Validation of Geant4 Balloon Test simulator (BalloonTestV13)

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1 Overview

We checked out whether detector geometry, materials and ID numbering are implemented correctly or not in Geant4 simulator BalloonTestV13. The parameters of this program are shown in the document "Detector Geometry used for Geant4 Balloon Test Simulator (BalloonTestV13)".

2 Check out geometry and materials

2.1 External Gamma-ray Target (XGT)

We shot geantinos, virtual particles that do not interact with any material, to scintillators and examined tracking verbose output file. An example of output file is shown in Figure 1, where we shot a particle from position (0 mm, 0 mm, 696.7 mm) and direction of (1, 1, 0). The length a beam went through in a material is given in the column StepLeng. The size of a scintillator along beam direction is shown in StepLeng of Step#2 and is the same as we intend to implement (100mm). We shot geantinos vertically to each scintillator surfaces and examined its tracking verbose output. Size and position of four XGTs are implemented correctly.

```
*****************************************************************************************************
* G4Track Information:   Particle = geantino,   Track ID = 1,   Parent ID = 0
*****************************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0        0        0      697     3e+03        0        0         0 worldPhys           initStep
    1     88.4     88.4      697     3e+03        0      125       125 Target          Transportation
    2      159      159      697     3e+03        0      100       225 TargetBox          Transportation
    3      258      258      697     3e+03        0      140       365 AcrylSupport          Transportation
    4      265      265      697     3e+03        0       10       375 TargetBox          Transportation
    5      269      269      697     3e+03        0        5       380 worldPhys          Transportation
    6      385      385      697     3e+03        0      164       544 PV          Transportation
    7      387      387      697     3e+03        0      2.5       547 worldPhys          Transportation
    8 1.09e+04 1.09e+04      697     3e+03        0 1.49e+04  1.55e+04  OutOfWorld Transportation
  ....
```

Figure 1: A part of tracking verbose output.

2.2 Tracker (TKR)

To check out z coordinate value of SSDs, we shot $\mu-$ along z axis and examined Geant4 output. TrackerOut.dat is shown in Figure 2, where XYZi gives a input position of a particle ($\mu-$). A z-position of all SSDs are the same as we intended to place. We made a figure of upper side SSDs in each tray and that of lower side to check out whether trays are implemented correctly or not. These are shown in Figure 3. Tray configuration (i.e., the number of 4-inch and 6-inch SSDs) are correctly implemented. We also checked out the thickness and order of materials by shooting geantino, a virtual particle that do not interact with any material. Tracking verbose output of geantino is shown in Figure 4. In this output, z coordinate, thickness and name of materials are given in columns 'Z (mm)', 'StepLeng', and 'NextVolume', respectively. All materials in TKR have the same thickness as we intend, and order of materials placement is also correct.

2.3 Anti Coincidence Detector (ACD) and Calorimter (CAL)

As we did in the previous section, we examined tracking verbose output to checkout whether geometry of ACD and CAL are implemented correctly or not. These tracking verbose outputs are shown in Figure 5 and 6. Thickness and order of materials in top ACD tiles and CAL are shown in these outputs, and implemented correctly.

2.4 Pressure Vessel (PV) and VME Crate

We shot geantinos to PV and VME crate and examined its tracking verbose output file to check out its geometry. Size of Upper Vessel, middle Vessel, lower Vessel and cover are implemented correctly. Size of VME Crate is also implemented correctly.

3 Materials of each Detector

In order to examine whether parameters of each materials (atomic number, density, etc...) are appropriately implemented or not, we shot heavy charged particle in our simulator and investigated that the energy loss is consistent with theoretical prediction or not.

