A search for partially contained cascades with 2 years of IceCube data

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DESY

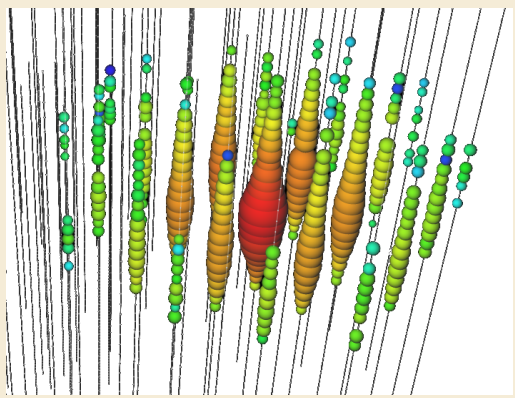
MANTS meeting, 20/09/2014, Geneva

Diffuse analysis - overview

- Search for superposition of individual Point Source flux
- All-sky ν_e, ν_τ, ν_μ(*cascades*), Northern sky ν_μ (tracks)
- Energy spectrum properties allow conclusions about source populations

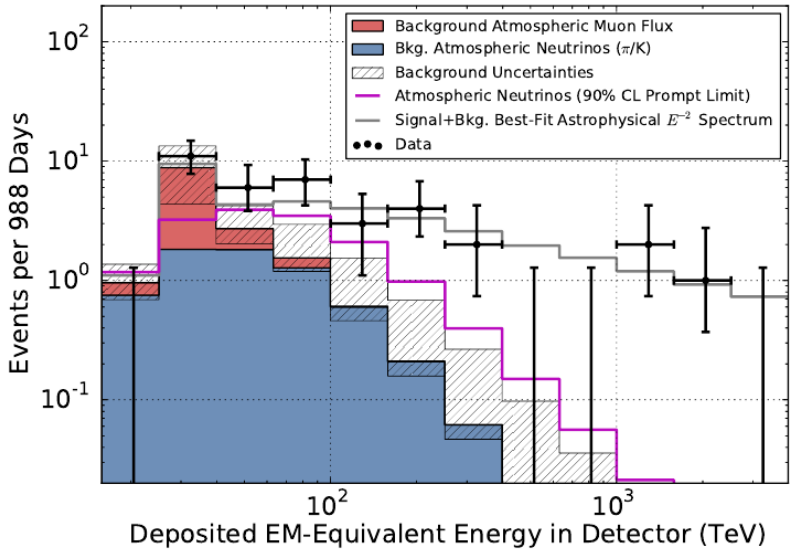
Event signature

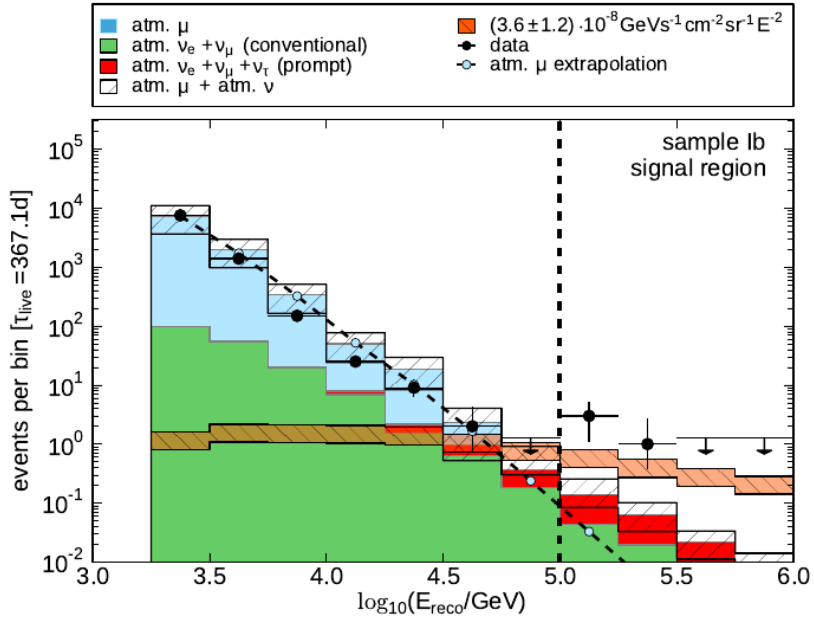
- Particle shower ("cascade")
- all-flavor NC, ν_e CC
- calorimetric energy measurement



IceCube's diffuse results

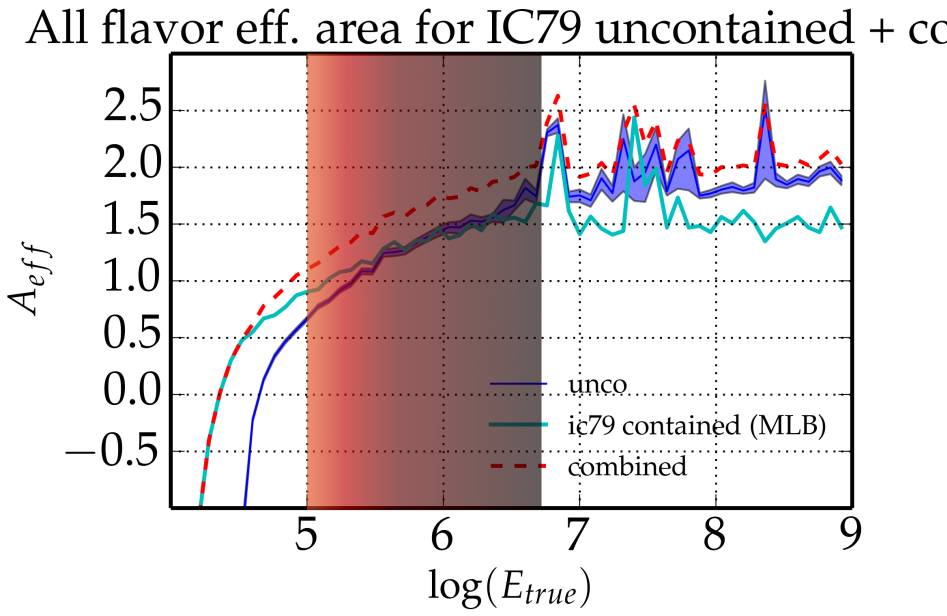
- HESE search: 5.7σ over atmospheric ν arXiv:1405.5303
- IC40 contained cascades: 2.7σ arXiv:1312.0104
- IC59 throughgoing tracks: 1.8σ arXiv:1311.7048
- Currently efforts on combining the results and setting further constraints on the spectrum





PCC - What to gain?

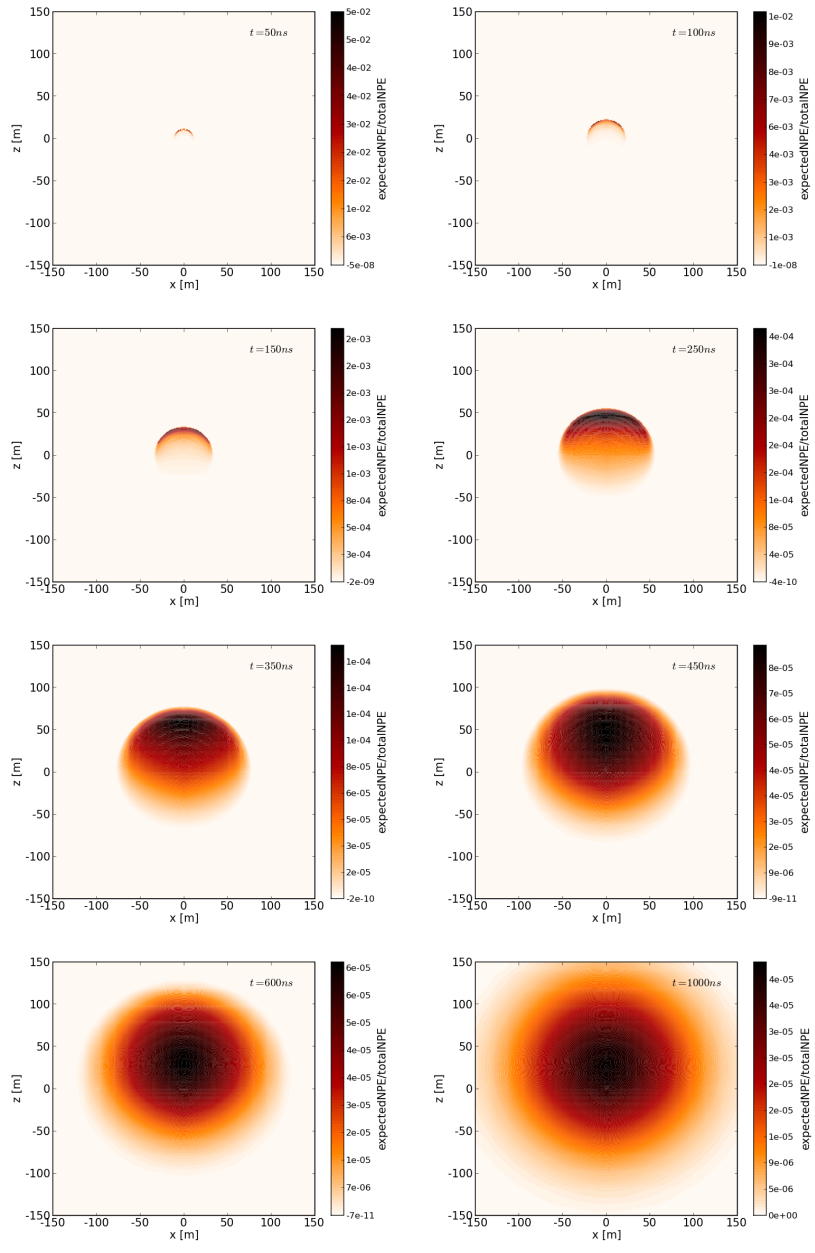
- We are still in the statistics limited regime
- Partially contained cascade volume: 347 MTon
- Sample mostly statistical independent from previous searches
- Sensitive to fluxes above 34 TeV reconstructed energy threshold
- Interesting region for measuring astrophysical ν_e spectrum



IC79 part.c. + IC79 fully c.
effective area,
yaxis: $\log(m^2)$

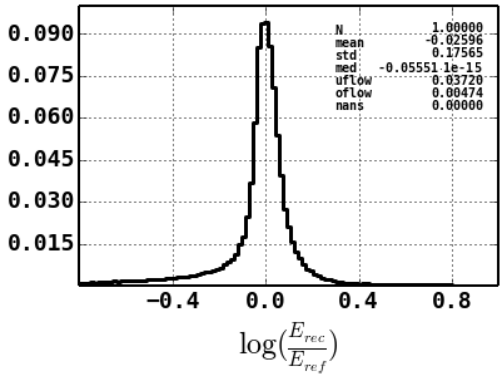
Cascade reconstruction

- 7-parameter Poisson likelihood reconstruction (energy,vertex,direction)
- Includes no-hit term
- Different ice-models can be plugged in
- Uses timing and charge information

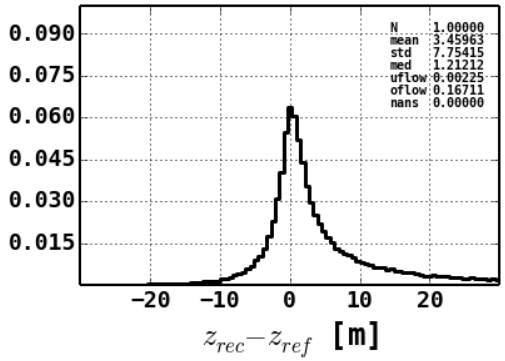


Cascade parameter resolution

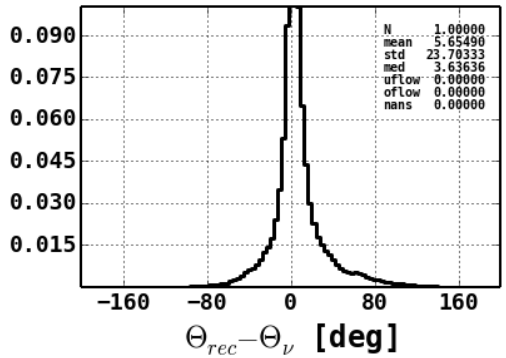
- Resolutions for partially contained events slightly worse than contained



mean = -0.05, std = .17

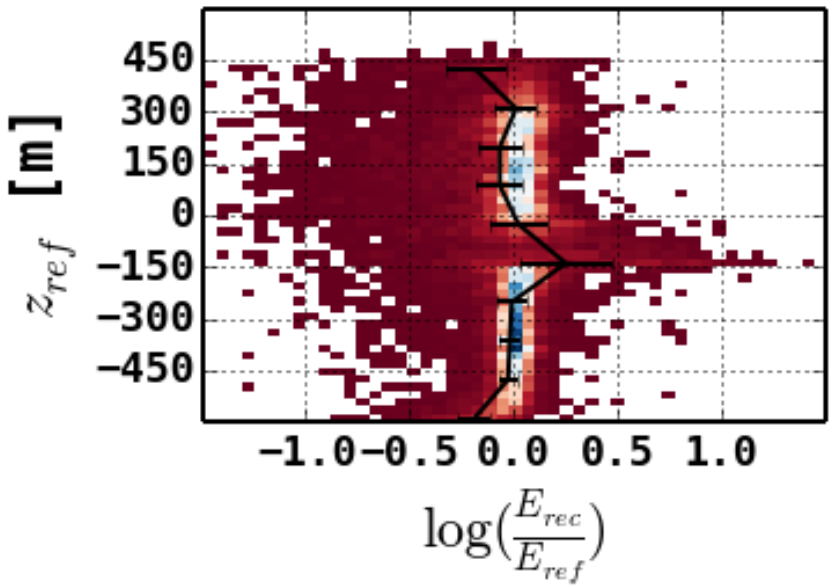


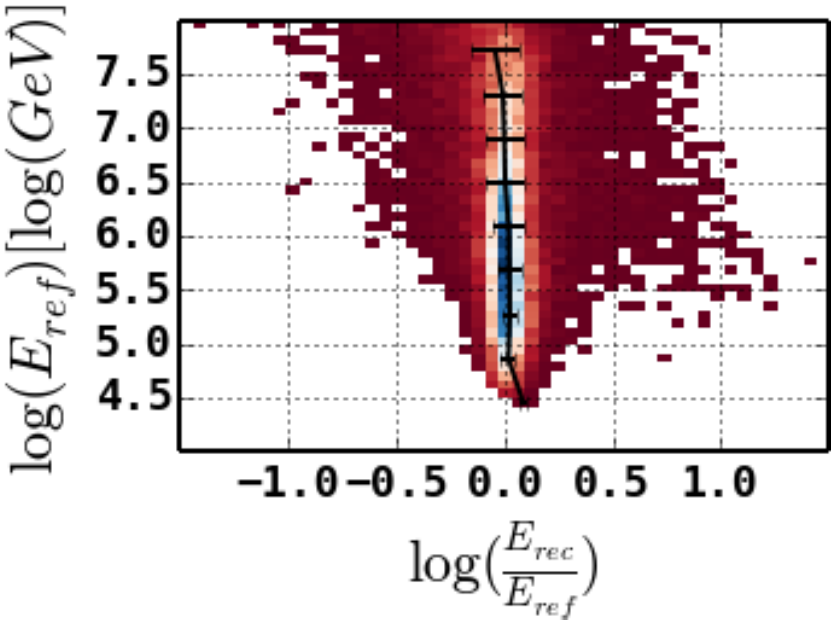
mean = 3.45, std = 7.75



mean = 5.65, std = 23.70

- For vertices further outside than 1/2 string spacing:



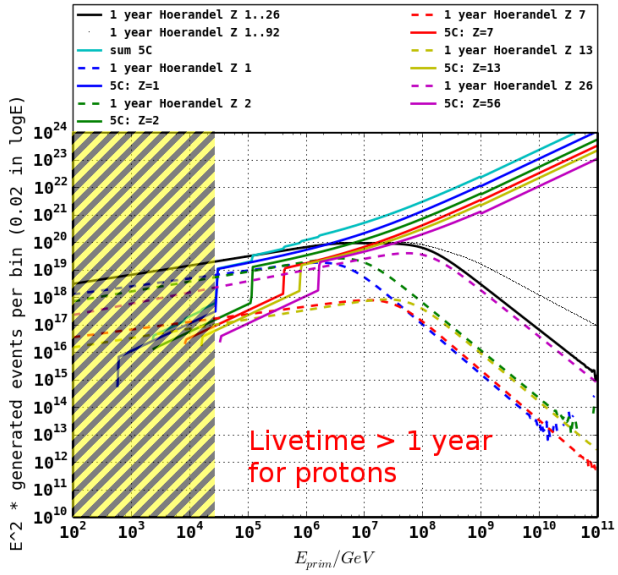


Analysis overview

target	$E^{-2}\nu$ all-flavor, all-sky
technique	Straight cuts
method	Partially contained cascades
background	MC Background prediction

Analysis - IceCube data

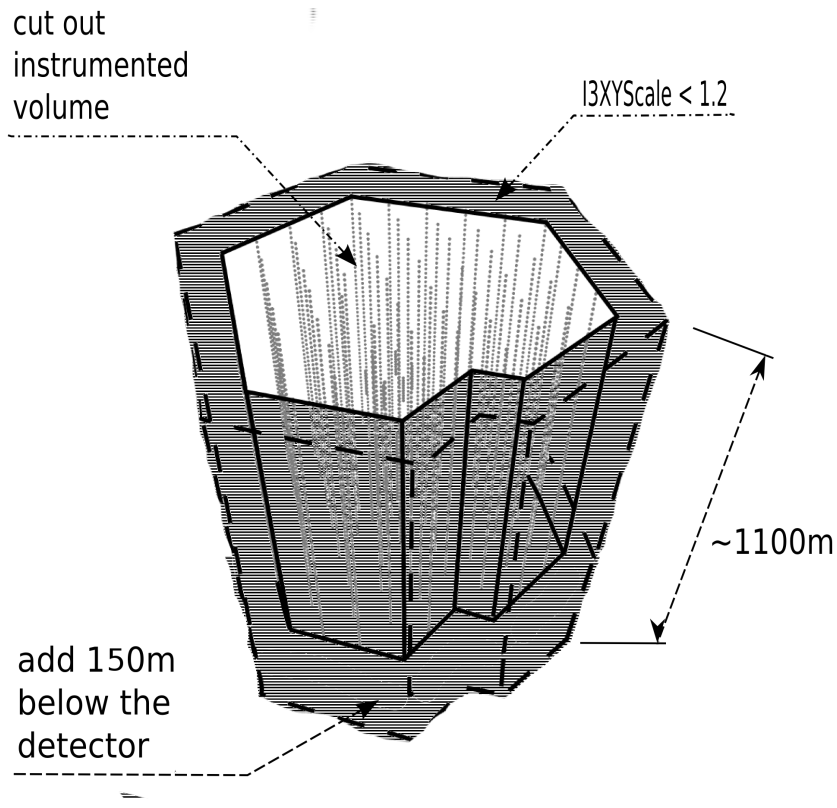
- Data of 79/86 string configuration used ($\approx$ 660 days)
- 10% data used for cut development, 3-step unblinding



