EIC Simulation Hands-on

CFNS QCD Summer School
August 3, 2019

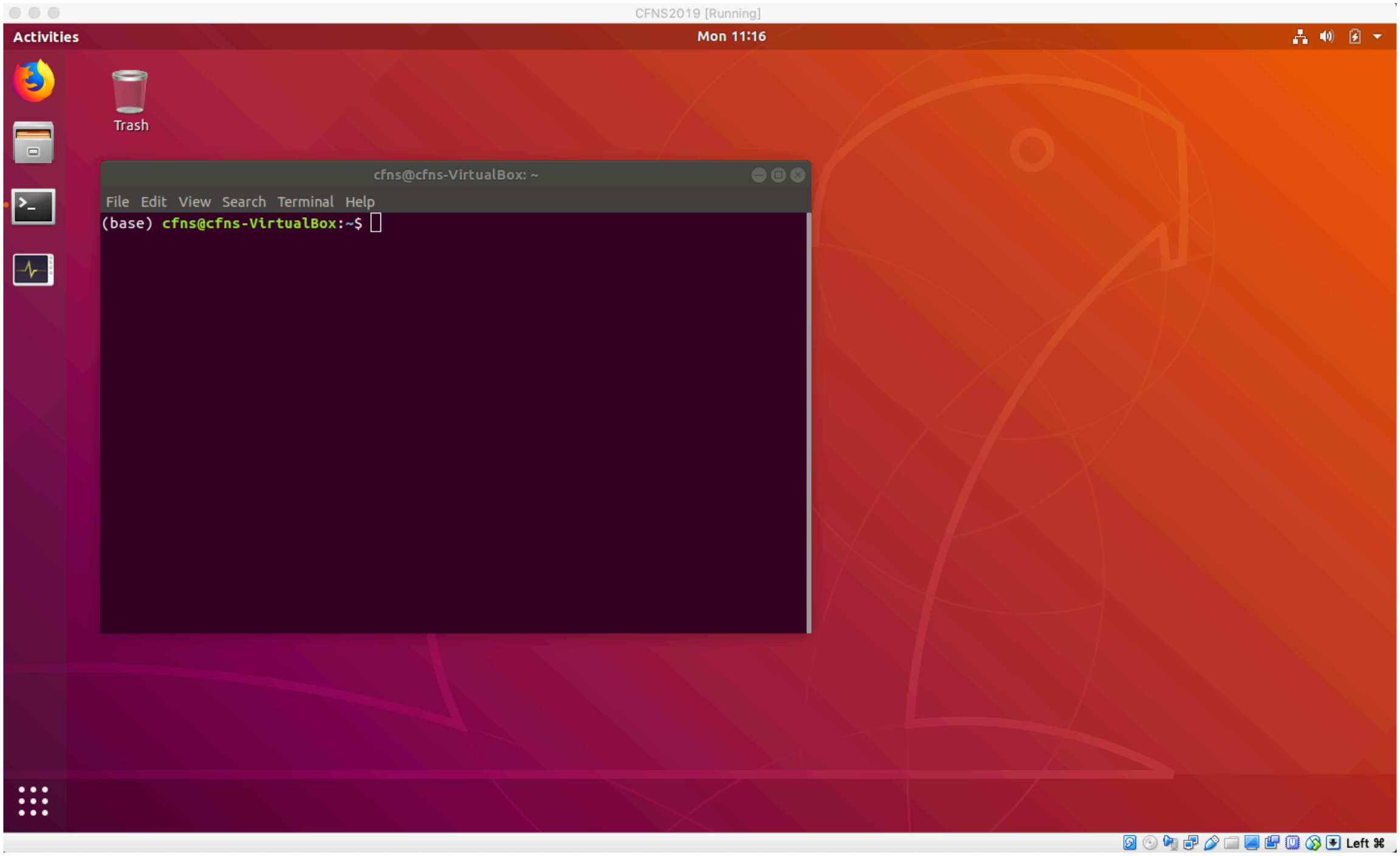
Outline

- Virtual Machine
- pythiaeRHIC
  - Controlling parameters
  - Event structure: text and EICTree
- Detector simulation for sPHENIX-EIC
  - e+p DIS event in lab frame
  - e+p DIS event in detector
  - Glimpse of tracking detector design

VM installation

- Install VirtualBox: https://www.virtualbox.org/wiki/Downloads
- Download from summer school webpage: https://indico.bnl.gov/event/5877/ , -> Virtual Machine Download -> CFNS2019_v0731.ova
- Lunch your Virtualbox and load the ova file: File -> Import Appliance

Ubuntu 18.04


CFNS2019 [Running]
Activities
Mon 11:16
Trash
cfns@cfns-VirtualBox: ~
File Edit View Search Terminal Help
(base) cfns@cfns-VirtualBox:~$
Left ⌘

Pythia

- Pythia6 : https://pythiasix.hepforge.org
  - One of the generators commonly used for simulating high energy particles collision, e.g. e+p
  - Manual: http://home.thep.lu.se/~torbjorn/pythia6/lutp0613man2.pdf
- PythiaeRHIC: (***BNL EIC task force***)
  - “pythiaeRHIC is the EIC science task force's programme for running PYTHIA. It is based on PYTHIA 6.4.28 and was modified to include radiative corrections using RADGEN.”
  - Reference to BNL EIC Wiki: https://wiki.bnl.gov/eic/index.php/PYTHIA
  - Installed on the VM: `/home/cfns/Install/pythiaeRHIC/1.0.0`
  - To run it: `pythiaeRHIC < configuration.file`

Pythia configuration file

- Go to the work directory:

  > `cd ~/Work/pythia_ep/`

- Open the example configuration file `tmp.txt`

  > `vi tmp.txt`

1. Output ASCII file name
2. Lepton beam type
3. Beam energies for proton, electron
4. Event number, print-out
5. x_min, x_max
6. y_min, y_max
7. Q2_min, Q2_max
8. F2 model, R-parametrization
9. Radiative correction 0 off, 1 on
10. Pythia-Model = 0 standard GVMD generation in Pythia-x and Q2; = 1 GVMD model with generation in y and Q2 as for radgen
11. A-Target and Z-Target
12. nuclear pdf parameter1: nucleon mass number A, charge number Z
13. nuclear pdf parameter2: correction order x*100+y x= 1:LO, 2:NLO y:error set
14. Select Processes to Simulate
15. Select sub-process

…

cfns@cfns-VirtualBox: ~/Work/pythia_ep

File Edit View Search Terminal Help

```
 1 pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.txt
 2 11
 3 250, 20
 4 1000,100
 5 1e-4, 1e0
 6 1e-09,1.00
 7 1e1,1e6
 8 F2PY,1998
 9 0
10 1
11 1,1
12 1,1
13 201
14 MSEL=1
15 MSUB(10)=1
16 MSTP(21)=5
17 MSTP(32)=8
18 MSTP(38)=4
19 MSTP(51)=10100
20 MSTP(52)=2
21 MSTP(53)=3
22 MSTP(54)=1
23 MSTP(55)=5
                                                              1,1           Top
```

