HOKKAIDO UNIVERSITY

Summer Institute

Introduction to Geant4

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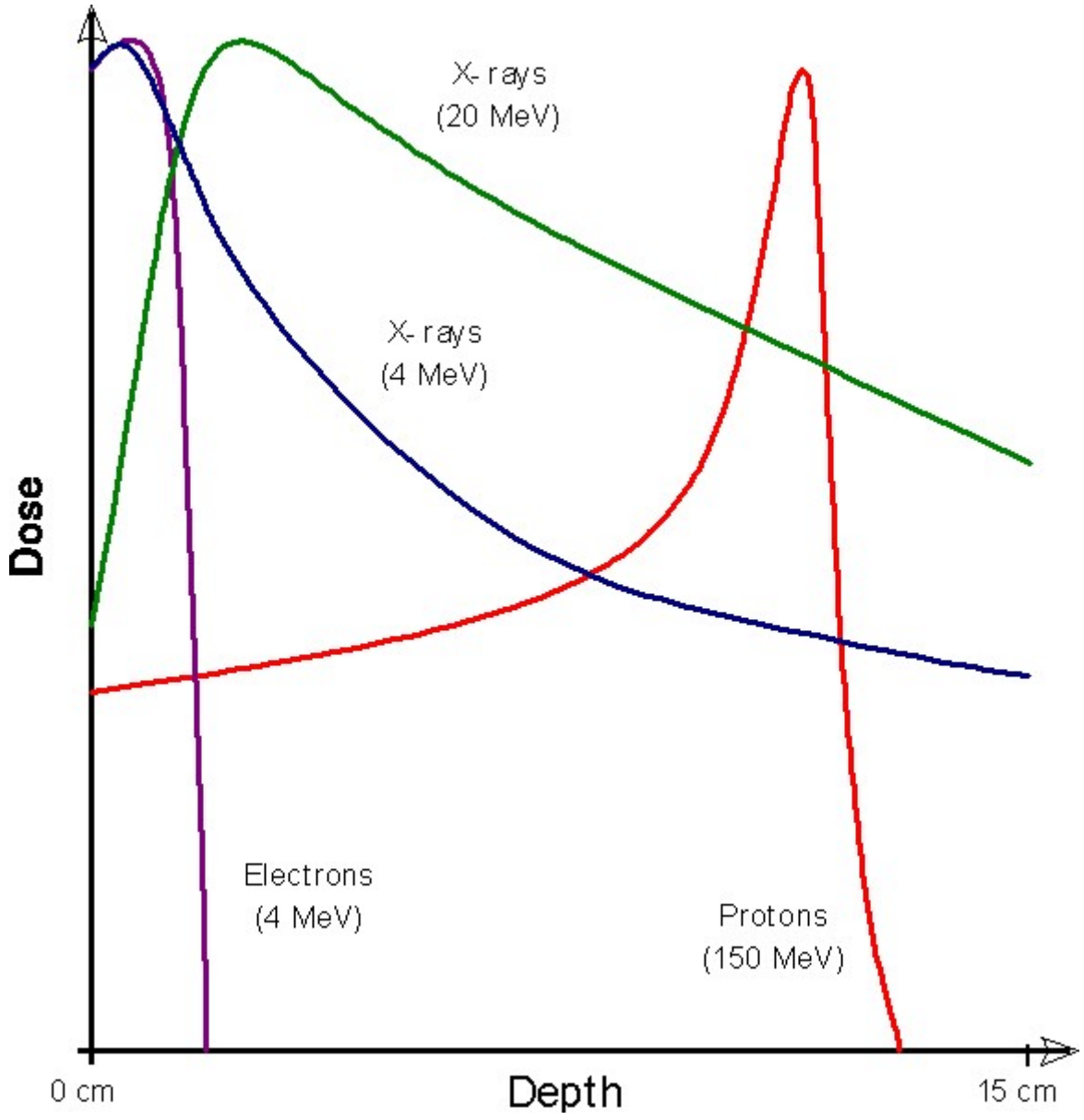
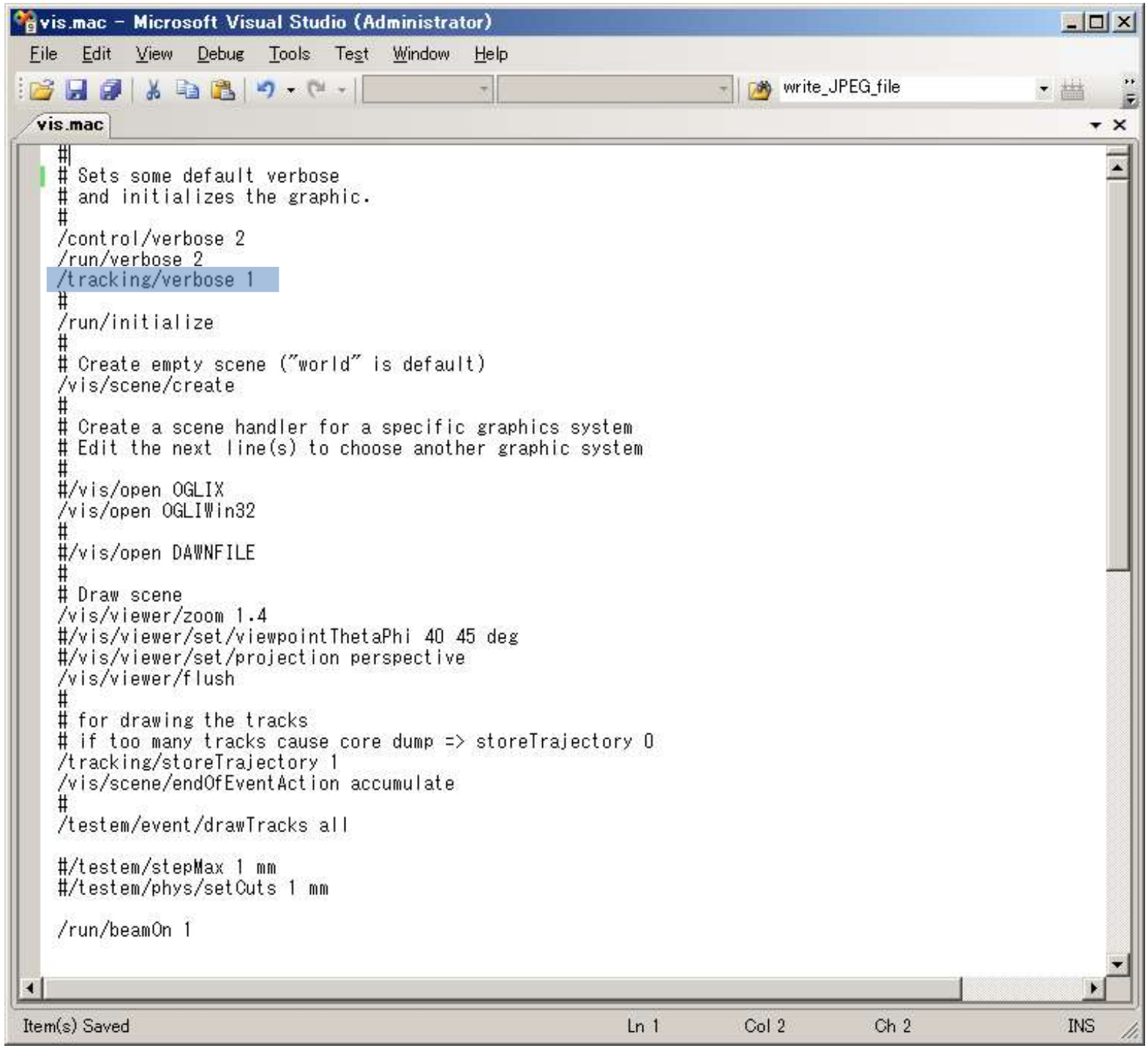
Outline

