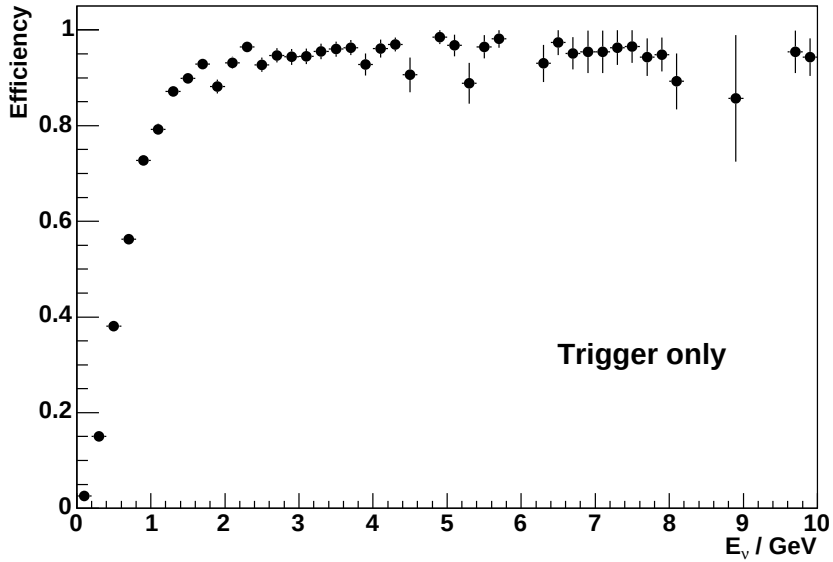
Atmospheric ν_e Search

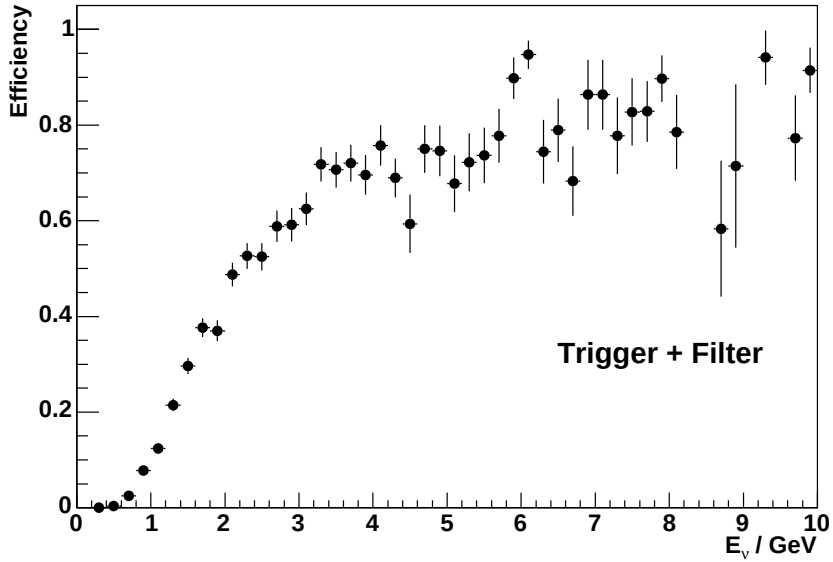
Pat Ward
University of Cambridge

- Can we identify atmospheric ν_e CC events?
  Normalization of flux for ν_μ analysis
- Worthwhile if get normalization to $\sim$10%
  $\Rightarrow$ 100 events in 4 years, or 12–13 in 0.5y
- Use ntuples (and some code and expertise) from Caius
  Signal MC: Run 127 (Battistoni flux, solar max), 95k ν events $\equiv$ 330kty
  Background MC: 2M full spectrum cosmics $\equiv$ 30 days
  Data: 2.52 kty total (1.85 kty fiducial) $\equiv$ 4088.4h

Atmospheric ν_e

- How many ν_e CC events do we expect?
- Using Battistoni solar max flux, expected ν_e CC events in 2.52kty:
  - Total (E_ν >100 MeV) : 167
  - Vertex in fid. vol. : 132
  - Pass trigger : 69
  - Pass (7 planes) filter : 22
- c.f. $\sim$ 11.4M cosmics
- Consider only events passing filter for now





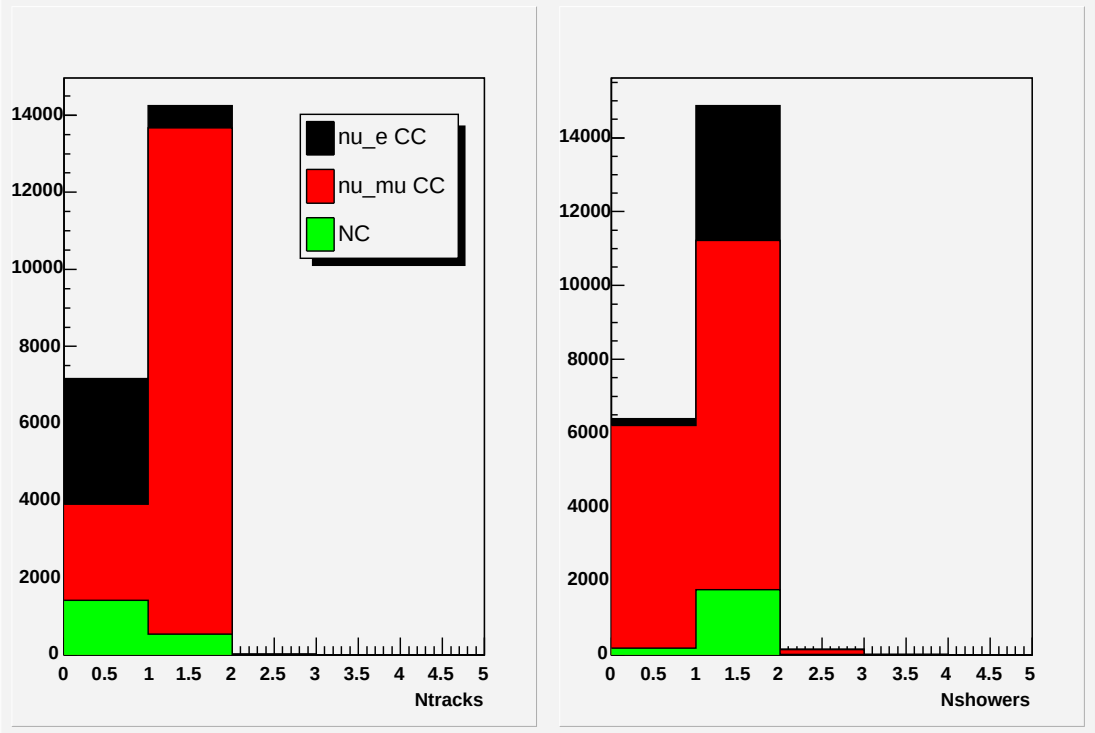
Atmospheric ν_e Selection Cuts 1

- Selection cuts need to

  (a) Remove cosmic background with high efficiency

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

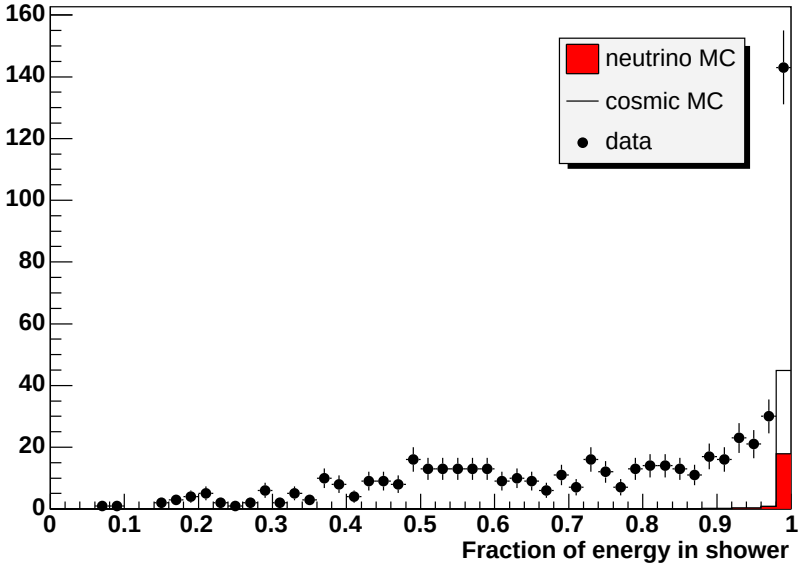
- Preselection
  - $<$5 PE outside fiducial volume
  - No reconstructed track
  - 1 reconstructed shower
- Reduces cosmic and ν_μ CC background, while retaining 84% of (contained) ν_e CC events

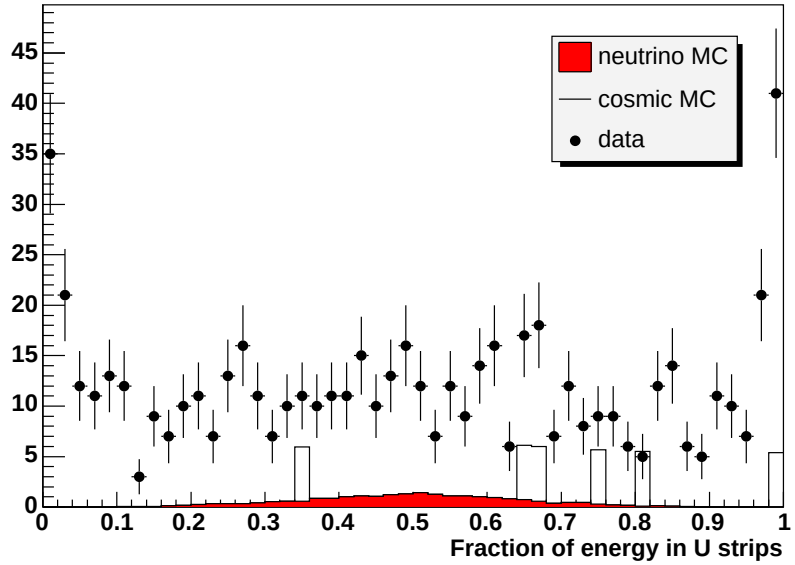


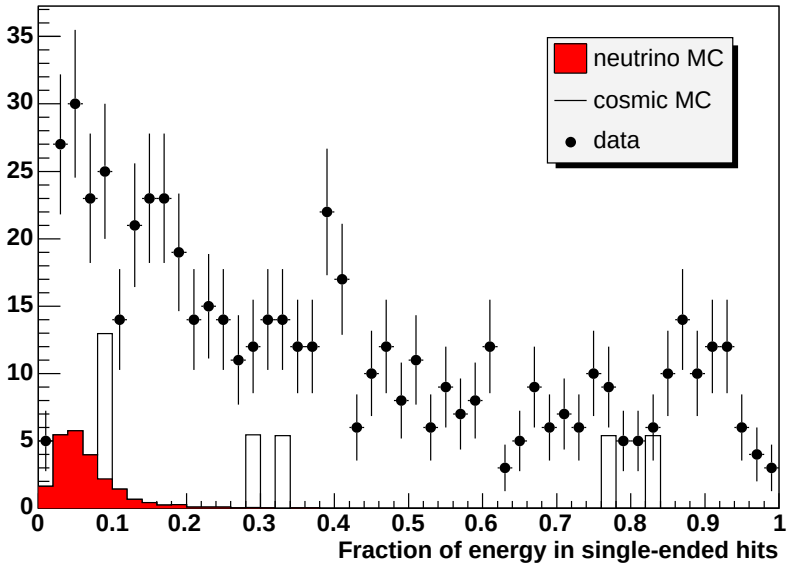
Atmospheric ν_e Selection Cuts 2

- 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, especially light injection relics, which otherwise pass subsequent shower shape cuts

Shower Quality





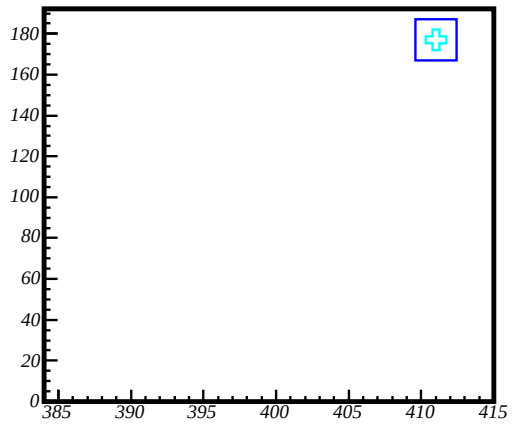


Distributions after all cuts except Shower Quality

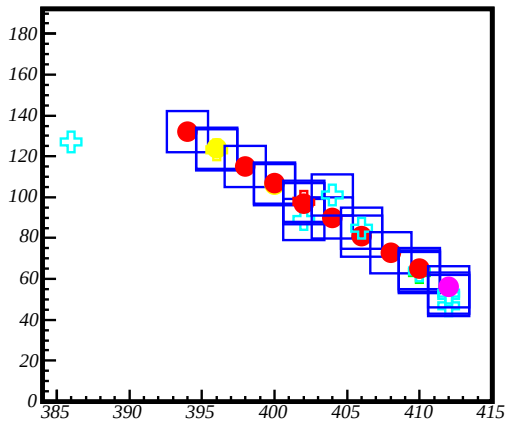
Background Rejection

Event removed by shower quality cut:

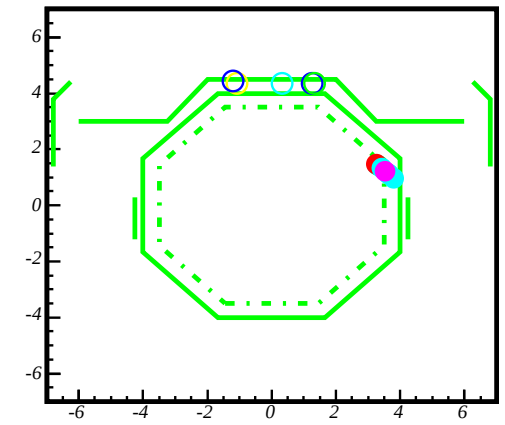
UZ



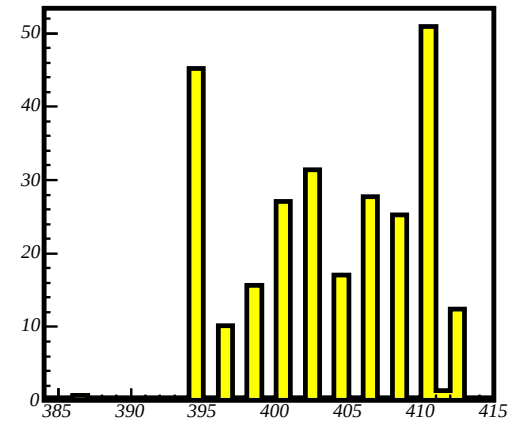
VZ



XY



PlaneCharge PE



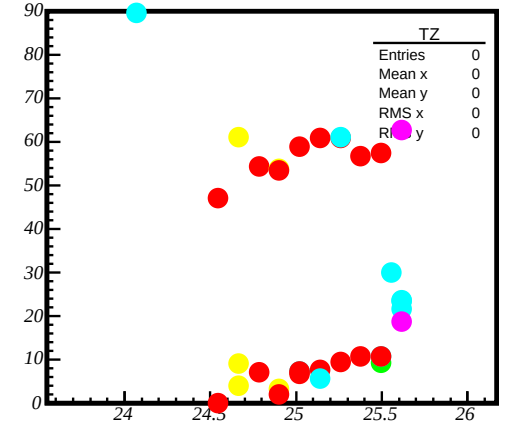
ID: -999 Iact: -999 Ires: -999
Run : 18167 Snarl: 72745 Trk: 0 Shw: 1