Background simulation: At 30TeV/Nukleon, the simulated proton live time exceeds the expectations from the 1-year cosmic ray proton flux [Hoerandel,arXiv:astro-ph/0402356]

eventselection - overview

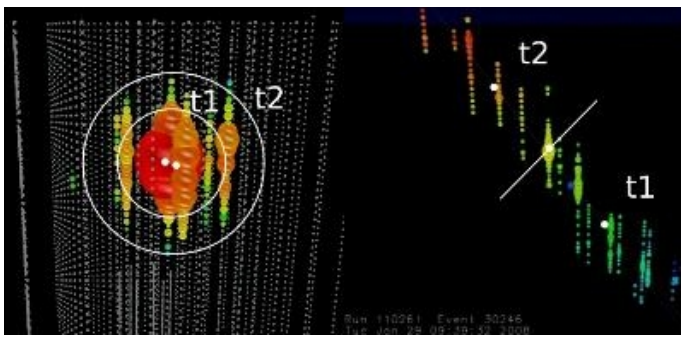
- L3 common cascade filter level
- L3a high energy precuts ($> 10\,TeV$)
- L4 fiducial volume cuts
- L5 cascade specific cuts
- L6 geometry cuts (remove "corner clippers")
- L7 final energy cut ($>\approx 30\,TeV$)



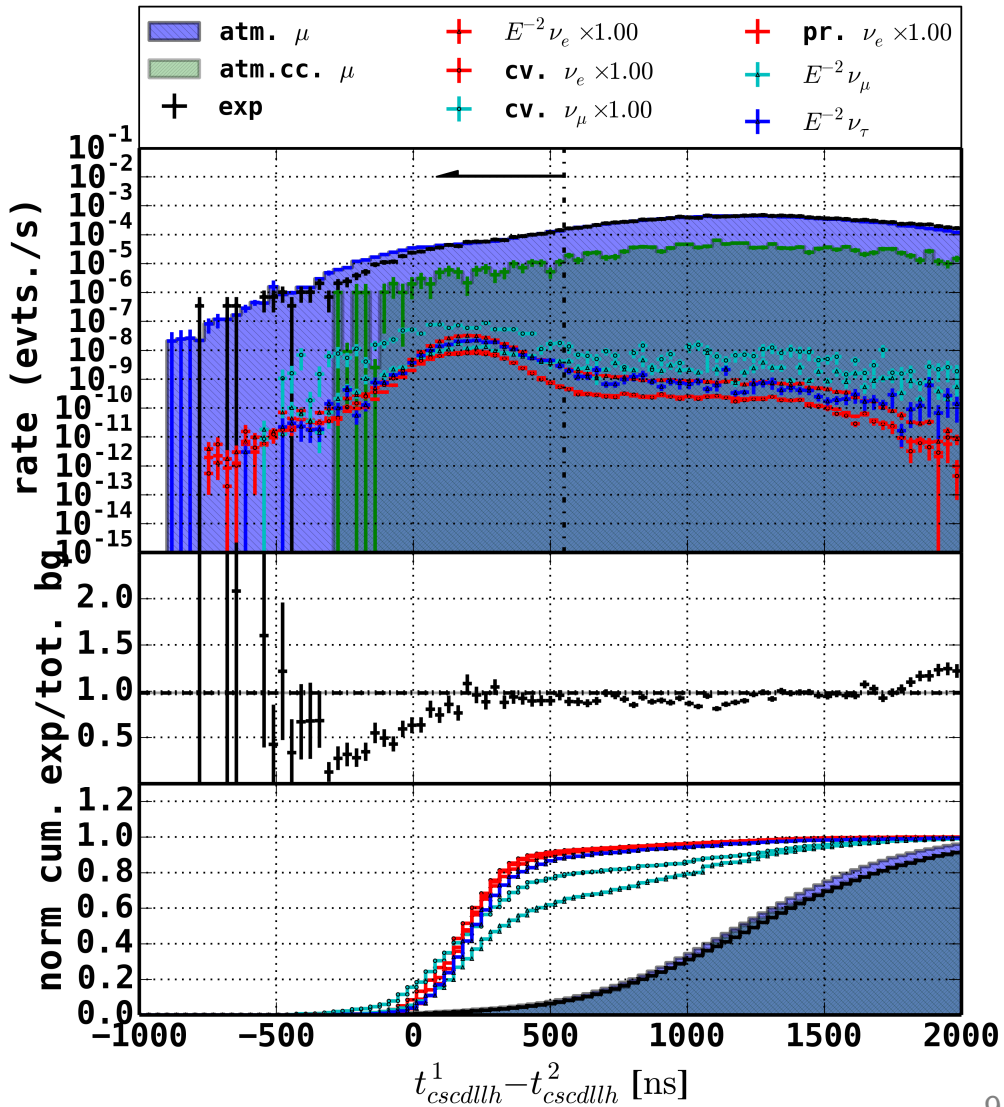
L5 cascade cuts - example cut

cascade variables

- topology
- timing
- direction
- quality

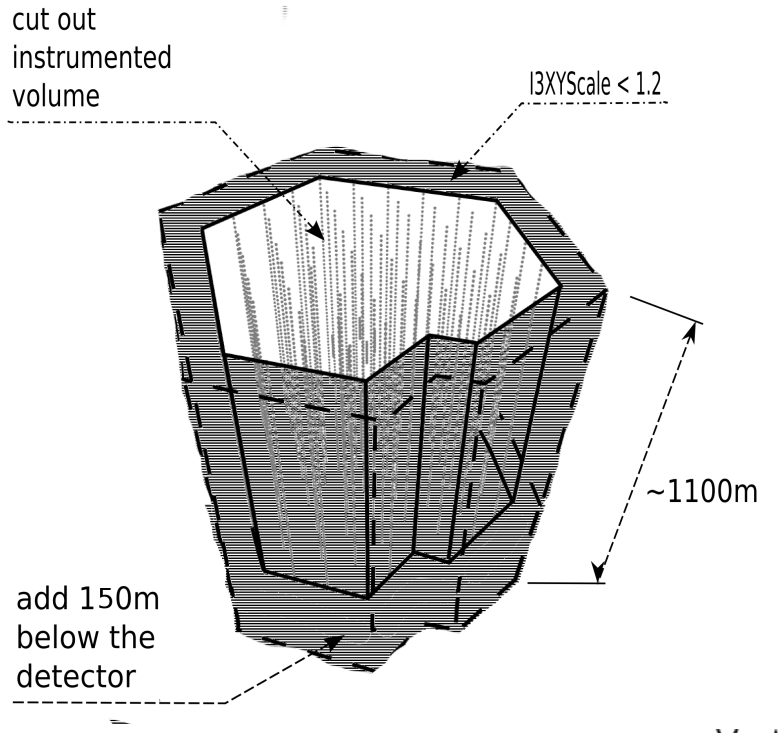


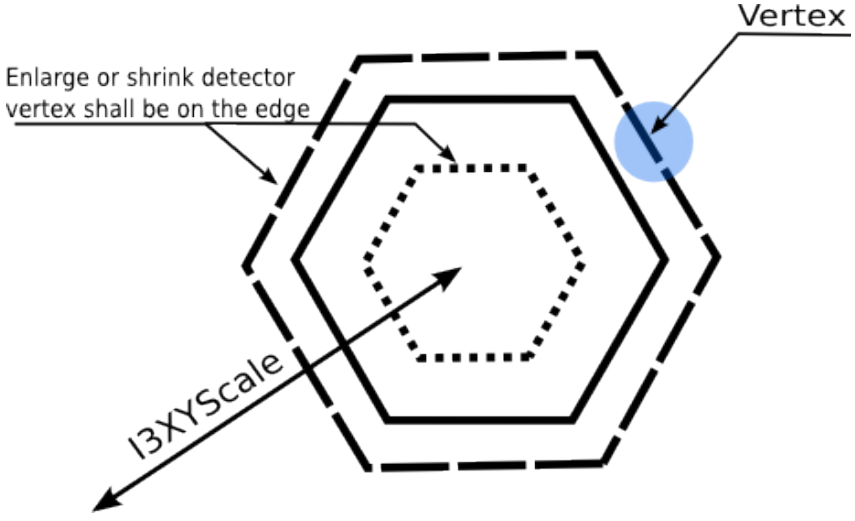
timesplit_dt@4i



Containment definitions

- Designed for minimal overlap with contained searches
- Cascade vertex position in "shell" region
- $\approx$ 1 string spacing in xy, $+150$ m below detector, 50m of these instrumented
- highest sensitivity in bottom region
- use scaling variable for xy scaling

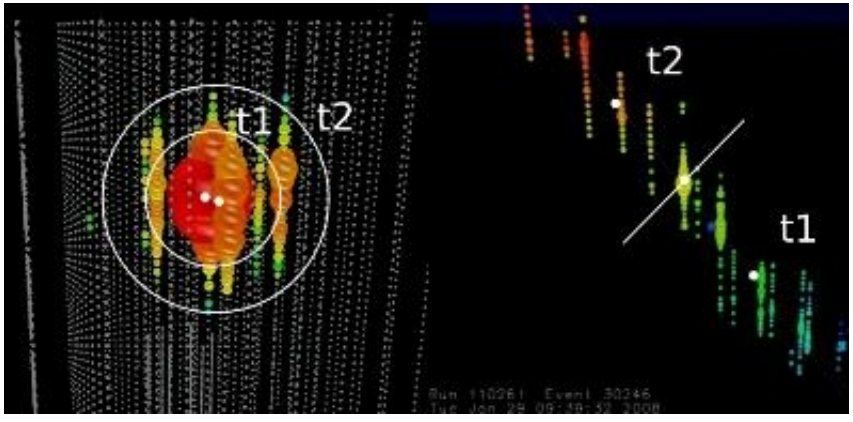


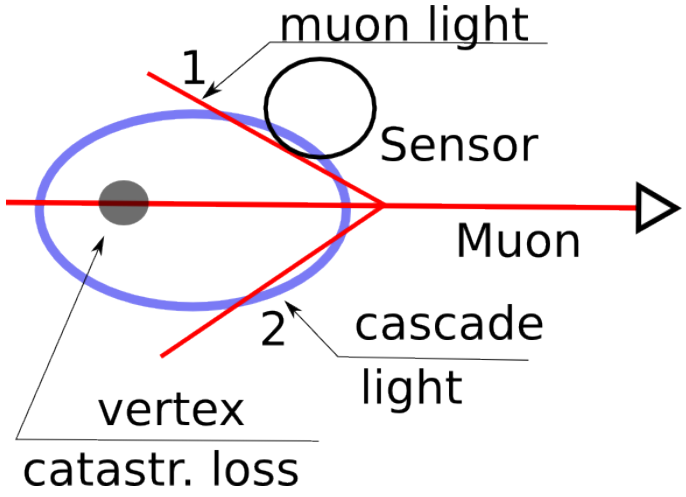


Event selection - variables

"Simple" variables:

- quality
- timing
- topology
- direction
- geometry



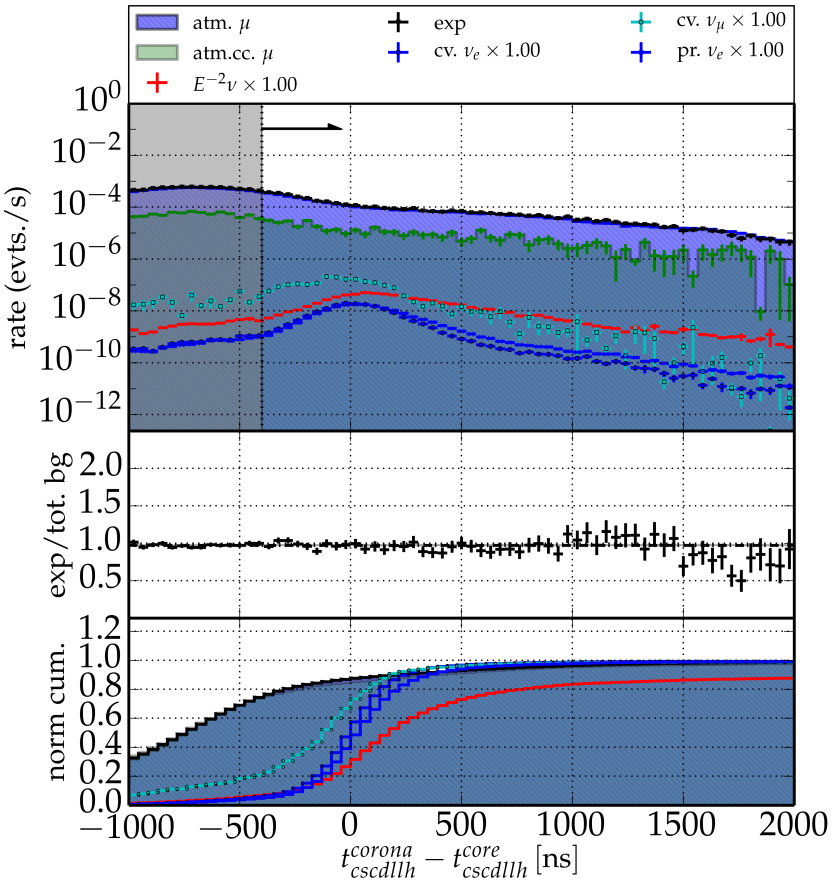


DTNearly (superluminosity): Time difference of first detected light (1) and expected first hit (2) from a cascade hypothesis with reconstructed vertex.

Negative values indicate for misreconstructed events or atmospheric muons with catastrophic losses.

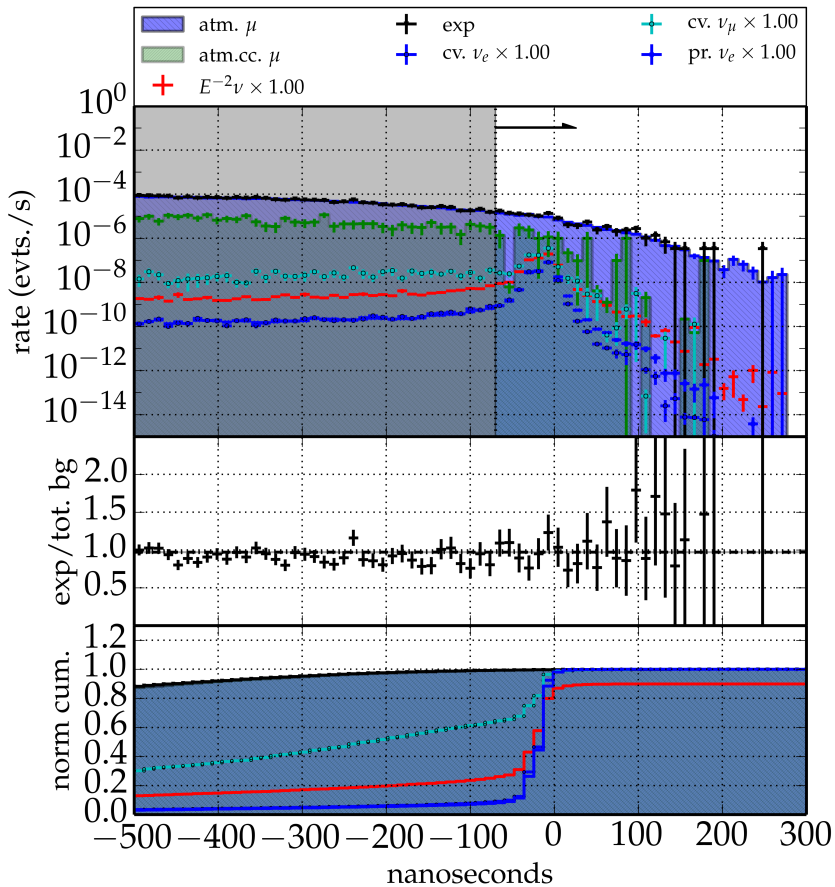
Example variable distributions

coronasplit-dt@4



CoronasplitDT: Time difference of two vertex reconstructions A and B - A uses only pulses in a sphere around a seed vertex, B uses pulses in a spherical shell further out

dt-nearly-ice@4

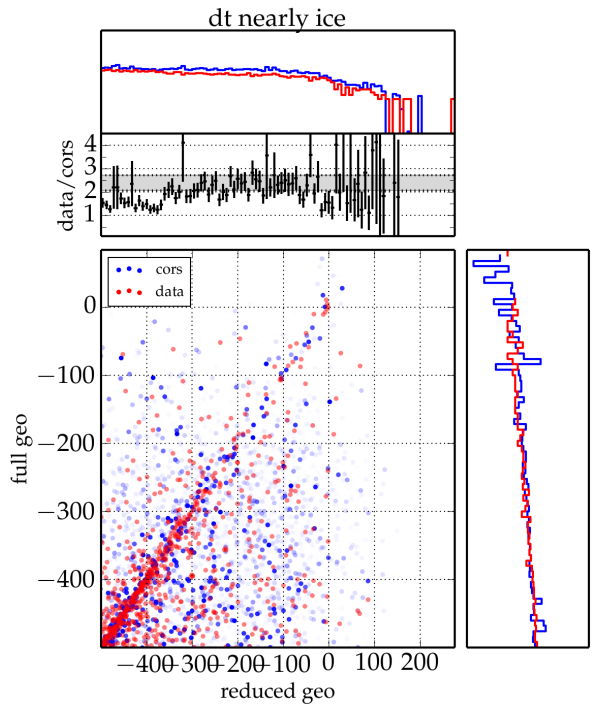


DTNearly: Time difference of first detected light and sum of reconstructed vertex time and geometrical flight time.