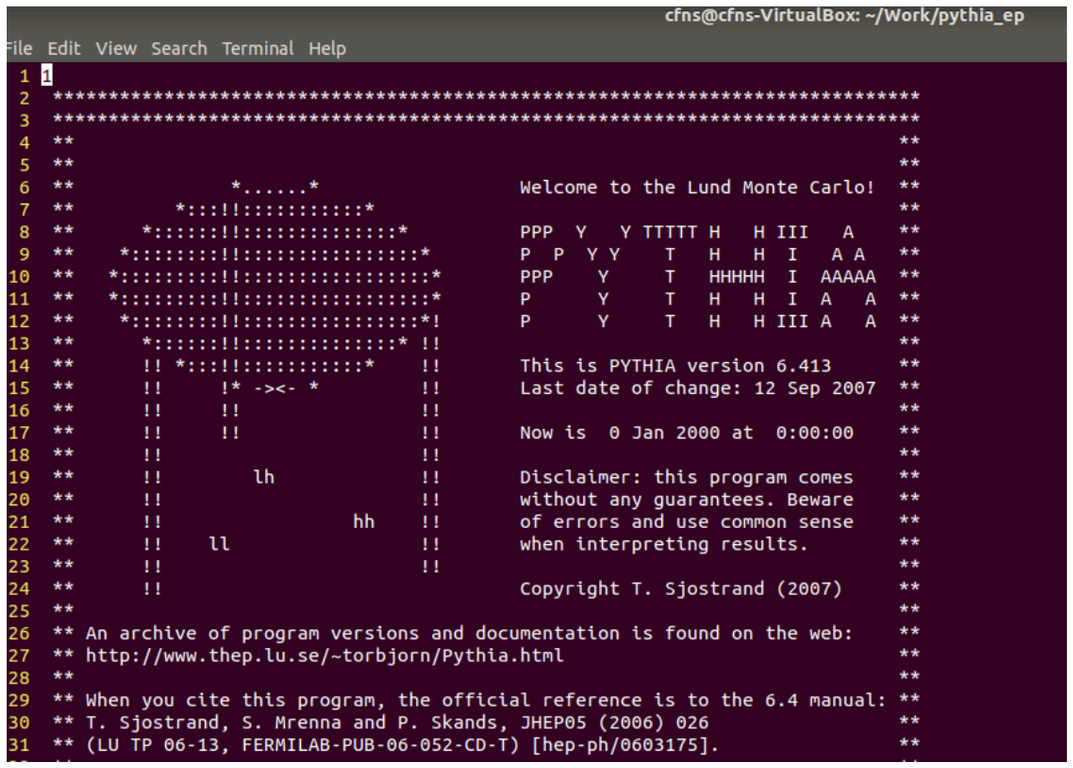
Pythia output

- Run pythia: pythiaeRHIC_rcf is a slightly modified version of pythiaeRHIC

  > `pythiaeRHIC_rcf < tmp.txt > log.txt &`

- Open the log file: `log.txt`

  > `vi log.txt`




```
 XSEC(96,1) increased to  6.651D-01
1********* PYSTAT:  Statistics on Number of Events and Cross-sections *********

 ===============================================================================
 I                                  I                            I            I
 I            Subprocess            I      Number of points      I    Sigma   I
 I                                  I                            I            I
 I----------------------------------I----------------------------I    (mb)    I
 I                                  I                            I            I
 I N:o Type                         I    Generated         Tried I            I
 I                                  I                            I            I
 ===============================================================================
 I                                  I                            I            I
 I   0 All included subprocesses    I         1000        921364 I  7.215D-05 I
 I  11 f + f' -> f + f' (QCD)       I            6             0 I  8.995D-07 I
 I  12 f + fbar -> f' + fbar'       I            0             0 I  0.000D+00 I
 I  13 f + fbar -> g + g            I            0             0 I  0.000D+00 I
 I  28 f + g -> f + g               I           15             0 I  2.055D-06 I
 I  53 g + g -> f + fbar            I            0             0 I  0.000D+00 I
 I  68 g + g -> g + g               I            4             0 I  3.420D-07 I
 I  95 Low-pT scattering            I           22         19234 I  2.206D-07 I
 I  99 q + gamma* -> q              I          932        163094 I  6.685D-05 I
 I 131 f + gamma*_T -> f + g        I            7         41062 I  5.678D-07 I
 I 132 f + gamma*_L -> f + g        I            0          2158 I  3.299D-08 I
 I 135 g + gamma*_T -> f + fbar     I           11        125690 I  9.387D-07 I
 I 136 g + gamma*_L -> f + fbar     I            3         20133 I  2.404D-07 I
```

Pythia output

- Open the output file:

  > `vi pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1d6.kT=1.0_1201.txt`

Event description

Event level variables

Particle level variables

```
 PYTHIA EVENT FILE
 ========================================
I, ievent, genevent, subprocess, nucleon,                targetparton, xtargparton, beamparton, xbeamparton,          thetabeamprtn, truey, trueQ2, truex, trueW2, trueNu, leptonphi,   s_hat, t
 _hat, u_hat, pt2_hat, Q2_hat, F2, F1, R, sigma_rad,     SigRadCor, EBrems, photonflux, t-diff, nrTracks
 ========================================
  I  K(I,1)  K(I,2)  K(I,3)  K(I,4)  K(I,5)          P(I,1)  P(I,2)  P(I,3)  P(I,4)  P(I,5)  V(I,1)  V(I,2)  V(I,3)
 ========================================
  0        1    1   99 2212         4  0.024584         22     0.948683     0.000000     0.09491910185      46.67043749339      0.02458423749     1852.59863281250     1011.64312744141
    0.55337083599     1667.33877186971       -833.669385935       -833.669385935          0.000000000      46.670437493          0.000000000          0.000000000          0.000000000
     0.000000000          0.000000000          0.000000000          0.491669062       -833.669385935           51
 ========================================
    1    21        11        0        3        4       0.000000       0.000000     -20.000000      20.000000       0.000510       0.000000       0.000000       0.000000
    2    21      2212        0        5        0      -0.000000       0.000000     250.000000     250.001761       0.938270       0.000000       0.000000       0.000000
    3    21        11        1        0        0      -5.529305       3.415743     -17.518235      18.684996       0.000510       0.000000       0.000000       0.000000
    4    21        22        1        0        0       5.529305      -3.415743      -2.481765       1.315004      -6.831577       0.000000       0.000000       0.000000
    5    21      2212        2        0        0       0.000000      -0.000000     250.000000     250.001761       0.938270       0.000000       0.000000       0.000000
    6    21        22        4        0        0       5.531869      -3.417327      -2.477217       1.321312      -6.831577       0.000000       0.000000       0.000000
    7    21         4        5        0        0      -0.000063       0.000039       6.143099       6.143099       0.000000       0.000000       0.000000       0.000000
    8    21        22        6        0        0       5.531869      -3.417327      -2.477217       1.321312      -6.831577       0.000000       0.000000       0.000000
    9    21         4        7        0        0      -0.000063       0.000039       6.143099       6.143099       0.000000       0.000000       0.000000       0.000000
   10    21         4        9        0        0       5.531806      -3.417288       3.665882       7.464411       0.000000       0.000000       0.000000       0.000000
   11    11      -413        5       17       18       0.191484       0.448029     211.215758     211.225884       2.010000       0.000000       0.000000       0.000000
   12     1        11        3        0        0      -5.529305       3.415743     -17.518235      18.684996       0.000510       0.000000       0.000000       0.000000
   13    12      2203        5       20       27       0.578940       0.074393      26.829649      26.847080       0.771330       0.000000       0.000000       0.000000
   14    12        21       10       20       27       1.128510      -2.863046       5.581110       6.373332       0.000000       0.000000       0.000000       0.000000
   15    12        21       10       20       27       2.128057      -2.241695       3.889887       4.968404       0.000000       0.000000       0.000000       0.000000
   16    11         4       10       20       27       1.502314       1.166575       0.001832       1.902064       0.000000       0.000000       0.000000       0.000000
   17    11      -421       11       28       30       0.187499       0.402908     192.081957     192.091520       1.864500       0.000000       0.000000       0.000000
   18     1      -211       11        0        0       0.003985       0.045121      19.133801      19.134364       0.139570       0.000000       0.000000       0.000000
   19    11        92       13       20       27       5.337821      -3.863773      36.302477      40.090881      15.683997       0.000000       0.000000       0.000000
   20    11      2214       13       31       32      -0.058139      -0.210698      17.492765      17.537545       1.233240       0.000000       0.000000       0.000000
   21    11       213       13       33       34       0.559788       0.216358       6.667163       6.763931       0.969296       0.000000       0.000000       0.000000
   22     1      -211       13        0        0       1.500002      -2.339334       3.879286       4.773974       0.139570       0.000000       0.000000       0.000000
   23     1       211       13        0        0       0.144954      -0.149989       3.104163       3.114292       0.139570       0.000000       0.000000       0.000000
   24    11       113       16       35       36       0.577759      -0.715332       1.245852       1.665833       0.614286       0.000000       0.000000       0.000000
   25     1      -321       16        0        0       0.378185      -0.465682       1.472213       1.664612       0.493600       0.000000       0.000000       0.000000
   26    11       313       16       37       38       0.494800      -0.163355       1.322047       1.685774       0.906926       0.000000       0.000000       0.000000
   27    11       413       16       39       40       1.740472      -0.035740       1.118990       2.884919       2.010000       0.000000       0.000000       0.000000
   28     1        13       17        0        0      -0.239440       0.638980      38.407083      38.413290       0.105660       0.006859       0.014740       7.026966
```