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

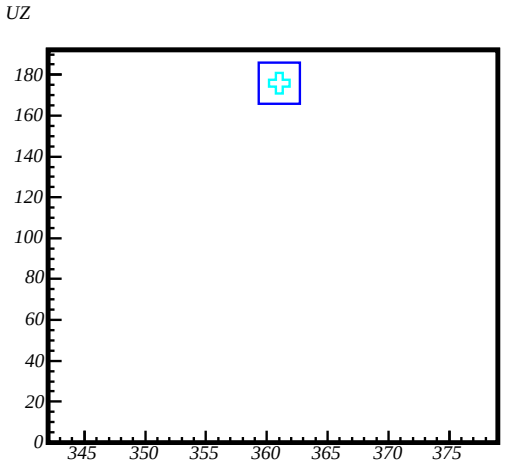
0/0/2/0/1 11 -1 M:D
15/2/1/0/1 448 -1 M:D
15/2/4/1/0 459 -1 M:D
15/2/4/1/2 461 459 M:D
2/2/1/0/0 113 -1 M:B
3/2/2/0/2 75 73 M:B
14/0/5/0/0 -1 -1 M:B
15/2/1/0/0 446 -1 M:D
15/2/1/0/2 448 446 M:D
15/2/4/1/1 461 -1 M:D
2/2/1/1/2 116 114 M:B
3/2/0/1/1 68 -1 M:B
4/2/5/1/0 -1 -1 M:B

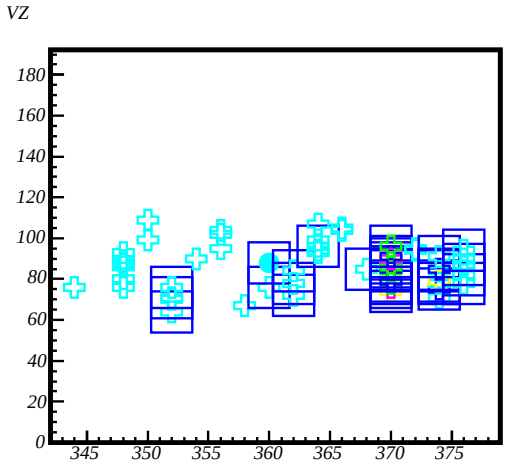
TZ

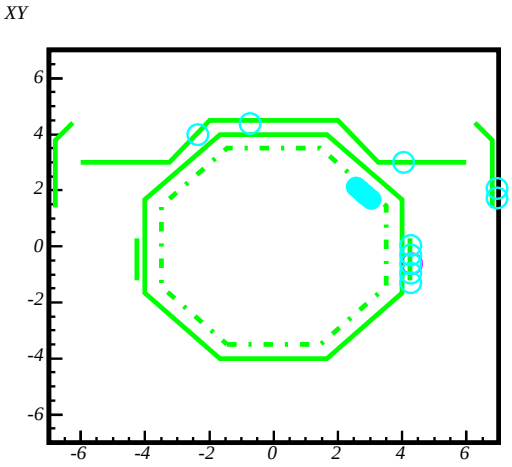


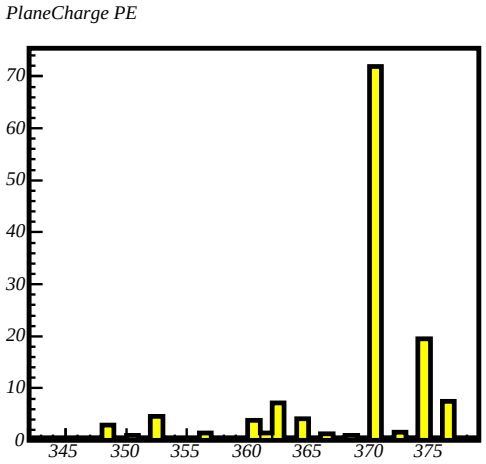
Background Rejection

Event removed by shower quality cut:





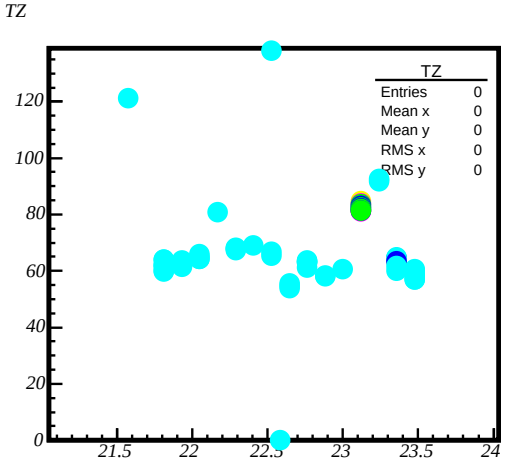




ID: -999 Iact: -999 Ires: -999
Run : 20589 Snarl: 9410 Trk: 0 Shw: 1

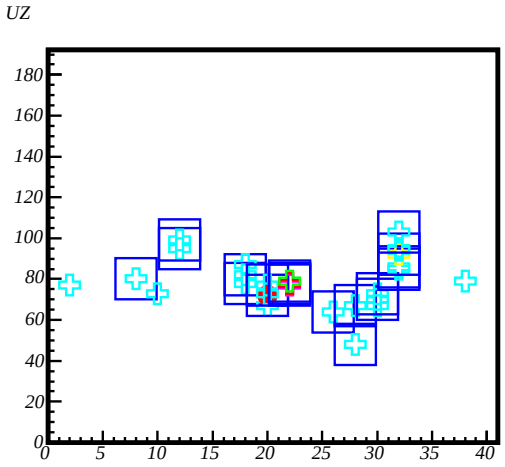
Reseed: 1 VShw: 0 Plane:369 E:1.13

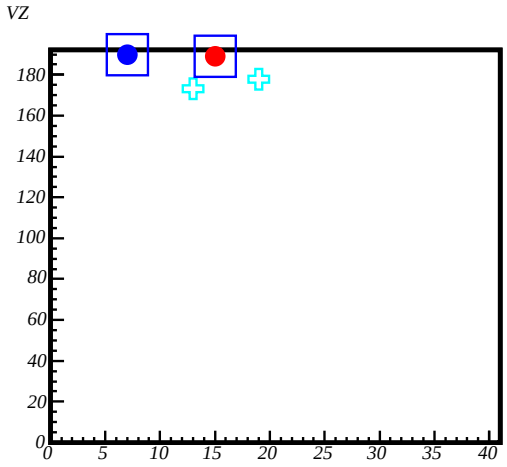
Q:4.04 5.10 T:1.00e+03 1.00e+03 S:2 P:4.29 -0.61
Q:0.00 0.37 T:9.99e+02 1.00e+03 S:4 P:4.27 -1.29
Q:0.00 0.29 T:9.99e+02 1.00e+03 S:4 P:4.27 -0.96
Q:0.00 0.58 T:9.99e+02 1.00e+03 S:4 P:4.27 -0.63
Q:0.00 0.94 T:9.99e+02 1.00e+03 S:4 P:4.27 -0.30
Q:0.00 0.26 T:9.99e+02 1.00e+03 S:4 P:4.27 0.03
Q:0.00 0.24 T:9.99e+02 1.00e+03 S:4 P:6.96 1.73
Q:0.00 0.43 T:9.99e+02 1.00e+03 S:4 P:6.96 2.06
Q:0.00 2.18 T:9.99e+02 1.00e+03 S:3 P:-0.73 4.38
Q:2.87 0.00 T:1.00e+03 9.99e+02 S:3 P:-2.36 3.98
Q:2.57 0.00 T:1.00e+03 9.99e+02 S:3 P:4.04 3.00

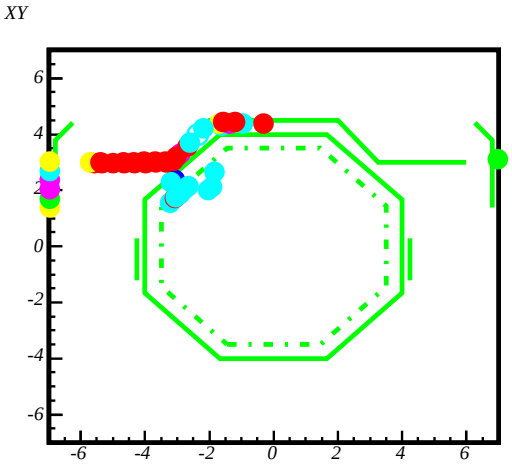


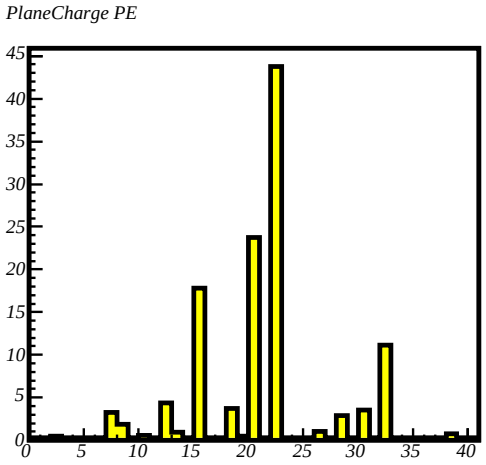
Background Rejection

Event removed by shower quality cut:





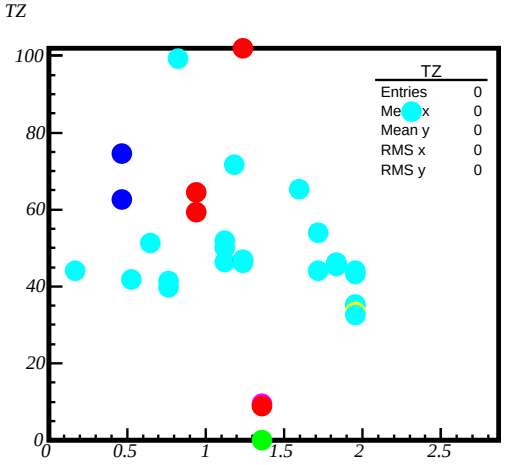




ID: -999 Iact: -999 Ires: -999
Run : 18191 Snarl: 95372 Trk: 0 Shw: 1

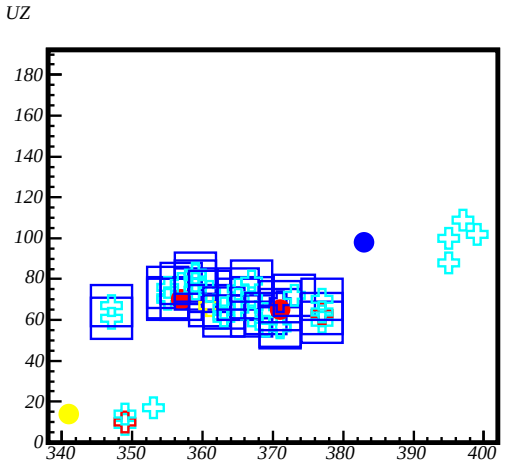
Reseed: 1 VShw: 0 Plane:21 E:1.10

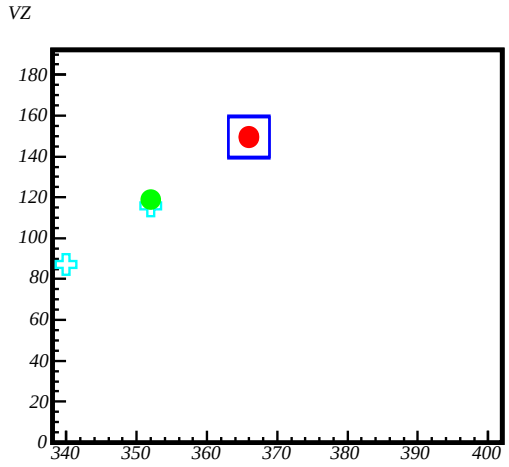
Q:0.00 1.73 T:-1.58e-01 -1.02e-06 S:2 P:-2.36 3.99
Q:1.57 0.00 T:-1.04e-06 -1.58e-01 S:2 P:-1.61 4.35
Q:6.33 17.36 T:4.96e-08 -1.22e-09 S:1 P:-5.58 2.97
Q:4.01 8.52 T:5.09e-08 1.95e-10 S:1 P:-5.33 2.97
Q:5.60 12.29 T:5.24e-08 2.09e-09 S:1 P:-5.00 2.97
Q:4.94 11.80 T:4.53e-08 -5.40e-09 S:1 P:-4.66 2.97
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

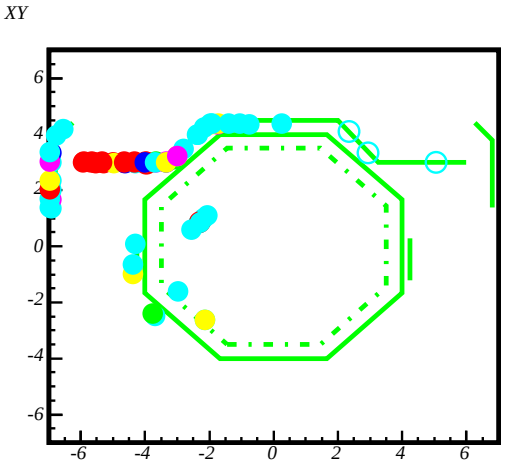


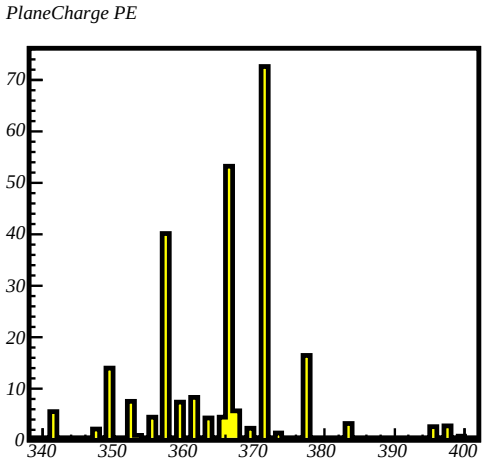
Background Rejection

Event removed by shower quality cut:





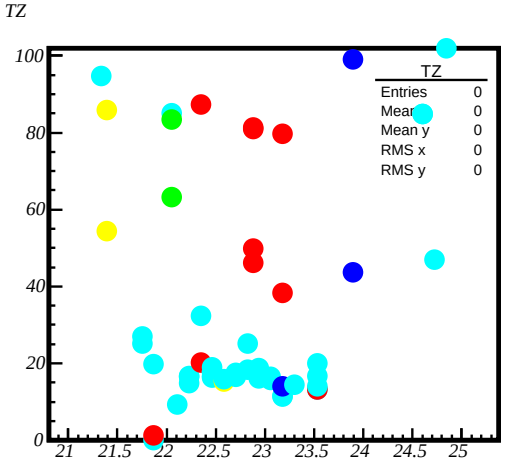




ID: -999 Iact: -999 Ires: -999
Run : 18246 Snarl: 60549 Trk: 0 Shw: 1

Reseed: 0 VShw: 0 Plane:365 E:1.78

Q:1.46 0.00 T:-4.63e-06 -1.28e-01 S:2 P:5.05 2.99
Q:6.24 27.80 T:4.24e-08 2.05e-08 S:4 P:-5.58 3.00
Q:12.79 62.38 T:4.37e-08 2.19e-08 S:4 P:-5.33 3.00
Q:6.33 13.02 T:4.52e-08 2.38e-08 S:4 P:-5.00 3.00
Q:7.66 38.03 T:3.80e-08 1.68e-08 S:4 P:-4.66 3.00
Q:5.96 20.04 T:3.97e-08 1.87e-08 S:4 P:-4.34 3.00
Q:1.27 9.48 T:4.45e-08 2.00e-08 S:4 P:-4.00 3.00
Q:0.86 8.03 T:4.76e-08 1.84e-08 S:4 P:-3.67 3.00
Q:0.98 2.52 T:4.59e-08 1.65e-08 S:4 P:-3.35 3.00
Q:3.86 3.80 T:4.24e-08 1.82e-08 S:4 P:-3.07 3.12
Q:4.66 3.66 T:5.29e-08 3.26e-08 S:4 P:-1.75 4.35
Q:0.72 0.62 T:6.12e-08 3.19e-08 S:4 P:-0.76 4.35