- Geant4 Sample - TestEm7
- DCMTK
- CT Volume Target
- DICOM-RT Dose
- Running in parallel

Depth Dose Curves



/tracking/verbose 1

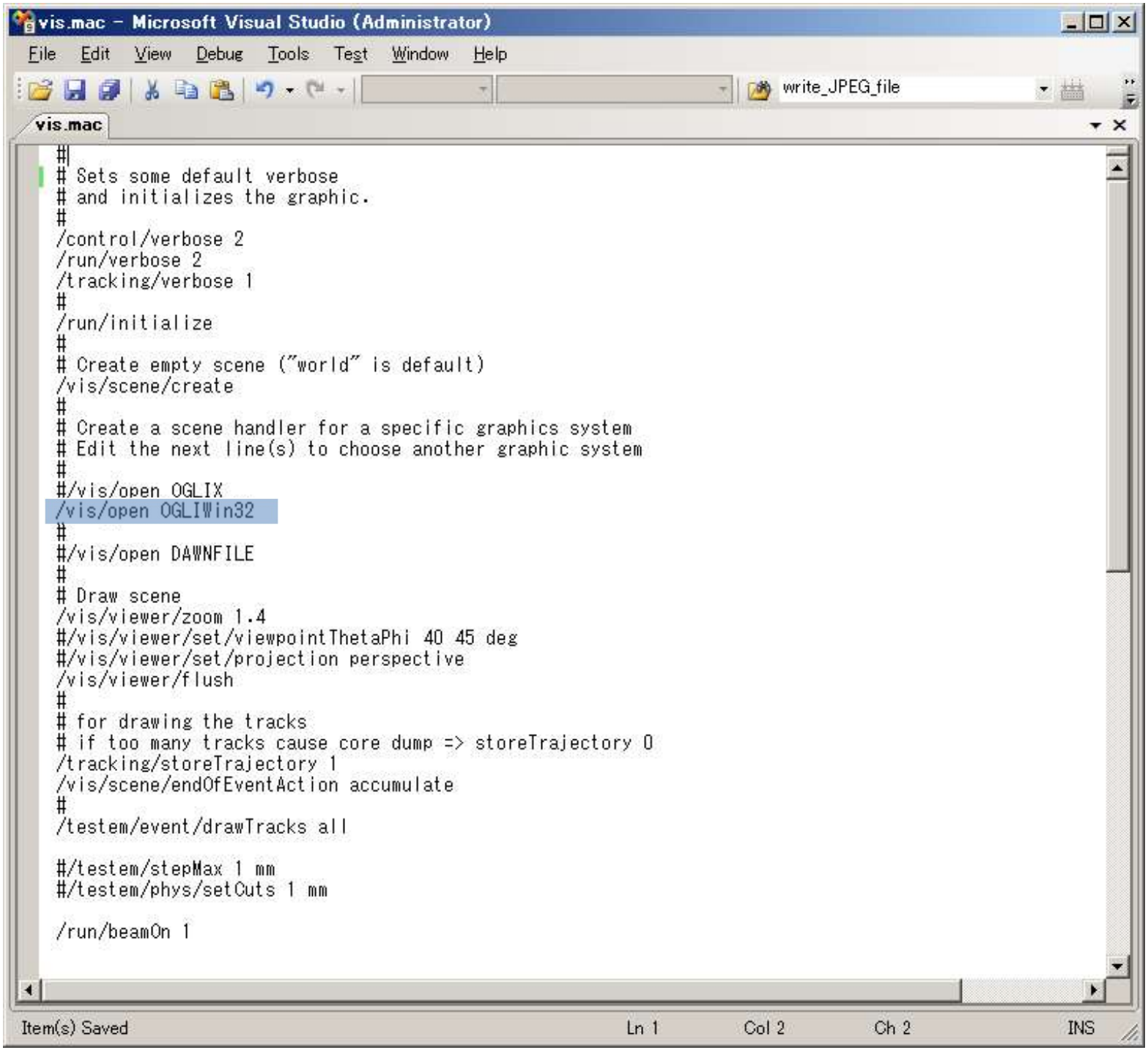


/tracking/verbose 1

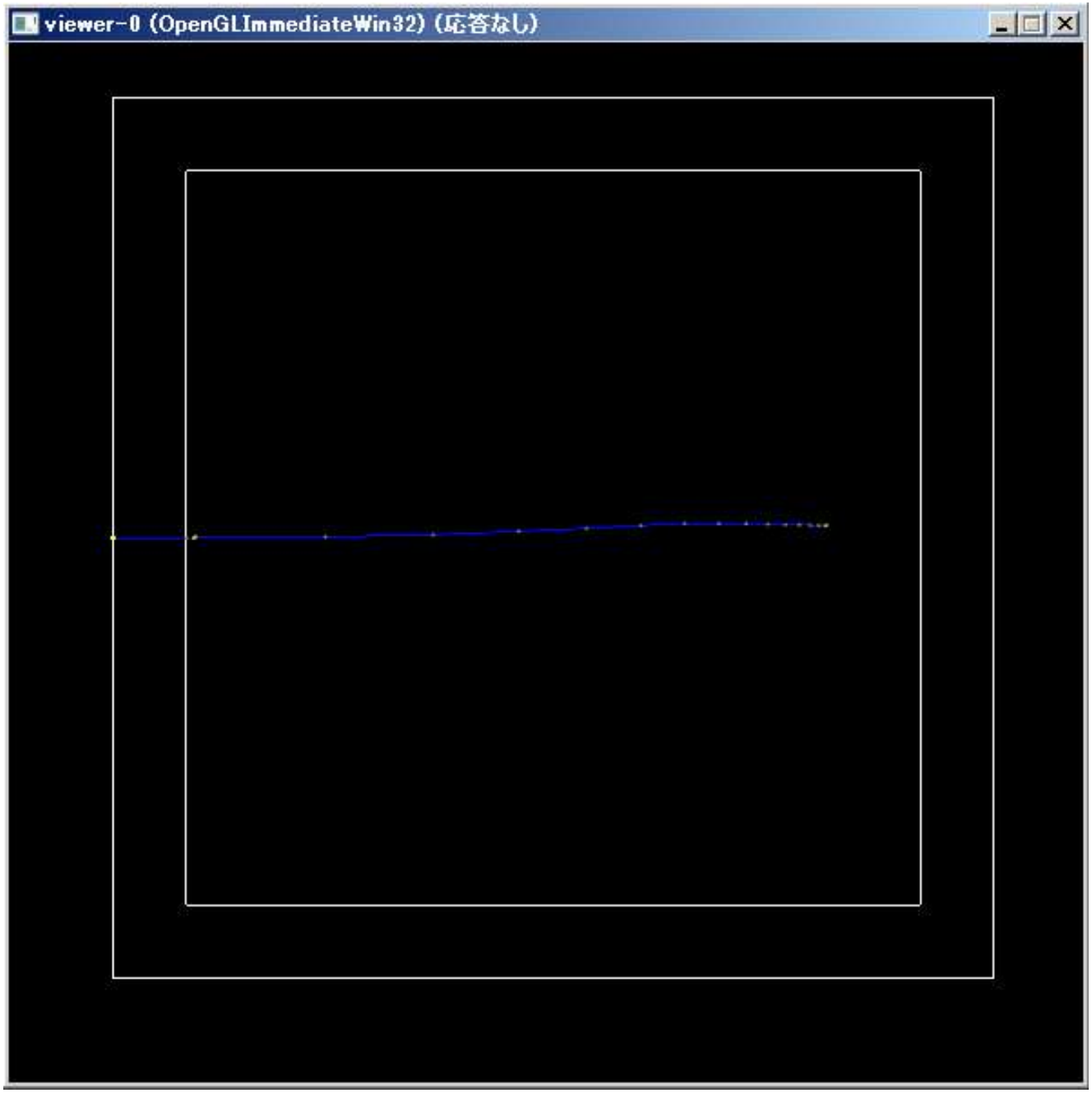
管理者: コマンド プロンプト - Release¥TestEm7.exe vis.mac

```
------------------------------------
Start Run processing.

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

Step#      X         Y         Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0    -12 cm      0 fm      0 fm    160 MeV     0 eV      0 fm      0 fm       World    initStep
    1    -10 cm      0 fm      0 fm    160 MeV1.54e-018 eV     2 cm      2 cm       World  Transportation
    2   -9.8 cm  -1.66 um   5.32 um    158 MeV  1.52 MeV  1.96 mm   2.2 cm     Absorber       hIoni
    3  -6.21 cm    278 um   -342 um    140 MeV  18.2 MeV  3.59 cm   5.79 cm     Absorber       hIoni
    4  -3.28 cm    867 um   -345 um    122 MeV    18 MeV  2.93 cm   8.72 cm     Absorber       hIoni
    5  -9.45 mm   1.78 mm   -443 um    106 MeV  15.7 MeV  2.33 cm   11.1 cm     Absorber       hIoni
    6   9.15 mm   2.59 mm   -389 um   92.2 MeV    14 MeV  1.86 cm   12.9 cm     Absorber       hIoni
    7    2.4 cm   3.37 mm   -377 um   80.1 MeV  12.1 MeV  1.48 cm   14.4 cm     Absorber       hIoni
    8   3.58 cm   3.96 mm   -526 um   68.6 MeV  11.4 MeV  1.19 cm   15.6 cm     Absorber       hIoni
    9   4.52 cm   3.95 mm   -654 um   58.3 MeV  10.3 MeV  9.38 mm   16.5 cm     Absorber       hIoni
   10   5.26 cm   3.86 mm   -489 um   49.8 MeV  8.56 MeV   7.4 mm   17.3 cm     Absorber       hIoni
   11   5.85 cm    3.7 mm   -440 um     42 MeV  7.79 MeV  5.94 mm   17.9 cm     Absorber       hIoni