Pythia output

- Build EICTree (TTree) from the output file: txt -> root

  > `root -l –b -q BuildTree.C`

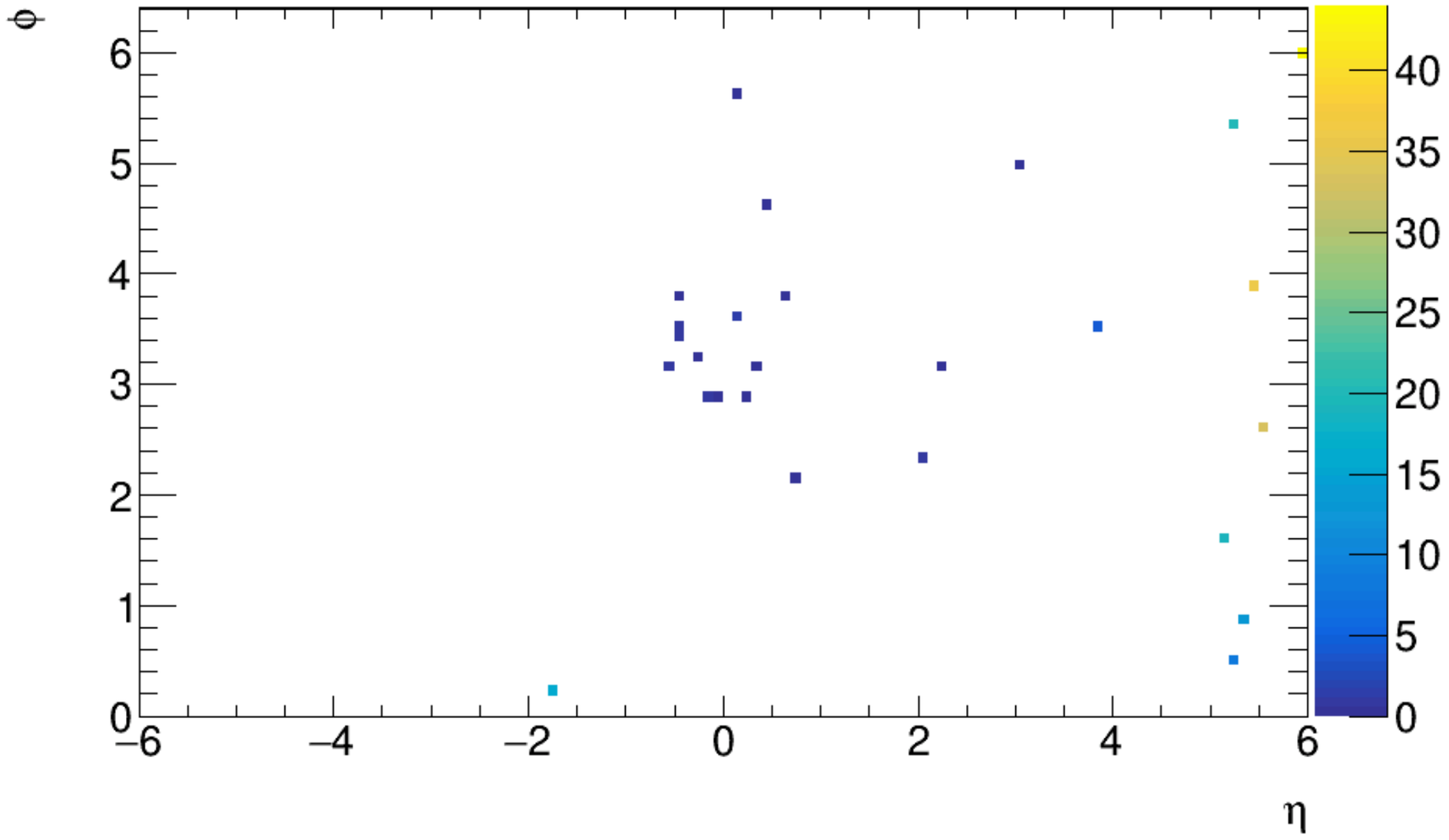
  Make sure the “inputfile” has been set to the ASCII file produced by PYTHIA.

```
(base) cfns@cfns-VirtualBox:~/Work/pythia_ep$ vi BuildTree.C
(base) cfns@cfns-VirtualBox:~/Work/pythia_ep$ root -l -b -q BuildTree.C
root [0]
Processing BuildTree.C...

Processing pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.txt

Processed pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.txt
TFile**         ./pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.root
 TFile*         ./pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.root
  OBJ: TTree    EICTree my EIC tree : 0 at: 0x5633a41947e0
  KEY: TProcessID       ProcessID0;1    16d8dcd8-b227-11e9-9717-0101007fbeef
  KEY: TTree    EICTree;1       my EIC tree
Began on Mon Jul 29 13:34:17 2019
Ended on Mon Jul 29 13:34:18 2019
Processed 1000 events containing 49174 particles in 1.01837 seconds (0.00101837 sec/event)
*****************************************
File: pythia.ep.20x250.1000events.RadCor=0.Q2=1e1-1e6.kT=1.0_1201.txt processed in directory ./
(int)0
(base) cfns@cfns-VirtualBox:~/Work/pythia_ep$
```

