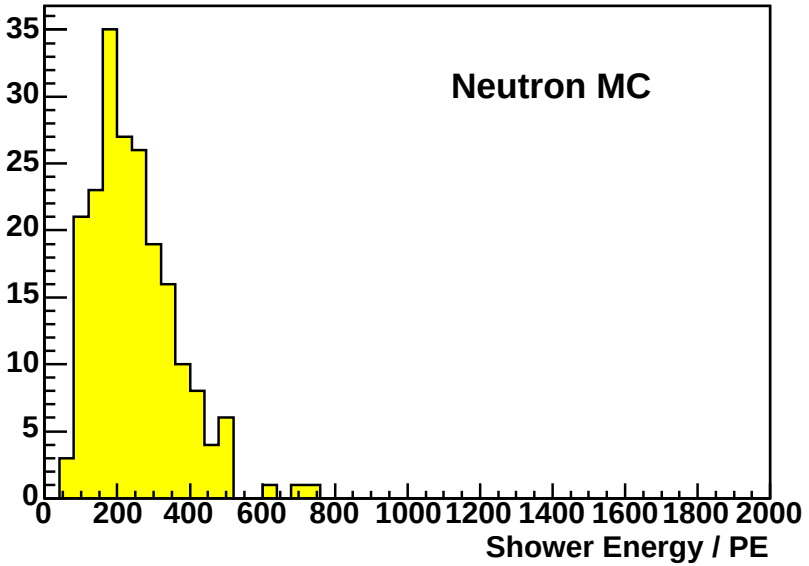
  From Soudan data, estimate $\sim$200 n/year with $E >$300 MeV hit MINOS

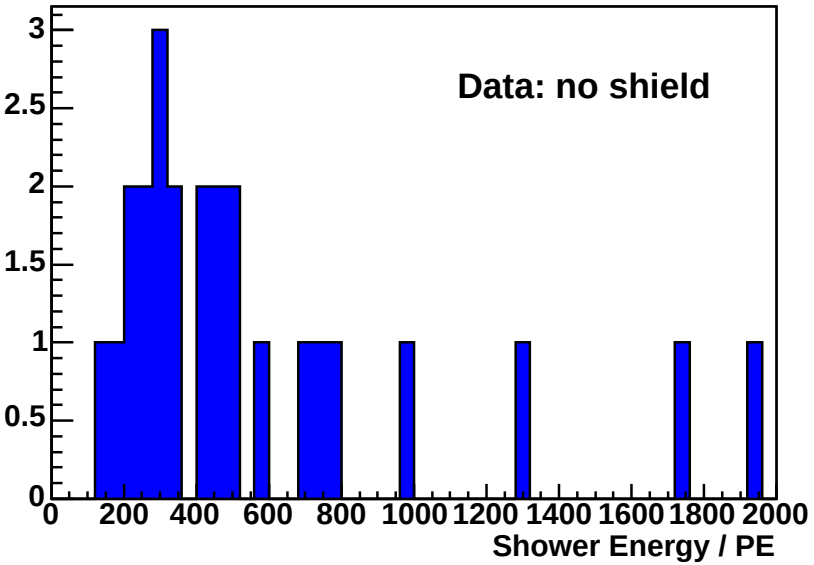
  But MC studies performed for Canfranc and Gran Sasso (deeper, higher E muons) give estimates of 10k–30k / year
- Check effect of ν_{e} selection cuts using MC neutron sample

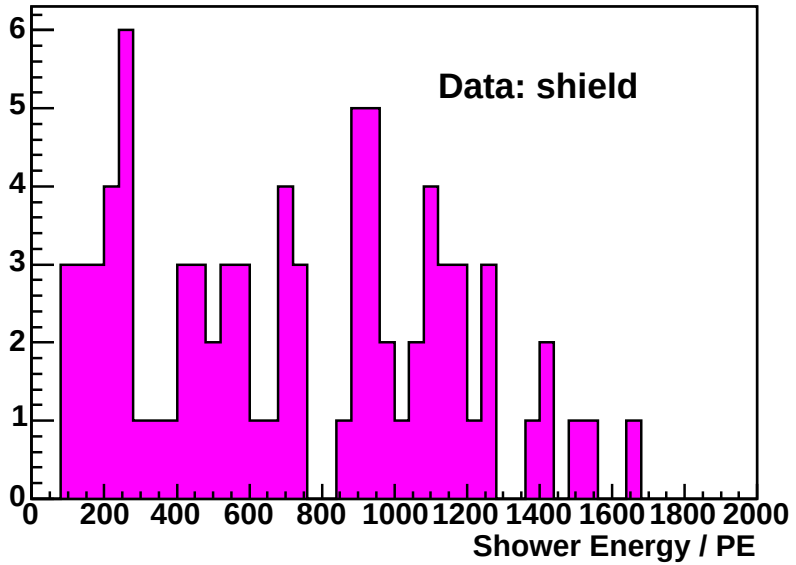
  uniform distribution in 0–2 GeV, isotropic
- 201 / 99k events pass cuts $\Rightarrow$ expect 0.2–30 in data
- BUT neutron energy spectrum falls steeply $\Rightarrow$ cannot explain data excess at high energies (or throughout detector)