3.1 Tracker (TKR)

We bombarded 10,000 muons of 3 GeV to TKR and compared energy loss in TKR with that expected from Bethe-Bloch formula. We derived Energy loss from TrackerOut.dat, and examined energy which was lost between top surface of bottommost SSD layer and top most SSD layer. Histogram of energy loss is given in Figure 7. The measured mean energy loss is 17.38 MeV. Materials $\mu-$ passed are given in Table 1, and expected energy loss calculated from Bethe-Bloch formula for 3 GeV $\mu-$ in TKR is 17.63 MeV. In this table polyamide is approximated as carbon of the same density. The difference between the measured value and theoretical one is only 1.4 %, so we regard that materials in TKR are appropriately implemented.

Table 1: Total thickness, density and theoretical energy loss.

material	density	total thickness	theoretical energy loss
Silicon	2.33 g cm^{-3}	1.00 cm	4.67 MeV
Pb	11.35 g cm^{-3}	0.62 cm	10.2 MeV
Cu	3.54 g cm^{-3}	0.0725 cm	0.434 MeV
Al	0.016 g cm^{-3}	33 cm	1.02 MeV
Carbon (face sheet)	1.47 g cm^{-3}	0.1875 cm	0.551 MeV
Carbon (polyamide)	1.42 g cm^{-3}	0.303 cm	0.859 MeV

3.2 Calorimeter (CAL)

Like we have done in the previous section, we shot a 3 GeV $\mu-$ 10,000 times and calculated energy deposit in CsI crystals from CalOut.dat. The result is shown in Figure 8. The measured mean deposit energy is 132 MeV, and 140 MeV is expected as energy loss from Bethe-Bloch formula for 3 GeV $\mu-$ in eight CsI layers which is 18.4 cm thickness. The difference is only 5.7 %, and this residual may be explained that some portion of the energy that primary particle ($\mu-$) lost is not deposited in CsI, but carried away as knock-on electrons those escaped out of calorimeter or were absorbed in rubber/Al sheets.

4 Examination of Detector IDs

To check out ID numbering of detectors is correct or not, we shot charged particles to detectors and examined output files.

4.1 External Gamma-ray Target (XGT)

We shot muons from center of each scintillator. We checked out ID numbering using TargetOut.dat. TargetOut.dat and position which we shot muons are shown in Figure 9 and 10, respectively. The first event corresponds to position1, the second event corresponds to position2, and so on. ID numbering of XGTs are implemented correctly.

4.2 Anti Coincidence Detector (ACD)

In Balloon experiment the ID numbering of each ACD tiles are renewed from BeamTest (See Table 6 in "Detector Geometry used for Geant4 Balloon Test Simulator (BalloonTestV13)"). To check out ID numbering, we shot muons to each ACD tiles and examined AntiOut.dat. Each tiles are numbered correctly.

4.3 Tracker (TKR)

We used TrackerOut.dat which is shown in Figure 2 to check out whether ID numbering of SSDs are implemented correctly or not. SSDs are numbered from 0 (bottommost Si) to 25 (topmost Si) as we intend.