   12   6.33 cm   3.56 mm   -532 um   34.6 MeV  7.38 MeV  4.76 mm   18.3 cm     Absorber       hIoni
   13   6.71 cm   3.51 mm   -648 um   27.7 MeV  6.91 MeV  3.79 mm   18.7 cm     Absorber       hIoni
   14   7.01 cm   3.46 mm   -710 um   20.9 MeV  6.77 MeV  3.01 mm     19 cm     Absorber       hIoni
   15   7.24 cm   3.44 mm   -731 um     14 MeV  6.94 MeV  2.34 mm   19.3 cm     Absorber       hIoni
   16   7.41 cm   3.38 mm   -639 um   6.26 MeV  7.71 MeV  1.68 mm   19.4 cm     Absorber       hIoni
   17   7.46 cm   3.37 mm   -582 um      0 eV   6.26 MeV   526 um   19.5 cm     Absorber       hIoni

*************************************************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 2,   Parent ID = 1
*************************************************************************************************************

Step#      X         Y         Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0   -9.8 cm  -1.66 um   5.32 um    357 keV     0 eV      0 fm      0 fm     Absorber    initStep
    1  -9.74 cm    258 um   -411 um   53.2 keV   303 keV  1.09 mm   1.09 mm     Absorber       eIoni
    2  -9.74 cm    280 um   -400 um      0 eV   53.2 keV  48.3 um   1.13 mm     Absorber       eIoni
G4VisManager: Using G4TrajectoryDrawByCharge as default trajectory model.
See commands in /vis/modeling/trajectories/ for other options.
Trajectory drawing configuration will be based on imode value of 1000
Run terminated.
Run Summary
  Number of events processed : 1
  User=0s Real=0s Sys=0s
Output saved in 'DepthEnergy0.csv'
1 event has been kept for refreshing and/or reviewing.
Idle>
```