Quick look at ep event

- Event “display” : eta: phi: p

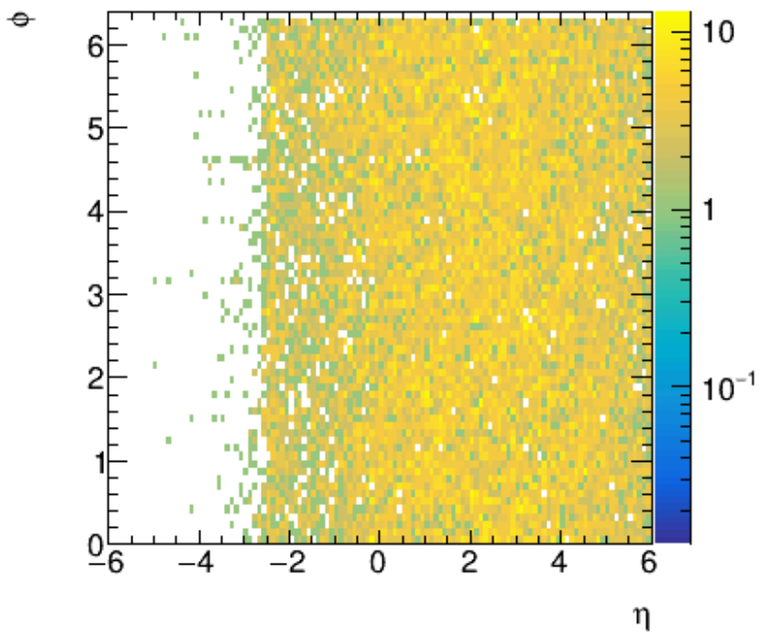
  > `root -l plot_2D_event.C'(2)'`

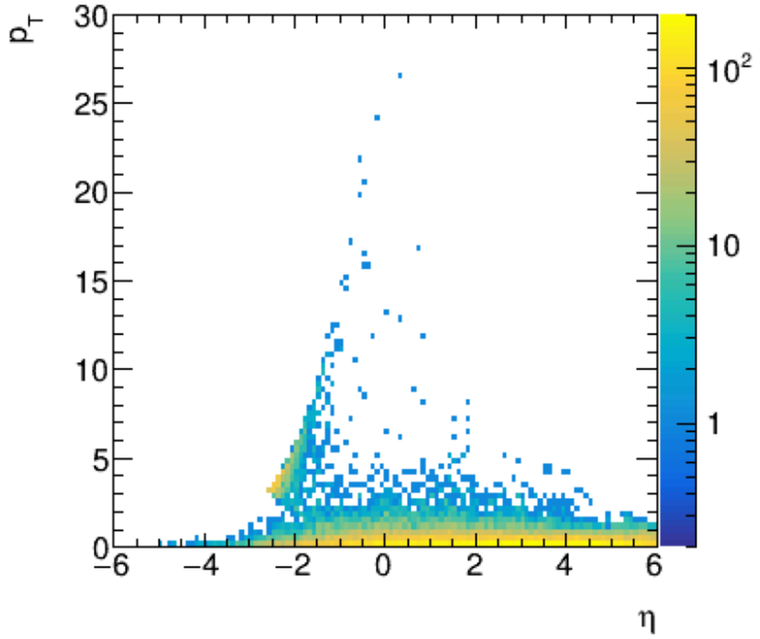


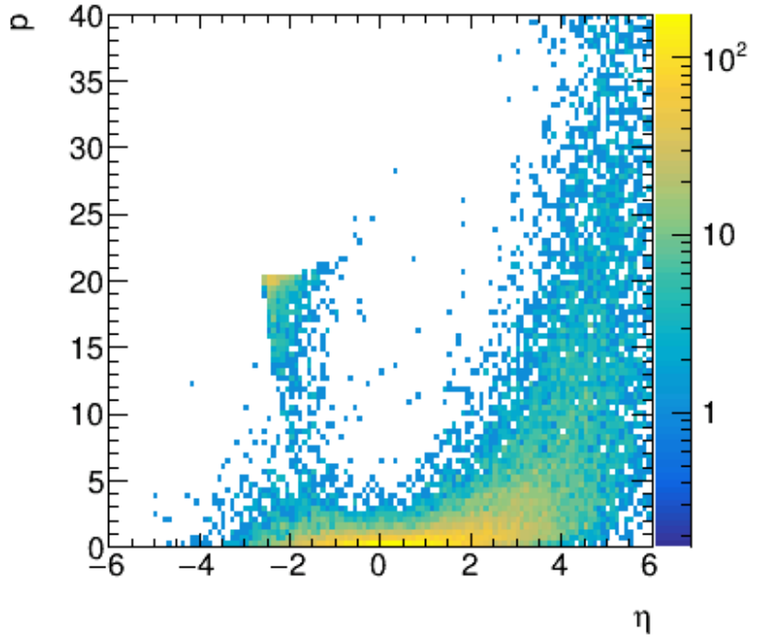
Quick look at ep events

- Eta-Phi Eta-Pt, Eta-P distribution

  > `root -l plot_eta_phi_pt.C`



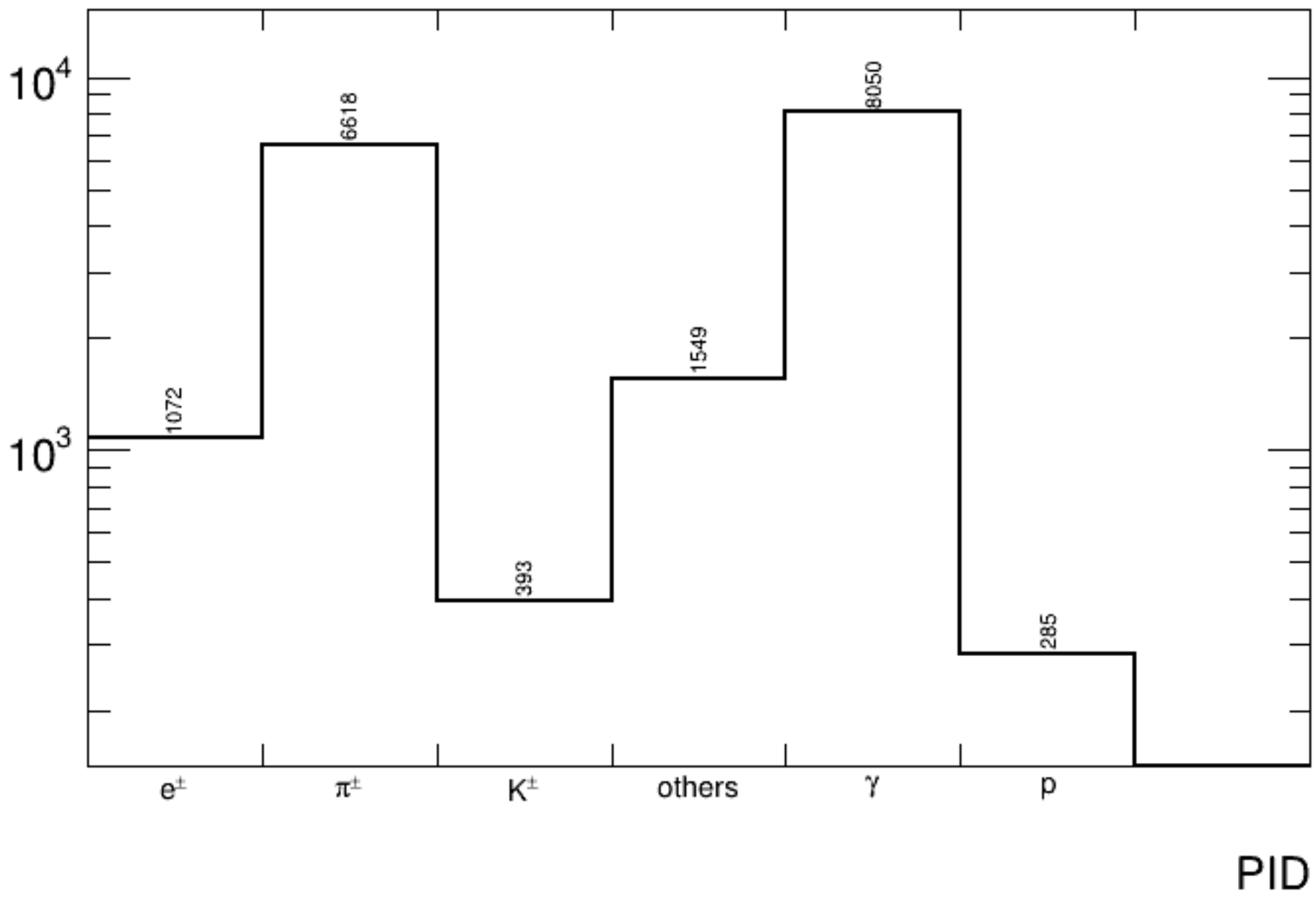




Quick look at ep events

- Particle specie (letal < 4.5)