4.4 Calorimeter (CAL)

CalOut.dat was used to check out CsI IDs. We shot muons into 5 points as given in Figure 11. At four corners we shot muons from top surface of topmost layer, and at position5 we shot a $\mu-$ from top surface of the bottommost CsI layer along Z-axis. The first event corresponds to position1, the second event corresponds to position2, and so on. Obtained CalOut.dat is shown in Figure 12. As you can see, there are three kinds of ID for CAL, LayerID, LogID and LogDID. LayerID should be numbered from 0 to 7 in increasing order with decreasing Z. LogID should be numbered from 0 to 79 in increasing order with decreasing Z and increasing X or Y. And LogDID is the number used only in Geant4. In the current simulation, one CsI log is divided into 10 blocks, to record a position where a particle goes through in a CsI log. These blocks are numbered from 0 to 9 n increasing order with increasing X or Y coordinate. We can see from Figure 12 that ID numbers are implemented as given above.

```
EventNo= 1
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= 0 0 700
 NoTrackerHit= 30
  ID= 25  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.0462958  0.0115618  388.108
   XYZo= -0.0466473  0.0115453  387.708   DepE= 0.10029  ParE= 3101.73
  ID= 24  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.0499251  0.0123709  384.992
   XYZo= -0.0504079  0.0124925  384.592   DepE= 0.114276  ParE= 3101.63
  ID= 23  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.0836473  0.0199334  356.042
   XYZo= -0.0837078  0.0197043  355.642   DepE= 0.0997751  ParE= 3101.14
  ID= 22  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.0837453  0.0184709  352.926
   XYZo= -0.0837515  0.018289  352.526   DepE= 0.160987  ParE= 3101.04
  ID= 21  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.0874487  0.00712023  323.976
   XYZo= -0.0869407  0.00710058  323.576   DepE= 0.128541  ParE= 3100.54
  ID= 20  ParSpc= mu-  TrkLen= 0.4  XYZi= -0.083563  0.00703021  320.86
   XYZo= -0.0830657  0.00702006  320.46   DepE= 0.111712  ParE= 3100.41
  ID= 19  ParSpc= mu-  TrkLen= 0.400001  XYZi= -0.0505858  -0.000428153  291.91
   XYZo= -0.049935  -0.000615499  291.51   DepE= 0.132821  ParE= 3098.85
  ID= 18  ParSpc= mu-  TrkLen= 0.400001  XYZi= -0.0450297  -0.00197016  288.794
   XYZo= -0.0443079  -0.00216986  288.394   DepE= 0.103419  ParE= 3098.72
  ID= 17  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.00681879  -0.00986245  259.844
   XYZo= 0.00742218  -0.00985809  259.444   DepE= 0.131966  ParE= 3098.24
  ID= 16  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.011604  -0.0102542  256.728
   XYZo= 0.0122194  -0.0103126  256.328   DepE= 0.135389  ParE= 3098.11
  ID= 15  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.0560374  -0.0145847  227.778
   XYZo= 0.0564806  -0.014728  227.378   DepE= 0.17386  ParE= 3097.54
  ID= 14  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.0594812  -0.0160883  224.662
   XYZo= 0.059923  -0.0162884  224.262   DepE= 0.109321  ParE= 3097.36
  ID= 13  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.0837112  -0.0343149  195.712
   XYZo= 0.0841304  -0.0342994  195.312   DepE= 0.0880487  ParE= 3096.86
  ID= 12  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.0874053  -0.0339928  192.596
   XYZo= 0.0878873  -0.0339477  192.196   DepE= 0.11424  ParE= 3096.77
  ID= 11  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.111882  -0.0356946  163.646
   XYZo= 0.112354  -0.0358175  163.246   DepE= 0.11937  ParE= 3096.3
  ID= 10  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.115689  -0.036306  160.53
   XYZo= 0.11618  -0.0363778  160.13   DepE= 0.118794  ParE= 3096.18
  ID= 9  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.148191  -0.0391701  131.78
   XYZo= 0.148218  -0.0390149  131.38   DepE= 0.0977857  ParE= 3093.07
  ID= 8  ParSpc= mu-  TrkLen= 0.4  XYZi= 0.147867  -0.0374776  128.464
   XYZo= 0.147818  -0.0372661  128.064   DepE= 0.116749  ParE= 3092.97
  ID= 7  ParSpc= mu-  TrkLen= 0.400001  XYZi= 0.150789  -0.0273323  99.714
   XYZo= 0.151015  -0.0280267  99.314   DepE= 0.1183  ParE= 3090.72
  ID= 6  ParSpc= mu-  TrkLen= 0.400001  XYZi= 0.152975  -0.033334  96.398
   XYZo= 0.153244  -0.034062  95.998   DepE= 0.105573  ParE= 3090.6
  ID= 5  ParSpc= mu-  TrkLen= 0.400002  XYZi= 0.182932  -0.0910283  67.648
   XYZo= 0.182996  -0.0921488  67.248   DepE= 0.10903  ParE= 3088.61
  ID= 4  ParSpc= mu-  TrkLen= 0.400002  XYZi= 0.183164  -0.101892  64.332
   XYZo= 0.183186  -0.103228  63.932   DepE= 0.125433  ParE= 3088.5
  ID= 3  ParSpc= mu-  TrkLen= 0.400002  XYZi= 0.18375  -0.186231  35.582
   XYZo= 0.183711  -0.187468  35.182   DepE= 0.104469  ParE= 3088.24
  ID= 2  ParSpc= mu-  TrkLen= 0.400002  XYZi= 0.183906  -0.196355  32.266
   XYZo= 0.183933  -0.197574  31.866   DepE= 0.123086  ParE= 3088.13
  ID= 1  ParSpc= mu-  TrkLen= 0.400001  XYZi= 0.180819  -0.271556  3.516
   XYZo= 0.18087  -0.272349  3.116   DepE= 0.141447  ParE= 3087.69
  ID= 0  ParSpc= mu-  TrkLen= 0.400001  XYZi= 0.180775  -0.278551  0.2
   XYZo= 0.180761  -0.279402  -0.2   DepE= 0.119405  ParE= 3087.55
  ....
```