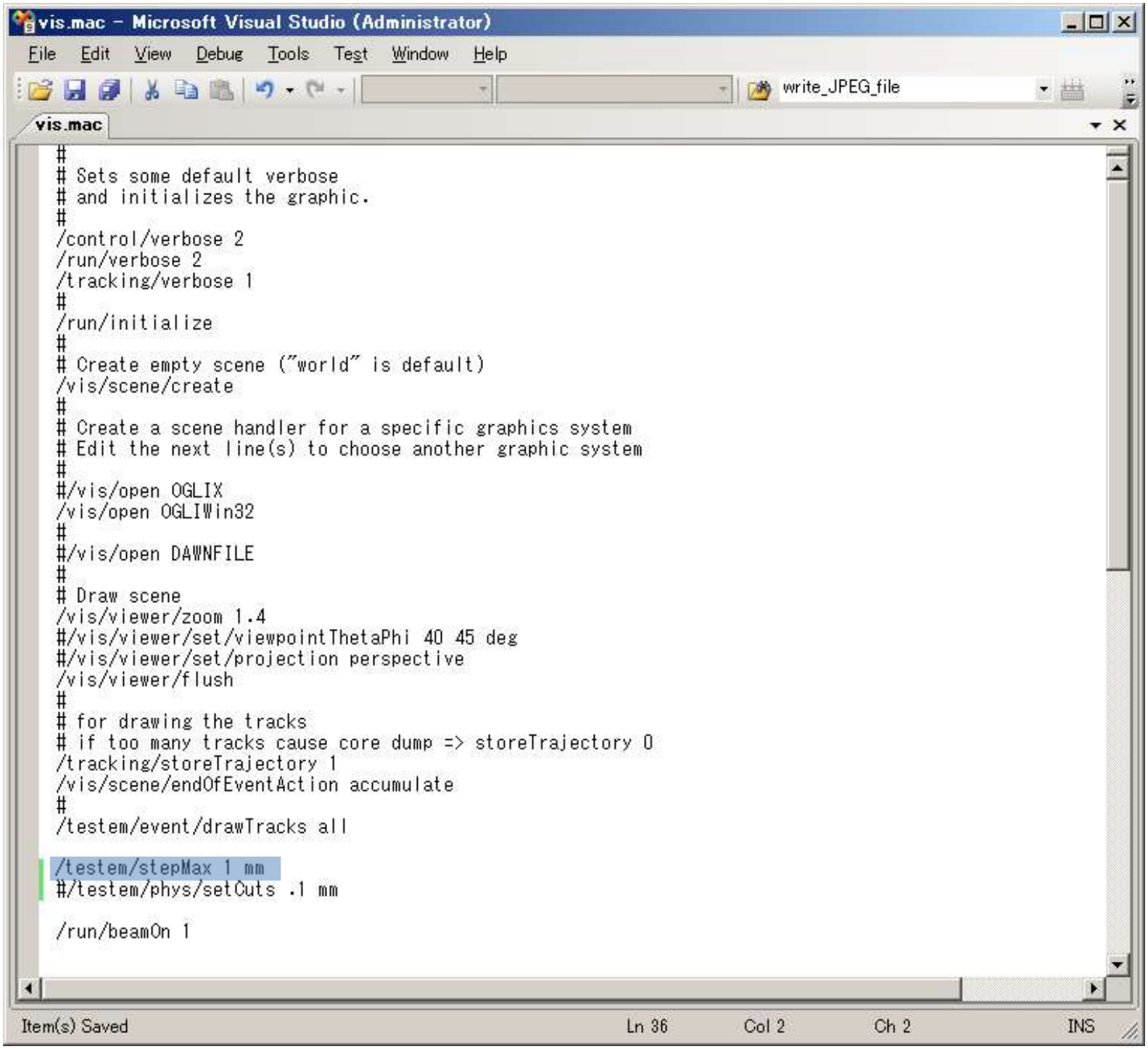
/vis/open OGLIWin32



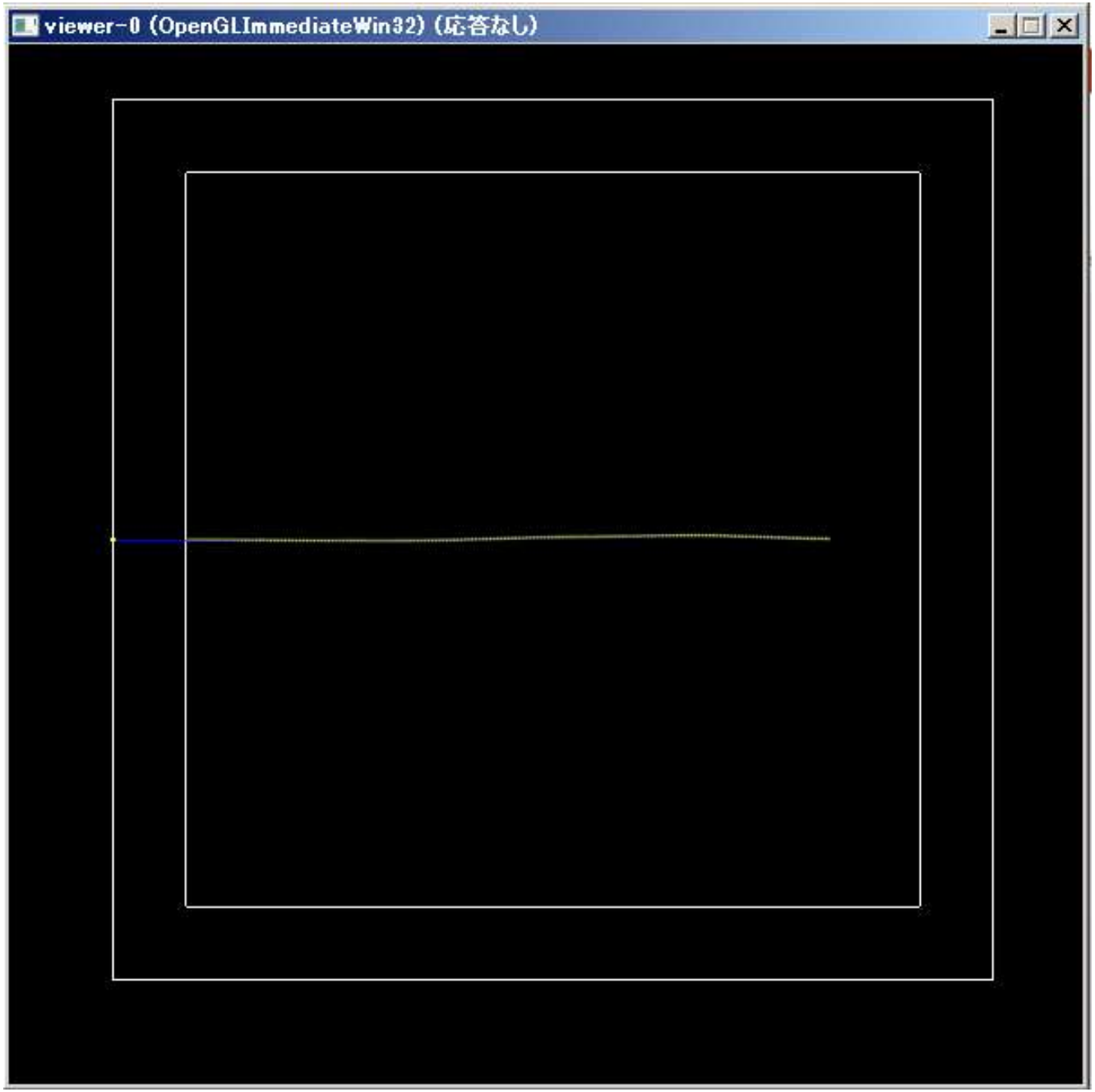
/vis/open OGLIWin32



/testem/stepMax 1 mm



/testem/stepMax 1 mm

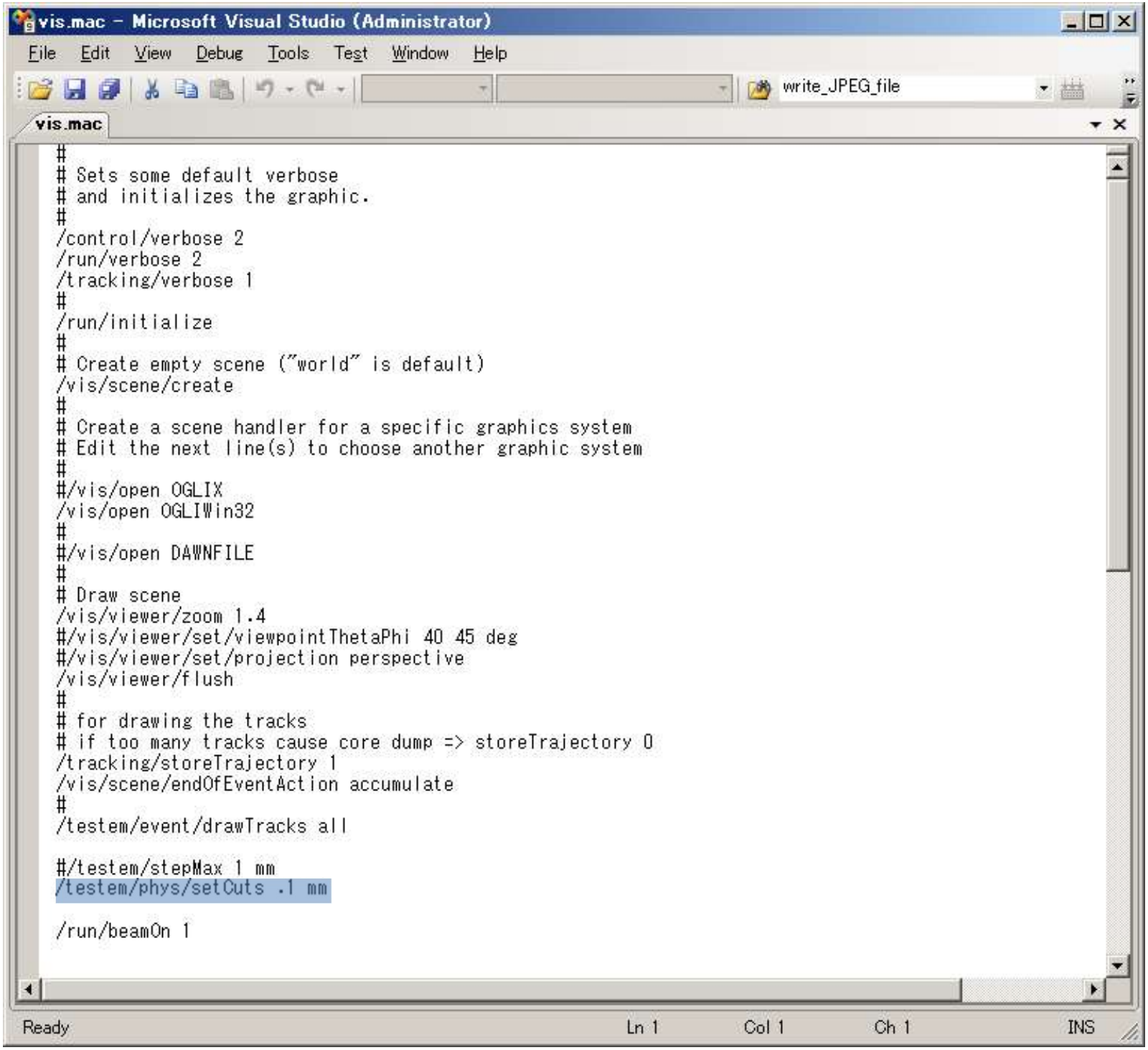


/testem/stepMax 1 mm

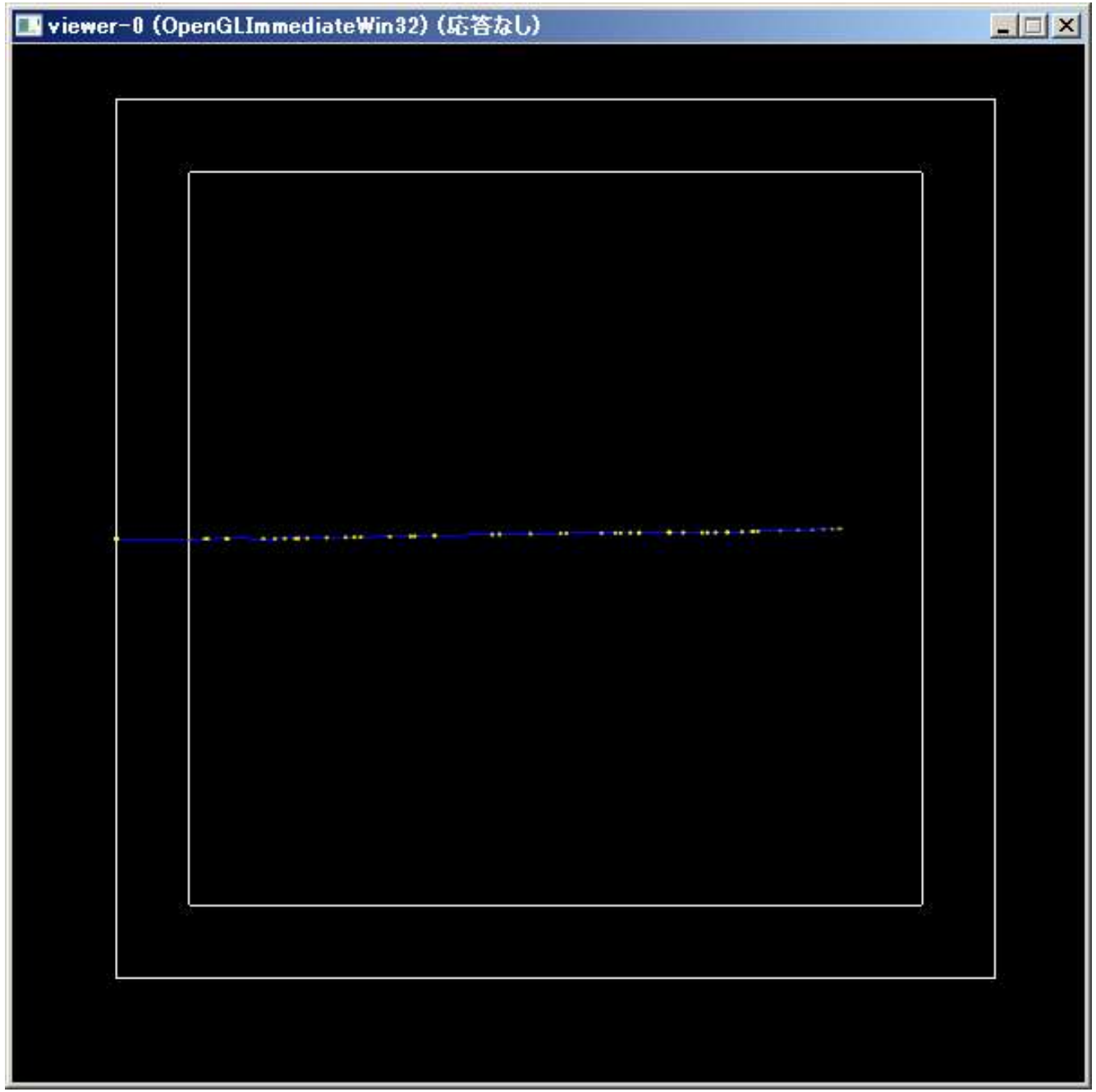
管理者: コマンド プロンプト - Release¥TestEm7.exe vis.mac

```
Start Run processing.

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

Step#       X          Y          Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0    -12 cm        0 fm       0 fm    160 MeV     0 eV      0 fm      0 fm       World    initStep
    1    -10 cm        0 fm       0 fm    160 MeV1.54e-018 eV     2 cm      2 cm       World  Transportation
    2   -9.9 cm  -1.56 um    1.77 um    159 MeV   750 keV     1 mm    2.1 cm    Absorber  UserMaxStep