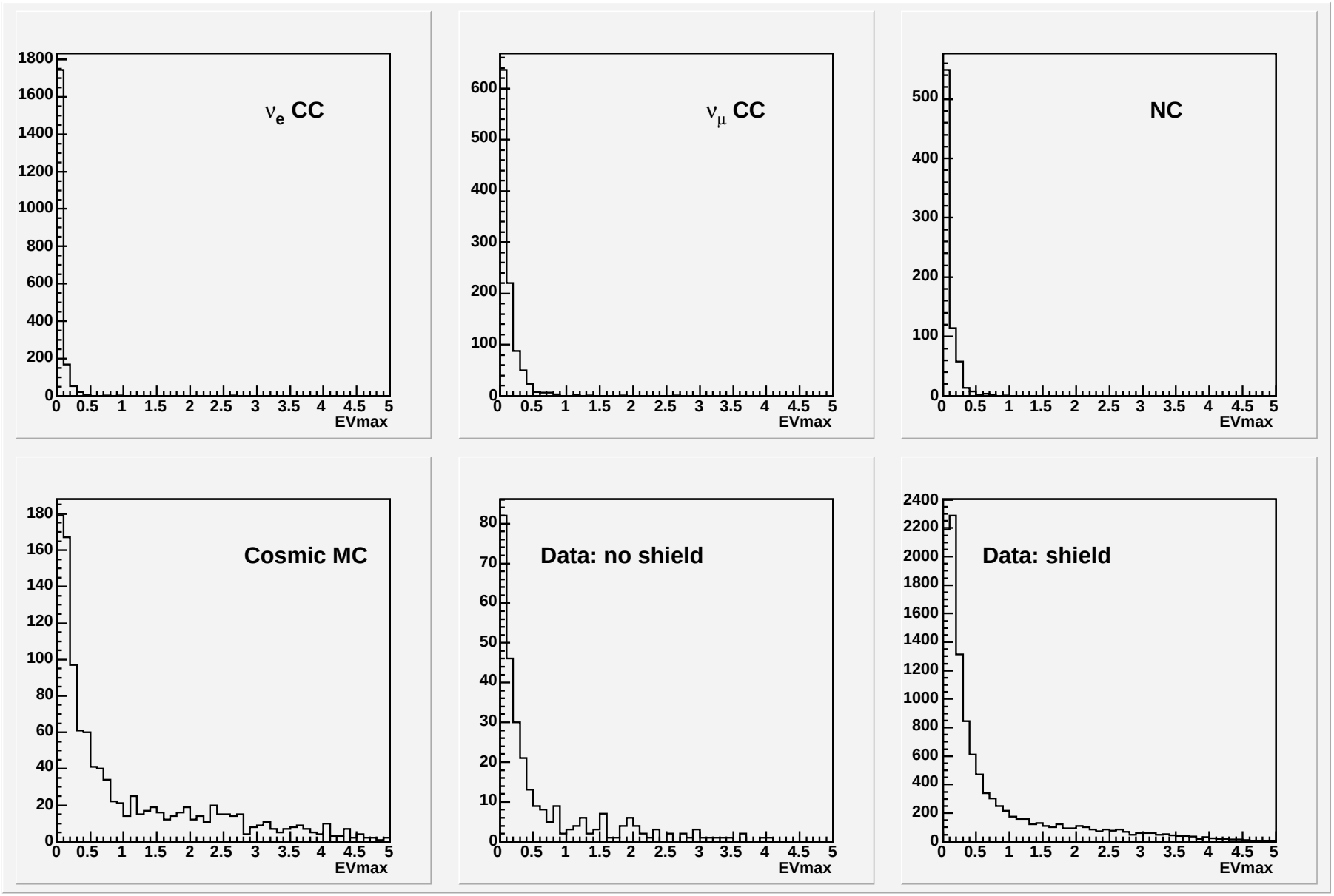


Atmospheric ν_e Selection Cuts 3

- 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 (VetoQCorrSS)

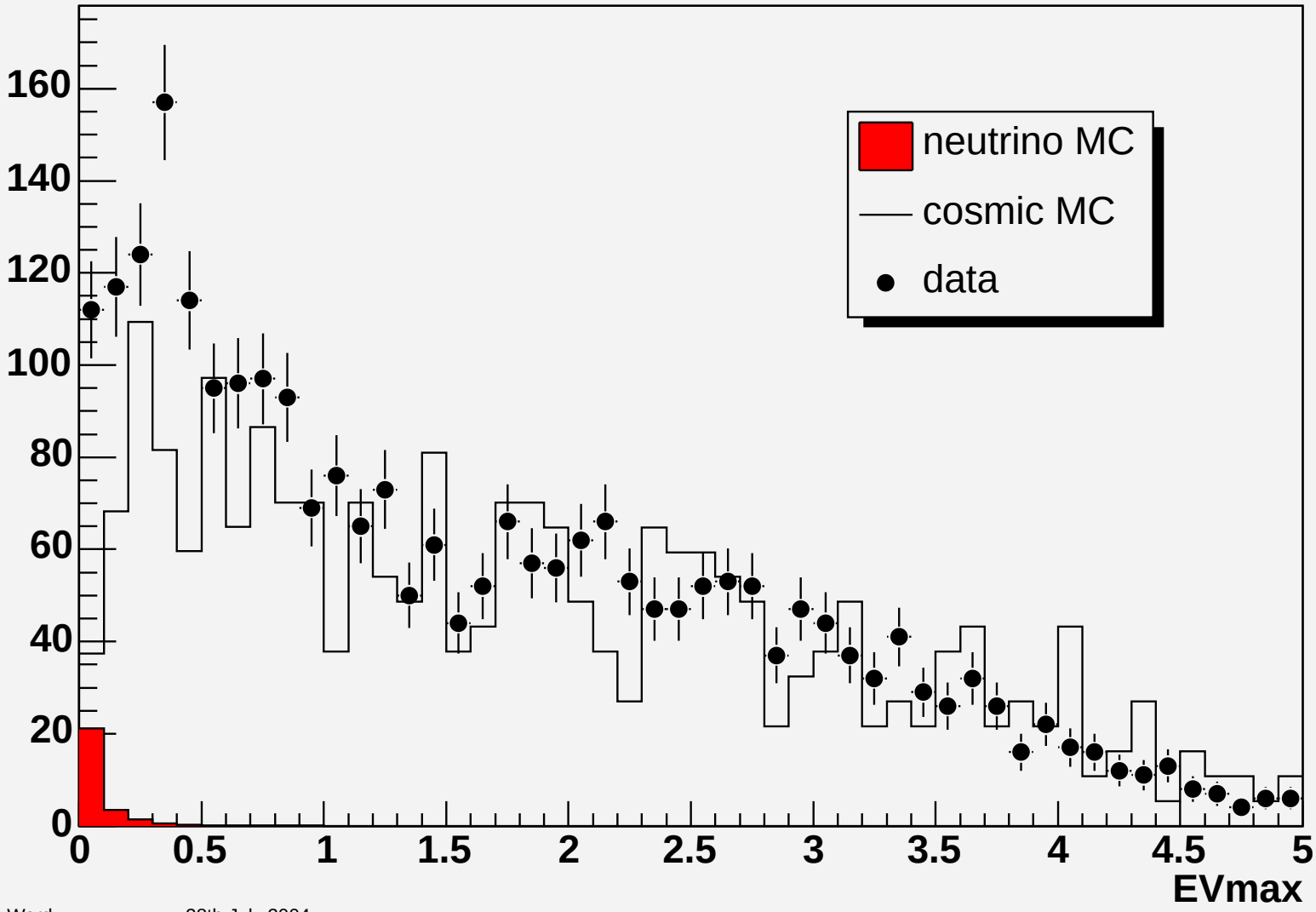
Shower length

Largest eigenvalue of ‘MoI’ tensor after Shower Quality cut.