Figure 2: TrackerOut.dat used to check out Z coordinate of SSDs layers.

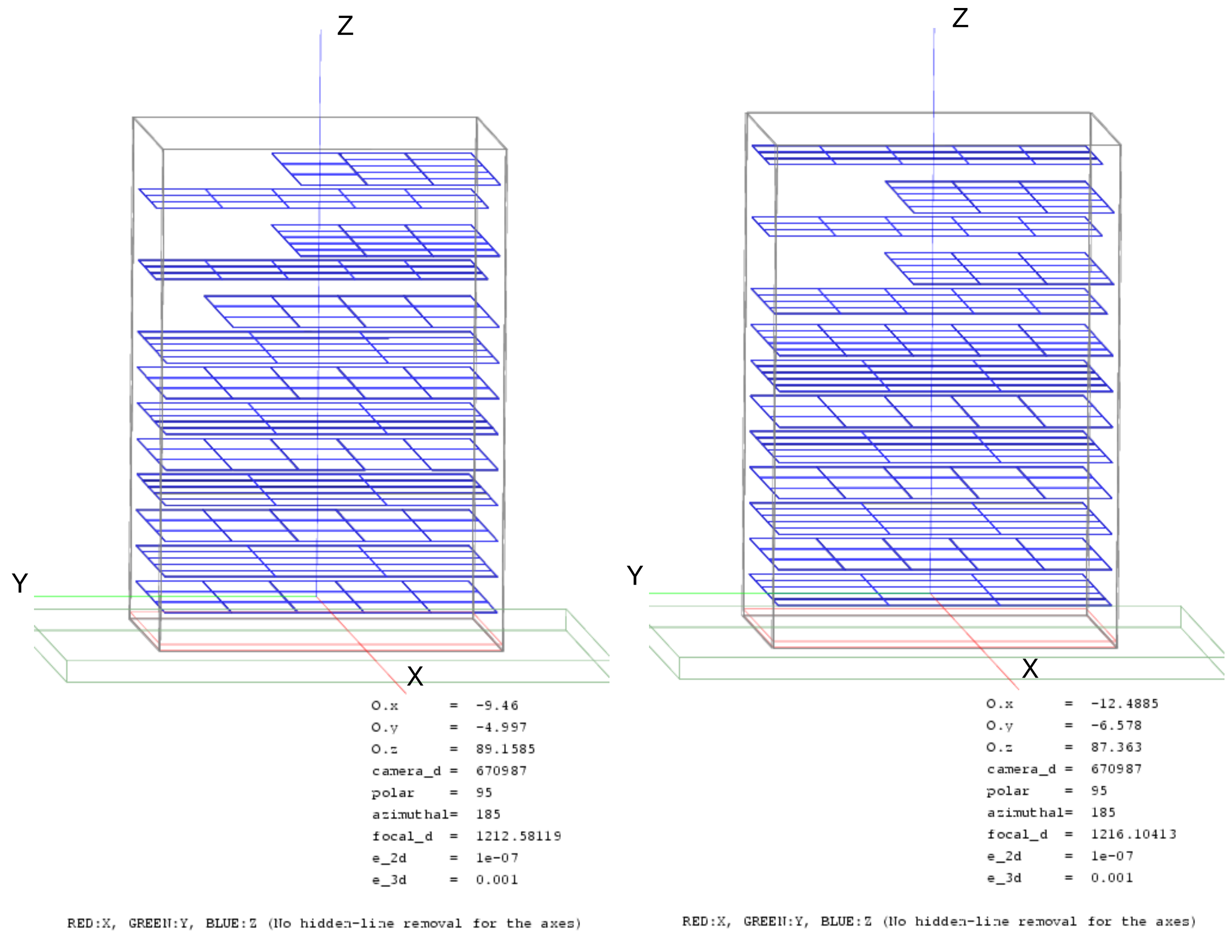

Figure 3: Left: Figure of upper SSDs in each trays. Right: Figure of lower SSDs in each trays.

```
Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
  ....
    9      -30      -30      417     1e+03        0      123       283 TopmostTray           Transportation
   10      -30      -30      417     1e+03        0     0.55       283 facesheet           Transportation
   11      -30      -30      416     1e+03        0    0.075       284 Core           Transportation
   12      -30      -30      389     1e+03        0     27.9       311 facesheet           Transportation
   13      -30      -30      388     1e+03        0    0.075       312 Pb           Transportation
   14      -30      -30      388     1e+03        0      0.2       312 KapCu           Transportation
   15      -30      -30      388     1e+03        0    0.029       312 KapPolyamide           Transportation
   16      -30      -30      388     1e+03        0    0.121       312 4inchSSD           Transportation
   17      -30      -30      388     1e+03        0      0.4       312 TopmostTray           Transportation
   18      -30      -30      388     1e+03        0     0.05       312 worldPhys           Transportation
  ....
```

Figure 4: A part of tracking verbose output. The thickness and order of Materials in a topmost tray are shown.

```
Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
  ....
    3      -30      -30      582      1e+03        0       50       118 ACD           Transportation
    4      -30      -30      572      1e+03        0       10       128 worldPhys           Transportation
    5      -30      -30      571      1e+03        0        1       129 ACD           Transportation
  ....
```

Figure 5: A part of tracking verbose output. Big tile and one of four top tiles are shown.

```
Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
  ....
  171      -30      -30      -63      1e+03        0      9.6       763 CalTopFrame           Transportation
  172      -30      -30      -83      1e+03        0       20       783 CalMotherPhys           Transportation
  173      -30      -30    -85.2      1e+03        0     2.19       785 RubPhys           Transportation
  174      -30      -30    -85.9      1e+03        0     0.71       786 PolyPhys           Transportation
  175      -30      -30    -86.2      1e+03        0     0.25       786 CsILogDPhys           Transportation
  176      -30      -30     -109      1e+03        0       23       809 PolyPhys           Transportation
  177      -30      -30     -109      1e+03        0     0.25       809 RubPhys           Transportation
  178      -30      -30     -110      1e+03        0     0.71       810 Alsheet           Transportation
  ....
```

Figure 6: A part of tracking verbose output. Thickness and order of materials in CAL are shown.