    3   -9.8 cm   -701 nm    5.15 um    159 MeV   493 keV     1 mm    2.2 cm    Absorber  UserMaxStep
    4   -9.7 cm   -989 nm    5.51 um    158 MeV   677 keV     1 mm    2.3 cm    Absorber  UserMaxStep
    5   -9.6 cm  -2.05 um    8.95 um    158 MeV   485 keV     1 mm    2.4 cm    Absorber  UserMaxStep
    6   -9.5 cm  -7.25 um    13.7 um    157 MeV   527 keV     1 mm    2.5 cm    Absorber  UserMaxStep
    7   -9.4 cm  -14.1 um      18 um    157 MeV   453 keV     1 mm    2.6 cm    Absorber  UserMaxStep
    8   -9.3 cm  -18.9 um    27.7 um    156 MeV   470 keV     1 mm    2.7 cm    Absorber  UserMaxStep
    9   -9.2 cm  -25.1 um    36.5 um    156 MeV   463 keV     1 mm    2.8 cm    Absorber  UserMaxStep
   10   -9.1 cm  -33.1 um    48.5 um    155 MeV   650 keV     1 mm    2.9 cm    Absorber  UserMaxStep
   11     -9 cm  -39.4 um    62.2 um    154 MeV   563 keV     1 mm      3 cm    Absorber  UserMaxStep
   12   -8.9 cm  -51.1 um    75.3 um    154 MeV   567 keV     1 mm    3.1 cm    Absorber  UserMaxStep
   13   -8.8 cm  -59.8 um    86.2 um    153 MeV   519 keV     1 mm    3.2 cm    Absorber  UserMaxStep
   14   -8.7 cm  -69.1 um    99.8 um    153 MeV   828 keV     1 mm    3.3 cm    Absorber  UserMaxStep
   15   -8.6 cm  -77.8 um     111 um    152 MeV   479 keV     1 mm    3.4 cm    Absorber  UserMaxStep
   16   -8.5 cm    -81 um     122 um    152 MeV   536 keV     1 mm    3.5 cm    Absorber  UserMaxStep
   17   -8.4 cm  -86.7 um     129 um    151 MeV   581 keV     1 mm    3.6 cm    Absorber  UserMaxStep
   18   -8.3 cm  -92.6 um     135 um    151 MeV   447 keV     1 mm    3.7 cm    Absorber  UserMaxStep
   19   -8.2 cm  -96.7 um     142 um    150 MeV   674 keV     1 mm    3.8 cm    Absorber  UserMaxStep
   20   -8.1 cm   -101 um     146 um    149 MeV   719 keV     1 mm    3.9 cm    Absorber  UserMaxStep
   21     -8 cm   -108 um     153 um    149 MeV   555 keV     1 mm      4 cm    Absorber  UserMaxStep
   22   -7.9 cm   -117 um     160 um    148 MeV   656 keV     1 mm    4.1 cm    Absorber  UserMaxStep
   23   -7.8 cm   -127 um     168 um    147 MeV   498 keV     1 mm    4.2 cm    Absorber  UserMaxStep
   24   -7.7 cm   -138 um     176 um    147 MeV   601 keV     1 mm    4.3 cm    Absorber  UserMaxStep
   25   -7.6 cm   -149 um     185 um    146 MeV   509 keV     1 mm    4.4 cm    Absorber  UserMaxStep
   26   -7.5 cm   -163 um     191 um    146 MeV   505 keV     1 mm    4.5 cm    Absorber  UserMaxStep
```