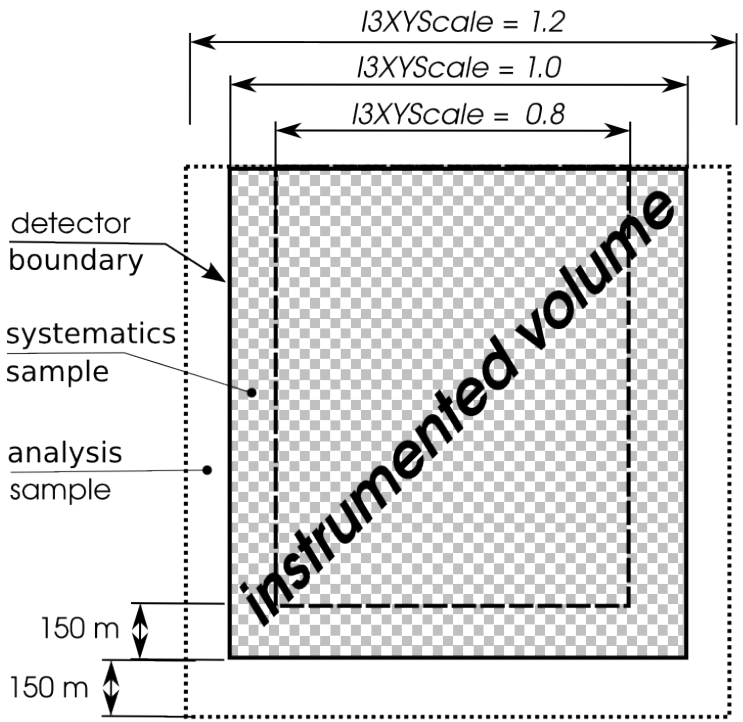
A perfectly reconstructed cascade would yield a value of 0 if the first hit is not scattered.

Systematic Studies

- Off-signal region defined for systematic checks
- Check influence of geometry on each variable

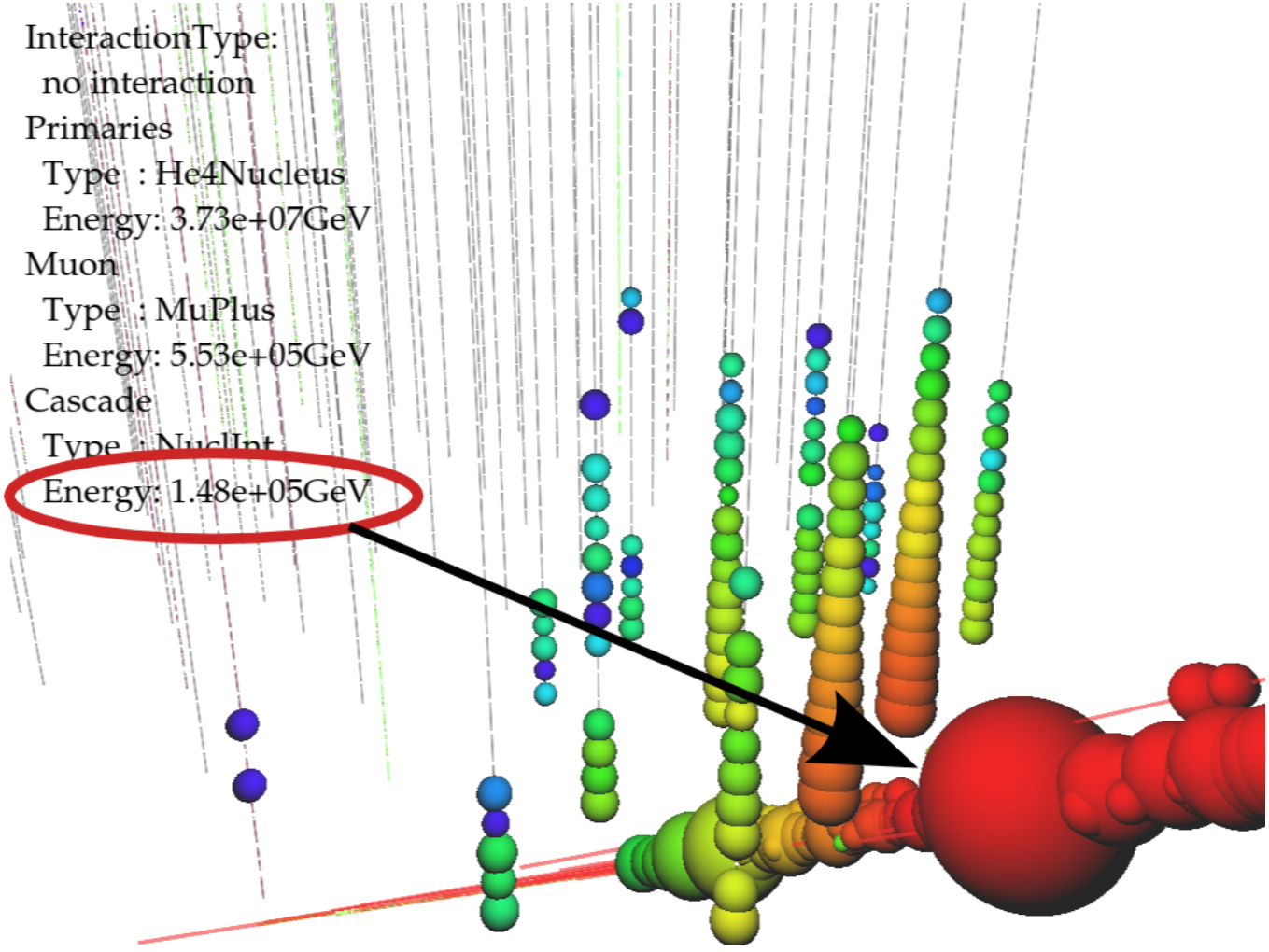


- Full-year data for off-signal region yields consistent results
- Also consistent with IceCube contained search



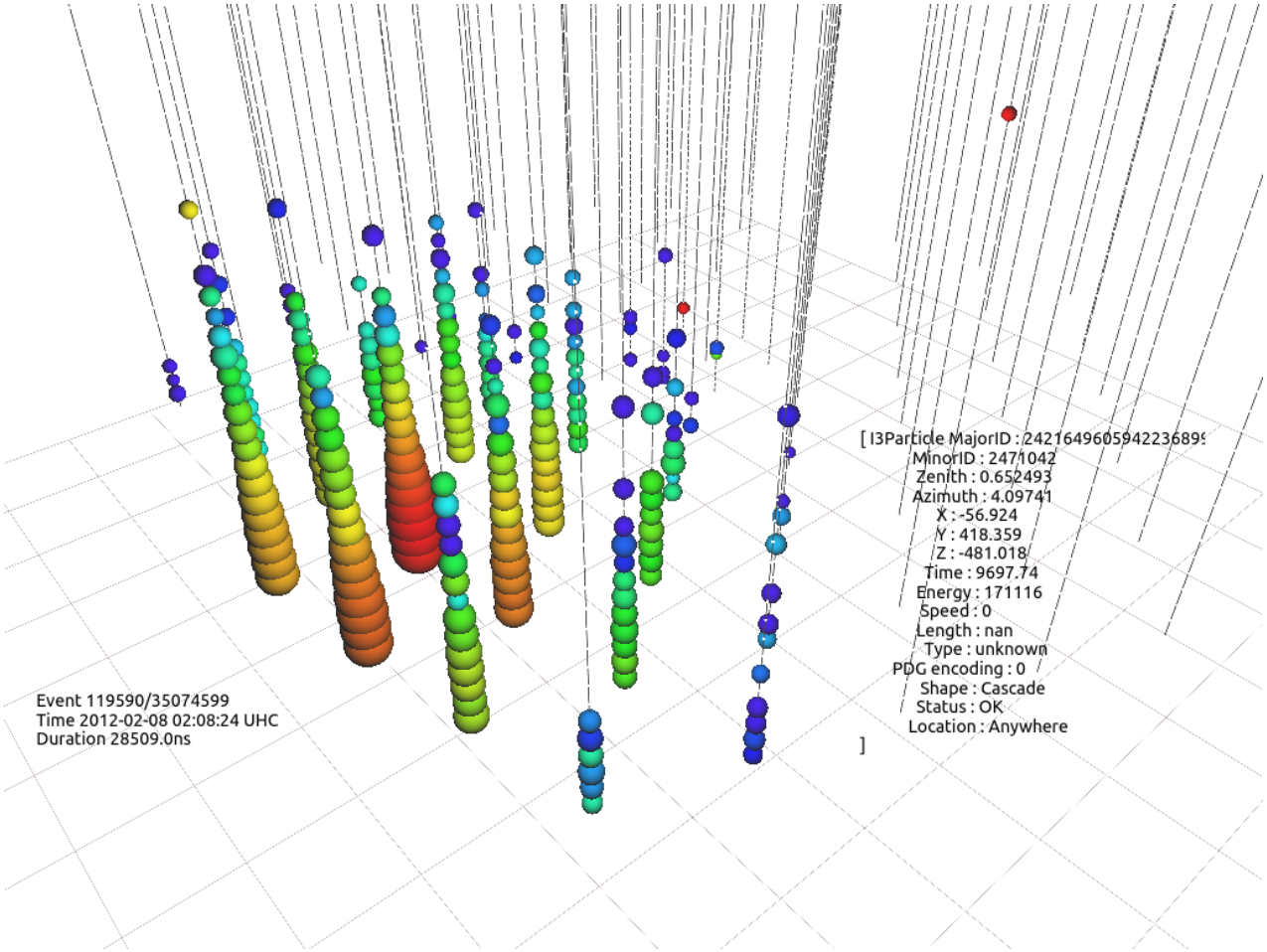
Dominant muon background

- $\approx$ 1.60 atmos. μ expected in IC79 data



Events in 10% test sample

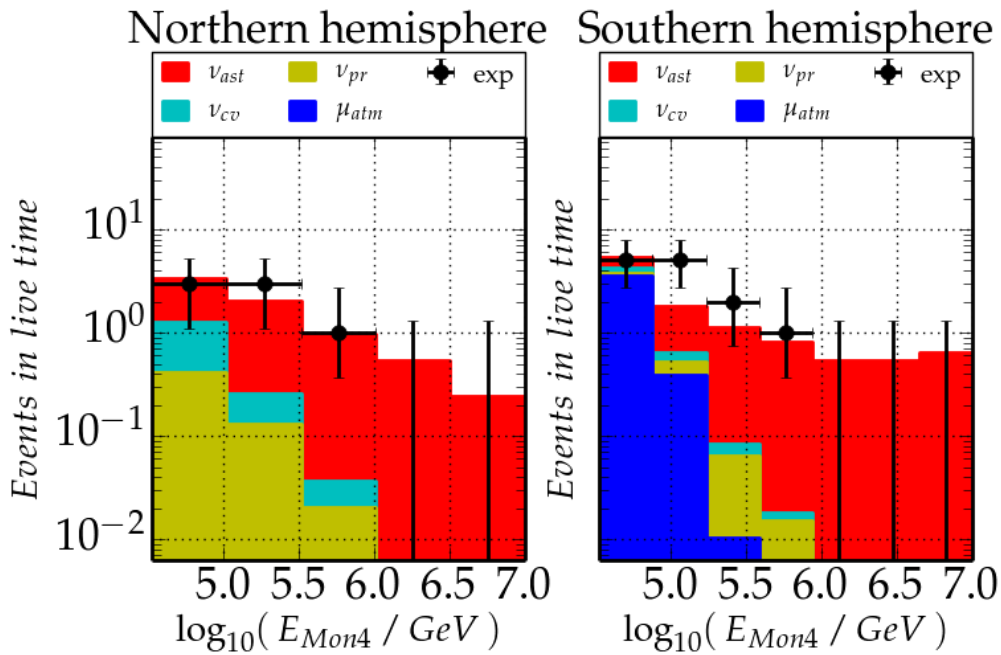
- 2 events found in IC86, none in IC79



- 171 TeV reconstructed energy
- starting on an inner string

Preliminary results

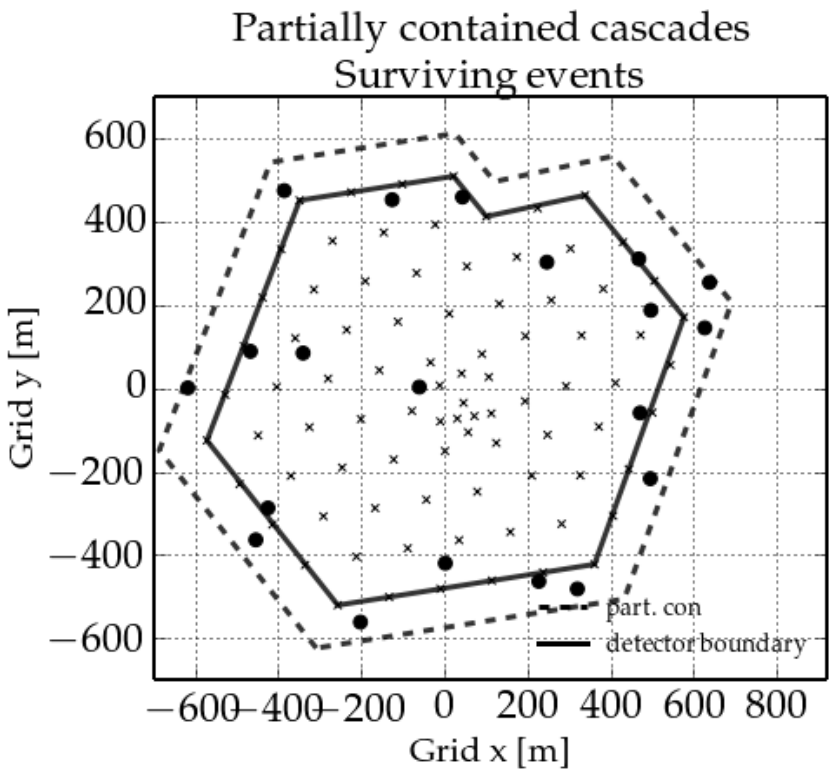
- 18 events found in 90% of data
- 2 events in 10% of data
- highest energy $\approx$ 578 TeV
- expected 11.7 ± 0.5 $1 \cdot 10^{-8} \nu_x E^{-2}$ signal
- expected background:
  - 3.8 ± 0.4 ν_{atmos} H06a/ERS w. knee (no veto)
  - 4.2 ± 1.8 μ_{atmos} (H3a)

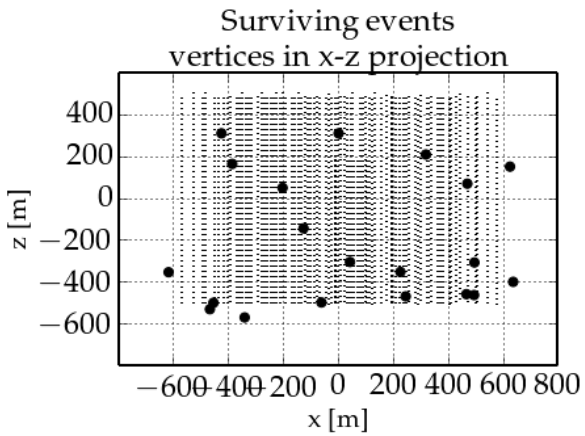


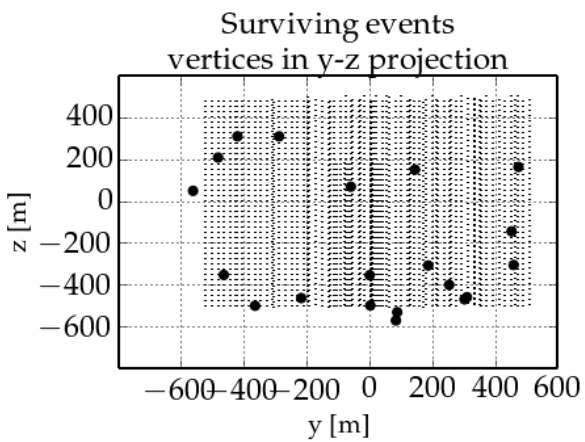
baseline models, stacked energy spectrum for 2 years of data,N/S split at $\approx$ 80 deg

Distributions of vertices

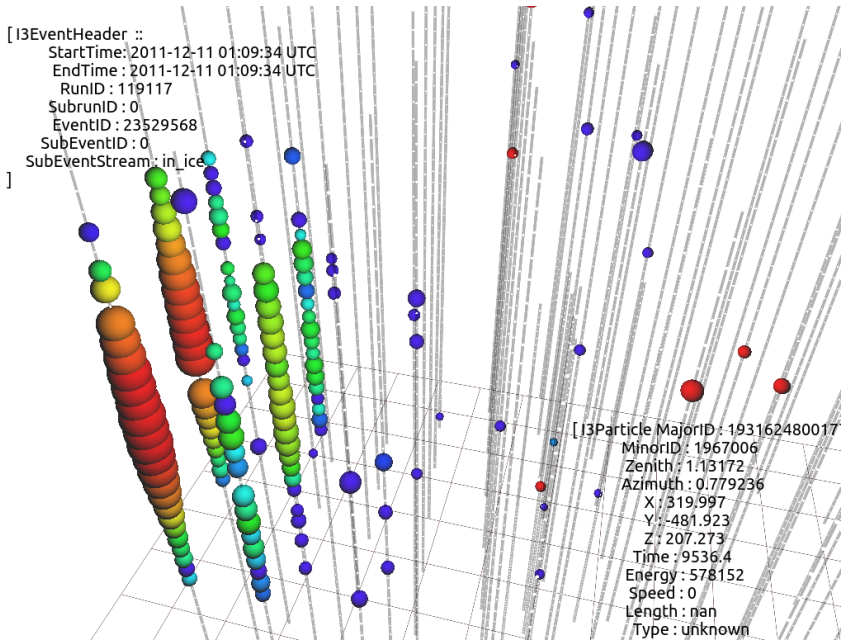
- fairly isotropic







Highest energetic event - 578 TeV



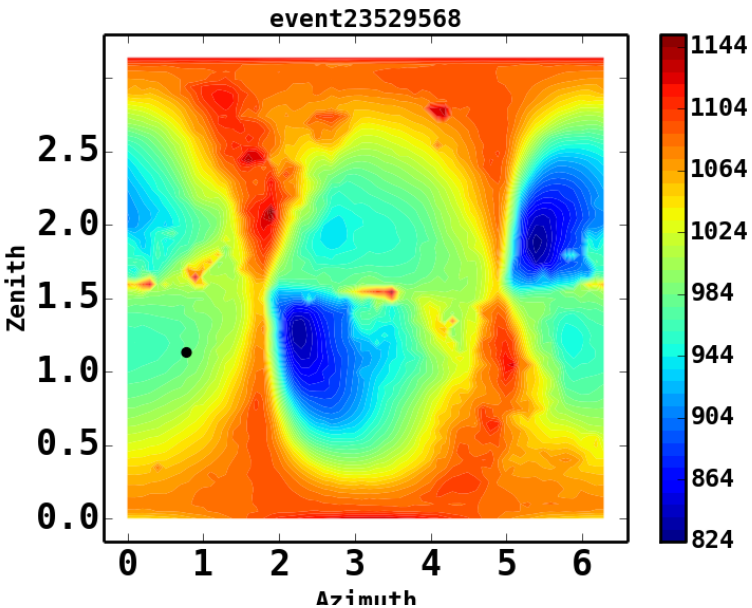
Variables

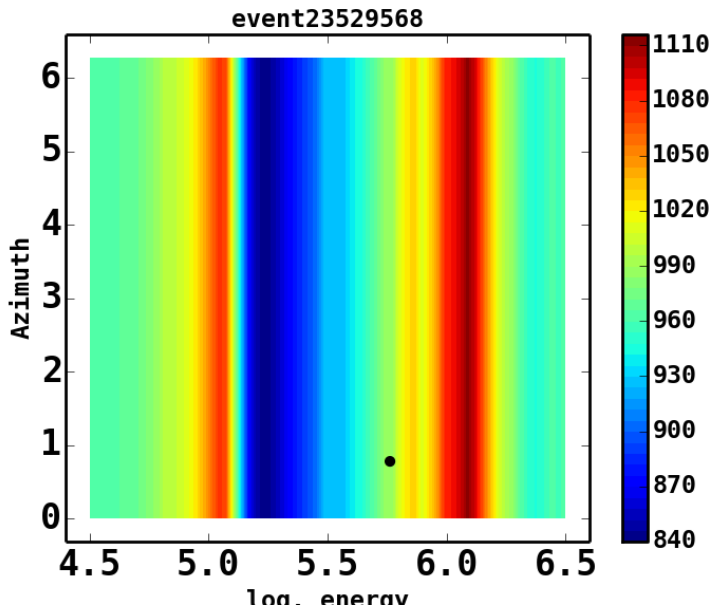
NChan	175
NStr	39
QTot	6621 PE
NChan (closest string)	24
closest DOM	72 m
XYScale	1.1
Zenith	64 deg
Azimuth	44 deg