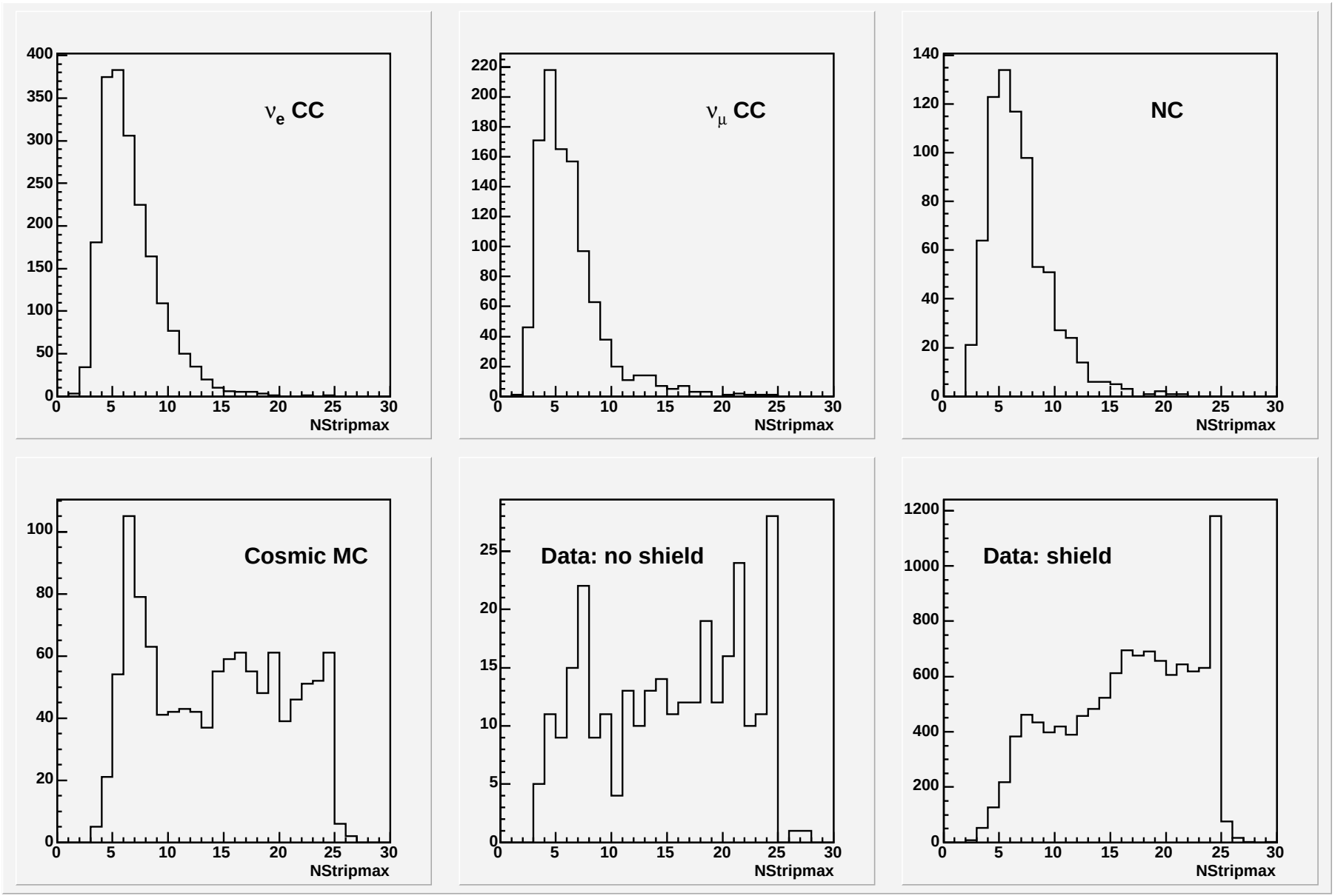
Shower length

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



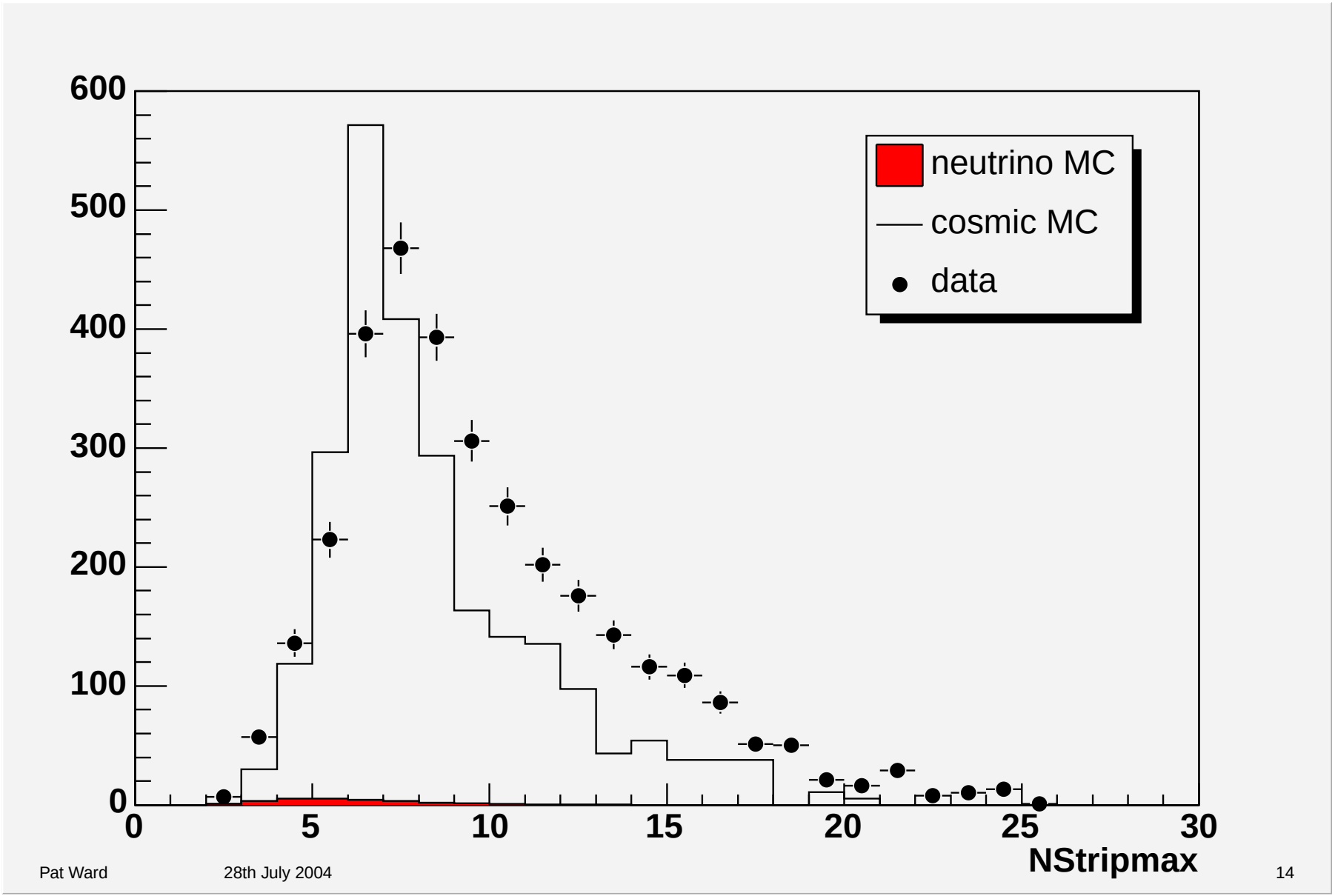
Max strips

Maximium number of hit strips in a plane after Shower Quality cut



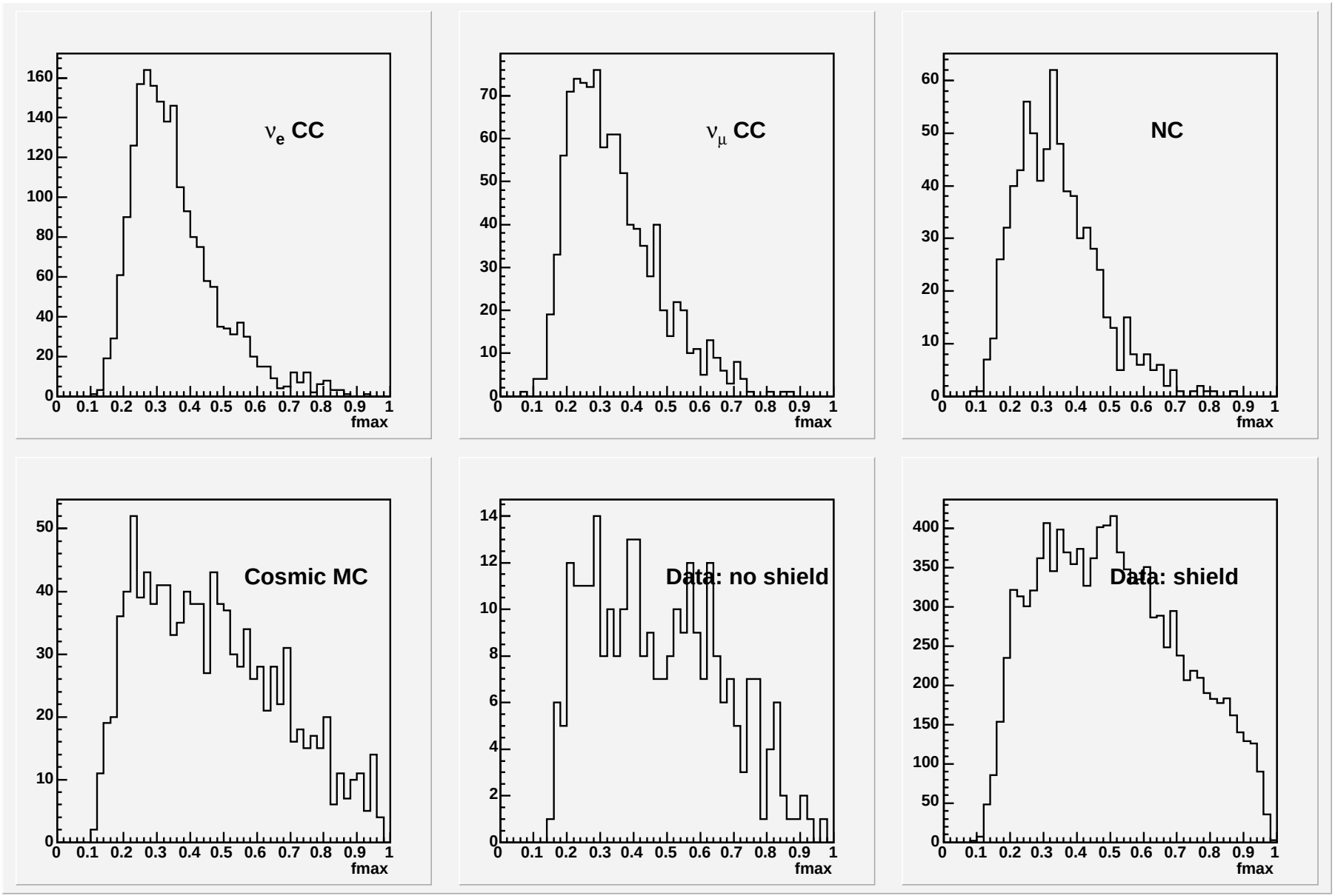
Max strips

Maximium number of hit strips in a plane after all cuts except shower length, max strips and shield



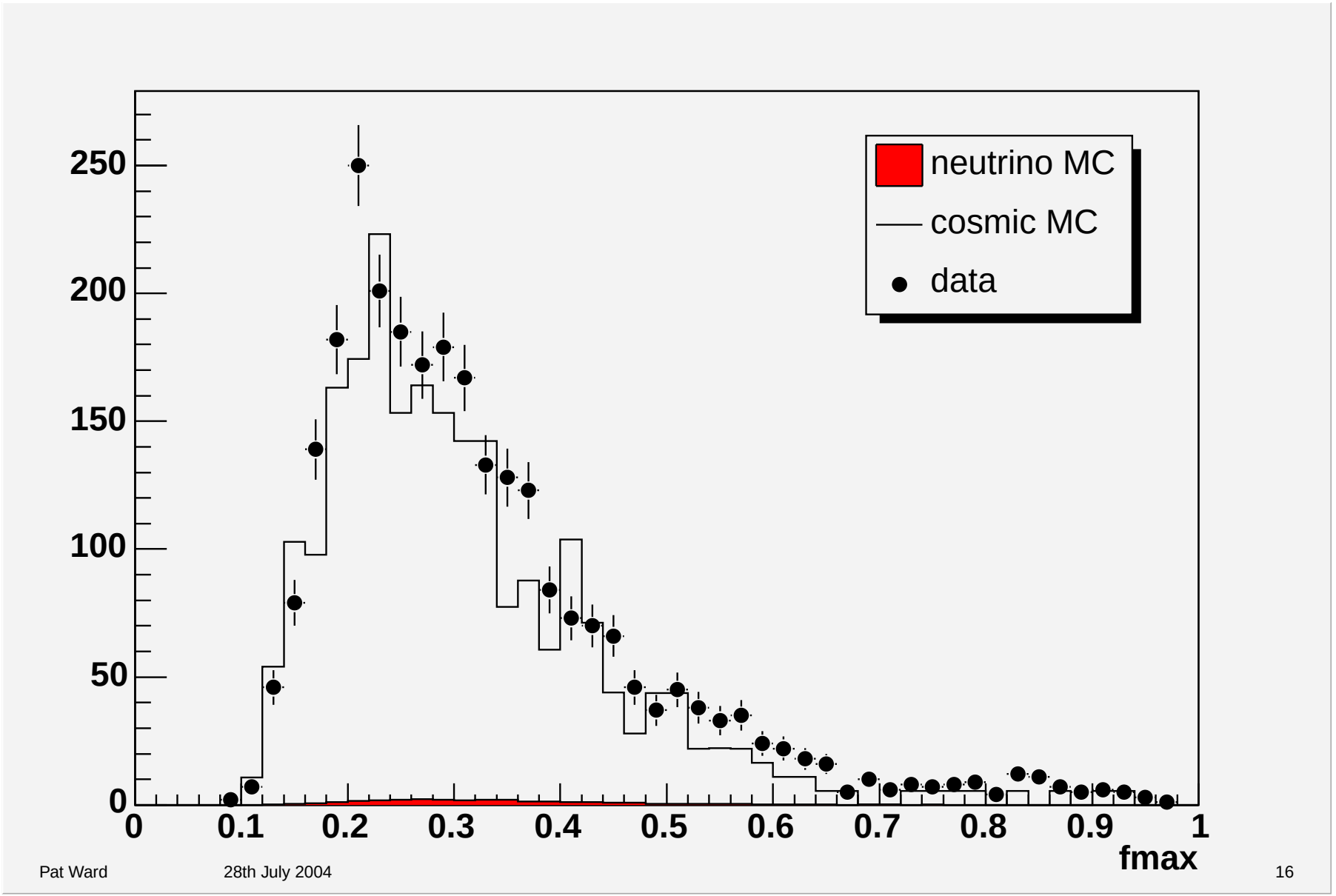
Max energy fraction

Maximium fraction of energy in a plane after Shower Quality cut



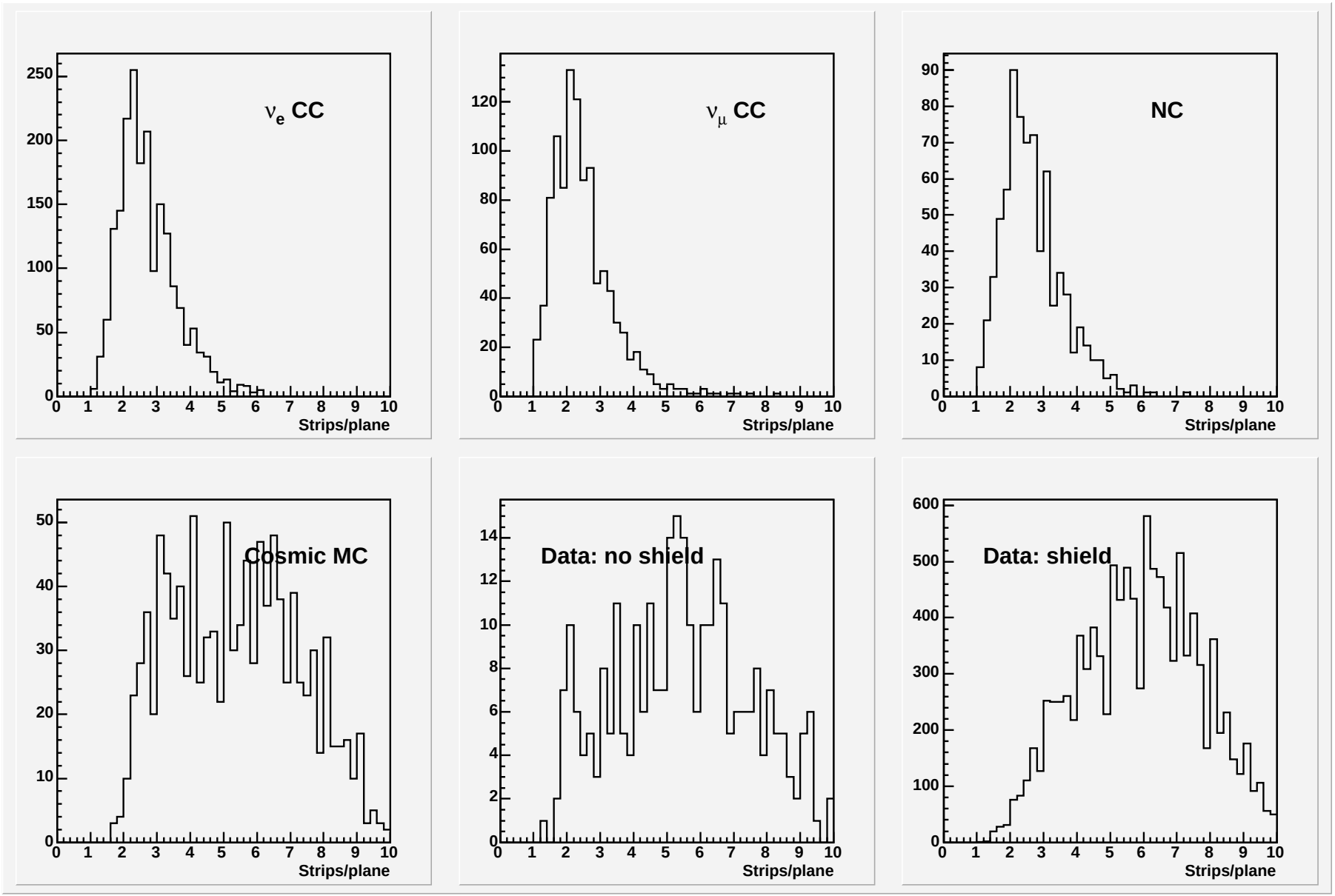
Max energy fraction

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



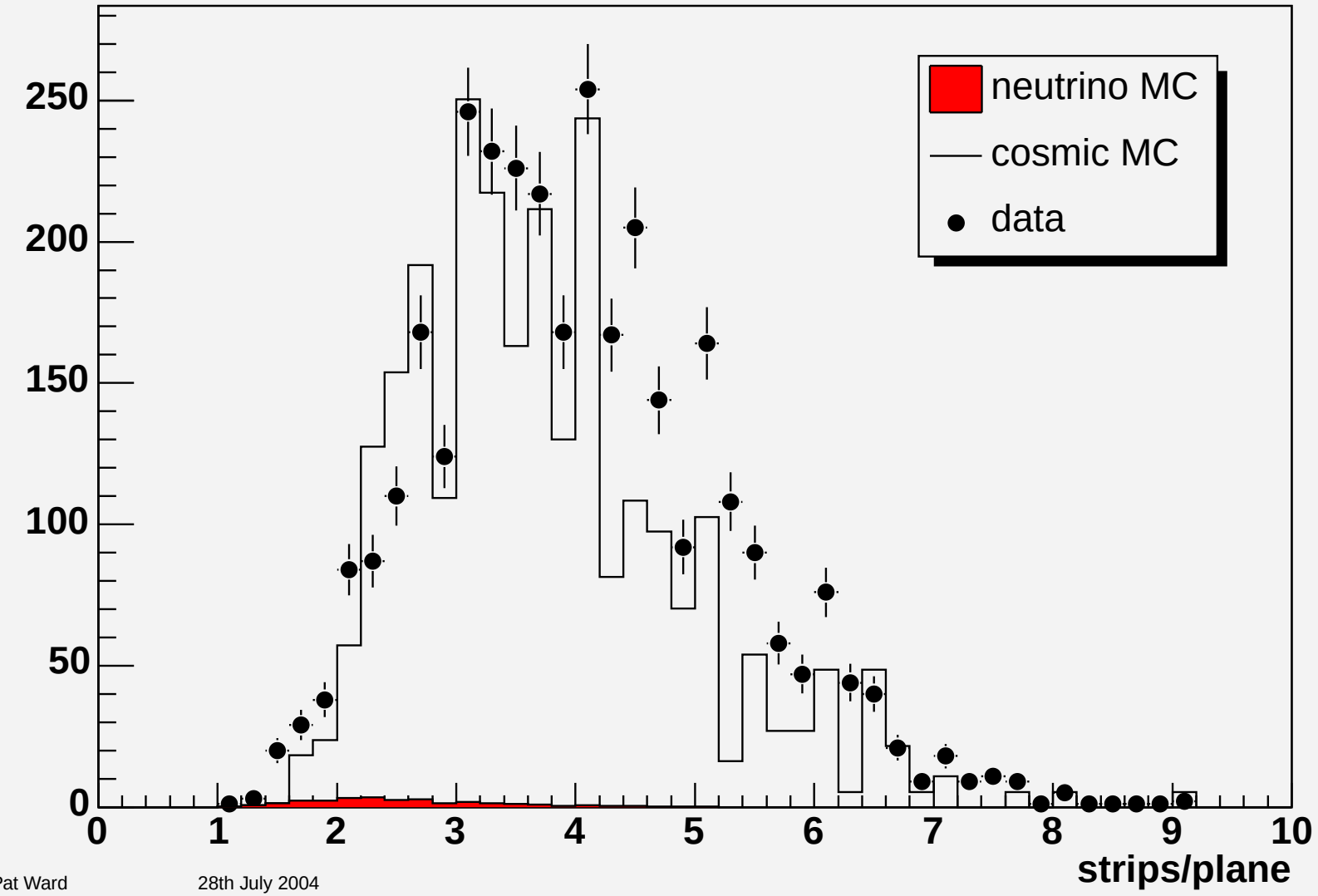
Mean strips

Mean number of hit strips per plane after Shower Quality cut



Mean strips

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



Atmospheric ν_e

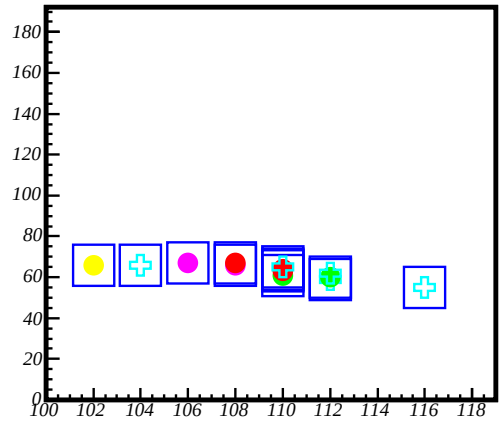
Expected/observed numbers for 2.52kty after each cut:

	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

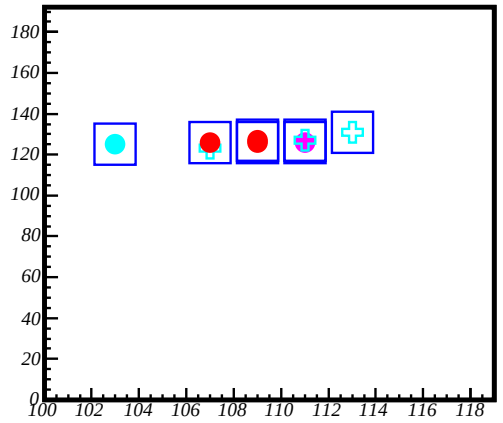
- Cosmic MC underestimates background at all stages