Shower Energy Spectrum

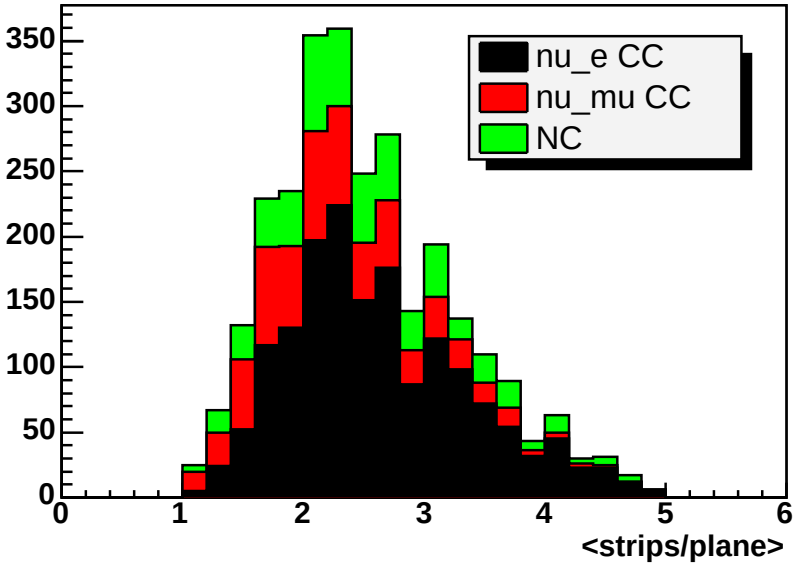


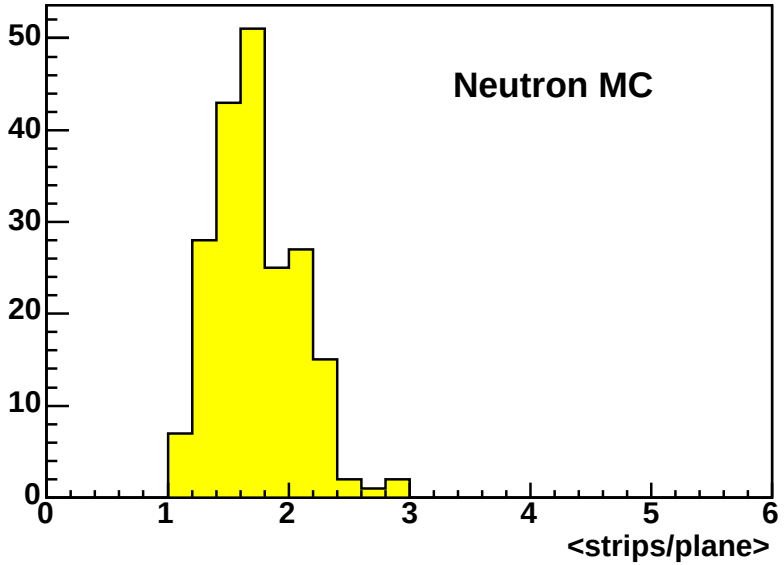


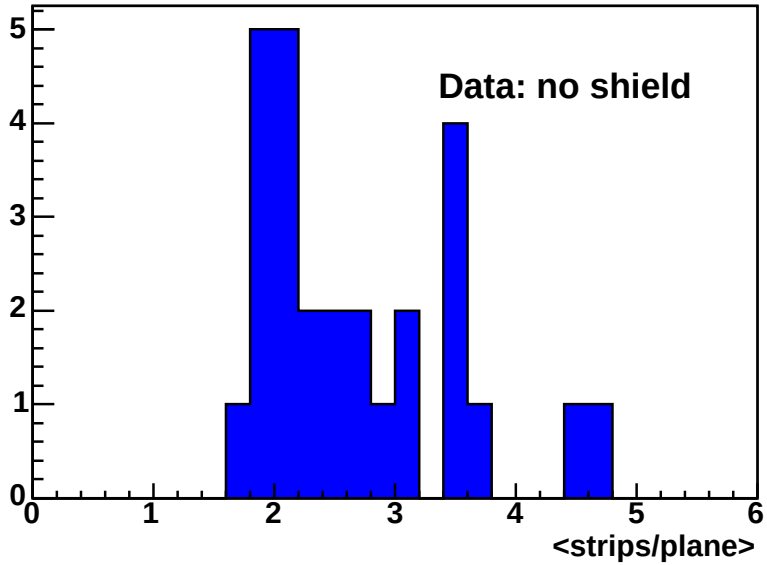


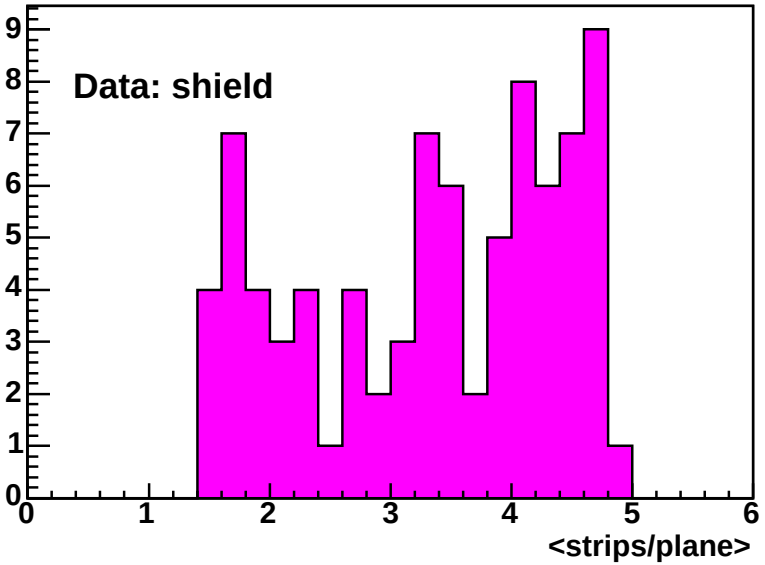


Mean Strips / Plane









Summary

- Atmospheric ν_e analysis in MINOS looks feasible
- In 2.52kty of data observe 112 events, of which 85 rejected by shield

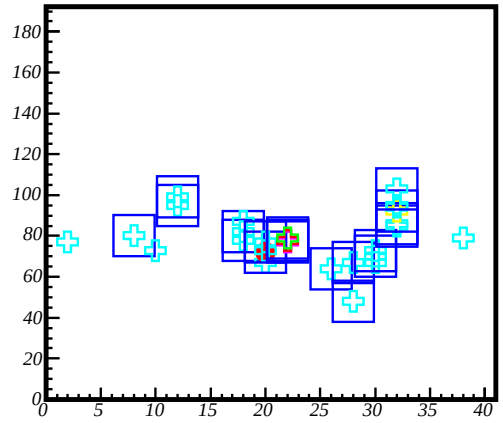
  $\Rightarrow$ expect $\sim$ 100 events in 4 years
- Excess of data over expectation from cosmic MC at all stages not understood