- variables comparable with contained events of about 90 100TeV

578 TeV event - Llh scans

- currently under study
- energy reco not constraint by azimuth





HESE Overlap

- Swedish Chef (IC79)

  HESE E_{rec} 165 TeV

  Θ_{rec} 38 deg

  PCC E_{rec} 168 TeV

  Θ_{rec} 53 deg

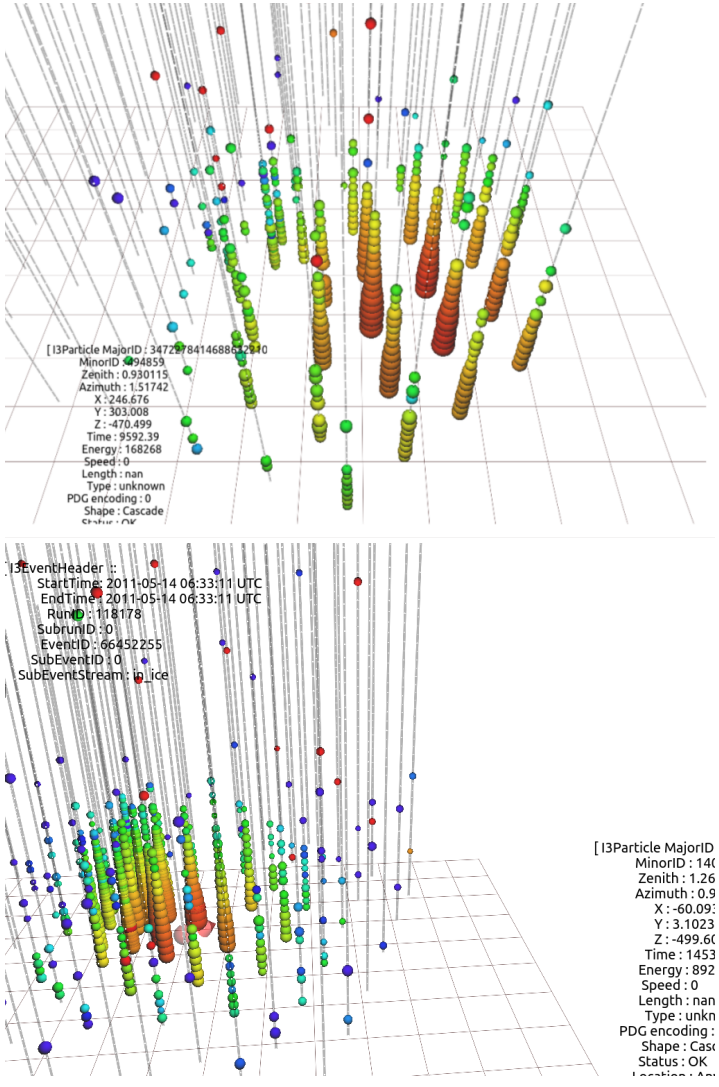
- Camilla the Chicken (IC86)

  HESE E_{rec} 97 TeV

  Θ_{rec} 60 deg

  PCC E_{rec} 89 TeV

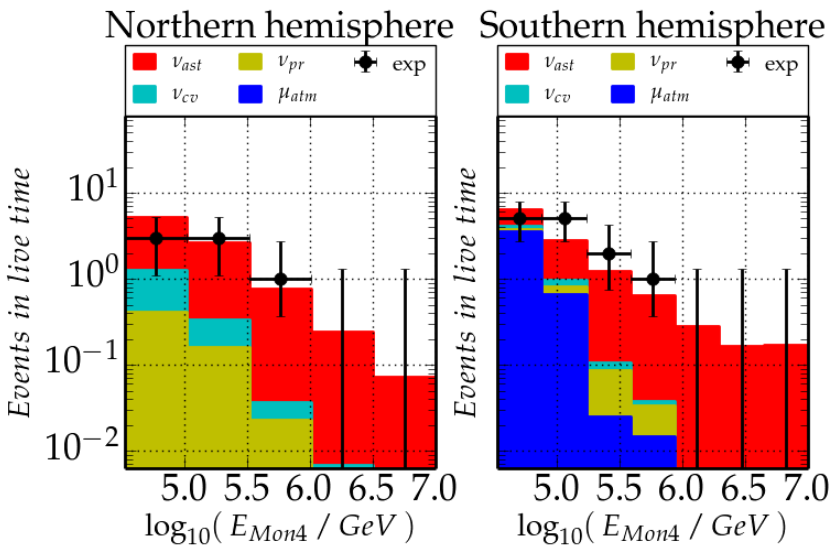
  Θ_{rec} 72 deg

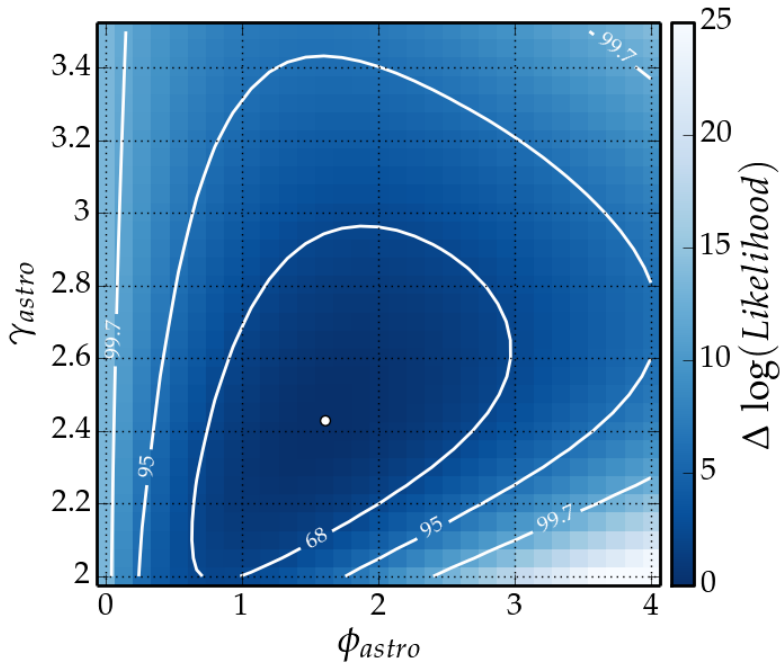


Best fit spectrum

- Fit astro. index + normalization
- Prompt set to ERS $\pm$ 40%
- Conventional set to H06/Gaisser $\pm$ 30%
- nuisance parameters θ_{Φ_E},$\theta_{\Delta\gamma_{cr}}$,$\theta_{\Phi_\mu}$
- currently working on θ_{γ_μ}
- astrophysical parameters not influenced by choice of ERS prior

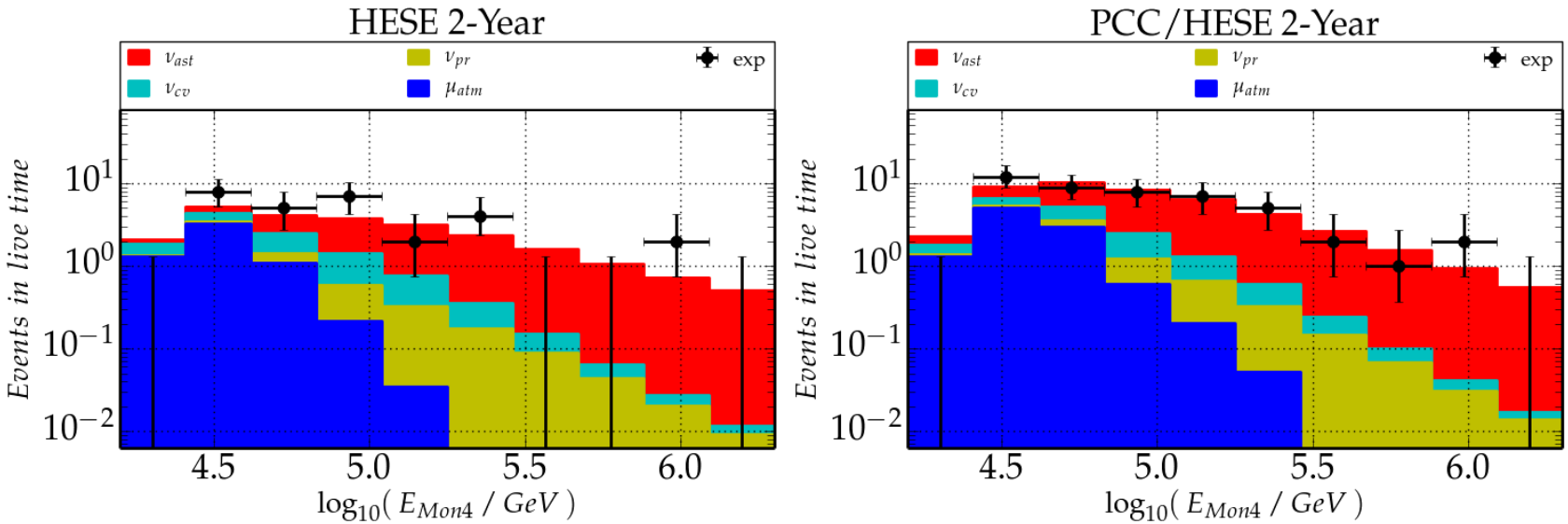
$$\Phi = (1.9 \pm .77) \cdot 10^{-18} GeVs^{-1}sr^{-1}cm^{-2} \left(\frac{E}{100\,TeV}\right)^{(2.48\pm0.3)}$$





Consistency with HESE

- PCC. adds 19 additional events to 2-year HESE spectrum
- stacked MC expectations
- HESE only: $E^{-2}\Phi(E) = 1.2 \pm 0.4\ 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$
  best fit spectrum $E^{-2.2\pm0.3}$
- HESE/PCC: $E^{-2}\Phi(E) = 1.8 \pm 0.6\ 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$
  best fit spectrum $E^{-2.4\pm0.3}$

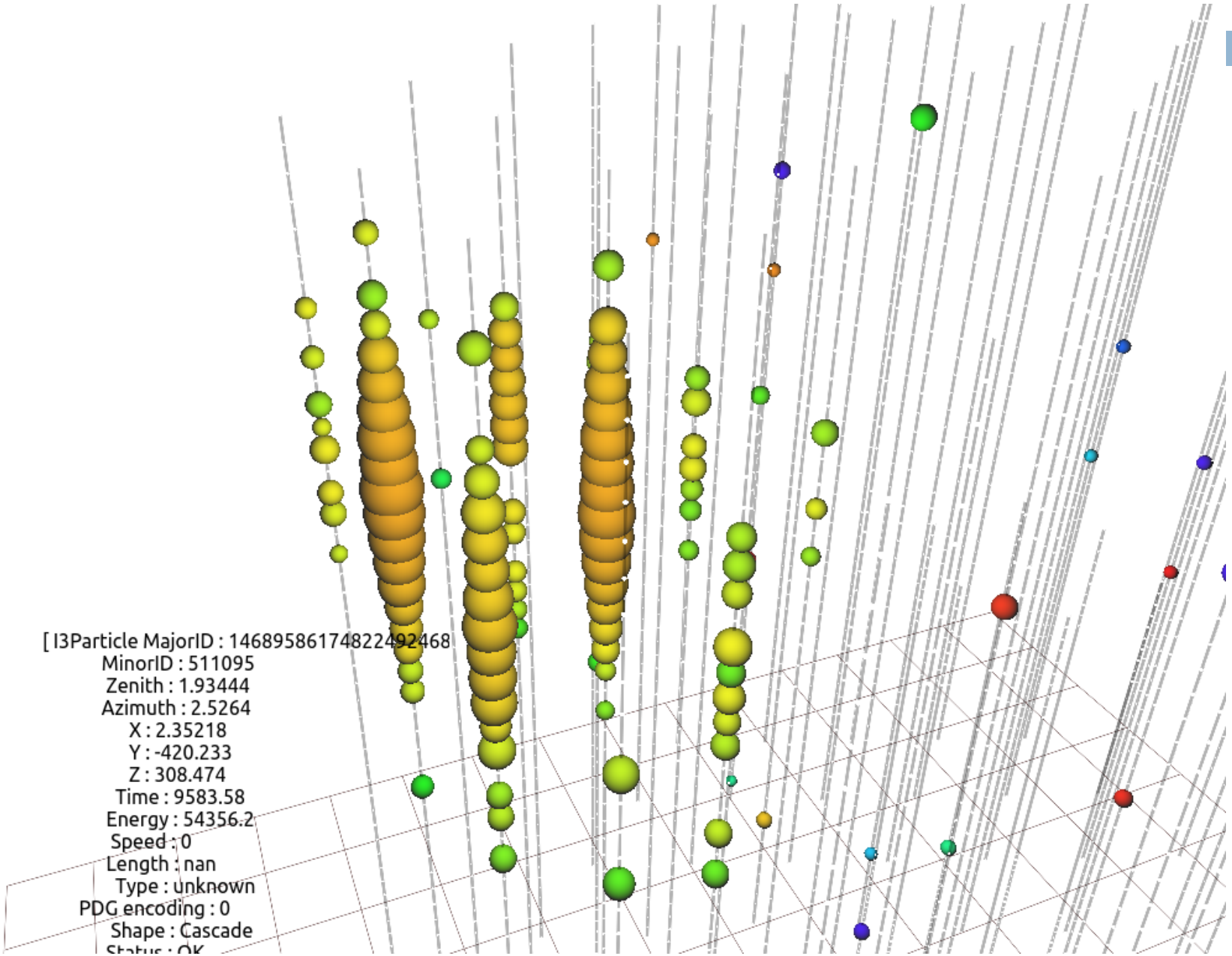


Summary

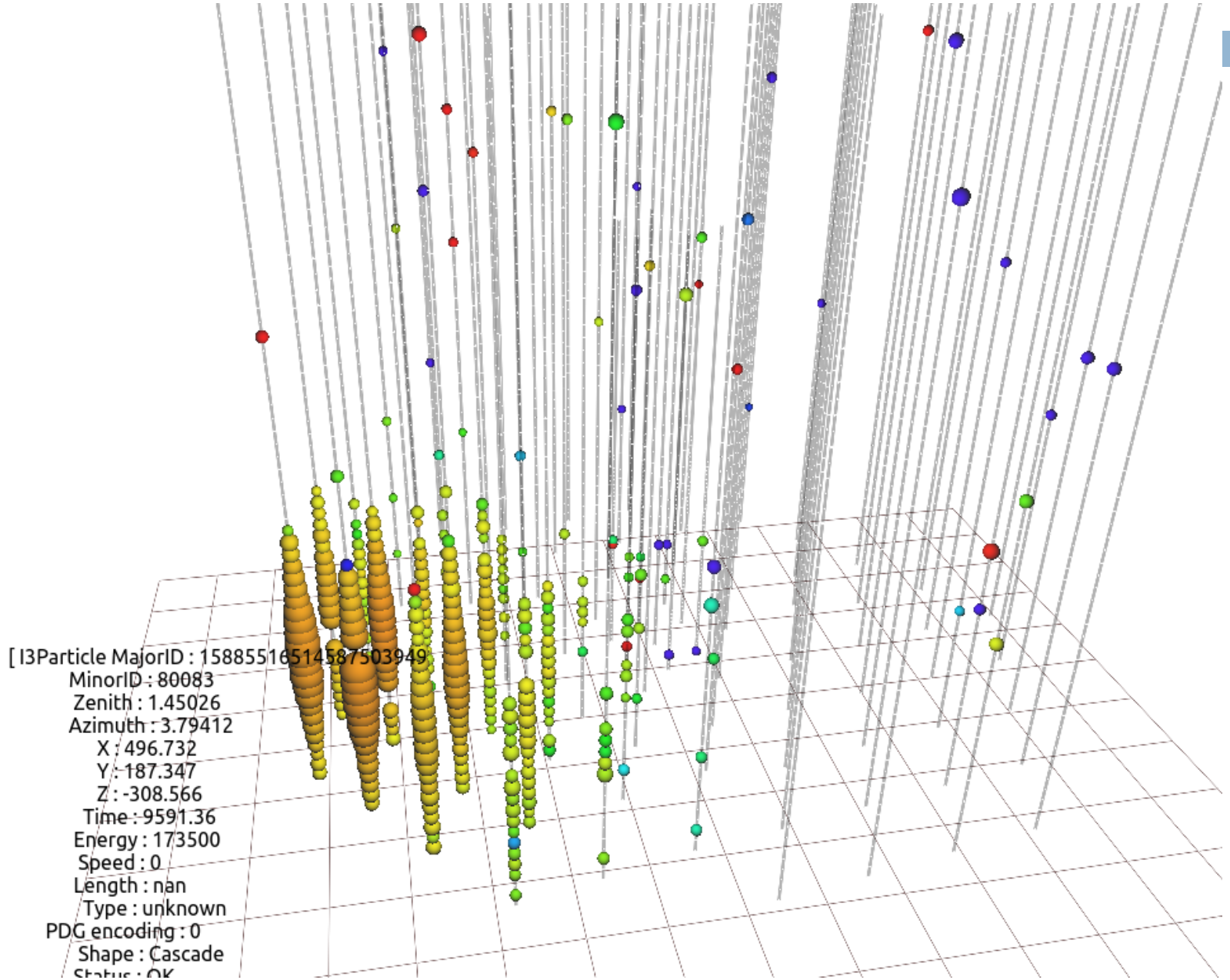
- Performed simple, straight cut search for partially contained cascade events
- MC background prediction
- 20 events found in 2 years of data
- events line up nicely in HESE-2-year spectrum - even partly filling up “the gap”
- indications for a softer index of 2.47
- joint publication with IC79/86 contained analysis in planning