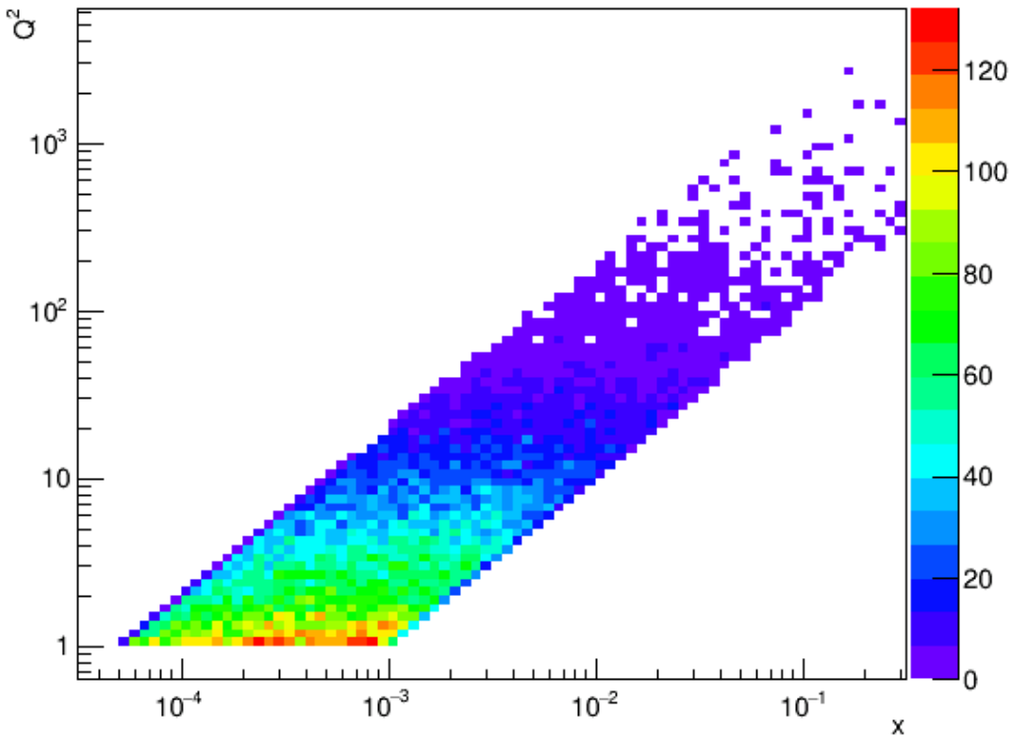
  > `root -l plot_pid.C`

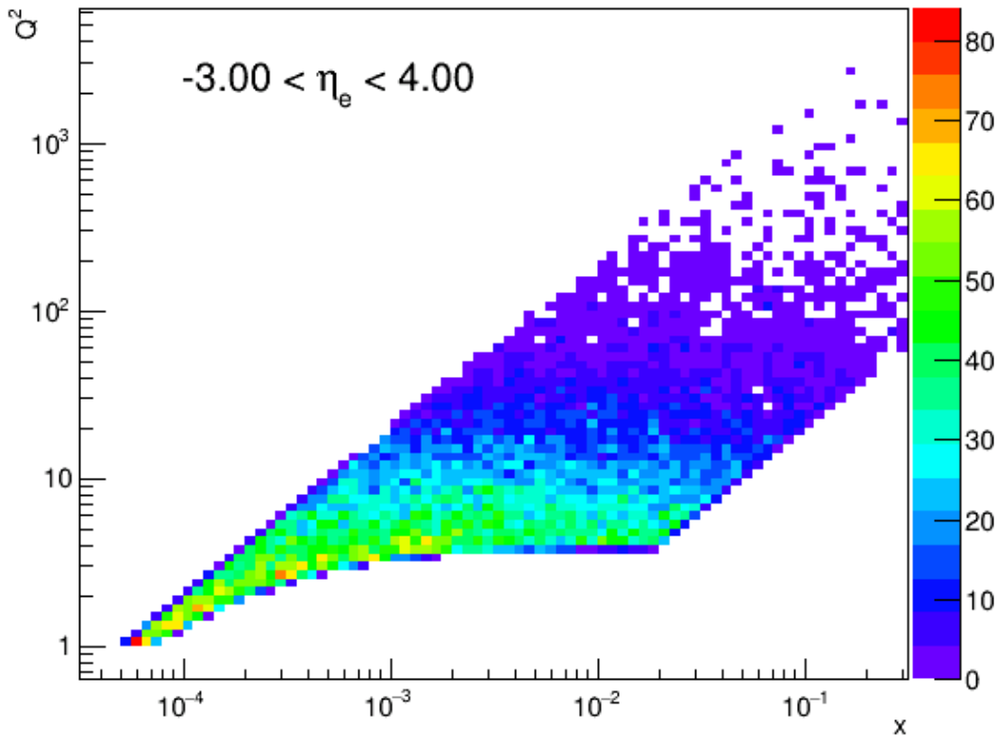


Quick look at ep events

- Event kinematics

  > `root -l plot_event_kin.C`





sPHENIX simulation framework — Fun4All

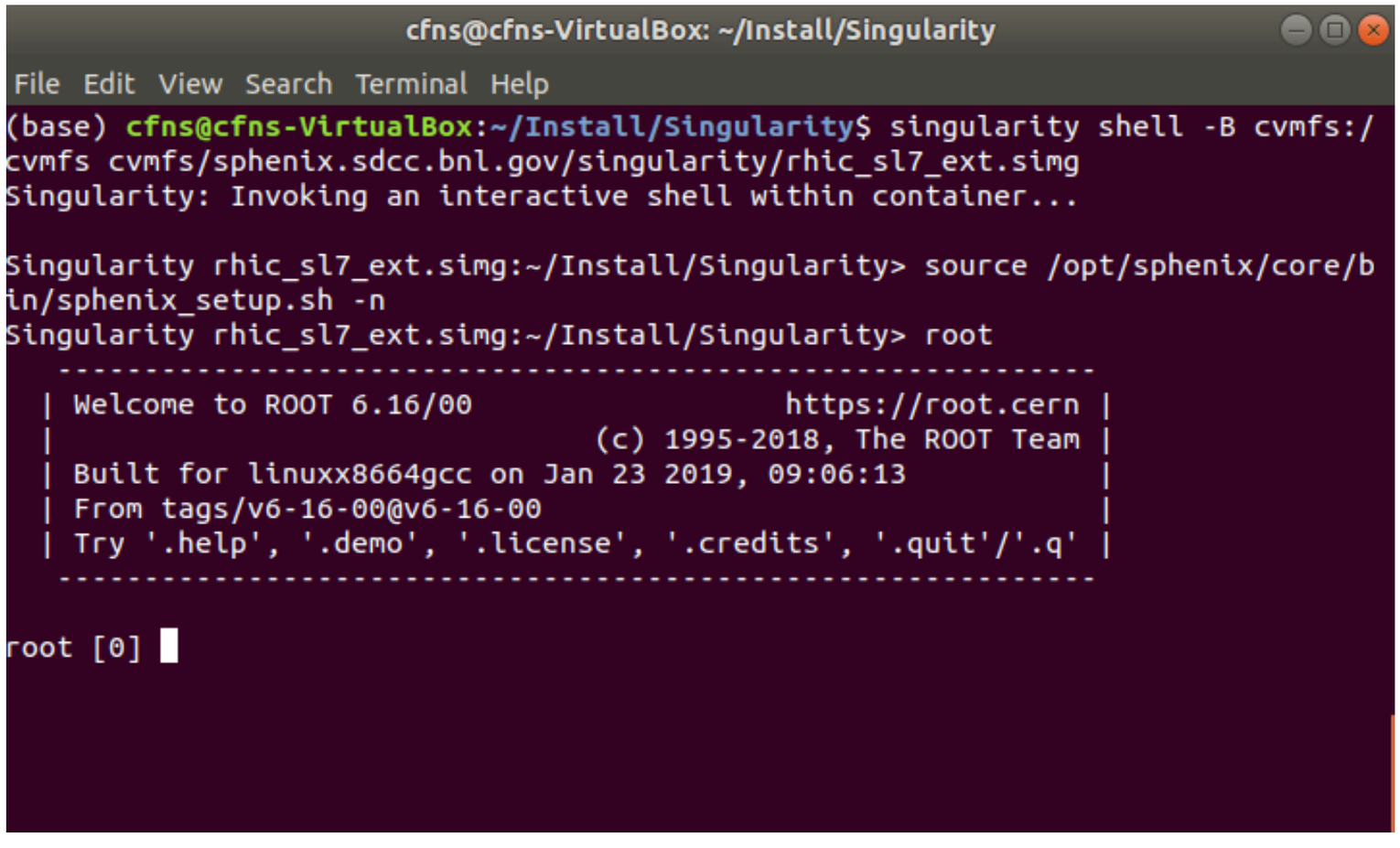
- Thanks to ***Jin Huang*** and ***Chris Pinkenburg*** for their supports.