  Geant4 shower simulation would probably not improve agreement

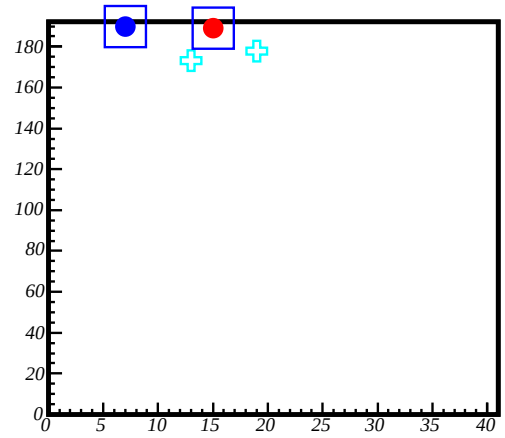
  Mostly too high energy to be neutrons
- Improved separation of signal from ν_μ CC and NC background probably needs likelihood or ANN
- Looks promising, but lots to do / understand

Event Rejected by Shower Quality

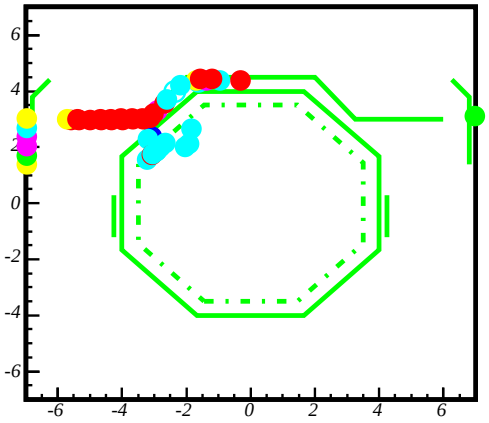
UZ



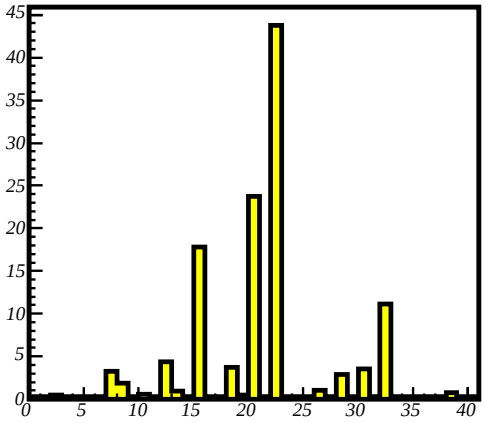
VZ



XY



PlaneCharge PE



ID: -999 Iact: -999 Ires: -999
Run : 18191 Snarl: 95372 Trk: 0 Shw: 1

Reseed: 1 VShw: 0 Plane:21 E:1.10

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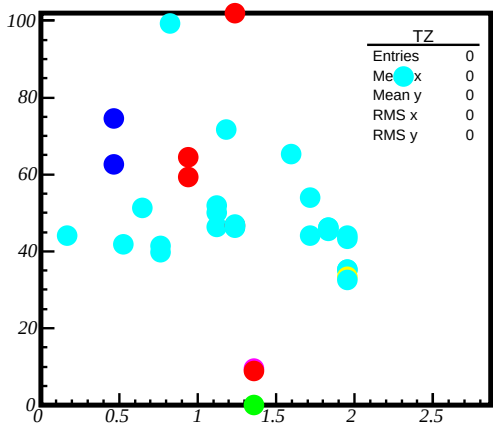
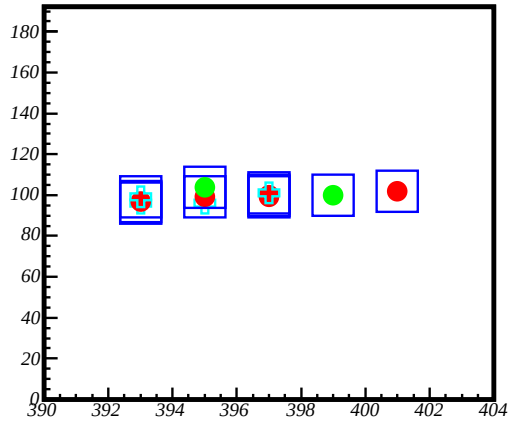
Q:1.57 0.00 T:-1.04e-06 -1.58e-01 S:2 P:-1.61 4.35
Q:6.33 17.36 T:4.96e-08 -1.22e-09 S:1 P:-5.58 2.97
Q:4.01 8.52 T:5.09e-08 1.95e-10 S:1 P:-5.33 2.97
Q:5.60 12.29 T:5.24e-08 2.09e-09 S:1 P:-5.00 2.97
Q:4.94 11.80 T:4.53e-08 -5.40e-09 S:1 P:-4.66 2.97
Q:12.20 19.02 T:4.70e-08 -3.51e-09 S:1 P:-4.33 2.97
Q:56.83 72.90 T:4.74e-08 1.92e-09 S:1 P:-3.99 2.98
Q:22.46 41.06 T:4.62e-08 4.52e-09 S:1 P:-3.66 2.99
Q:12.44 27.38 T:4.45e-08 2.62e-09 S:1 P:-3.33 2.99
Q:17.83 31.20 T:4.25e-08 -2.35e-10 S:1 P:-3.11 3.07
Q:3.60 5.84 T:4.10e-08 -2.13e-09 S:1 P:-2.90 3.32
[redacted]D