Selected MC ν_e CC Event

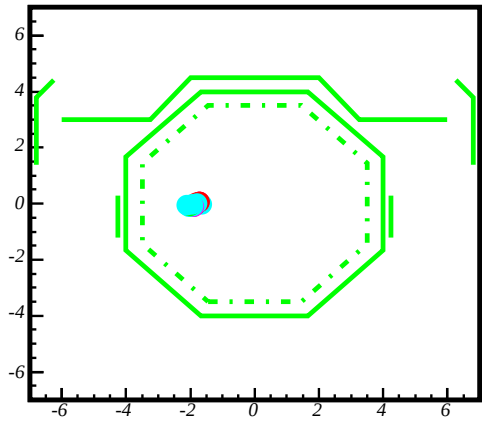
UZ



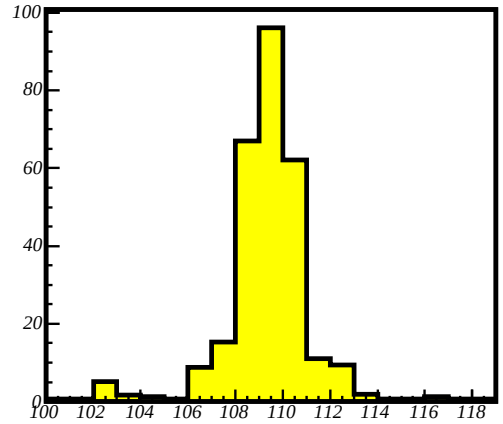
VZ



XY



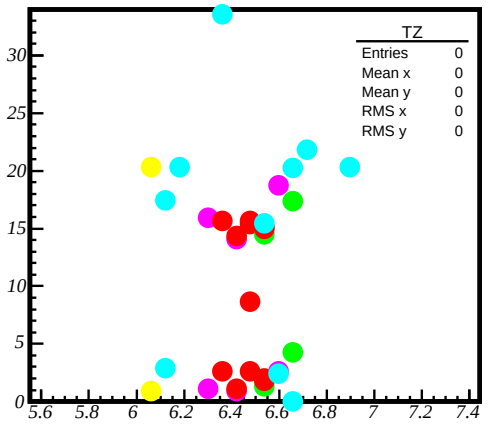
PlaneCharge PE



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

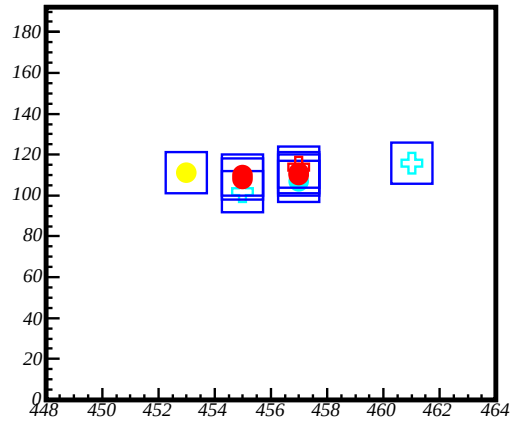
Reseed: 0 VShw: 0 Plane:108 E:2.12

TZ

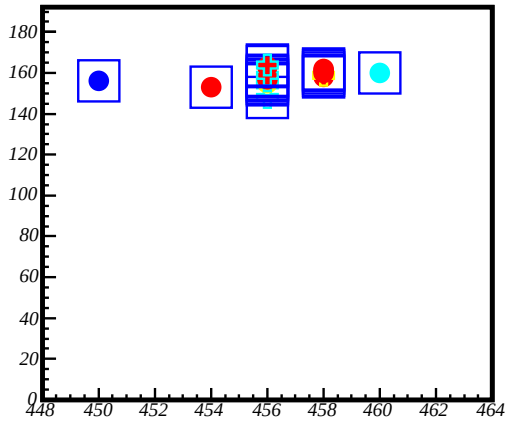


Selected MC ν_e CC Event

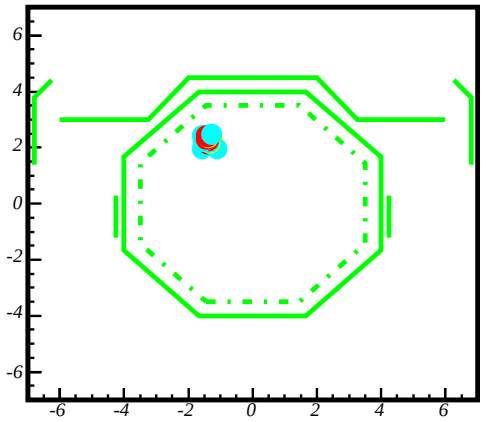
UZ



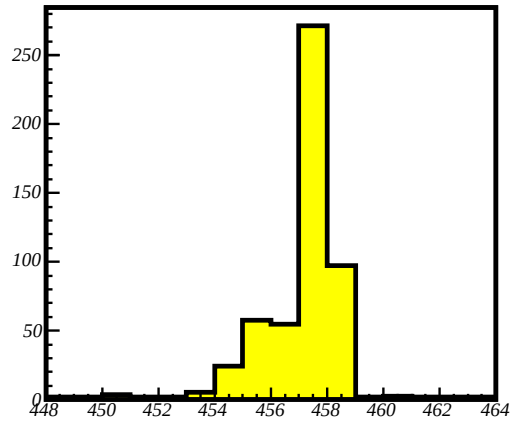
VZ



XY



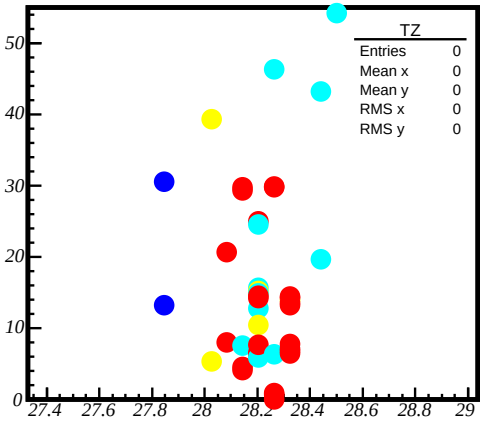
PlaneCharge PE



ID: 12 Iact: 1 Ires: 1002
Run : 127 Snarl: 14 Trk: 0 Shw: 1

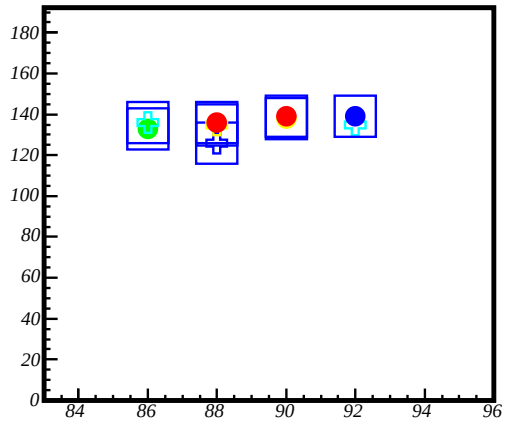
Reseed: 0 VShw: 0 Plane:456 E:3.61

TZ

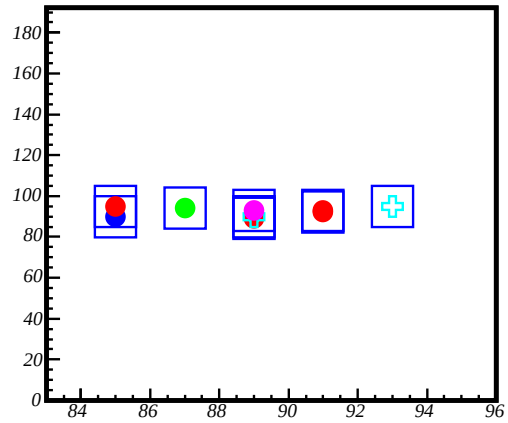


Selected MC ν_μ CC Event

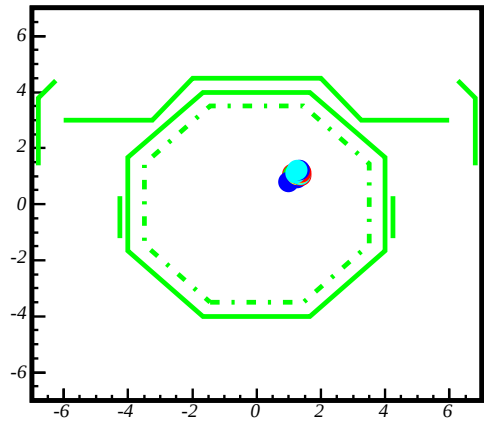
UZ



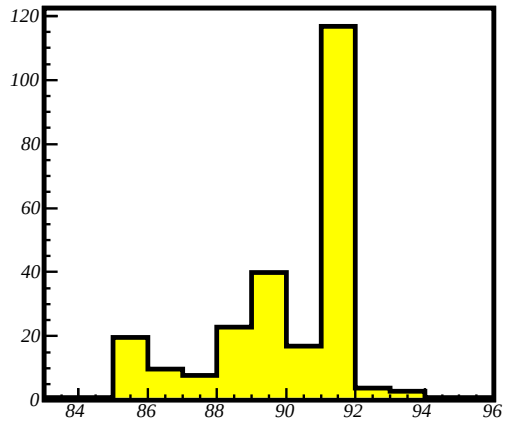
VZ



XY



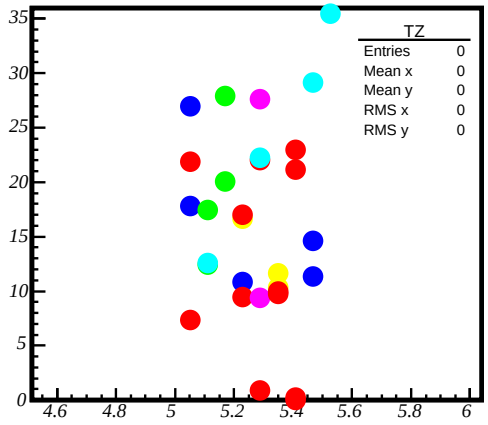
PlaneCharge PE



ID: 14 Iact: 1 Ires: 1003
Run : 127 Snarl: 22 Trk: 0 Shw: 1

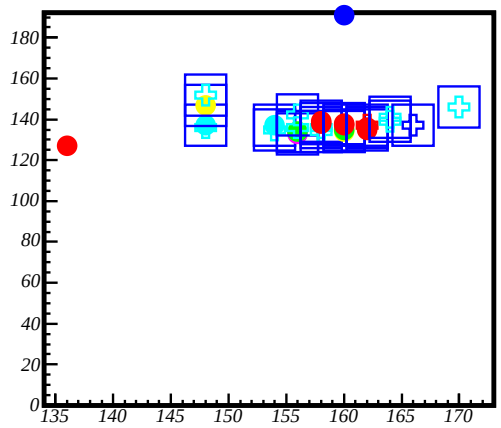
Reseed: 1 VShw: 0 Plane:89 E:1.87

TZ

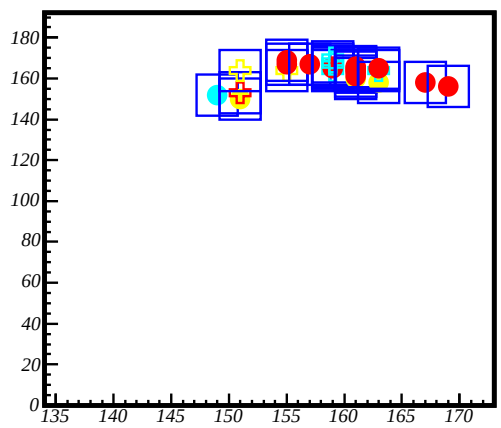


Selected MC ν_μ NC Event

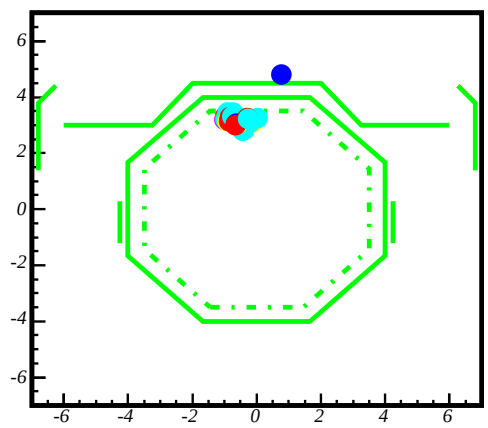
UZ



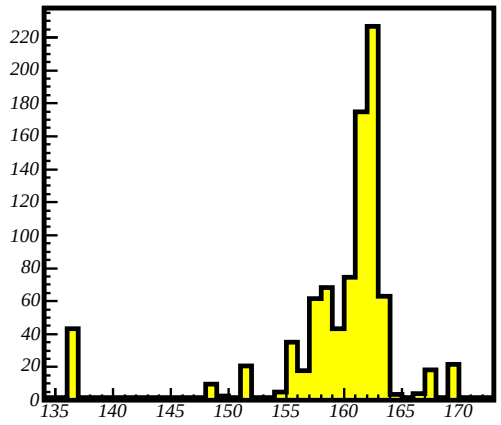
VZ



XY



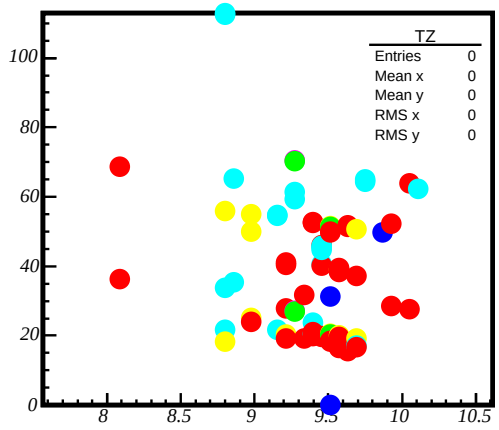
PlaneCharge PE



ID: 14 Iact: 0 Ires: 1003
Run : 127 Snarl: 82 Trk: 0 Shw: 1

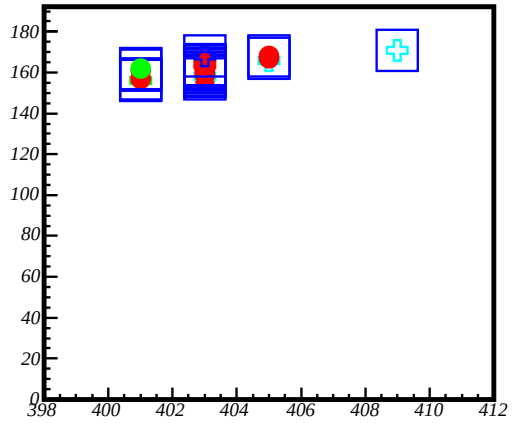
Reseed: 0 VShw: 0 Plane:160 E:5.66

TZ

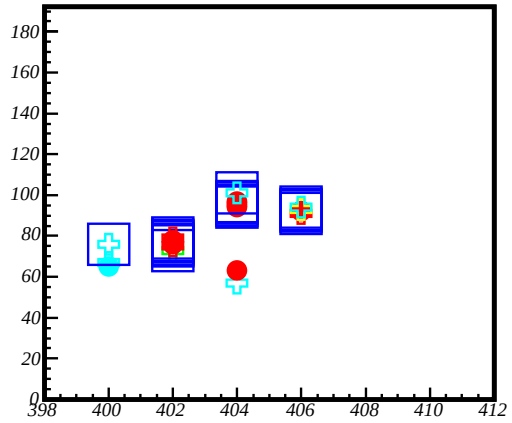


Selected MC Cosmic Event

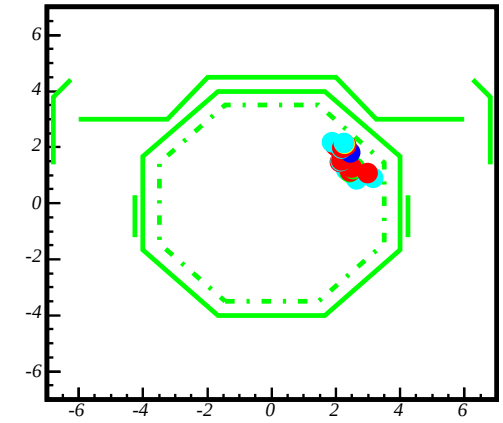
UZ



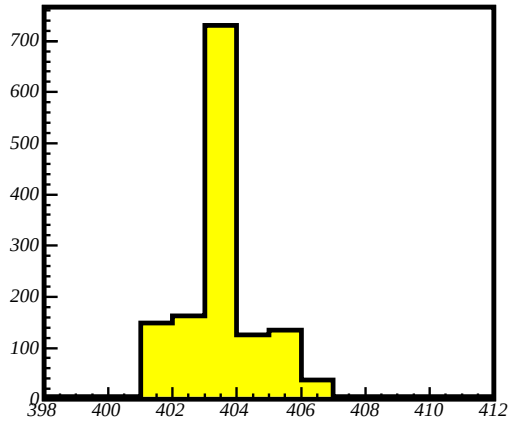
VZ



XY



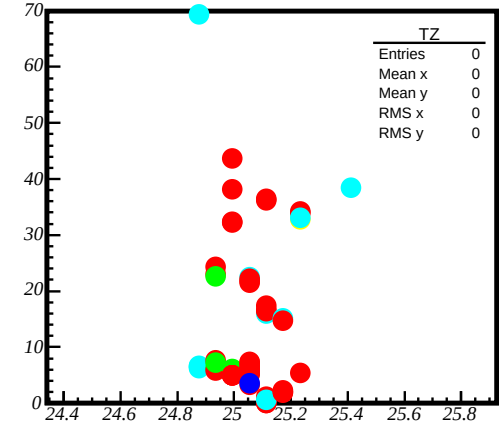
PlaneCharge PE



ID: 0 Iact: -1 Ires: 0
Run : 461 Snarl: 5092 Trk: 0 Shw: 1

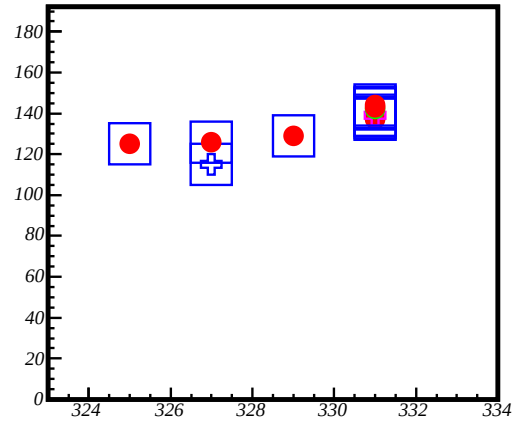
Reseed: 0 VShw: 0 Plane:403 E:8.66