Backup

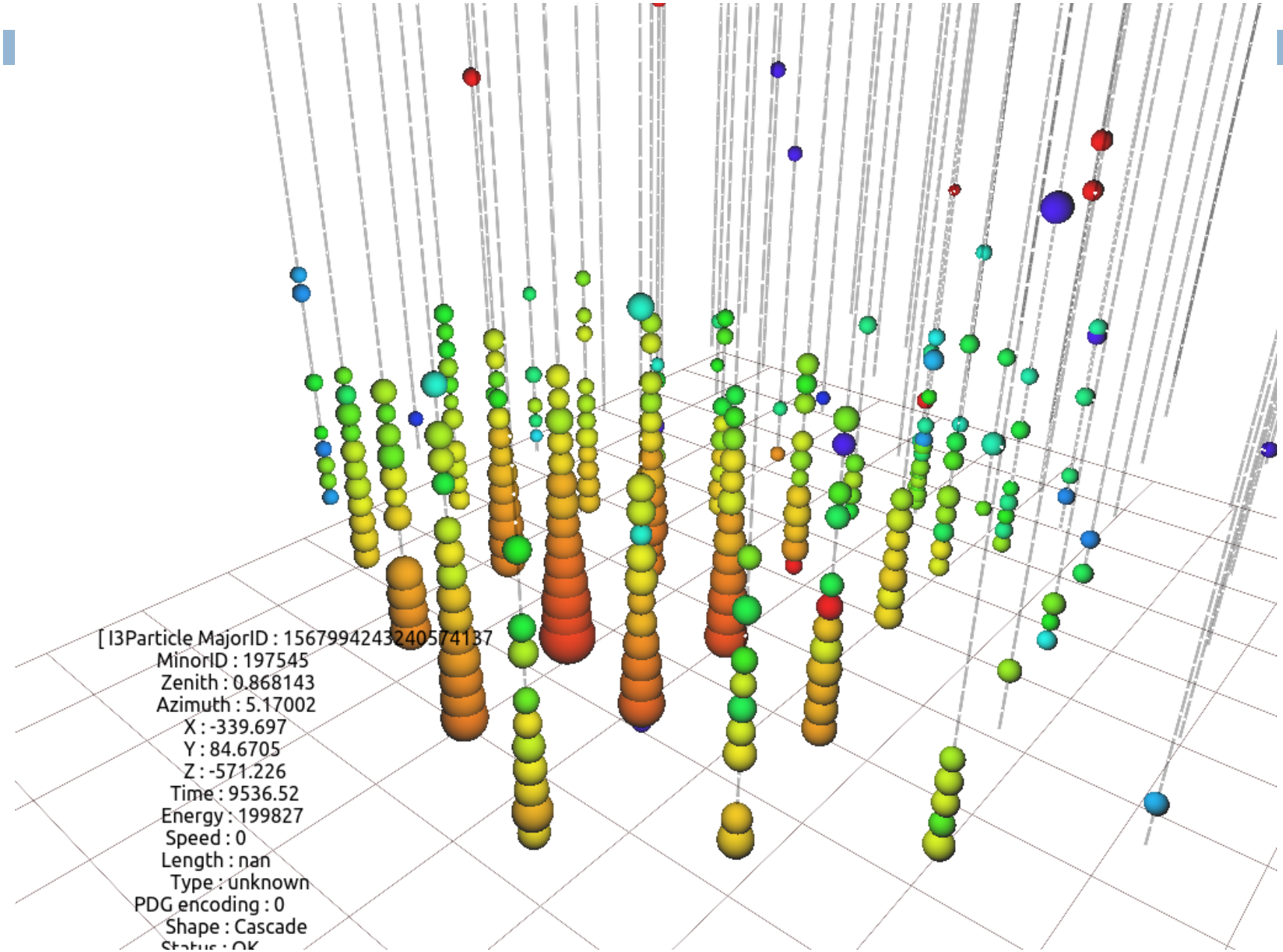
IC79 Event 1


[I3Particle MajorID : 14689586174822492468
MinorID : 511095
Zenith : 1.93444
Azimuth : 2.5264
X : 2.35218
Y : -420.233
Z : 308.474
Time : 9583.58
Energy : 54356.2
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

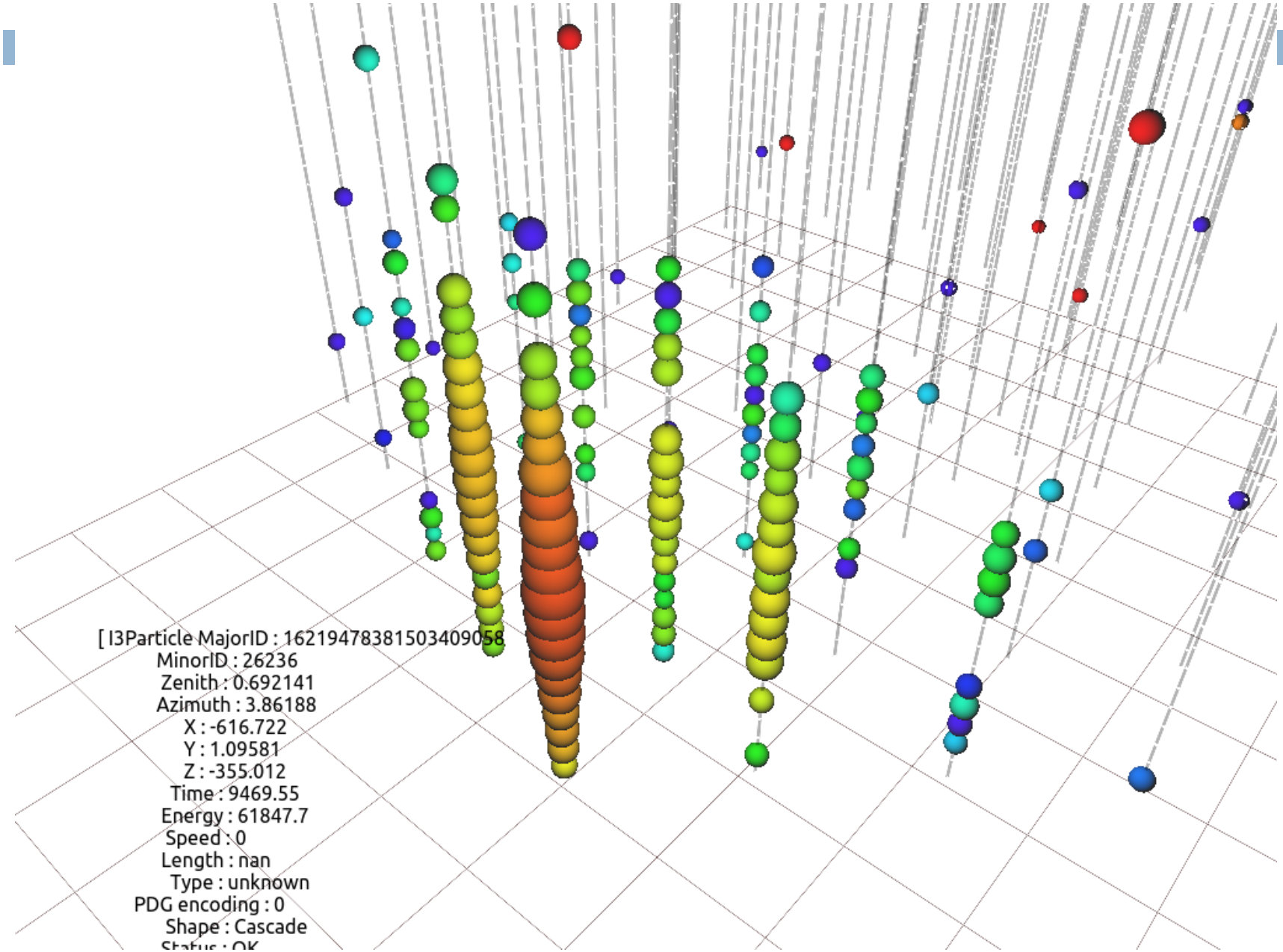
IC79 Event 2


[I3Particle MajorID : 158855165145875039 49
MinorID : 80083
Zenith : 1.45026
Azimuth : 3.79412
X : 496.732
Y : 187.347
Z : -308.566
Time : 9591.36
Energy : 173500
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

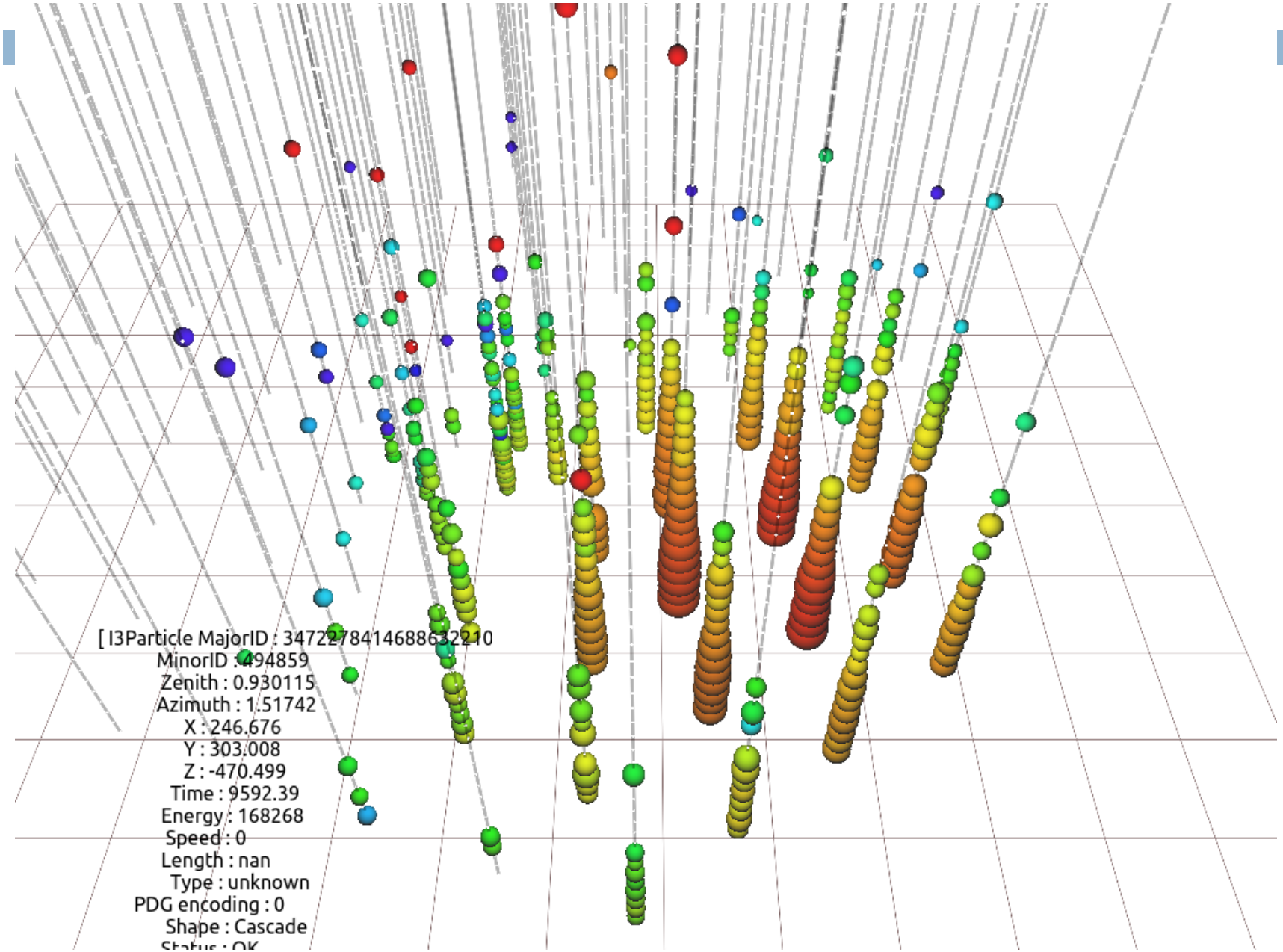
IC79 Event 3


[I3Particle MajorID : 15679942432405741 37
MinorID : 197545
Zenith : 0.868143
Azimuth : 5.17002
X : -339.697
Y : 84.6705
Z : -571.226
Time : 9536.52
Energy : 199827
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade
Status : OK

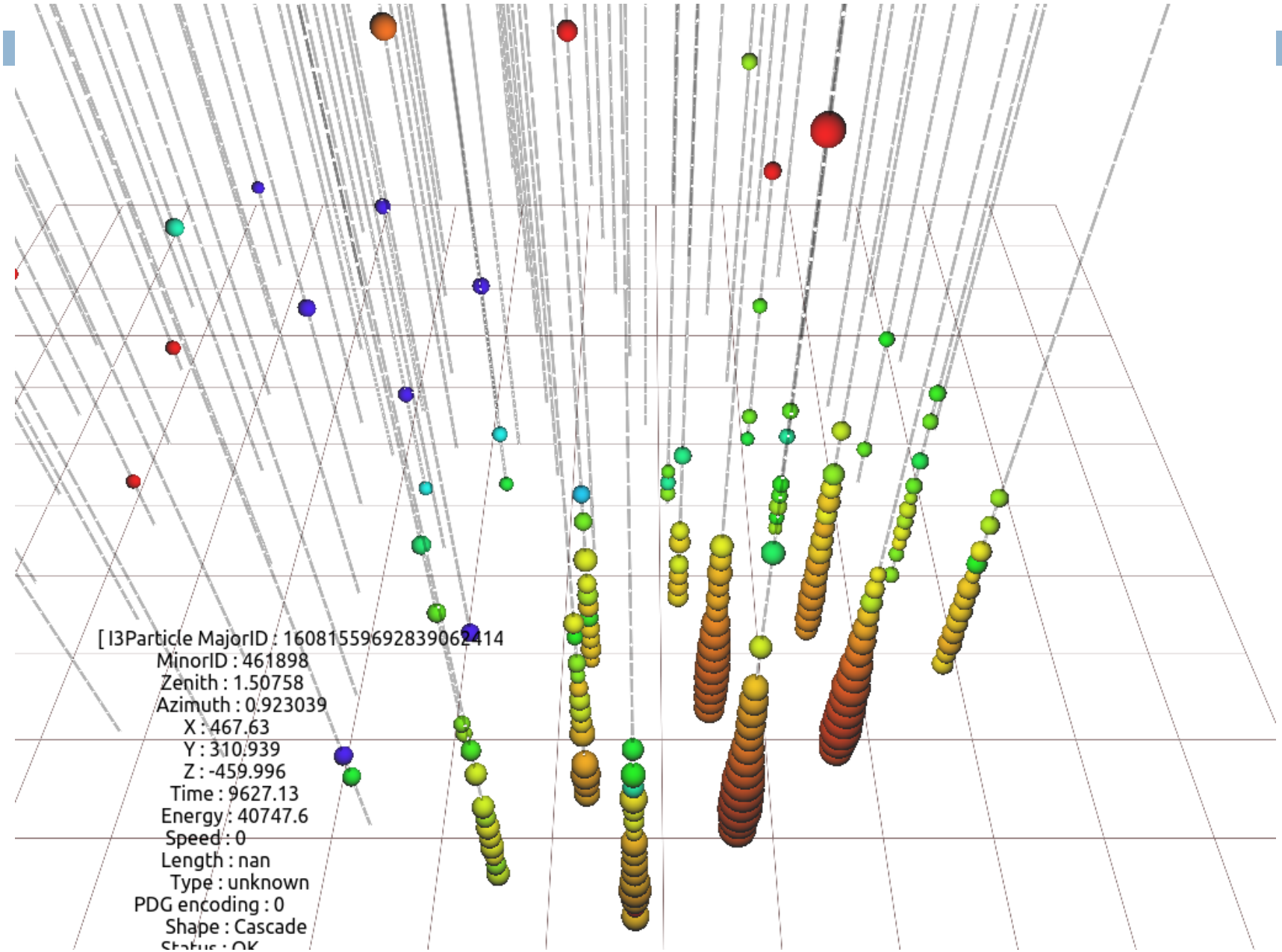
IC79 Event 4


[I3Particle MajorID : 16219478381503409058
MinorID : 26236
Zenith : 0.692141
Azimuth : 3.86188
X : -616.722
Y : 1.09581
Z : -355.012
Time : 9469.55
Energy : 61847.7
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

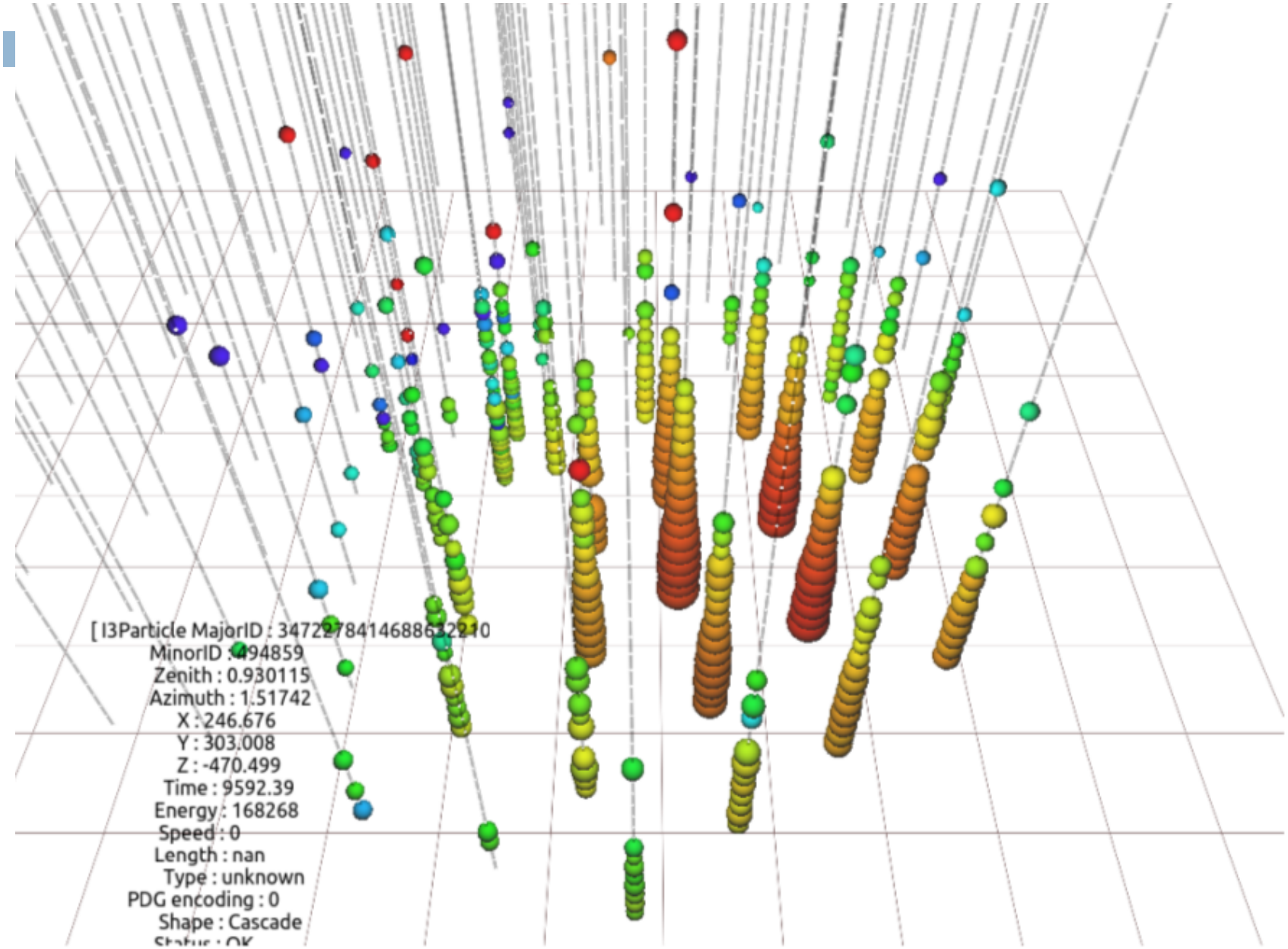
IC79 Event 5


[I3Particle MajorID : 34722784146886322 10
MinorID : 494859
Zenith : 0.930115
Azimuth : 1.51742
X : 246.676
Y : 303.008
Z : -470.499
Time : 9592.39
Energy : 168268
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