- Dedicated tutorial for Fun4All could be found at: https://indico.bnl.gov/event/1237/overview (2015 sPHENIX software and simulation workfest)

- We will use sPHENIX Singularity container for today.

Start the singularity

```
> cd ~/Install/Singularity/
> singularity shell -B cvmfs:/cvmfs cvmfs/
  sphenix.sdcc.bnl.gov/singularity/rhic_sl7_ext.simg
> source /opt/sphenix/core/bin/sphenix_setup.sh -n
```



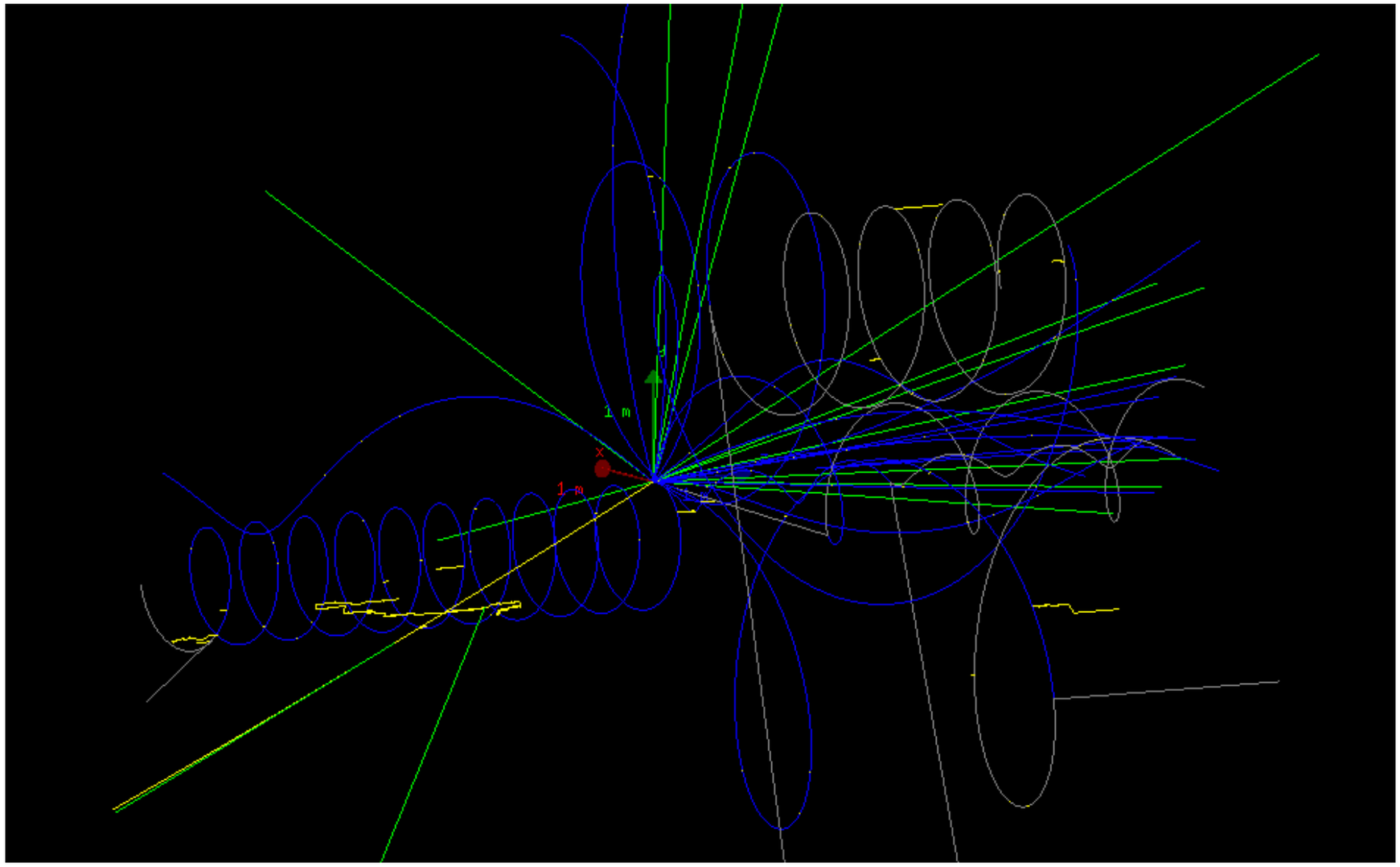
Event Display

```
> cd ~/Work/tutorials/eventgenerator_display/
> root -l
> .x Fun4All_Generator_Display.C(1,"~/Work/pythia_ep/pythia.root")
```

```
File  Edit  View  Search  Terminal  Help
Singularity rhic_sl7_ext.simg:~> cd ~/Work/tutorials/eventgenerator_display/
Singularity rhic_sl7_ext.simg:~/Work/tutorials/eventgenerator_display> root -l
root [0] .x Fun4All_Generator_Display.C(1,"~/Work/pythia_ep/pythia.root")
ReadEICFiles: Input Branch Event Class = erhic::EventPythia

*******************************************************
 Geant4 version Name: geant4-10-02-patch-02    (17-June-2016)
                      Copyright : Geant4 Collaboration
                      Reference : NIM A 506 (2003), 250-303
                            WWW : http://cern.ch/geant4
*******************************************************

<<< Geant4 Physics List simulation engine: QGSP_BERT 4.0
```

Event Display

```
> cd ~/Work/tutorials/eventgenerator_display/
> root -l
> .x Fun4All_Generator_Display.C(1,"~/Work/pythia_ep/pythia.root")
```