TZ

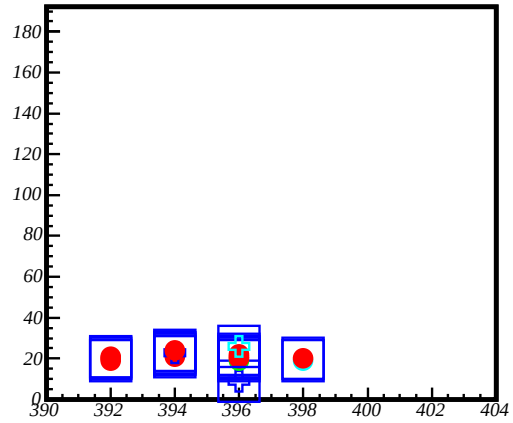


Selected Data Event

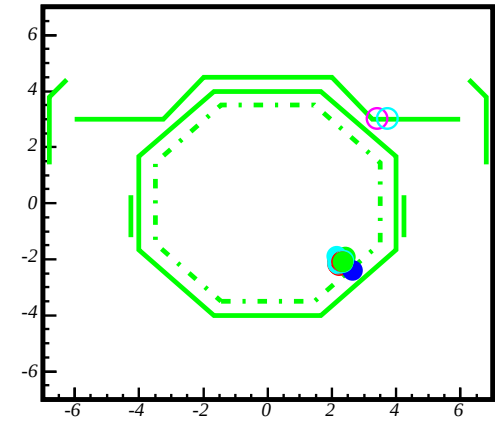
UZ



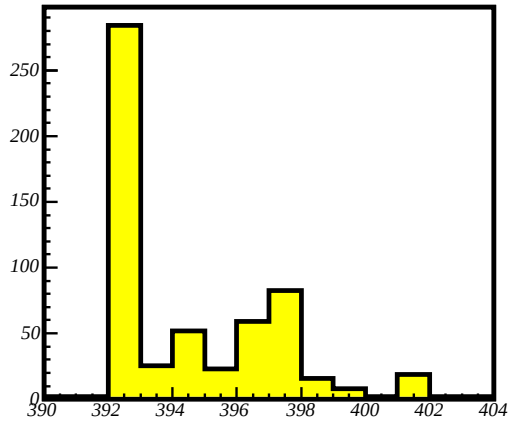
VZ



XY



PlaneCharge PE



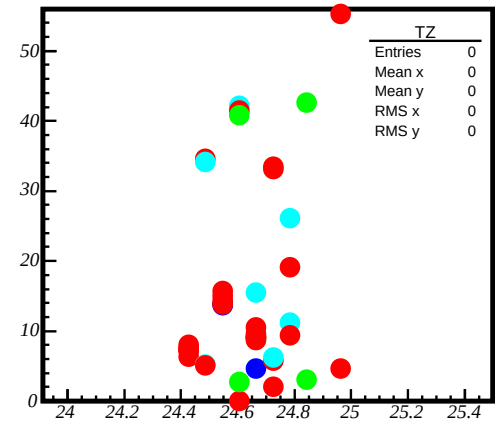
ID: -999 Iact: -999 Ires: -999
Run : 18884 Snarl: 72289 Trk: 0 Shw: 1

Reseed: 0 VShw: 0 Plane:394 E:3.92

Q:1.34 8.21 T:-3.24e-06 -3.27e-06 S:1 P:3.41 3.04
Q:1.03 0.00 T:-3.24e-06 -7.99e-01 S:1 P:3.74 3.04

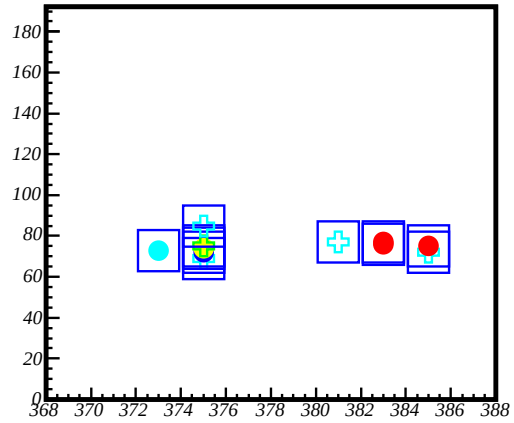
0/0/2/0/1 11 -1 M:D
5/0/5/1/2 -1 -1 M:B
13/2/1/0/1 384 -1 M:B
1/0/5/1/2 -1 -1 M:B
13/2/0/0/2 380 378 M:B