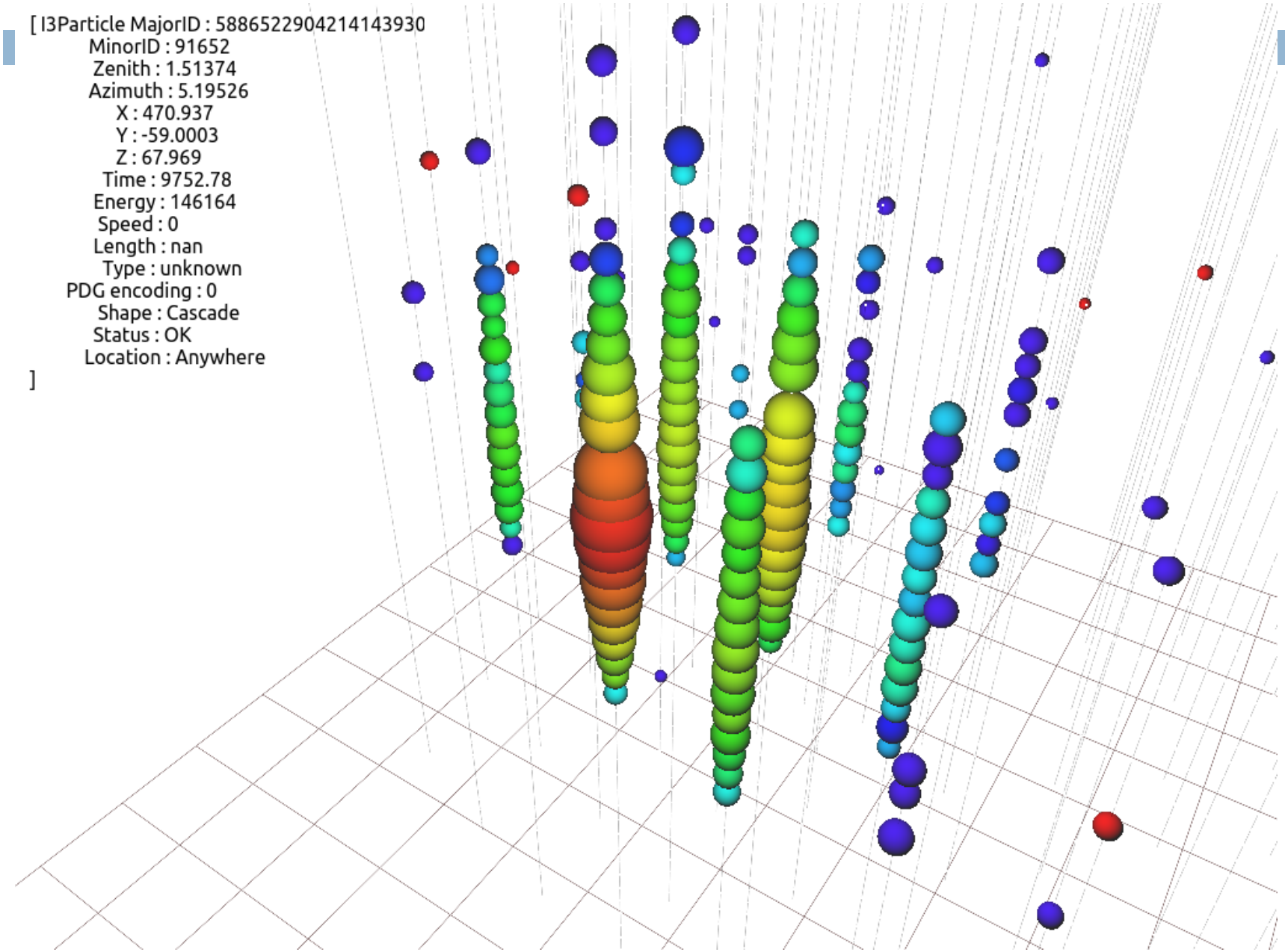
IC79 Event 6


[I3Particle MajorID : 160815596928390624 14
MinorID : 461898
Zenith : 1.50758
Azimuth : 0.923039
X : 467.63
Y : 310.939
Z : -459.996
Time : 9627.13
Energy : 40747.6
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

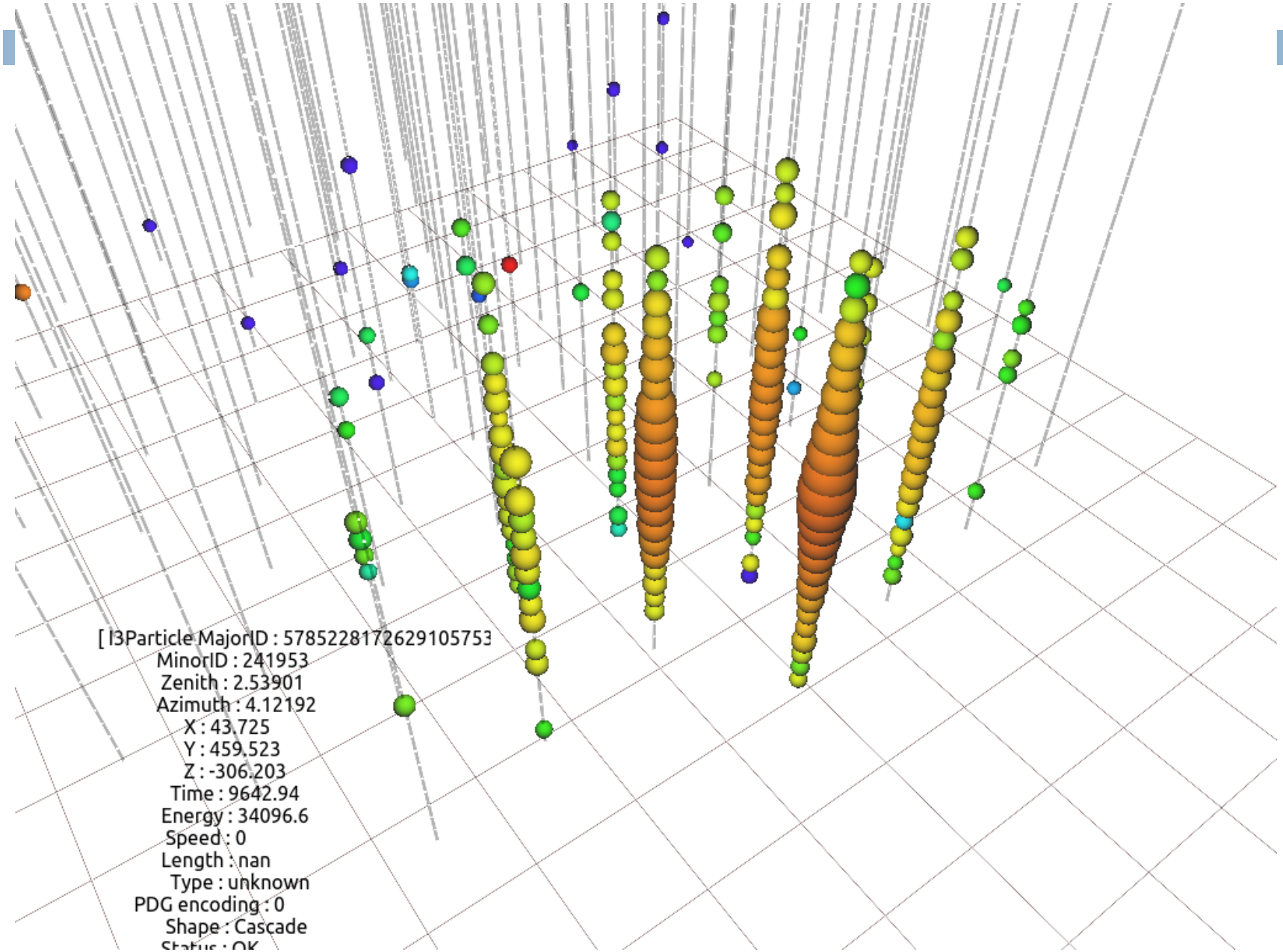
IC79 Event 7 - Swedish Chef



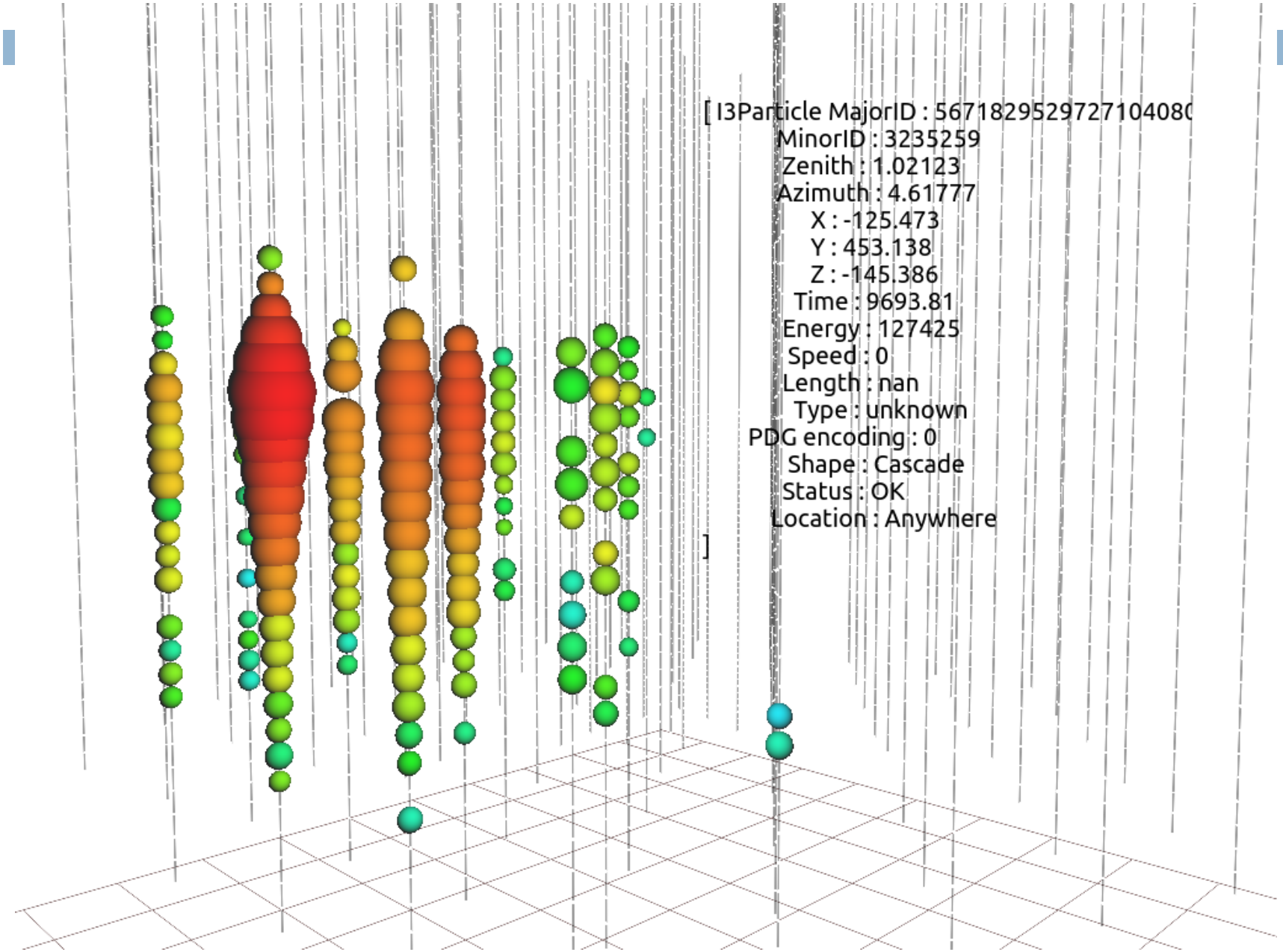
IC79 Event 8


[I3Particle MajorID : 5886522904214143930
MinorID : 91652
Zenith : 1.51374
Azimuth : 5.19526
X : 470.937
Y : -59.0003
Z : 67.969
Time : 9752.78
Energy : 146164
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade
Status : OK
Location : Anywhere
]

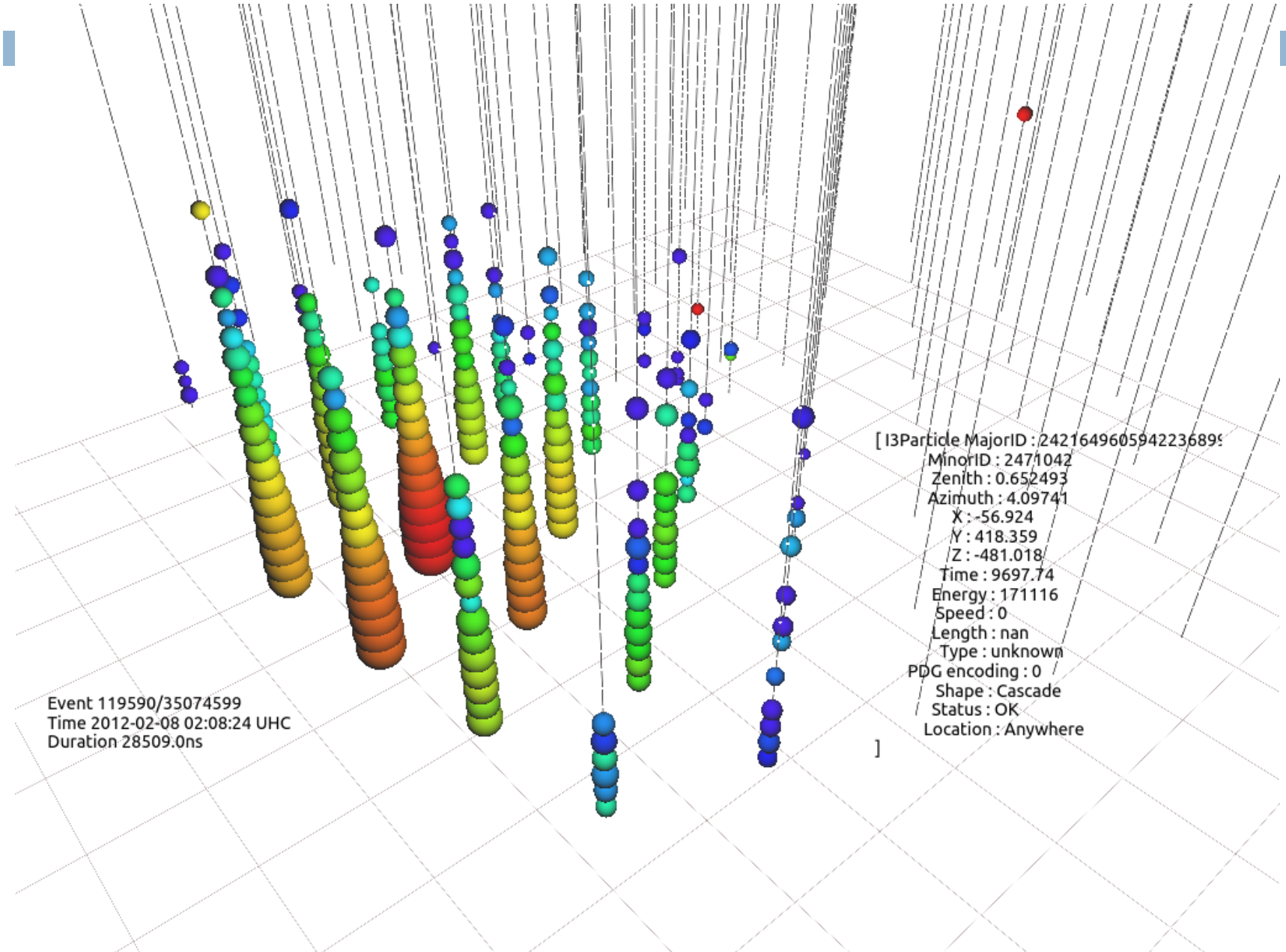
IC79 Event 9


[I3Particle MajorID : 5785228172629105753
MinorID : 241953
Zenith : 2.53901
Azimuth : 4.12192
X : 43.725
Y : 459.523
Z : -306.203
Time : 9642.94
Energy : 34096.6
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