Geant4 commands

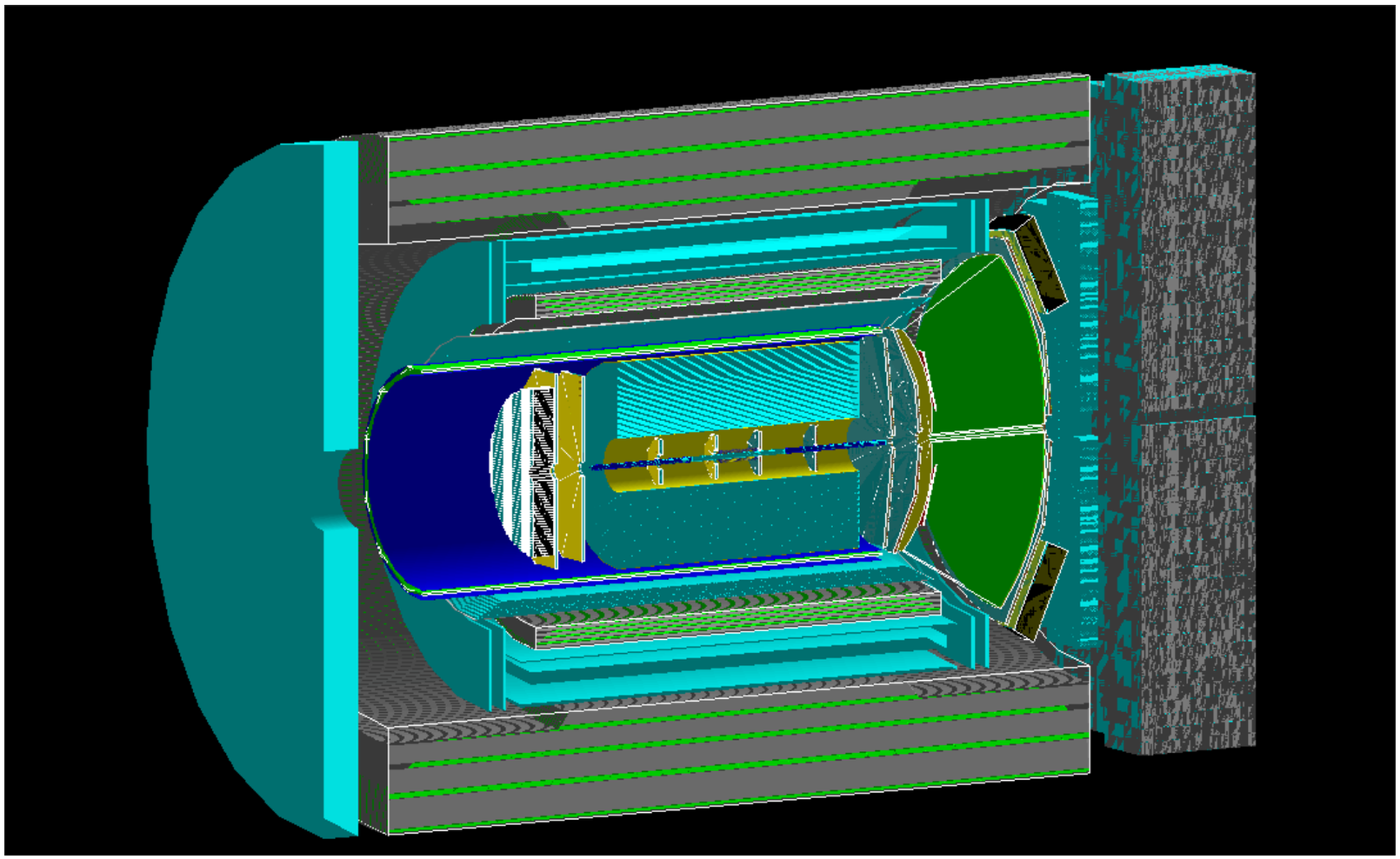
```
root [1] displaycmd()
draw 1m axis:
 g4->ApplyCommand("/vis/scene/add/axes 0 0 0 100 cm")
zoom
 g4->ApplyCommand("/vis/viewer/zoom 1")
viewpoint:
 g4->ApplyCommand("/vis/viewer/set/viewpointThetaPhi 0 0")
panTo:
 g4->ApplyCommand("/vis/viewer/panTo 0 0 cm")
print to eps:
 g4->ApplyCommand("/vis/ogl/printEPS")
set background color:
 g4->ApplyCommand("/vis/viewer/set/background white")
root [2]
```

Most of the Geant4 commands could be directly called.
Refer to Geant4 tutorials for more information.

Event Display with full detector sPHENIX-EIC

```
cd Work/macros/macros/g4simulations/
Singularity rhic_sl7_ext.simg:~/Work/macros/macros/g4simulations> root -l
root [0] .x Fun4All_G4_EICDetector.C(-1)
root [1] .L DisplayOn.C
root [2] PHG4Reco* g4 = DisplayOn()
```

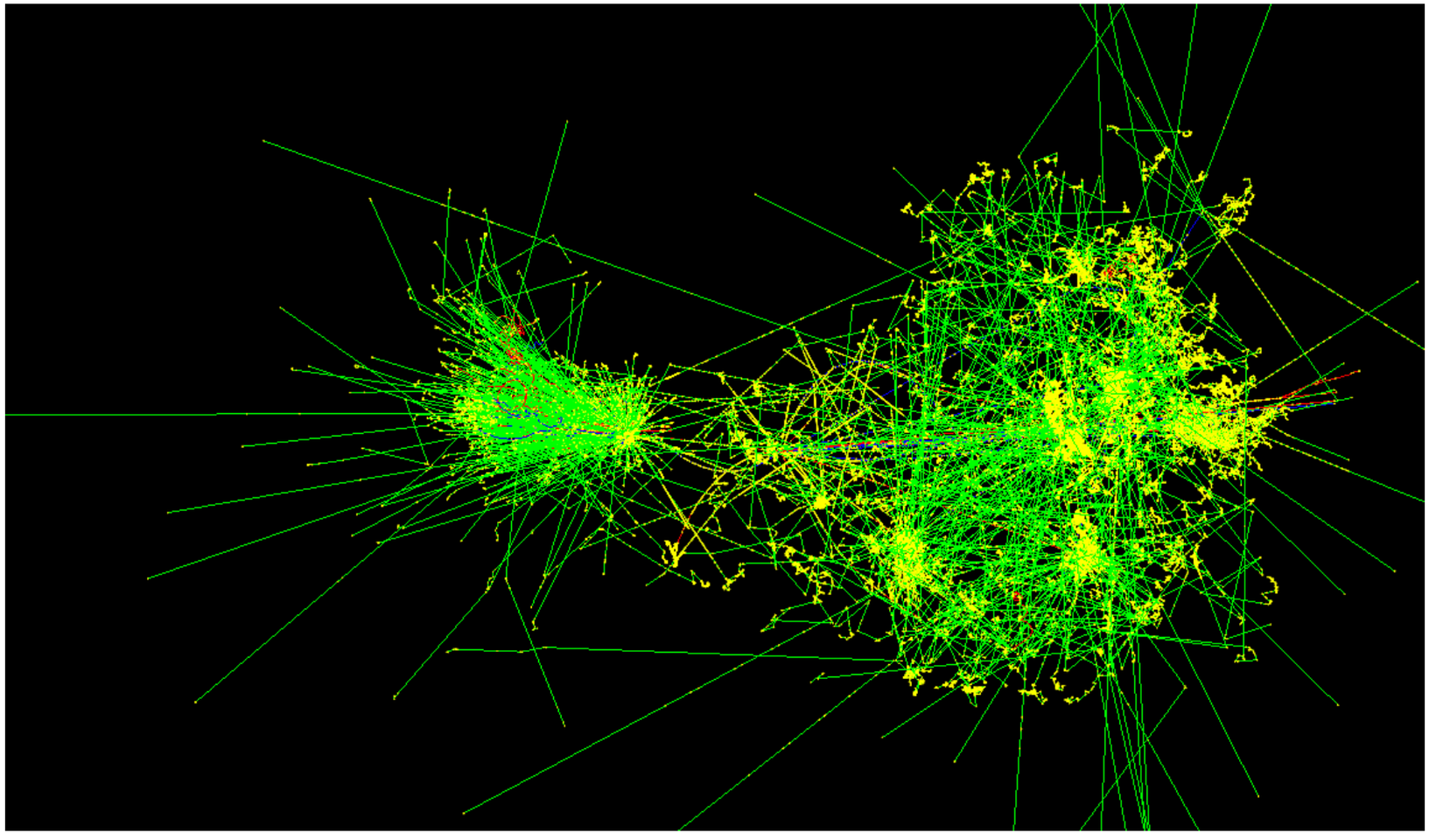
Very slow ~minute



Event Display with full detector sPHENIX-EIC

```
cd Work/macros/macros/g4simulations/
Singularity rhic_sl7_ext.simg:~/Work/macros/macros/g4simulations> root -l
root [0] .x Fun4All_G4_EICDetector.C(-1)
root [1] .L DisplayOn.C
root [2] PHG4Reco* g4 = DisplayOn()
root [3] Fun4AllServer *se = Fun4AllServer::instance();
root [4] se->run(1)
```