TZ

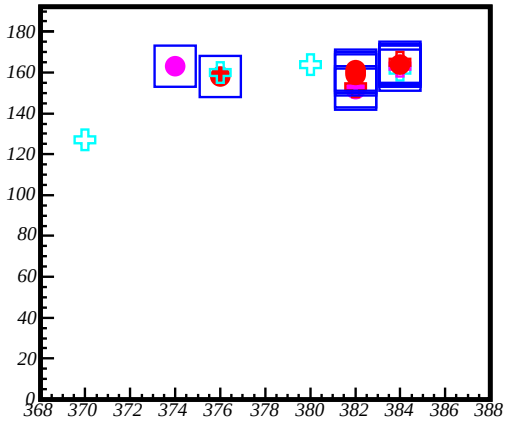


Selected Data Event

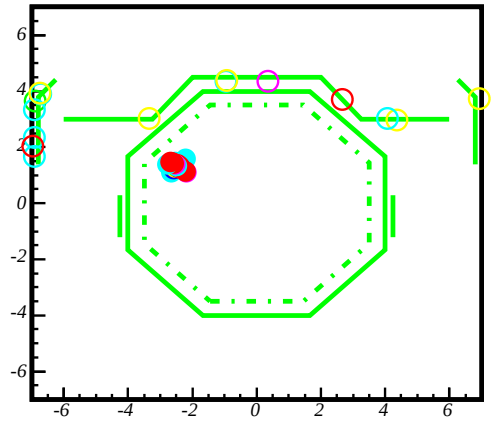
UZ



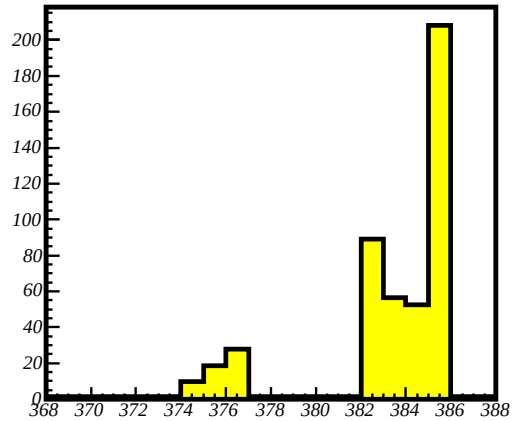
VZ



XY



PlaneCharge PE

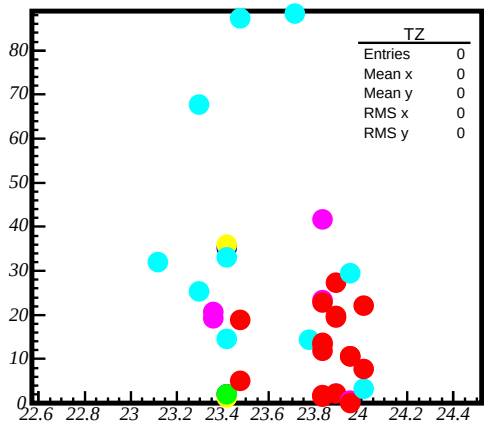


ID: -999 Iact: -999 Ires: -999
Run : 24151 Snarl: 16298 Trk: 0 Shw: 1

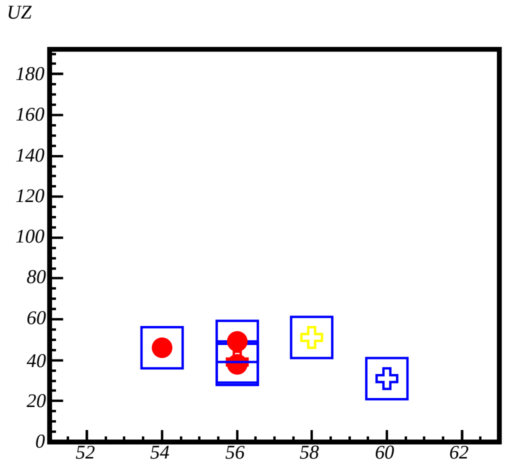
Reseed: 0 VShw: 0 Plane:384 E:3.28

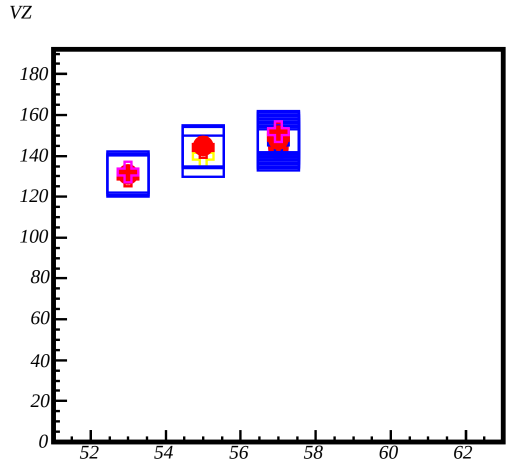
Q:0.00 7.51 T:-1.54e-01 -2.77e-05 S:2 P:-6.89 3.65
Q:0.00 0.39 T:-1.54e-01 -2.77e-05 S:2 P:-6.72 3.90
Q:3.86 1.62 T:-1.89e-05 -1.88e-05 S:2 P:6.93 3.73
Q:0.00 4.86 T:-1.54e-01 -9.68e-06 S:4 P:-3.34 3.02
Q:0.00 1.66 T:-1.54e-01 -1.32e-05 S:4 P:-0.96 4.37
Q:0.00 8.01 T:-1.54e-01 -1.35e-05 S:4 P:0.36 4.37
Q:2.92 7.71 T:-1.31e-05 -1.31e-05 S:4 P:2.67 3.72
Q:0.00 2.08 T:-1.54e-01 -1.84e-05 S:4 P:-6.92 1.68
Q:0.00 2.47 T:-1.54e-01 -2.73e-05 S:4 P:-6.92 2.34
Q:0.92 0.00 T:-2.44e-05 -1.54e-01 S:4 P:-6.92 3.33
Q:4.66 0.00 T:-2.44e-05 -1.54e-01 S:4 P:-6.73 3.93
Q:4.09 0.00 T:-1.96e-05 -1.54e-01 S:1 P:4.37 2.97