TZ

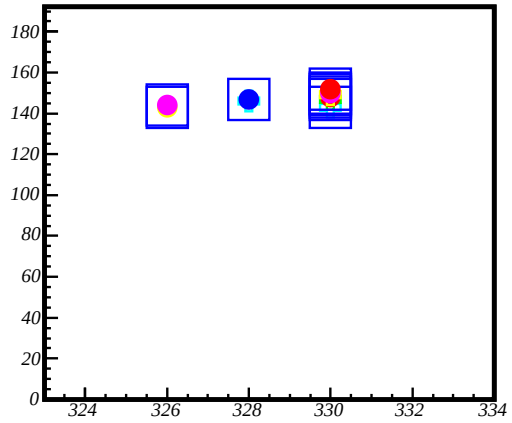


Selected MC Cosmic Event

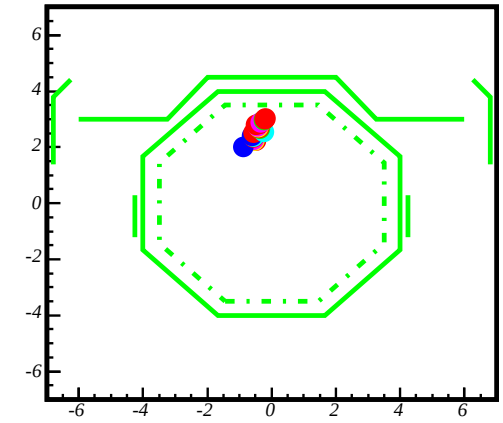
UZ



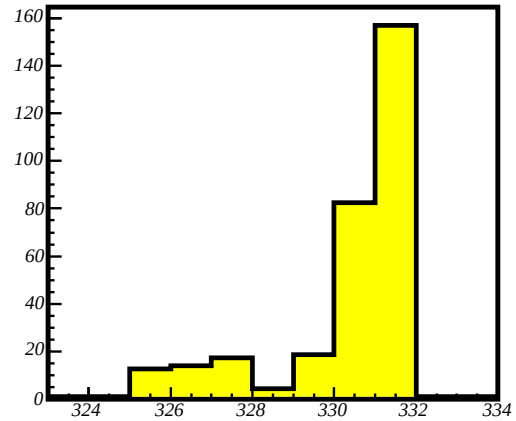
VZ



XY



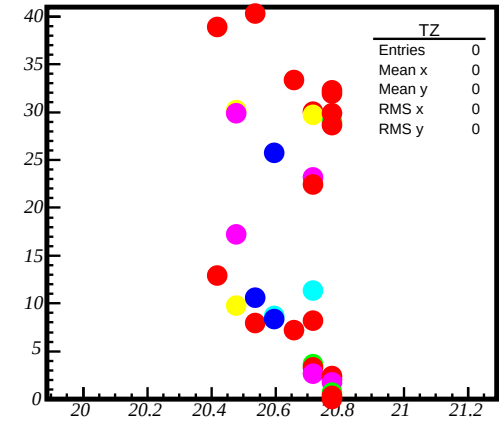
PlaneCharge PE



ID: 0 Iact: -1 Ires: 0
Run : 472 Snarl: 72234 Trk: 0 Shw: 1

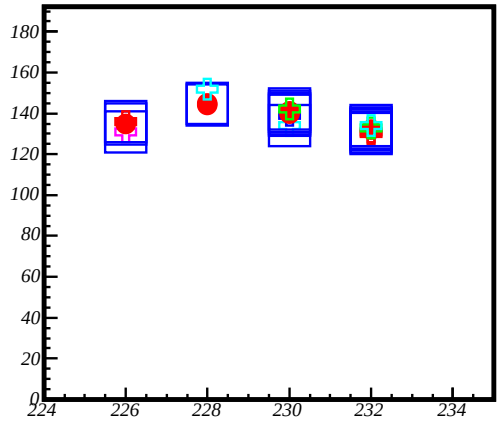
Reseed: 1 VShw: 0 Plane:329 E:2.29

TZ

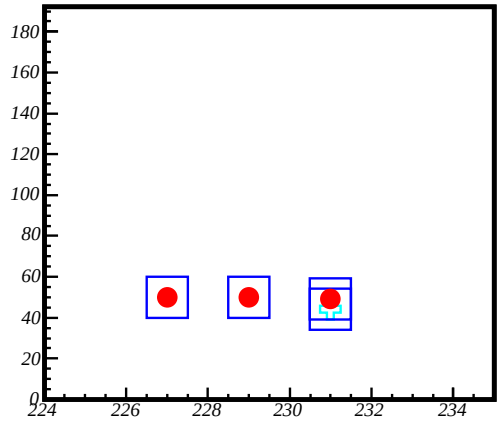


Selected MC Cosmic Event

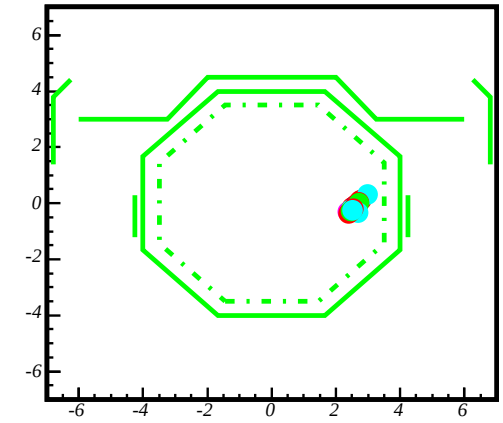
UZ



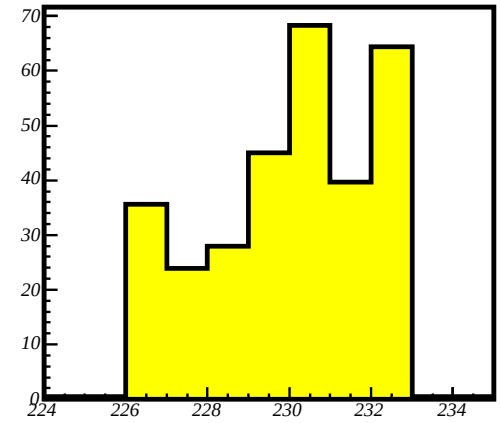
VZ



XY



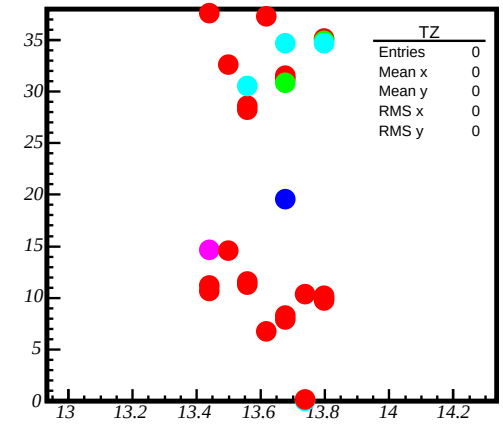
PlaneCharge PE



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

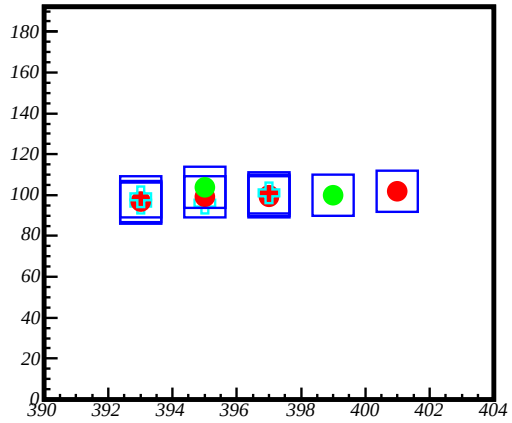
Reseed: 1 VShw: 0 Plane:229 E:2.28

TZ

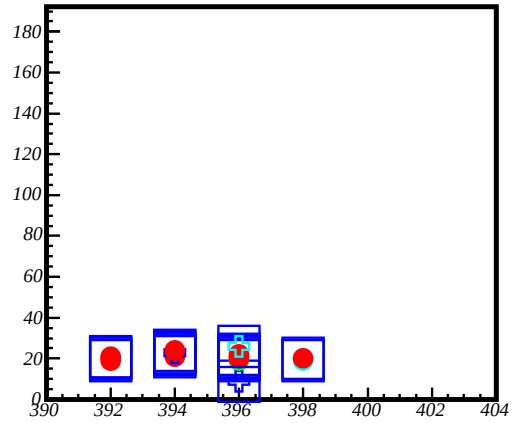


Selected Data Event

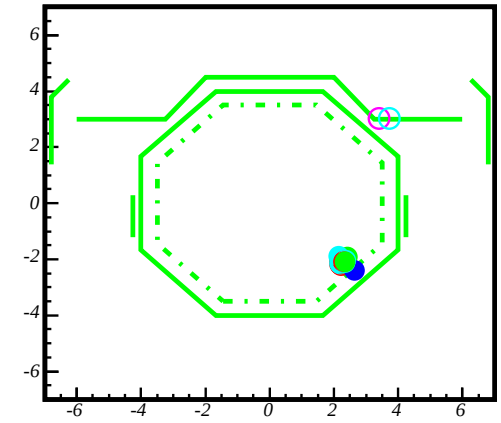
UZ



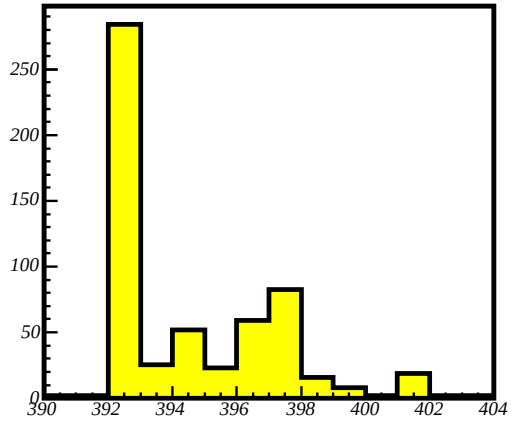
VZ



XY



PlaneCharge PE



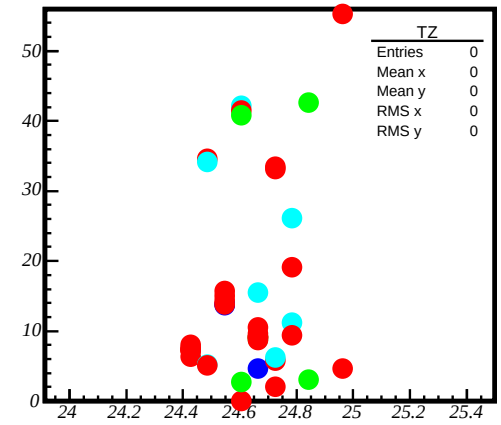
ID: -999 Iact: -999 Ires: -999
Run : 18884 Snarl: 72289 Trk: 0 Shw: 1

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

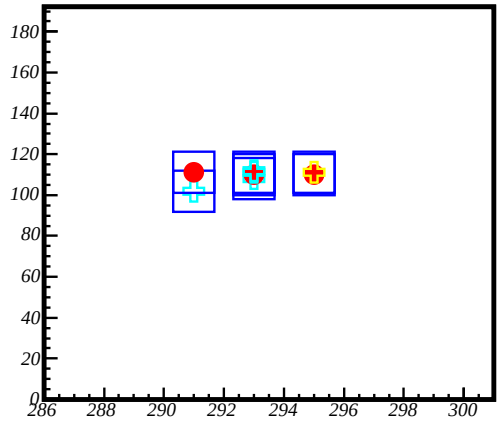
0/0/2/0/1 11 -1 M:D
5/0/5/1/2 -1 -1 M:B
13/2/1/0/1 384 -1 M:B
1/0/5/1/2 -1 -1 M:B
13/2/0/0/2 380 378 M:B

TZ

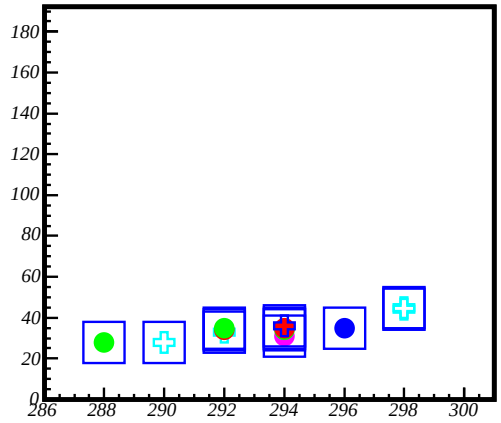


Selected Data Event

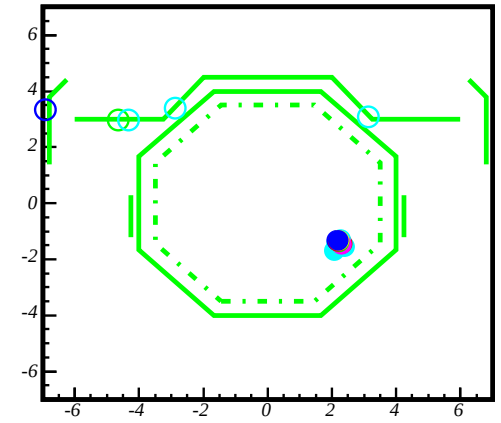
UZ



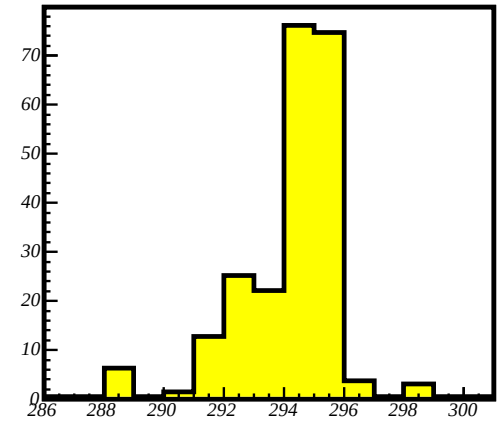
VZ



XY



PlaneCharge PE



ID: -999 Iact: -999 Ires: -999
Run : 21283 Snarl: 39583 Trk: 0 Shw: 1

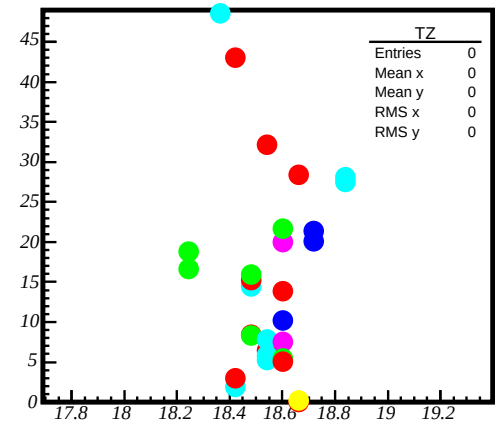
Reseed: 0 VShw: 0 Plane:293 E:1.78

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

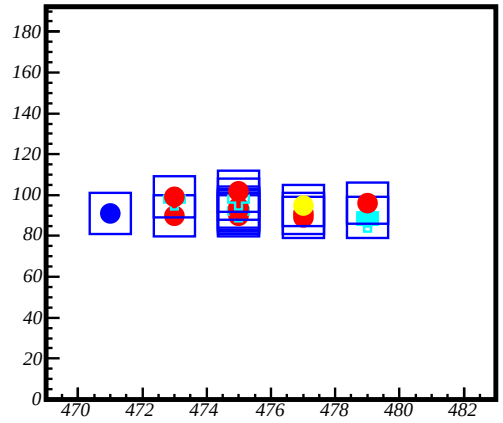
9/2/0/0/1 252 -1 M:D
5/1/1/0/2 155 153 M:B
6/2/5/1/1 -1 -1 M:B
8/0/5/1/1 -1 -1 M:B
14/0/5/1/0 -1 -1 M:B