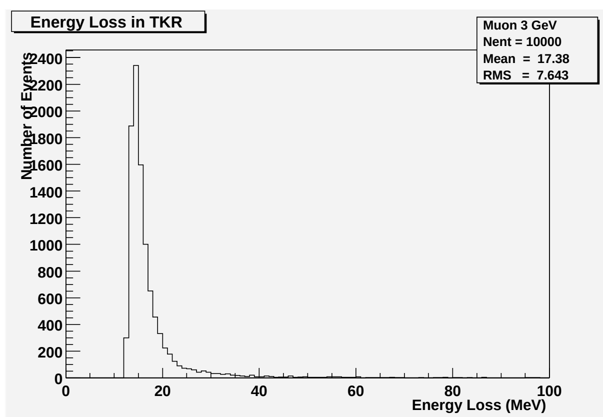

Figure 7: Energy loss distribution for 3 GeV $\mu-$ in Tracker.

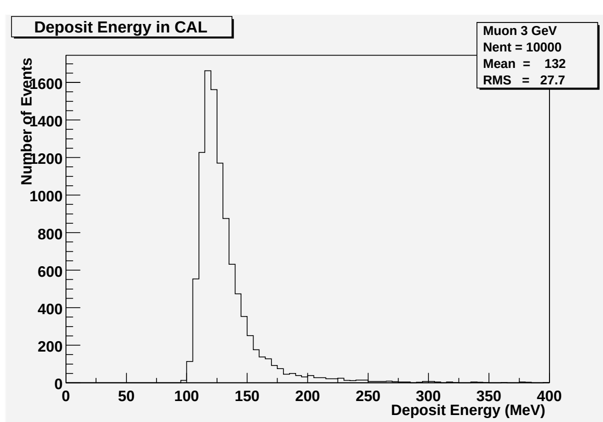

Figure 8: Energy deposit distribution in Calorimeter.

```
EventNo= 1
 ParSpc= mu- PXYZ= 2194.76 2194.76 0
 NoTargetHit= 1
  ID= 0    DepE= 9.13643
EventNo= 1
 ParSpc= mu- PXYZ= -2194.76 2194.76 0
 NoTargetHit= 1
  ID= 3    DepE= 14.4129
EventNo= 1
 ParSpc= mu- PXYZ= -2194.76 -2194.76 0
 NoTargetHit= 1
  ID= 2    DepE= 9.31571
EventNo= 1
 ParSpc= mu- PXYZ= 2194.76 -2194.76 0
 NoTargetHit= 1
  ID= 1    DepE= 9.16206
```

Figure 9: TargetOut.dat used to check out IDs of XGT.

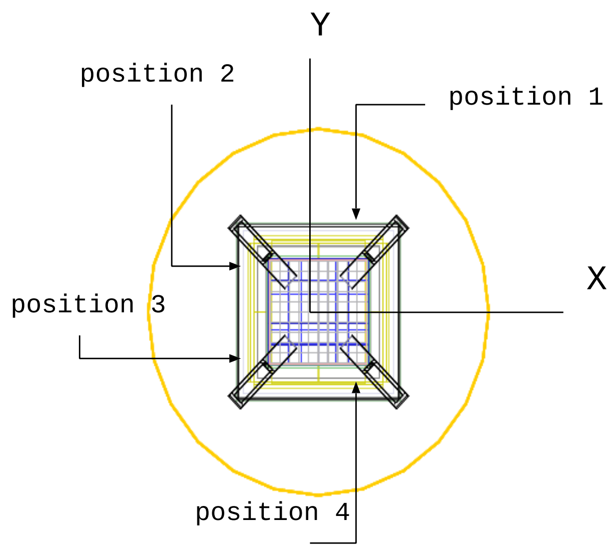

Figure 10: Input position of μ-. Position numbers correspond to the order that we shot particles.