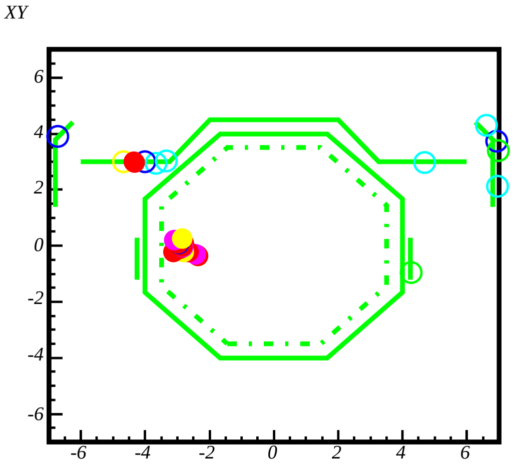
TZ

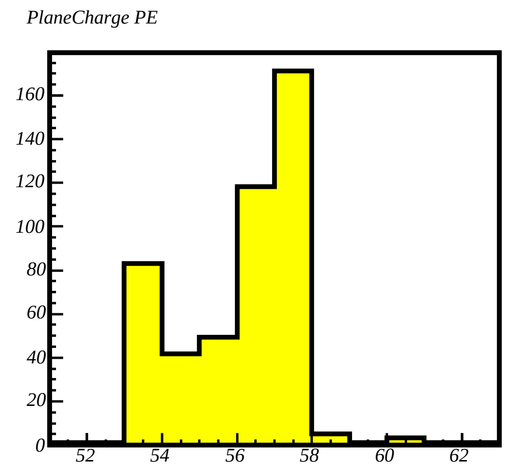


Event with Shield Hits





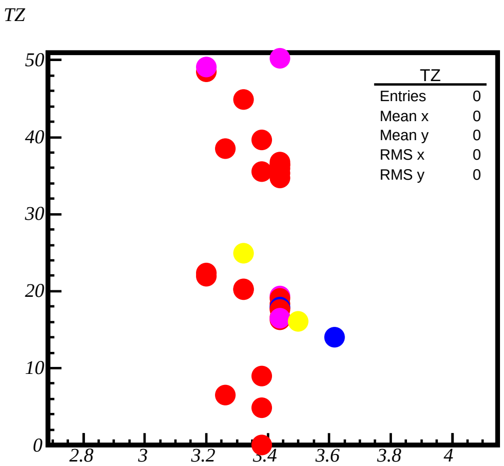




ID: -999 Iact: -999 Ires: -999
Run : 22702 Snarl: 11938 Trk: 0 Shw: 1

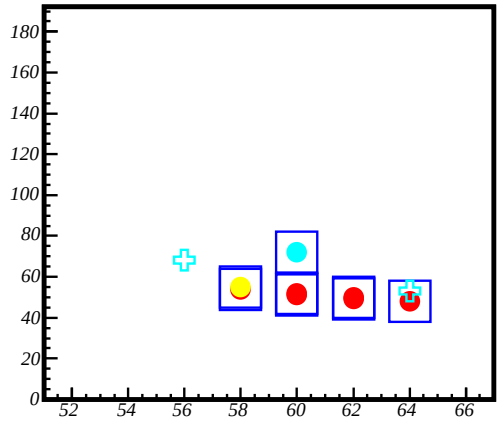
Reseed: 0 VShw: 0 Plane:56 E:3.32

Q:0.00 1.54 T:-1.65e-01 -1.39e-05 S:2 P:-3.67 2.95
Q:3.08 0.00 T:-2.30e-05 -1.65e-01 S:2 P:-4.00 3.00
Q:0.00 3.01 T:-1.65e-01 -1.97e-05 S:2 P:-6.72 3.90
Q:1.63 0.00 T:-7.53e-06 -1.65e-01 S:2 P:6.95 2.11
Q:0.00 3.81 T:-1.65e-01 -8.93e-06 S:2 P:6.93 3.73
Q:0.00 4.48 T:-1.65e-01 -2.31e-05 S:4 P:-4.66 3.00
Q:2.28 0.00 T:-7.66e-06 -1.65e-01 S:4 P:-3.34 3.02
Q:6.32 7.46 T:2.34e-08 -3.63e-09 S:1 P:-4.33 2.97
Q:2.27 0.00 T:-1.21e-05 -1.65e-01 S:1 P:4.70 2.97
Q:7.13 13.78 T:2.40e-08 -3.30e-09 S:1 P:-4.36 3.01
Q:6.69 0.00 T:-1.09e-05 -1.65e-01 S:1 P:4.26 -0.96
Q:0.00 1.69 T:-1.65e-01 -2.94e-05 S:1 P:6.59 4.30
[illegible] e-05 -4.77e-[illegible]