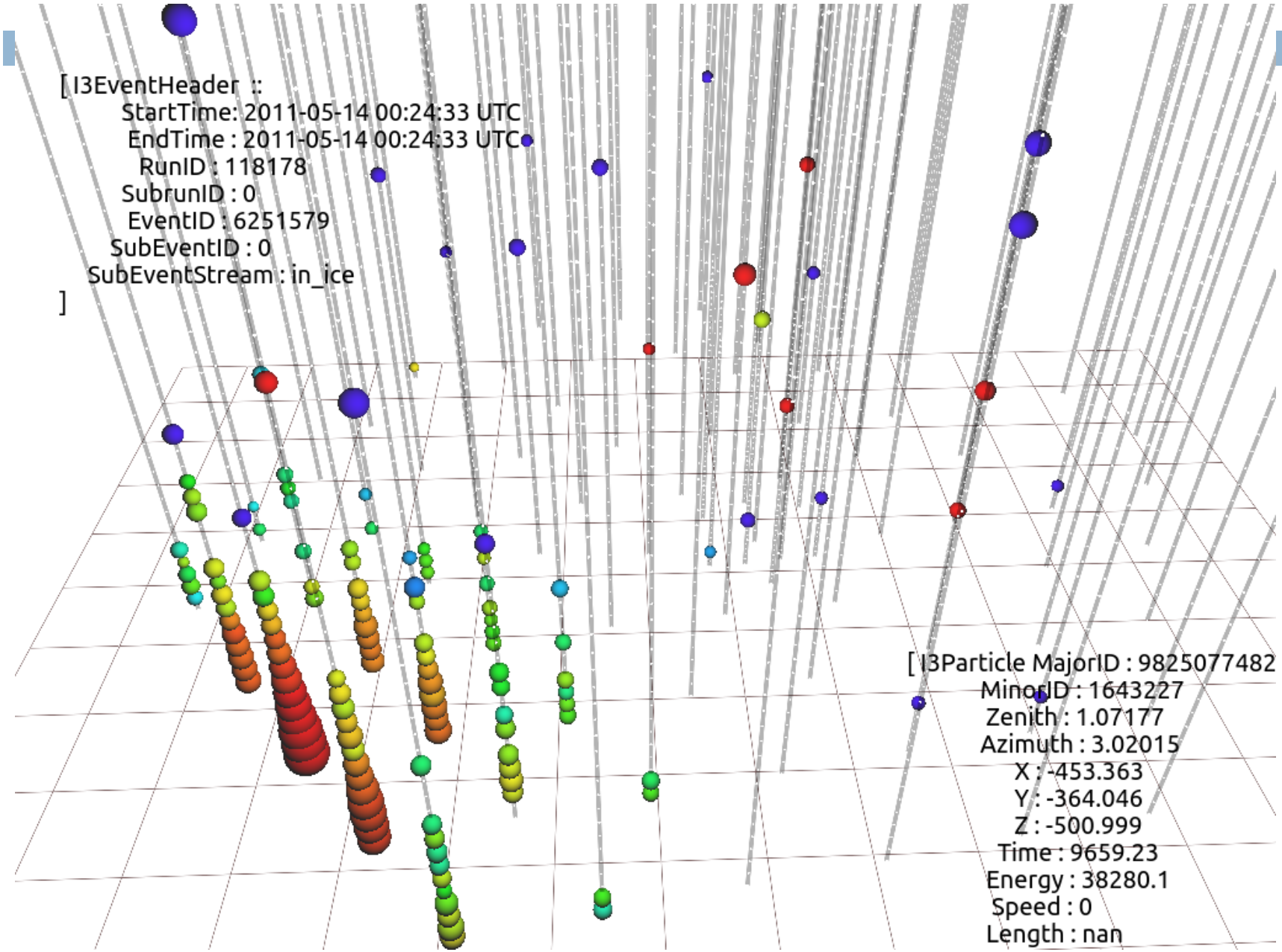
IC86 BURNSAMPLE Event 1



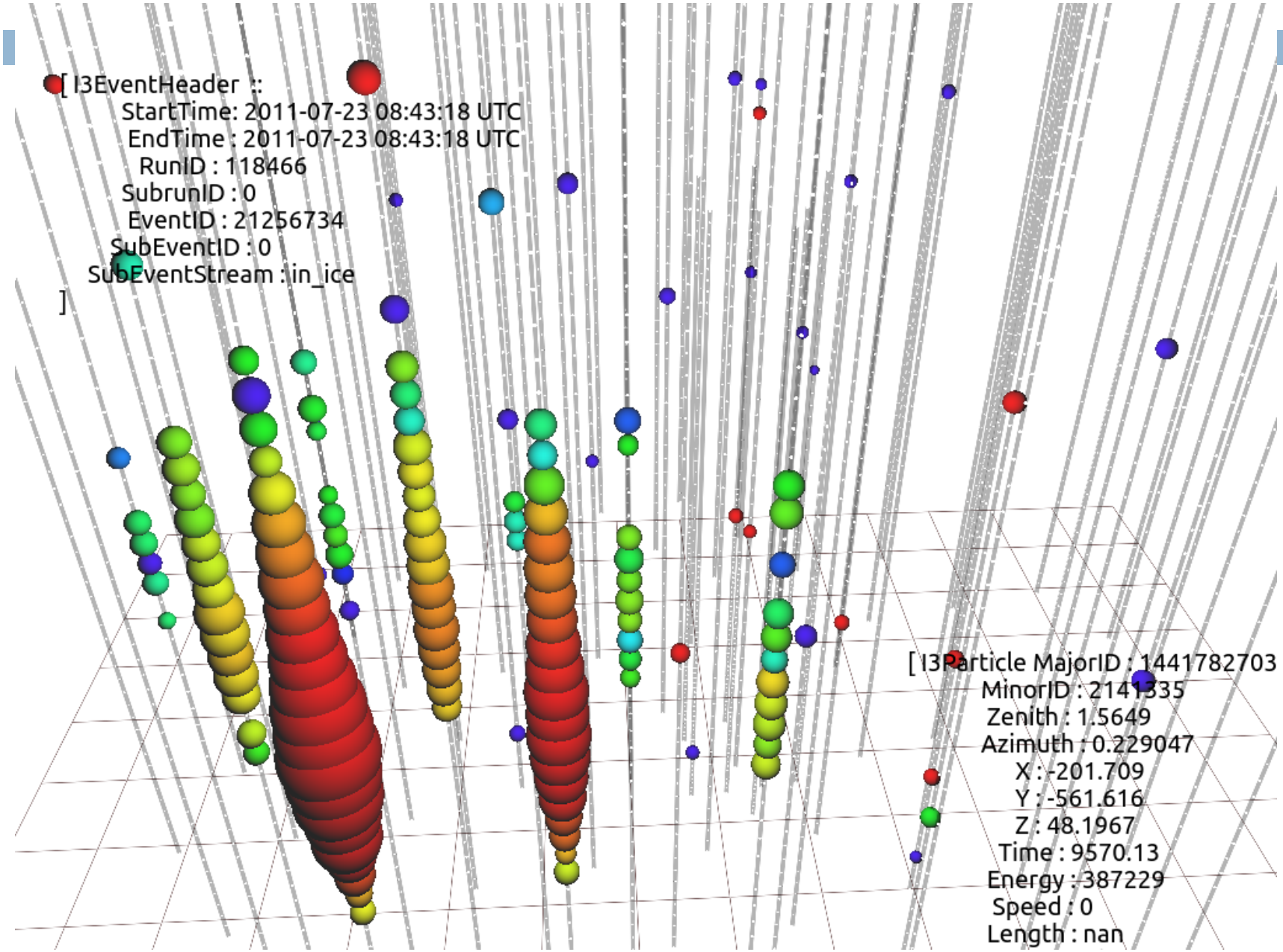
IC86 BURNSAMPLE Event 2



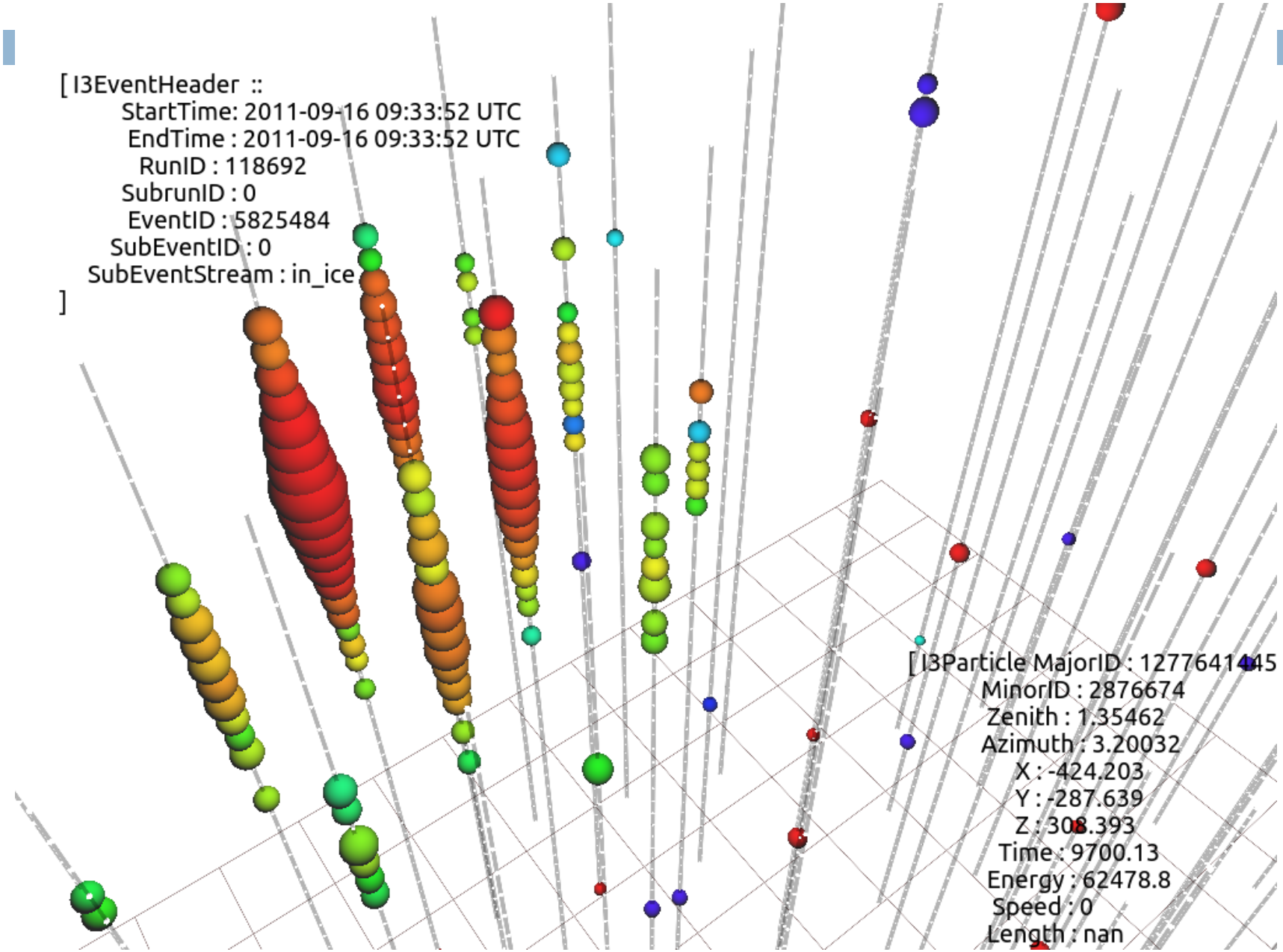
IC86 Event 1


[I3EventHeader ::
StartTime: 2011-05-14 00:24:33 UTC
EndTime : 2011-05-14 00:24:33 UTC
RunID : 118178
SubrunID : 0
EventID : 6251579
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 9825077482
MinorID : 1643227
Zenith : 1.07177
Azimuth : 3.02015
X : -453.363
Y : -364.046
Z : -500.999
Time : 9659.23
Energy : 38280.1
Speed : 0
Length : nan

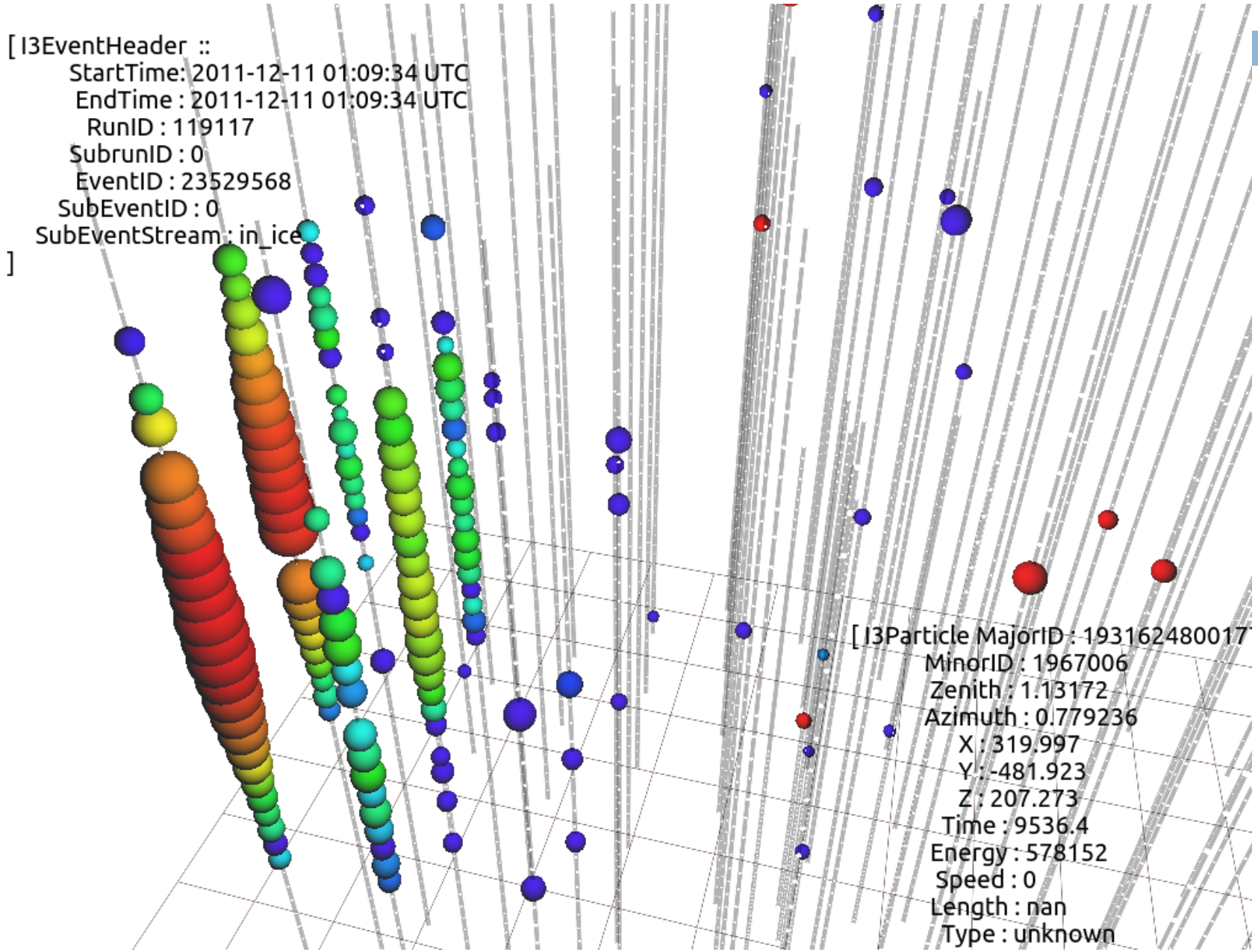
IC86 Event 2


[I3EventHeader ::
StartTime: 2011-07-23 08:43:18 UTC
EndTime : 2011-07-23 08:43:18 UTC
RunID : 118466
SubrunID : 0
EventID : 21256734
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 1441782703
MinorID : 2141335
Zenith : 1.5649
Azimuth : 0.229047
X : -201.709
Y : -561.616
Z : 48.1967
Time : 9570.13
Energy : 387229
Speed : 0
Length : nan

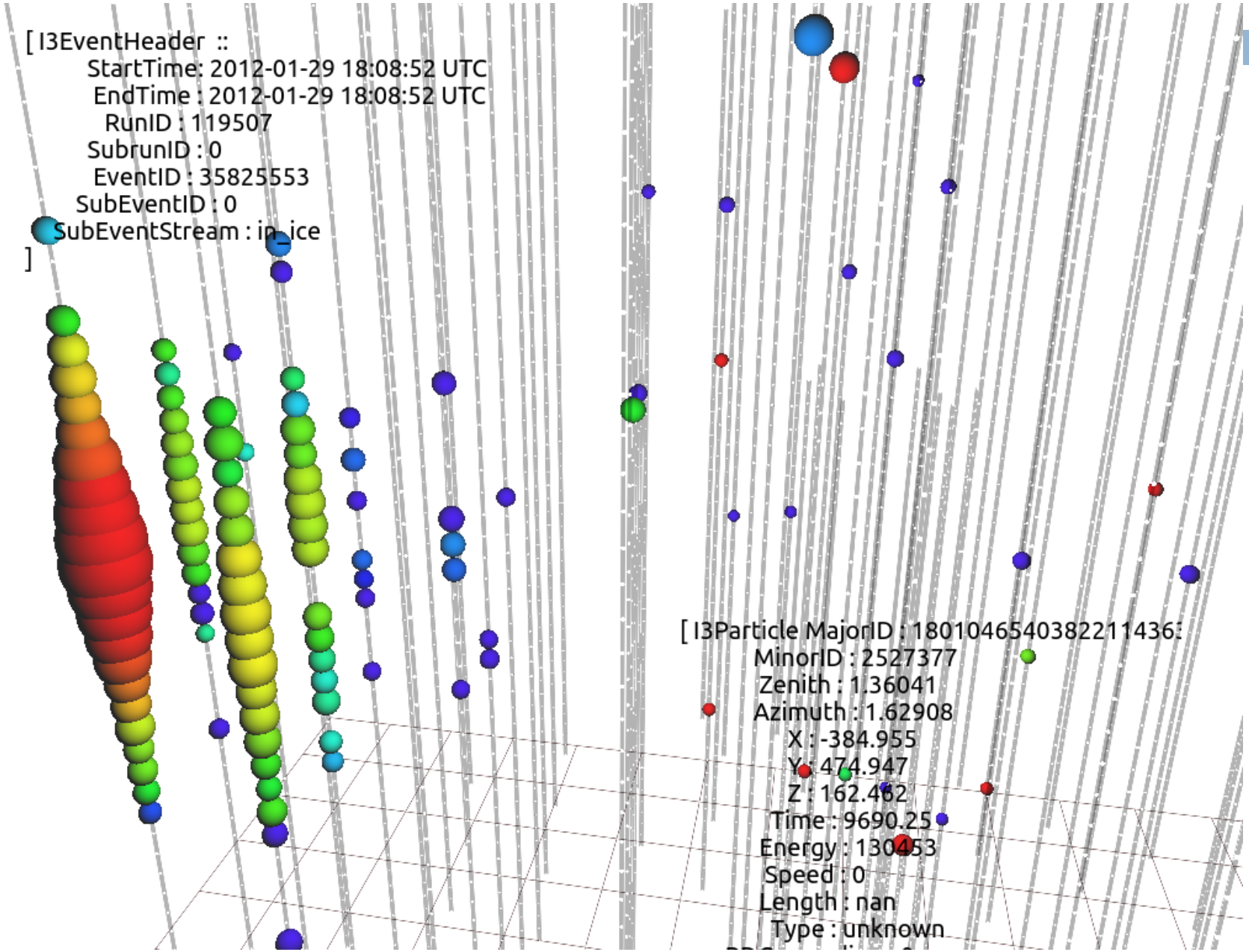
IC86 Event 3


[I3EventHeader ::
StartTime: 2011-09-16 09:33:52 UTC
EndTime : 2011-09-16 09:33:52 UTC
RunID : 118692
SubrunID : 0
EventID : 5825484
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 1277641445
MinorID : 2876674
Zenith : 1.35462
Azimuth : 3.20032
X : -424.203
Y : -287.639
Z : 308.393
Time : 9700.13
Energy : 62478.8
Speed : 0
Length : nan