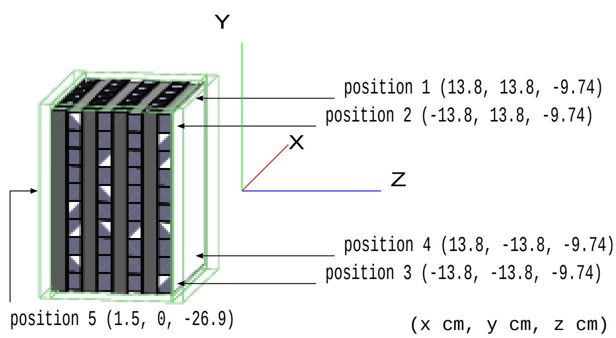

Figure 11: Input position of μ-, where coordinates are also given.

```
....
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= 138 138 -97.4
 NoCalHit= 8
  LogDID= 9 LogID= 9 LayerID= 0  DepE= 6.03937
  LogDID= 9 LogID= 19 LayerID= 1  DepE= 17.3748
  LogDID= 9 LogID= 29 LayerID= 2  DepE= 16.5698
  LogDID= 9 LogID= 39 LayerID= 3  DepE= 18.2604
  LogDID= 9 LogID= 49 LayerID= 4  DepE= 15.659
  LogDID= 9 LogID= 59 LayerID= 5  DepE= 14.3415
  LogDID= 9 LogID= 69 LayerID= 6  DepE= 29.0506
  LogDID= 9 LogID= 79 LayerID= 7  DepE= 21.9186
  TotCalE= 139.214
....
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= -138 138 -97.4
 NoCalHit= 8
  LogDID= 0 LogID= 9 LayerID= 0  DepE= 5.57607
  LogDID= 9 LogID= 10 LayerID= 1  DepE= 12.5648
  LogDID= 0 LogID= 29 LayerID= 2  DepE= 10.5098
  LogDID= 9 LogID= 30 LayerID= 3  DepE= 14.2863
  LogDID= 0 LogID= 49 LayerID= 4  DepE= 12.9758
  LogDID= 9 LogID= 50 LayerID= 5  DepE= 18.2945
  LogDID= 0 LogID= 69 LayerID= 6  DepE= 12.6843
  LogDID= 9 LogID= 70 LayerID= 7  DepE= 13.097
  TotCalE= 99.9886
....
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= -138 -138 -97.4
 NoCalHit= 8
  LogDID= 0 LogID= 0 LayerID= 0  DepE= 5.9966
  LogDID= 0 LogID= 10 LayerID= 1  DepE= 13.2384
  LogDID= 0 LogID= 20 LayerID= 2  DepE= 30.4868
  LogDID= 0 LogID= 30 LayerID= 3  DepE= 20.2233
  LogDID= 0 LogID= 40 LayerID= 4  DepE= 16.7999
  LogDID= 0 LogID= 50 LayerID= 5  DepE= 13.7105
  LogDID= 0 LogID= 60 LayerID= 6  DepE= 12.4952
  LogDID= 0 LogID= 70 LayerID= 7  DepE= 10.828
  TotCalE= 123.779
....
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= 138 -138 -97.4
 NoCalHit= 8
  LogDID= 9 LogID= 0 LayerID= 0  DepE= 7.99065
  LogDID= 0 LogID= 19 LayerID= 1  DepE= 13.3424
  LogDID= 9 LogID= 20 LayerID= 2  DepE= 9.90978
  LogDID= 0 LogID= 39 LayerID= 3  DepE= 17.0917
  LogDID= 9 LogID= 40 LayerID= 4  DepE= 15.2332
  LogDID= 0 LogID= 59 LayerID= 5  DepE= 12.0528
  LogDID= 9 LogID= 60 LayerID= 6  DepE= 13.1123
  LogDID= 0 LogID= 79 LayerID= 7  DepE= 13.6935
  TotCalE= 102.426
....
 BEAM= mu- Mass= 105.658
  PXYZ= 0 0 -3103.86 XYZi= 15 0 -269
 NoCalHit= 1
  LogDID= 5 LogID= 75 LayerID= 7  DepE= 13.5245
  TotCalE= 13.5245
....
```

Figure 12: CalOut.dat used to check out LayerID, LogID, and LogDID. Each events corresponds to each positions in Figure 11.