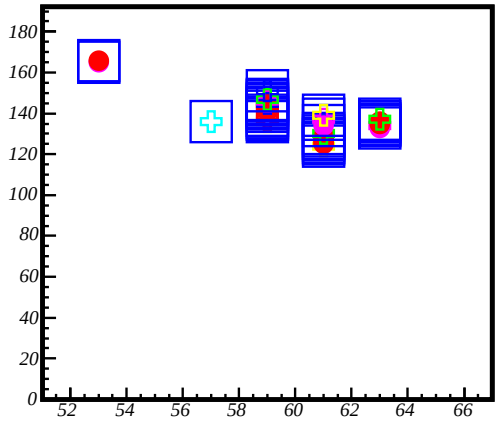


Event with Shield Hits

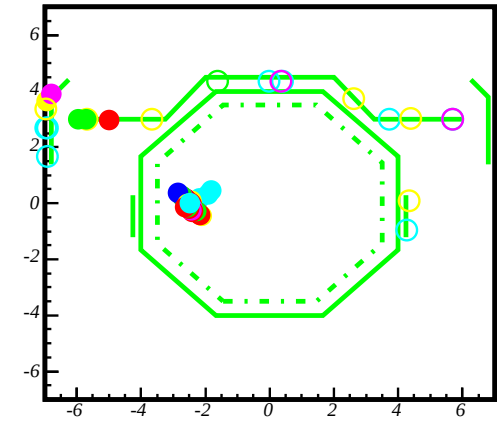
UZ



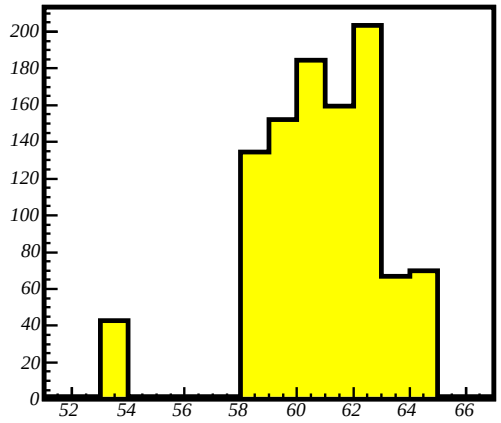
VZ



XY



PlaneCharge PE

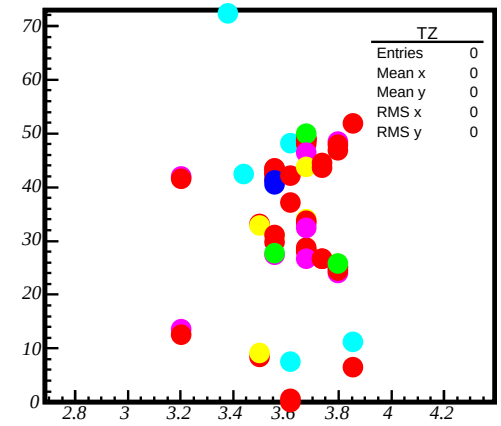


ID: -999 Iact: -999 Ires: -999
Run : 25008 Snarl: 112522 Trk: 0 Shw: 1

Reseed: 0 VShw: 0 Plane:60 E:6.70

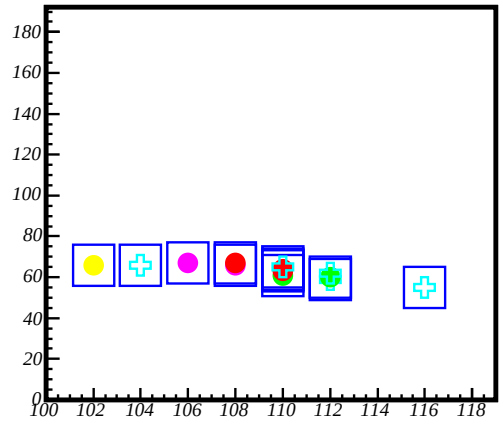
Q:0.00 4.54 T:-3.14e-01 -5.28e-06 S:2 P:2.61 3.75
Q:3.90 1.68 T:-2.87e-06 -2.84e-06 S:2 P:-5.69 3.00
Q:6.09 0.00 T:-1.26e-05 -3.14e-01 S:2 P:-1.61 4.35
Q:2.61 0.00 T:-1.30e-05 -3.14e-01 S:2 P:0.40 4.34
Q:0.00 2.33 T:-3.14e-01 -5.27e-06 S:2 P:3.73 3.01
Q:1.63 0.37 T:-7.04e-06 -5.27e-06 S:2 P:5.70 3.01
Q:2.29 0.00 T:-1.97e-05 -3.14e-01 S:2 P:-6.91 2.69
Q:4.06 0.00 T:-1.52e-05 -3.14e-01 S:4 P:-3.67 3.00
Q:2.21 0.00 T:-2.27e-05 -3.14e-01 S:4 P:-0.01 4.35
Q:5.91 3.49 T:-9.85e-06 -9.83e-06 S:4 P:0.36 4.37
Q:1.37 0.00 T:-1.49e-05 -3.14e-01 S:4 P:-6.92 1.68
Q:5.01 6.86 T:1.30e-08 -7.69e-09 S:1 P:-5.00 2.97