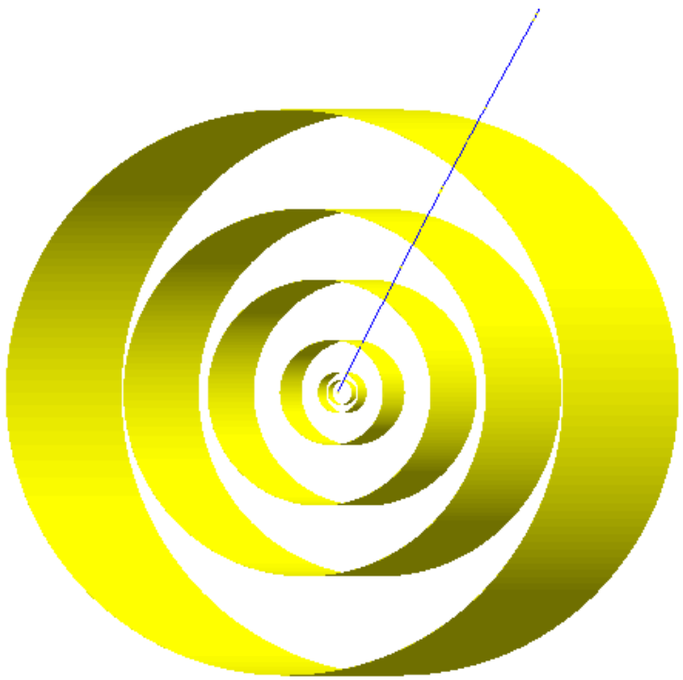
Very slow ~minutes



Design a Si Tracker

```
Singularity rhic_sl7_ext.simg:~> cd ~/Work/tutorials/Momentum
Singularity rhic_sl7_ext.simg:~/Work/tutorials/Momentum> root -l
root [0] .x Fun4All_G4_Momentum.C(-1)
root [1] .L DisplayOn.C
root [2] PHG4Reco* g4 = DisplayOn()
root [3] Fun4AllServer *se = Fun4AllServer::instance();
root [4] se->run(1)
```

```
53   double si_thickness[6] = {0.02, 0.02, 0.0625, 0.032, 0.032, 0.032}; //cm
54   double svxrad[6] = {2.71, 4.63, 11.765, 25.46, 41.38, 63.66};  //cm
55   double length[6] = {20., 20., 36., -1., -1., -1.};  // -1 use eta coverage to
determine length
56   PHG4CylinderSubsystem *cyl;
57   // here is our silicon:
58   for (int ilayer = 0; ilayer < 6; ilayer++)
59   {
60     cyl = new PHG4CylinderSubsystem("SVTX", ilayer);
61     cyl->set_double_param("radius", svxrad[ilayer]);
62     cyl->set_string_param("material", "G4_Si");
63     cyl->set_double_param("thickness", si_thickness[ilayer]);
64     cyl->SetActive();
65     cyl->SuperDetector("SVTX");
66     if (length[ilayer] > 0)
67     {
68       cyl->set_double_param("length", length[ilayer]);
69     }
70     g4Reco->registerSubsystem(cyl);
71   }
```



Momentum Resolution

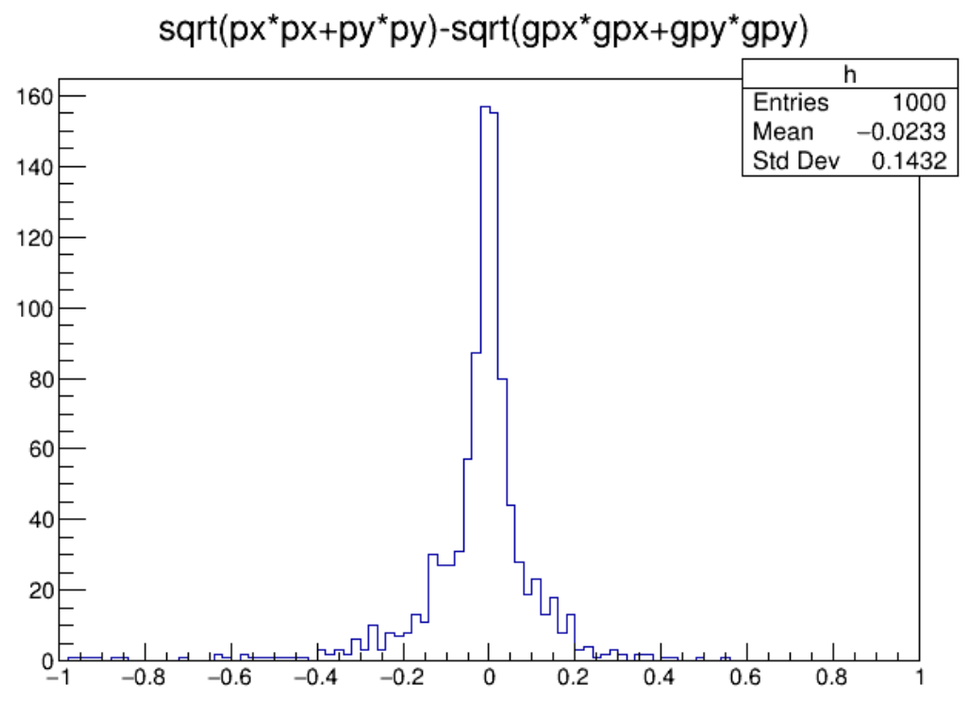
```
Singularity rhic_sl7_ext.simg:~/Work/tutorials/Momentum> root -l -b -q
Fun4All_G4_Momentum.C'(1000)'
root [0]
Processing Fun4All_G4_Momentum.C(1000)...
```

Run 1000 events…

```
Singularity rhic_sl7_ext.simg:~/Work/tutorials/Momentum> root -l
root [0] TFile fin("FastTrackingEval.root")
root [1] .ls
TFile**         FastTrackingEval.root
 TFile*         FastTrackingEval.root
  KEY: TTree    tracks;1  FastSim Eval => tracks
  KEY: TH2D     _h2d_Delta_mom_vs_truth_eta;1  #frac{#Delta p}{truth p} vs. truth #eta
  KEY: TH2D     _h2d_Delta_mom_vs_truth_mom;1  #frac{#Delta p}{truth p} vs. truth p
```

Open the output root file …

```
root [2] tracks->Show(0)
======> EVENT:0
 event               = 1
 gtrackID            = 1
 gflavor             = -11
 gpx                 = 3.43829
 gpy                 = 5.75362
 gpz                 = 0.0177823
 gvx                 = -9999
 gvy                 = -9999
 gvz                 = -9999
 trackID             = 0
 charge              = 1
 nhits               = 0
 px                  = 3.45495
 py                  = 5.78271
 pz                  = 0.0184097
 dca2d               = 4.55142e-05
root [3] tracks->Draw("sqrt(px*px+py*py)-sqrt(gpx*gpx+gpy*gpy) >> h(100,-1,1)”)
```




This is just a quick skim!
More fun if you go deeper!