TZ

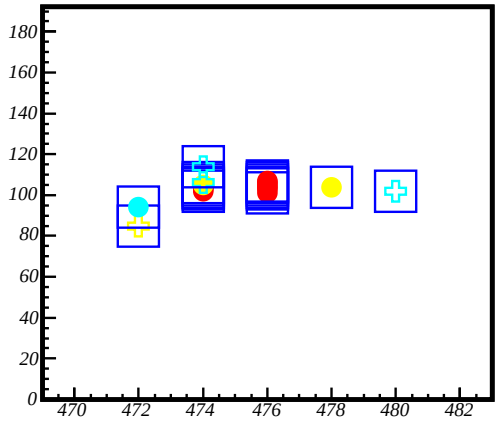


Selected Data Event

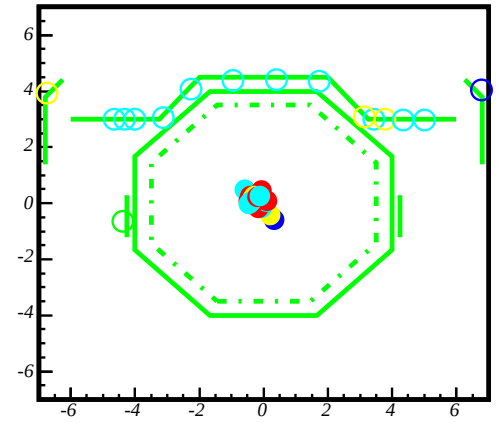
UZ



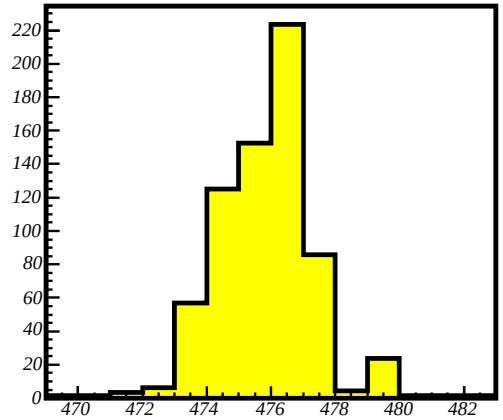
VZ



XY



PlaneCharge PE

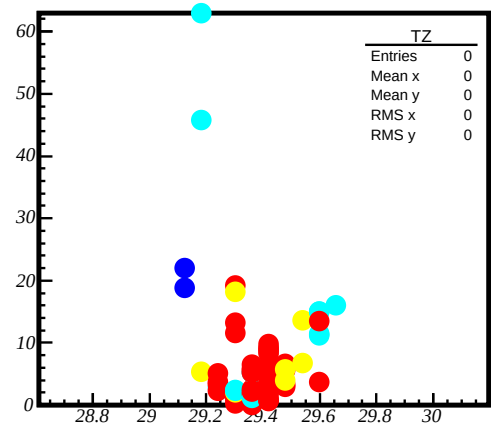


ID: -999 Iact: -999 Ires: -999
Run : 22614 Snarl: 57236 Trk: 0 Shw: 1

Reseed: 0 VShw: 0 Plane:475 E:4.63

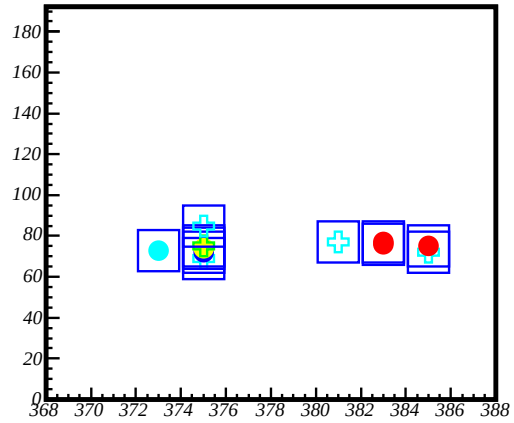
Q:0.00 1.61 T:-3.72e-01 -4.42e-06 S:2 P:-4.65 3.00
Q:0.00 2.20 T:-3.72e-01 -2.32e-05 S:2 P:-4.00 3.00
Q:0.00 2.39 T:-3.72e-01 -2.88e-05 S:2 P:1.73 4.34
Q:0.00 0.76 T:-3.72e-01 -2.57e-05 S:4 P:3.44 3.00
Q:2.30 2.70 T:-2.57e-05 -2.57e-05 S:4 P:3.76 3.00
Q:7.06 0.00 T:-1.00e-05 -3.72e-01 S:4 P:-4.38 -0.65
Q:5.71 0.00 T:-9.56e-07 -3.72e-01 S:4 P:-6.73 3.93
Q:0.00 2.30 T:-3.72e-01 -1.43e-05 S:1 P:-3.11 3.07
Q:0.00 1.87 T:-3.72e-01 -1.44e-05 S:1 P:-2.27 4.08
Q:2.28 0.00 T:-5.09e-06 -3.72e-01 S:1 P:-0.95 4.37
Q:4.39 0.00 T:-2.45e-05 -3.72e-01 S:1 P:3.14 3.09
Q:1.79 0.00 T:-1.85e-05 -3.72e-01 S:1 P:0.41 4.42
Q:[illegible] -3.72e-[illegible]

TZ

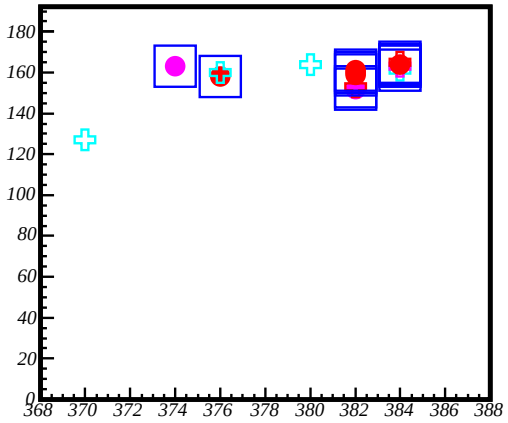


Selected Data Event

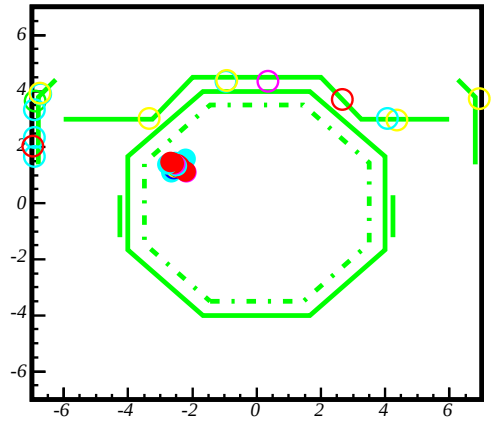
UZ



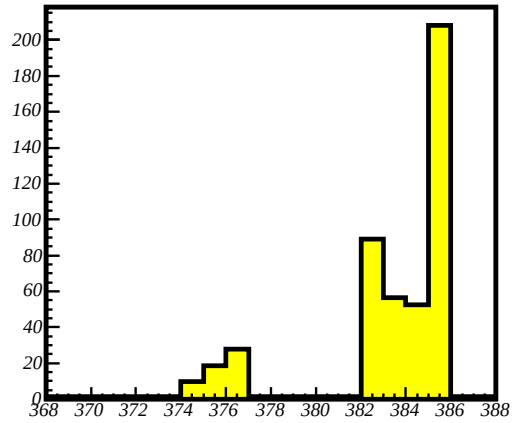
VZ



XY



PlaneCharge PE

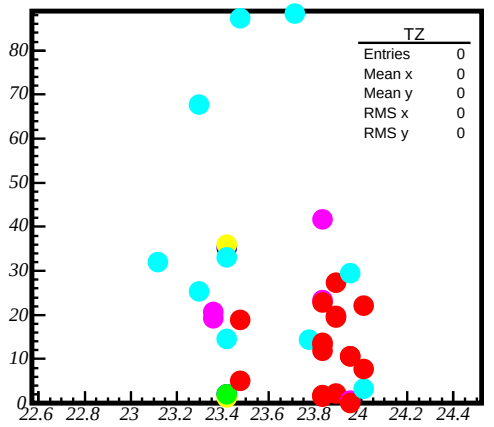


ID: -999 Iact: -999 Ires: -999
Run : 24151 Snarl: 16298 Trk: 0 Shw: 1

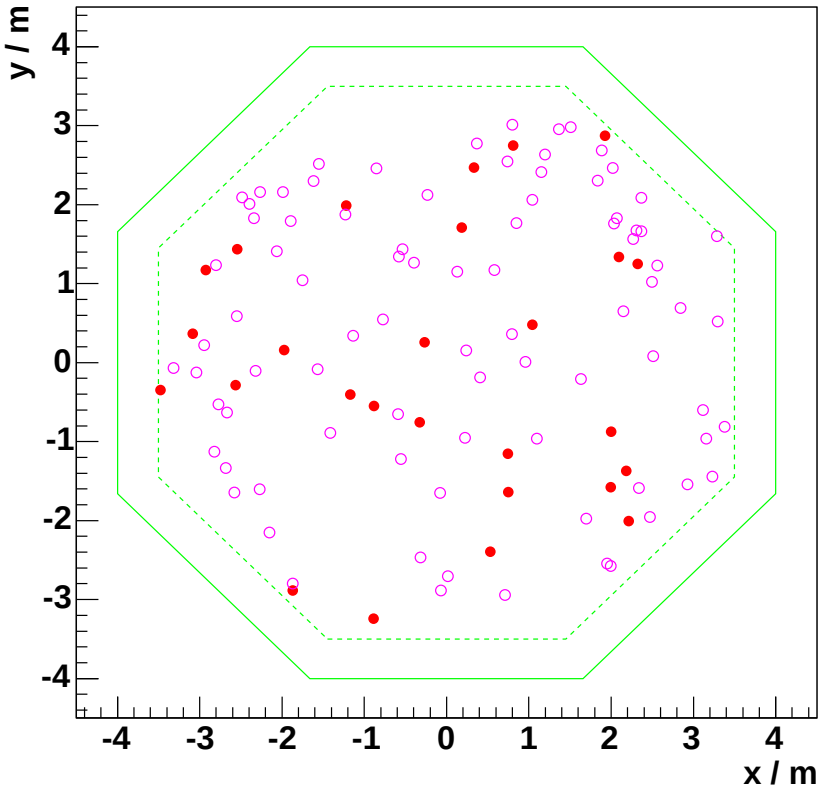
Reseed: 0 VShw: 0 Plane:384 E:3.28

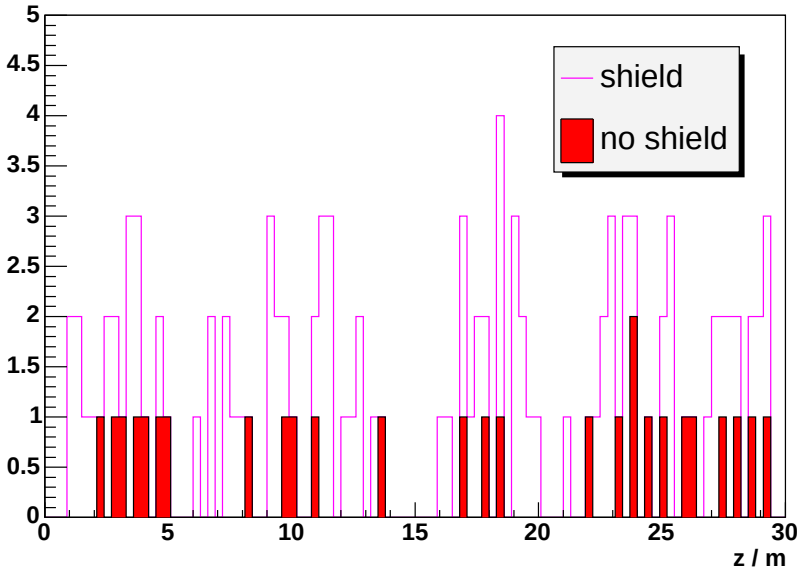
Q:0.00 7.51 T:-1.54e-01 -2.77e-05 S:2 P:-6.89 3.65
Q:0.00 0.39 T:-1.54e-01 -2.77e-05 S:2 P:-6.72 3.90
Q:3.86 1.62 T:-1.89e-05 -1.88e-05 S:2 P:6.93 3.73
Q:0.00 4.86 T:-1.54e-01 -9.68e-06 S:4 P:-3.34 3.02
Q:0.00 1.66 T:-1.54e-01 -1.32e-05 S:4 P:-0.96 4.37
Q:0.00 8.01 T:-1.54e-01 -1.35e-05 S:4 P:0.36 4.37
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

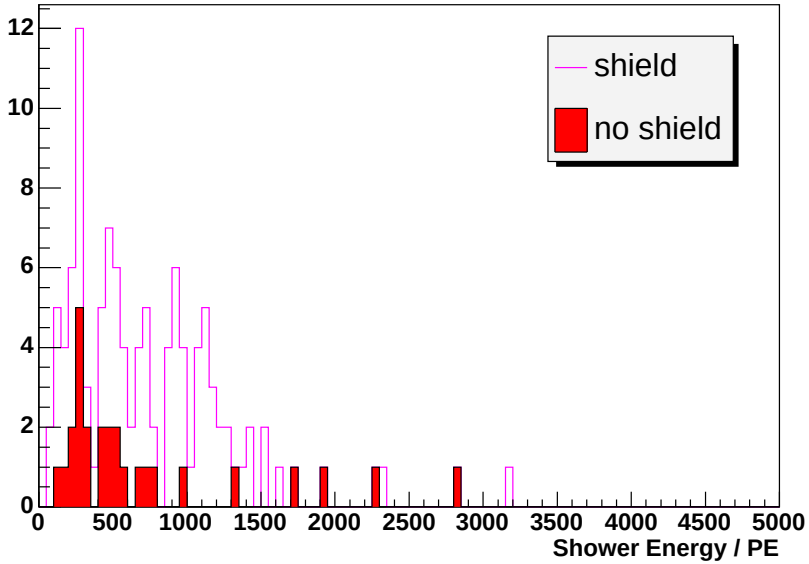
TZ



Selected Events







Atmospheric ν_e

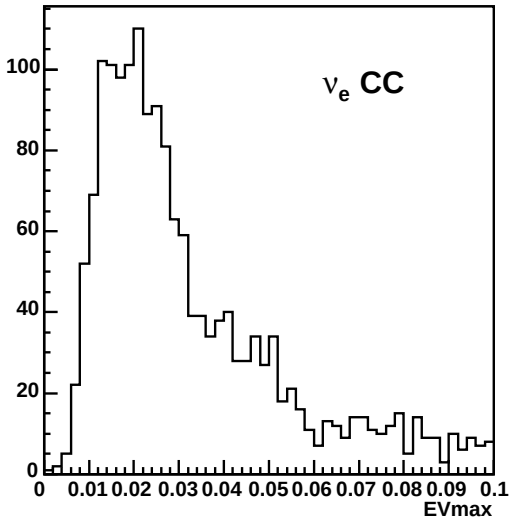
- Current cuts: observe 112 events in data, of which 85 rejected by shield
- Assuming shield efficiency $\simeq$97%, after shield cut, sample contains 2–3 cosmic background events, giving expected composition:

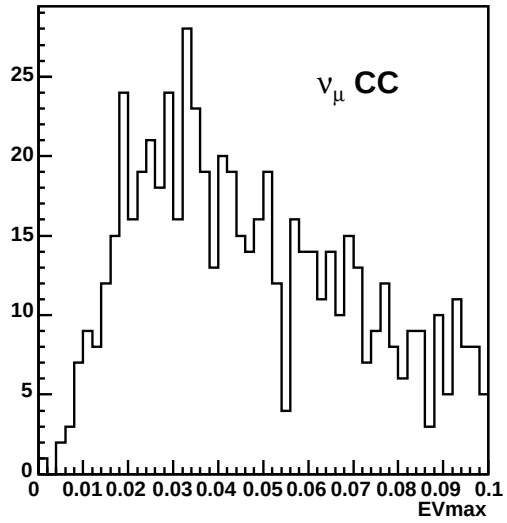
ν_e CC	12.6	53%
ν_μ CC	4.7	20%
NC	4.0	17%
Cosmic	2.5	10%
Total	24	
Observed	27	

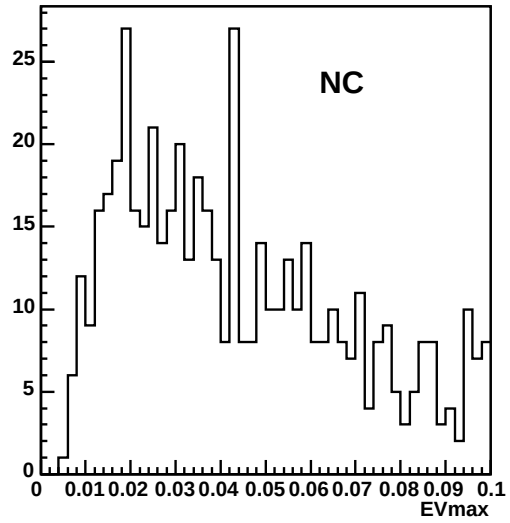
- Separation of signal from ν_μ CC and NC background probably needs likelihood or ANN
- Looks promising, but lots to do / understand

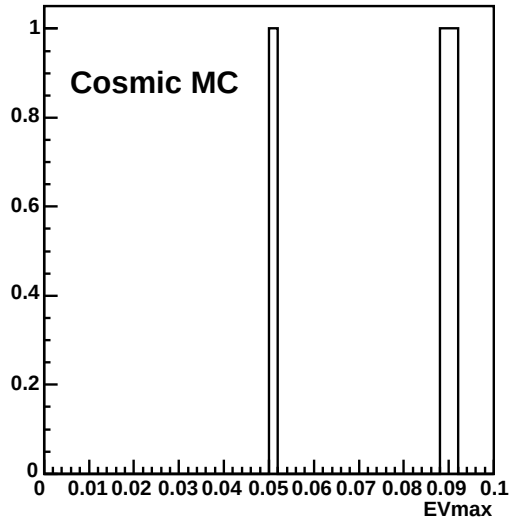
Shower Length

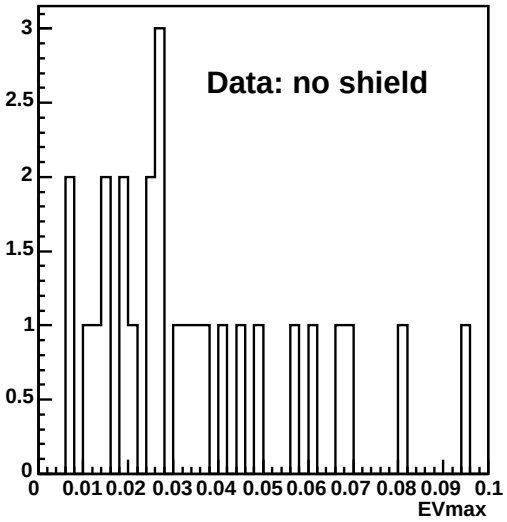
Largest eigenvalue of ‘MoI’ tensor after all cuts.

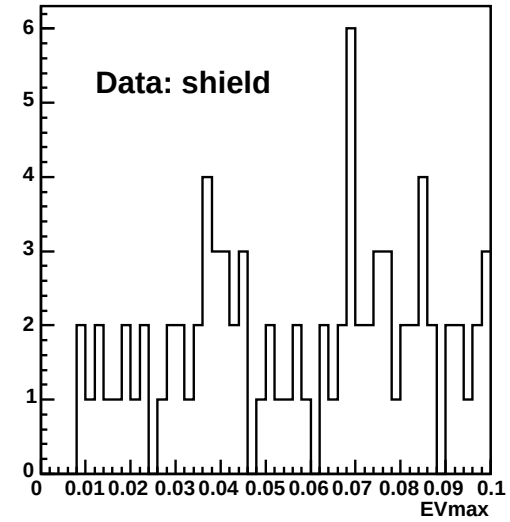






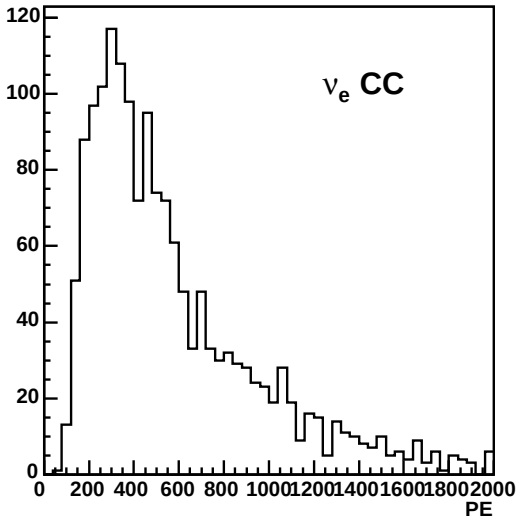


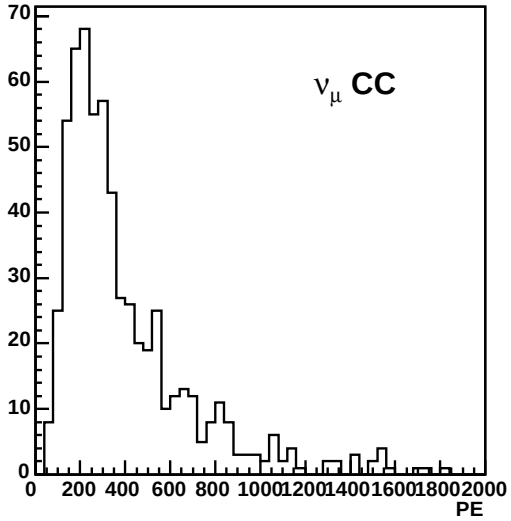


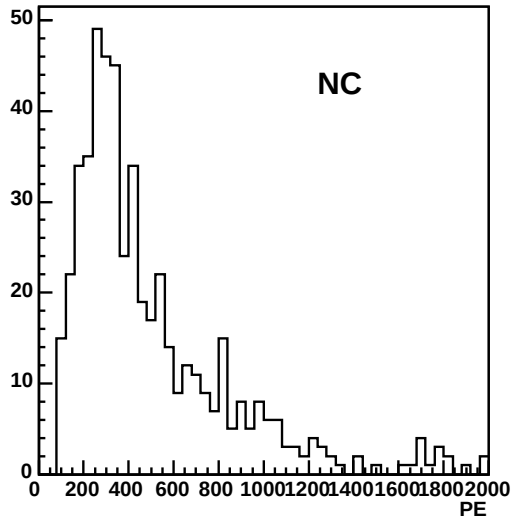


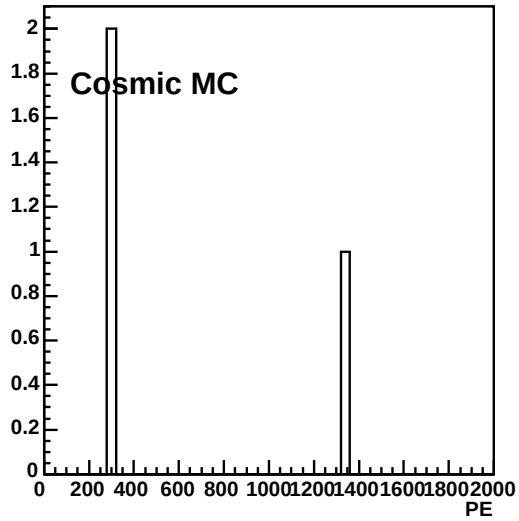
Shower Energy

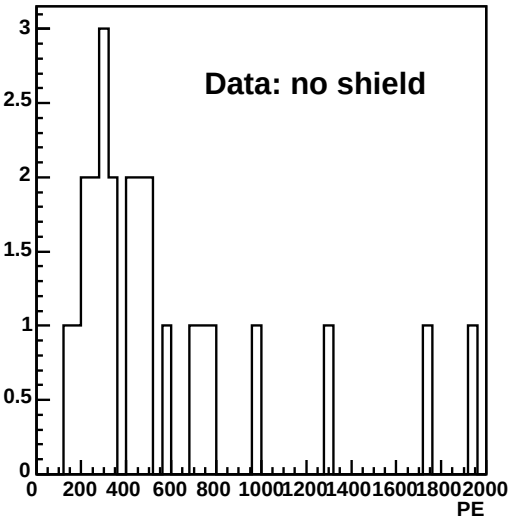
Shower energy (in PE) after all cuts.

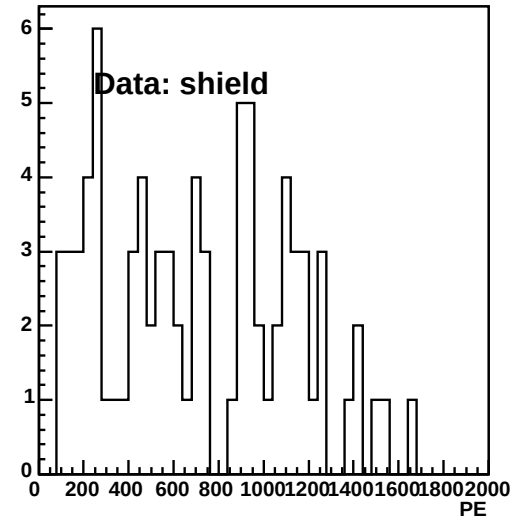






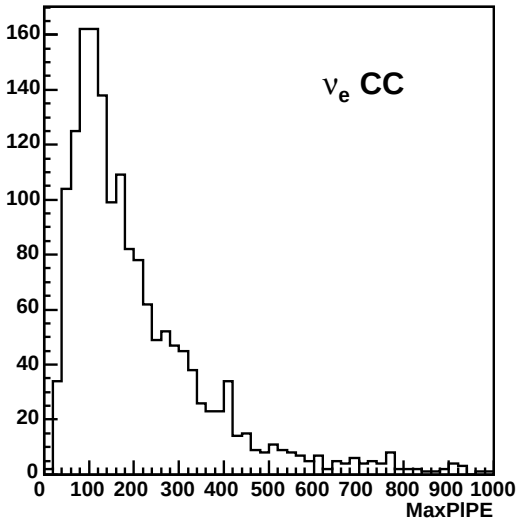


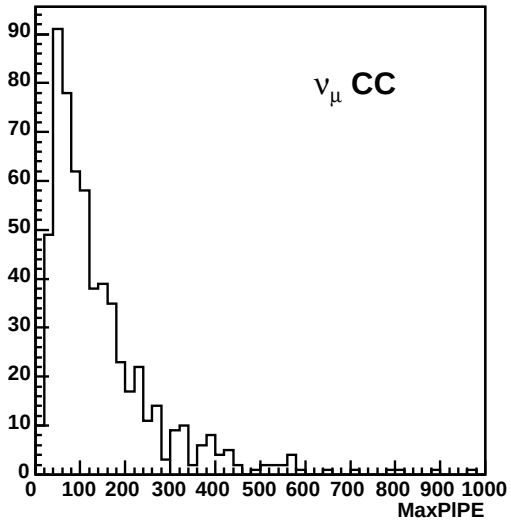


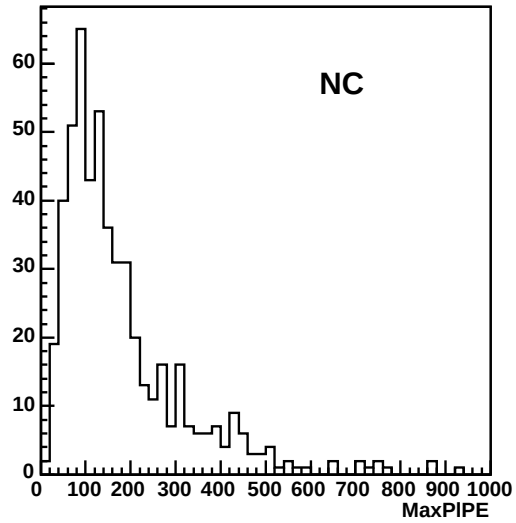


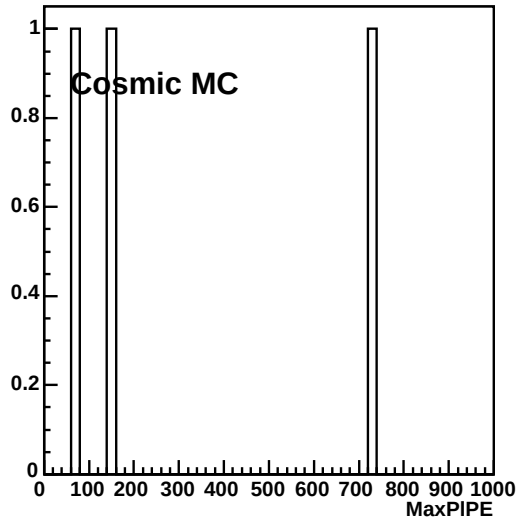
Plane Energy

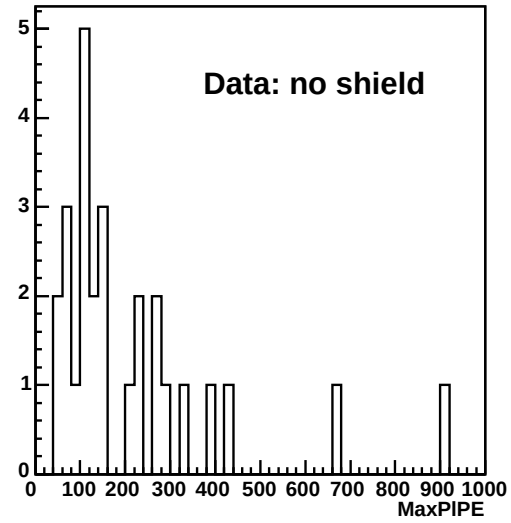
Maximum energy (in PE) in a plane after all cuts.

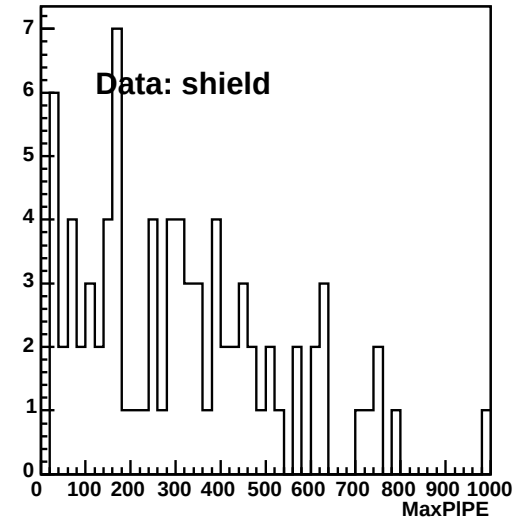












Plane Energy

Mean energy (in PE) in a plane after all cuts.