TZ

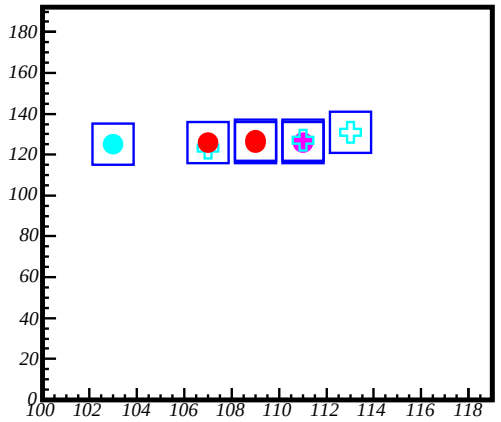


Selected MC ν_e CC Event

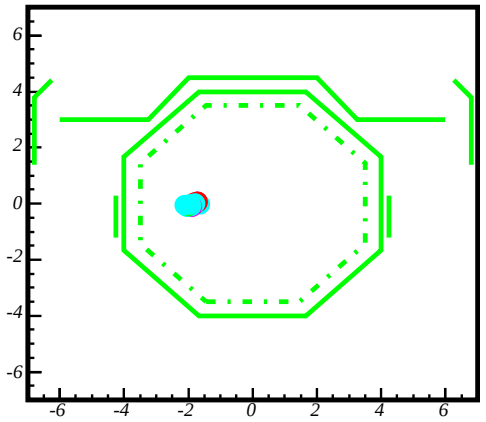
UZ



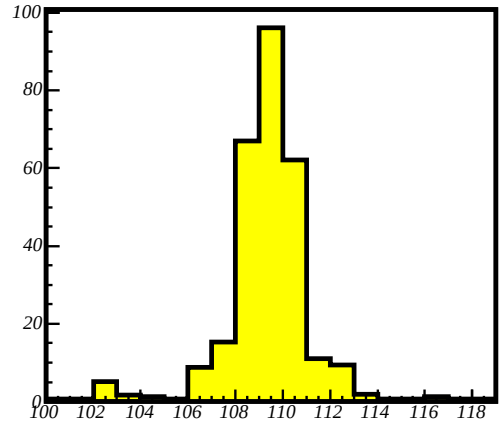
VZ



XY



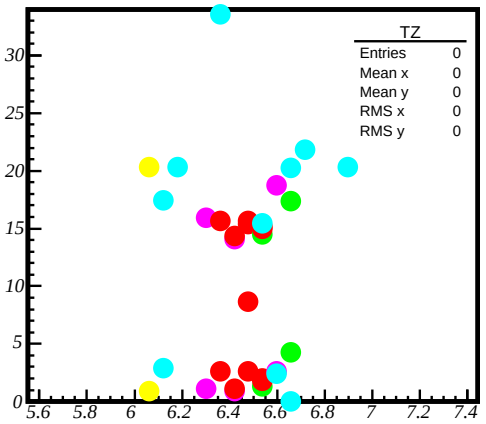
PlaneCharge PE



ID: -12 Iact: 1 Ires: 1002
Run : 127 Snarl: 10 Trk: 0 Shw: 1

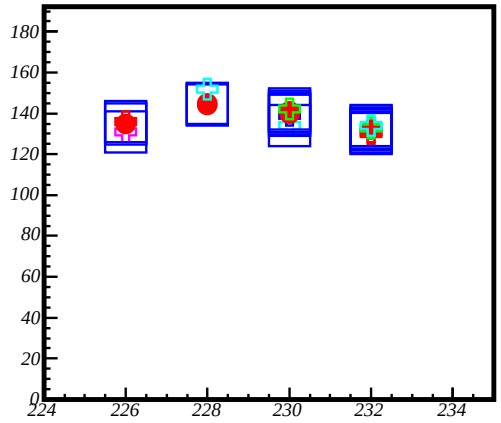
Reseed: 0 VShw: 0 Plane:108 E:2.12

TZ

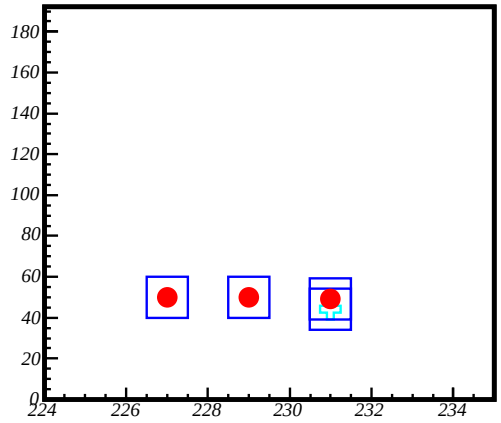


Selected MC Cosmic Muon

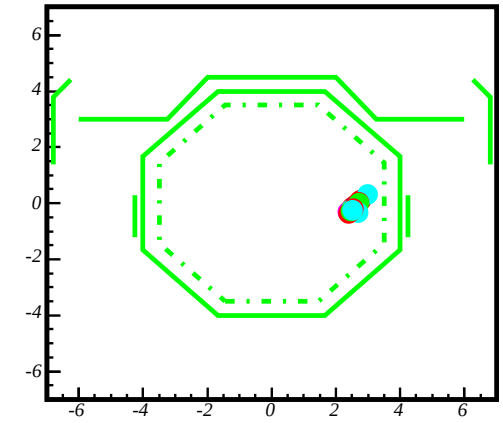
UZ



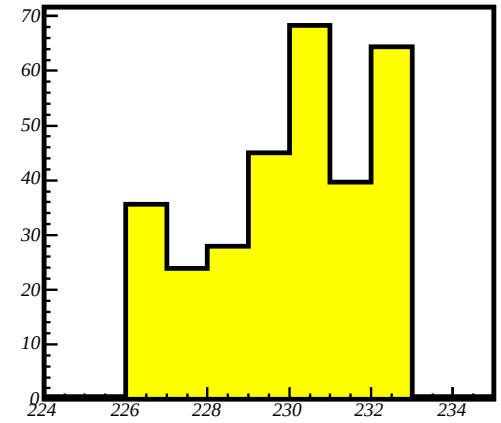
VZ



XY



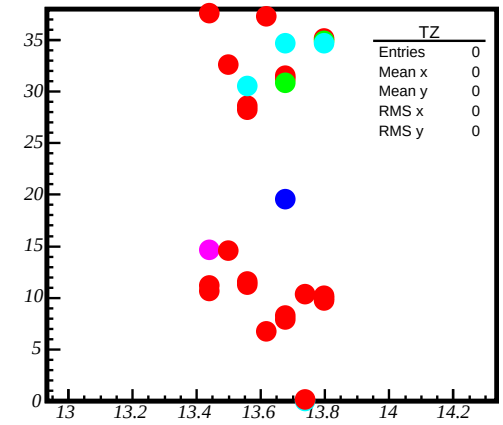
PlaneCharge PE



ID: 0 Iact: -1 Ires: 0
Run : 473 Snarl: 7687 Trk: 0 Shw: 1

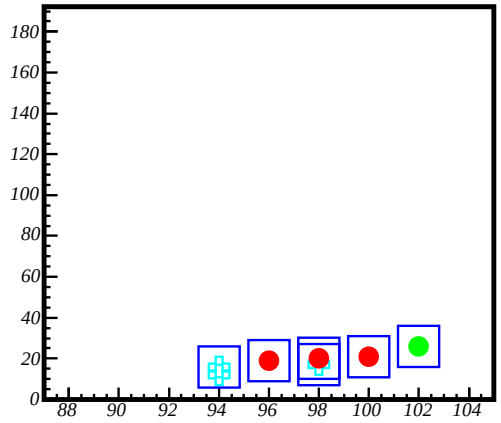
Reseed: 1 VShw: 0 Plane:229 E:2.28

TZ

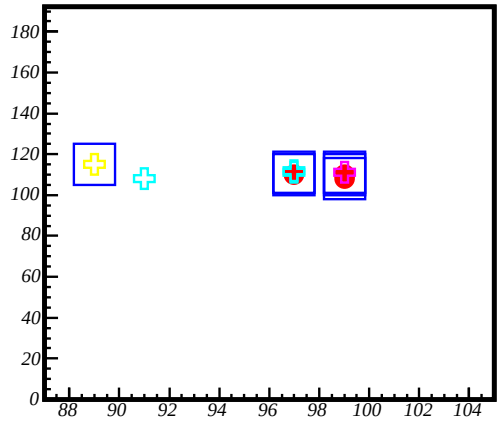


Selected MC Neutron Event

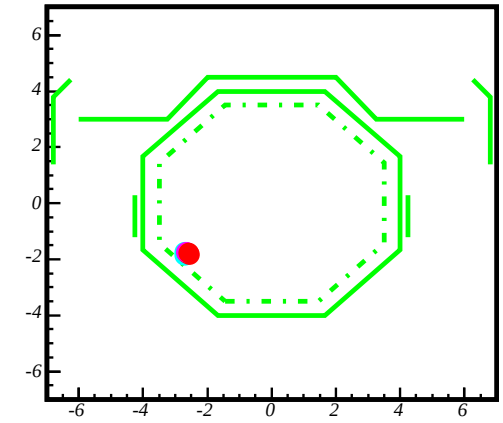
UZ



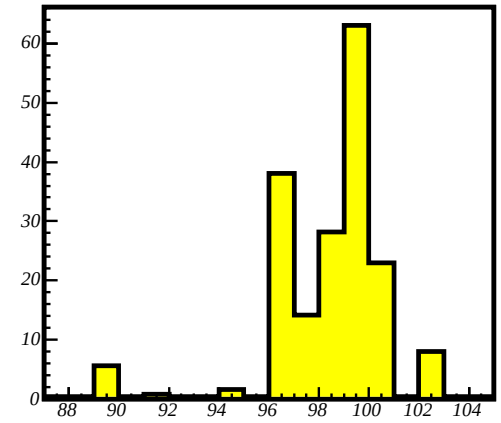
VZ



XY



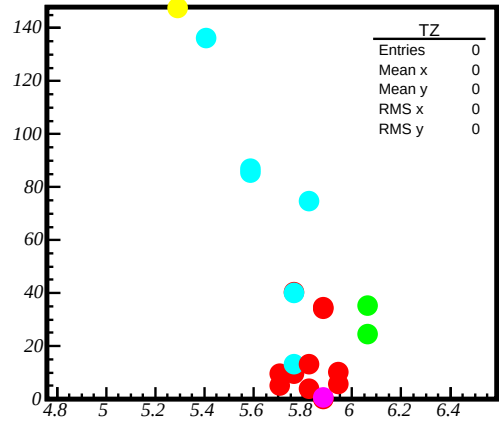
PlaneCharge PE



ID: 0 Iact: -1 Ires: 0
Run : 3000 Snarl: 26664 Trk: 0 Shw: 1

Reseed: 1 VShw: 0 Plane:98 E:1.51

TZ



Neutron MC Study