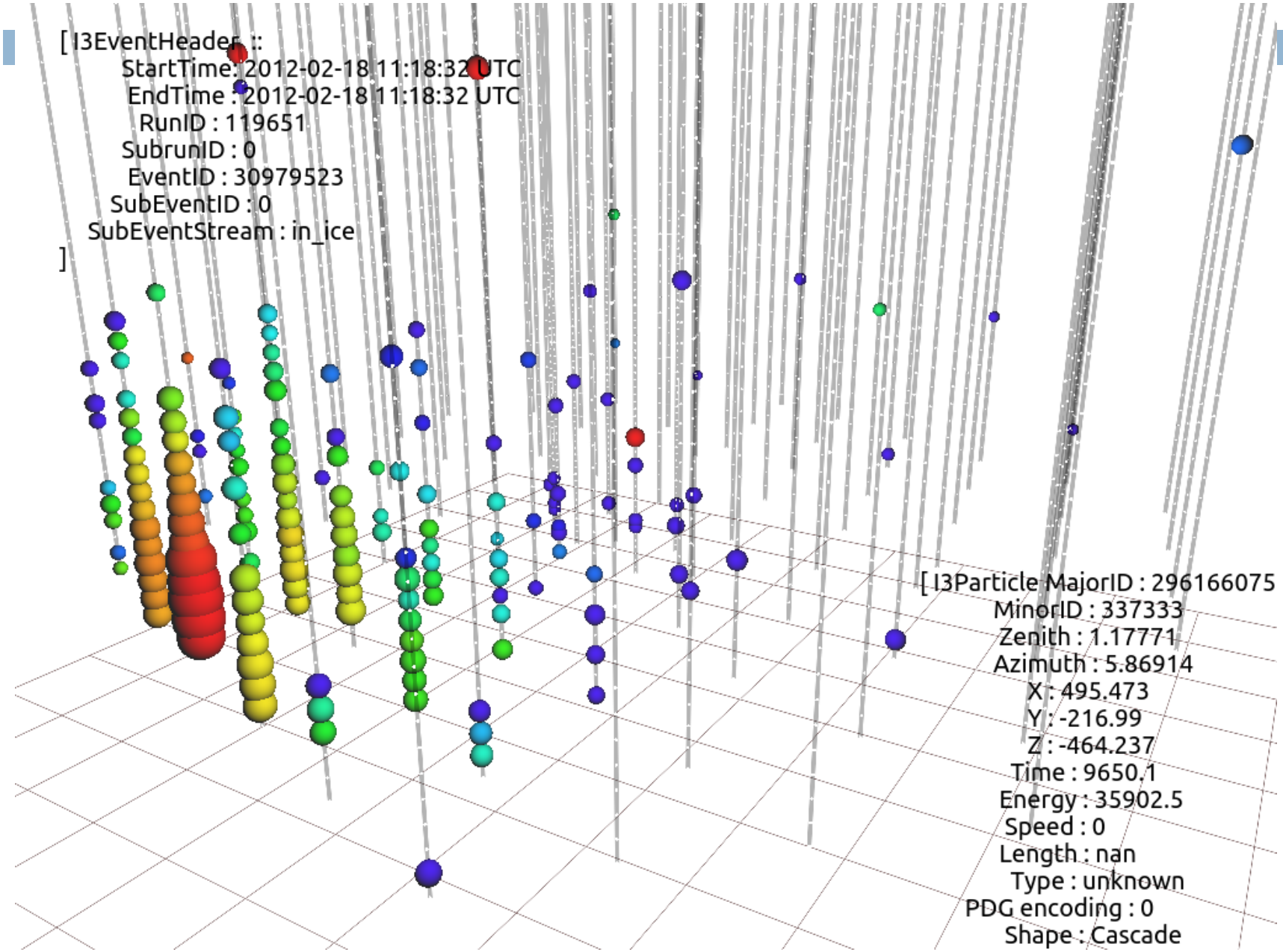
IC86 Event 4


[I3EventHeader ::
StartTime: 2011-12-11 01:09:34 UTC
EndTime : 2011-12-11 01:09:34 UTC
RunID : 119117
SubrunID : 0
EventID : 23529568
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 193162480017
MinorID : 1967006
Zenith : 1.13172
Azimuth : 0.779236
X : 319.997
Y : -481.923
Z : 207.273
Time : 9536.4
Energy : 578152
Speed : 0
Length : nan
Type : unknown

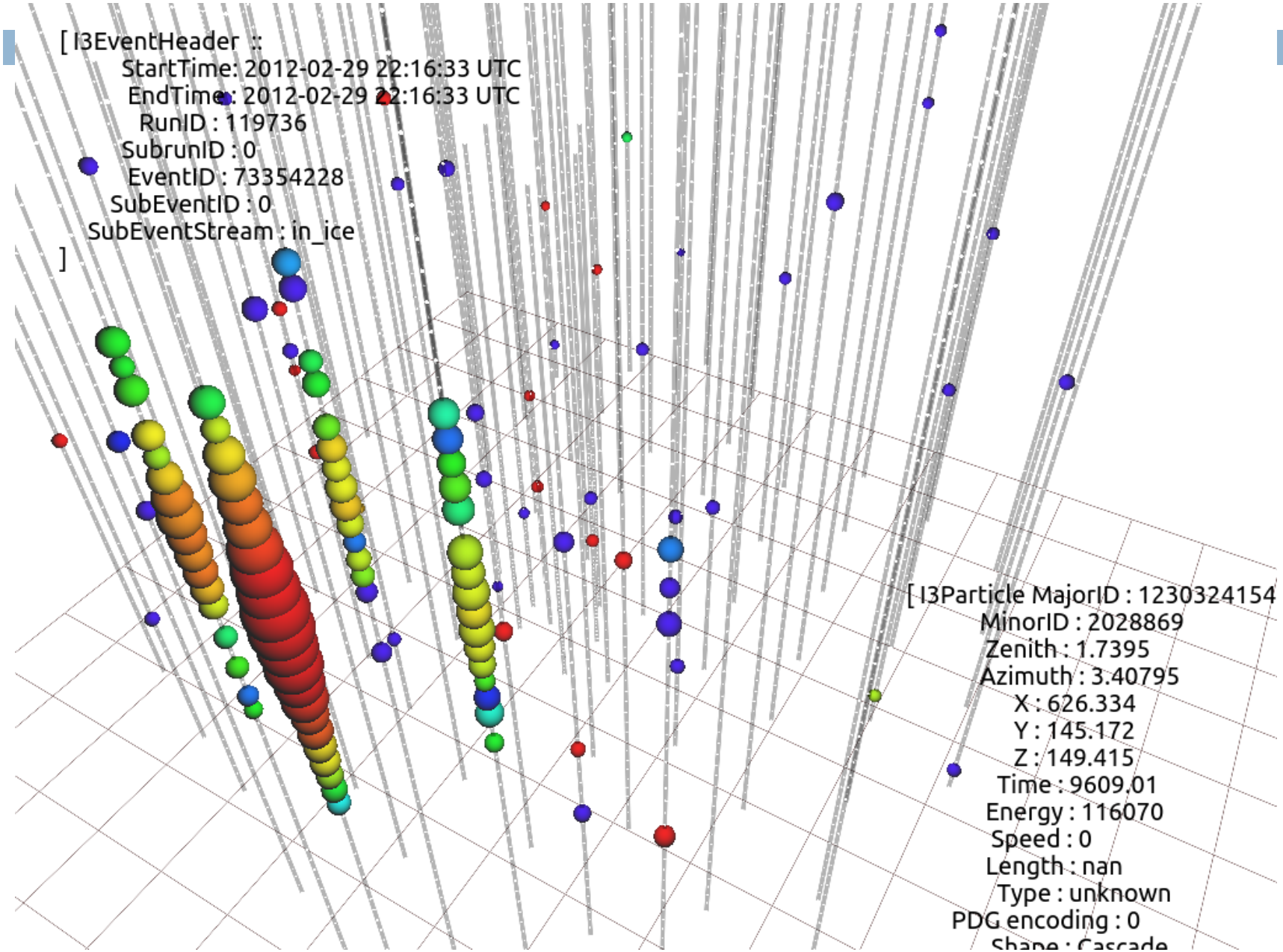
IC86 Event 5


[I3EventHeader ::
StartTime: 2012-01-29 18:08:52 UTC
EndTime : 2012-01-29 18:08:52 UTC
RunID : 119507
SubrunID : 0
EventID : 35825553
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 18010465403822114367
MinorID : 2527377
Zenith : 1.36041
Azimuth : 1.62908
X : -384.955
Y : 474.947
Z : 162.462
Time : 9690.25
Energy : 130453
Speed : 0
Length : nan
Type : unknown

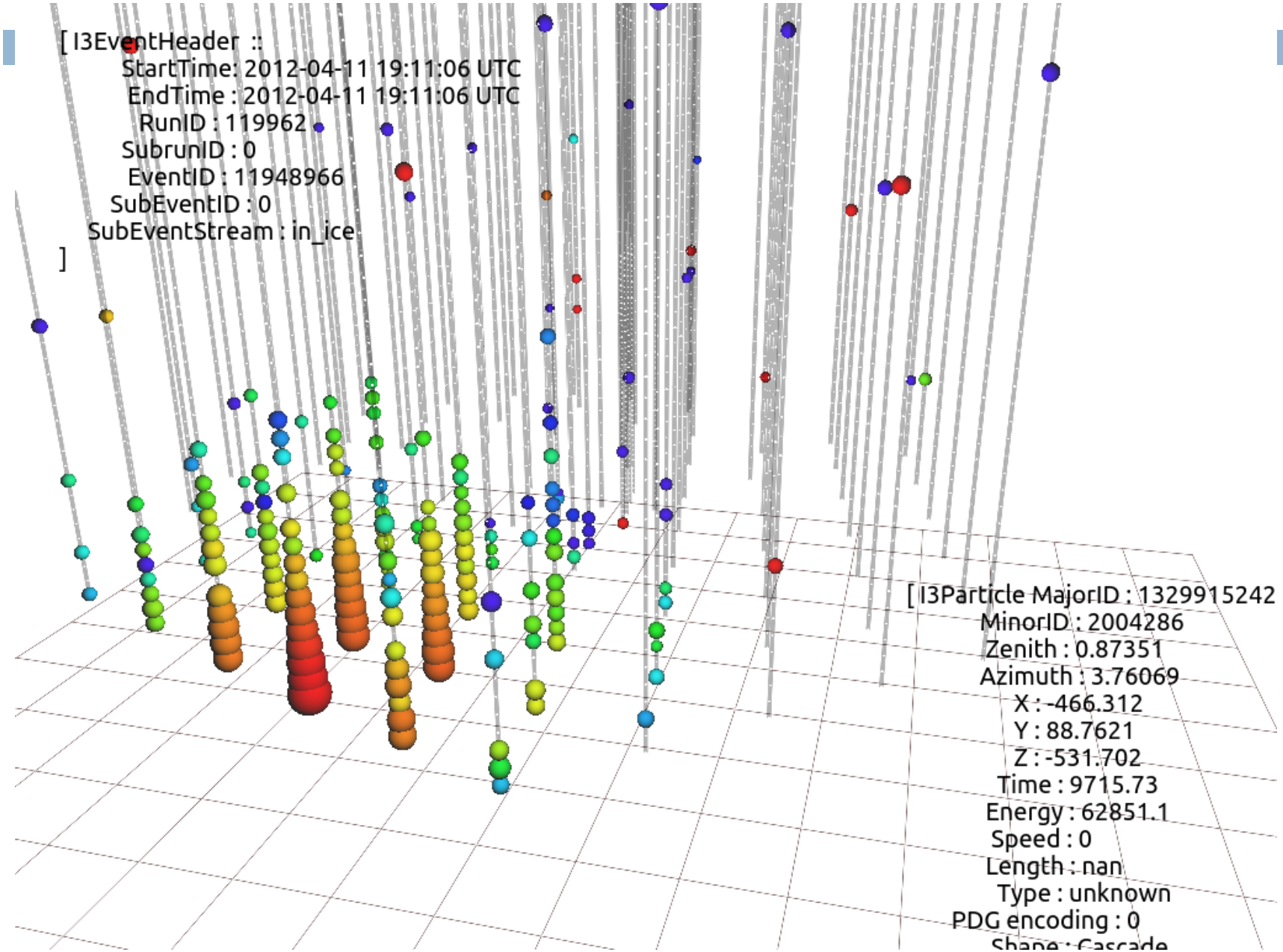
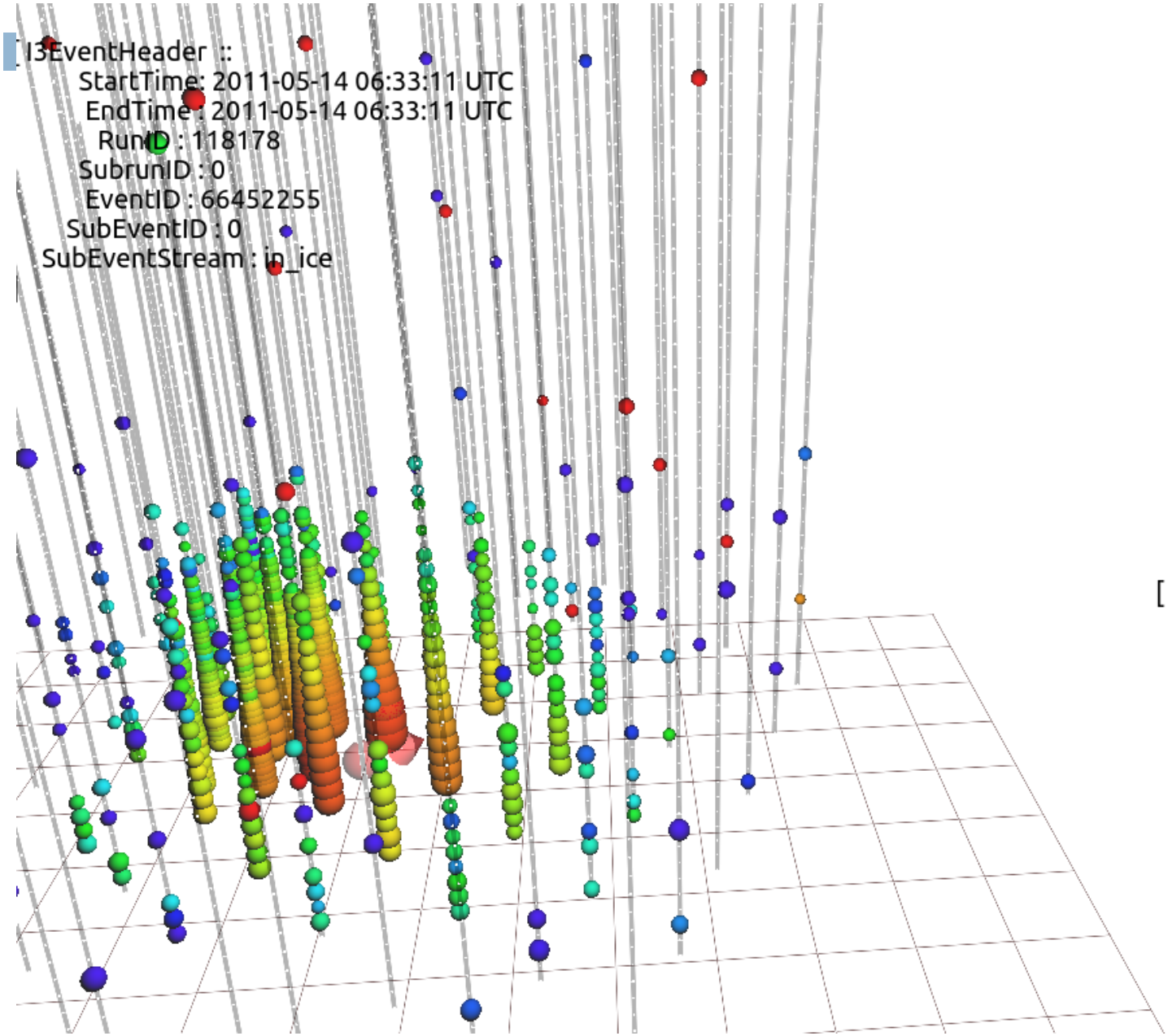
IC86 Event 6


[I3EventHeader ::
StartTime: 2012-02-18 11:18:32 UTC
EndTime : 2012-02-18 11:18:32 UTC
RunID : 119651
SubrunID : 0
EventID : 30979523
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 296166075
MinorID : 337333
Zenith : 1.17771
Azimuth : 5.86914
X : 495.473
Y : -216.99
Z : -464.237
Time : 9650.1
Energy : 35902.5
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

IC86 Event 7


[I3EventHeader ::
StartTime: 2012-02-29 22:16:33 UTC
EndTime: 2012-02-29 22:16:33 UTC
RunID : 119736
SubrunID : 0
EventID : 73354228
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 1230324154
MinorID : 2028869
Zenith : 1.7395
Azimuth : 3.40795
X : 626.334
Y : 145.172
Z : 149.415
Time : 9609.01
Energy : 116070
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

IC86 Event 8


[I3EventHeader ::
StartTime: 2012-04-11 19:11:06 UTC
EndTime : 2012-04-11 19:11:06 UTC
RunID : 119962
SubrunID : 0
EventID : 11948966
SubEventID : 0
SubEventStream : in_ice
]
[I3Particle MajorID : 1329915242
MinorID : 2004286
Zenith : 0.87351
Azimuth : 3.76069
X : -466.312
Y : 88.7621
Z : -531.702
Time : 9715.73
Energy : 62851.1
Speed : 0
Length : nan
Type : unknown
PDG encoding : 0
Shape : Cascade

IC86 Event 9 - Camilla the Chicken