/testem/phys/setCuts .1 mm



/testem/phys/setCuts .1 mm

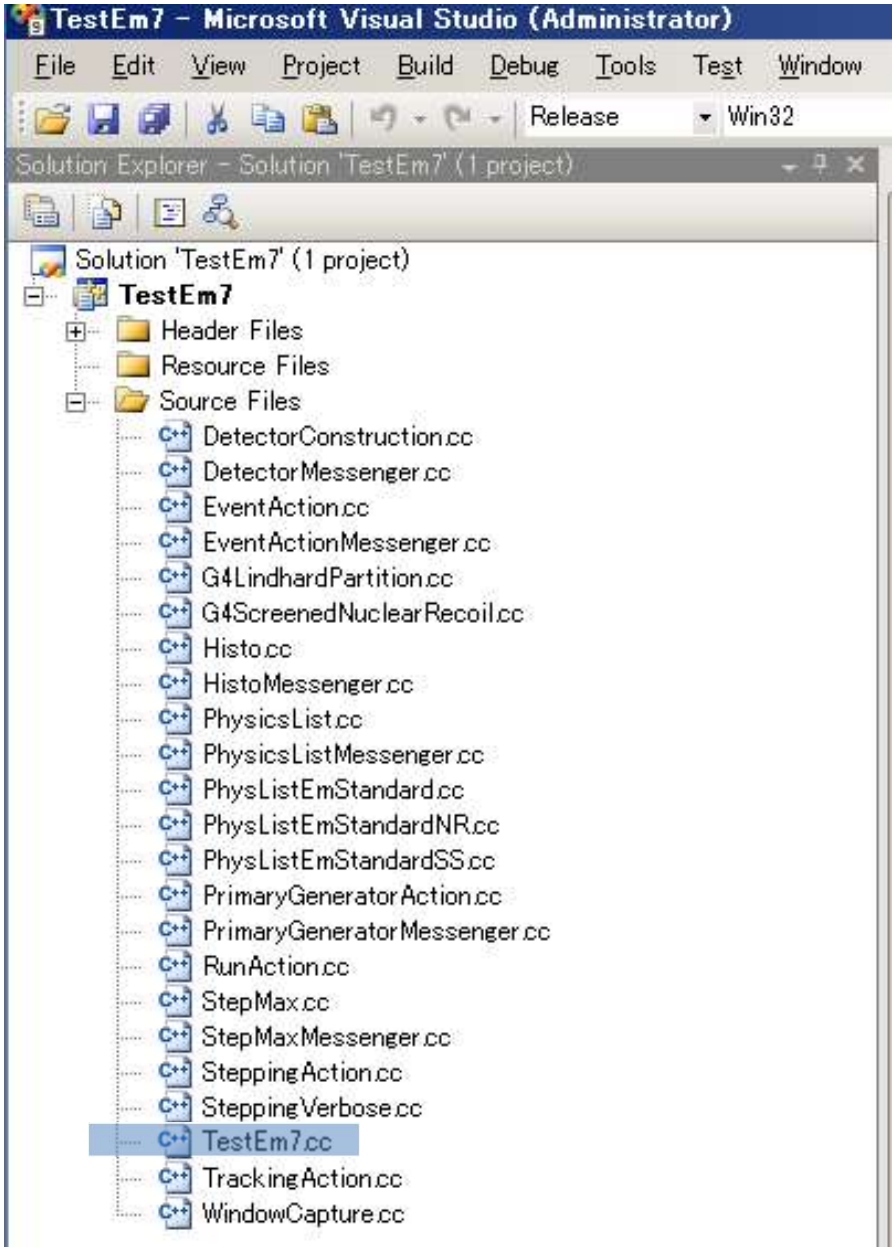


/testem/phys/setCuts .1 mm

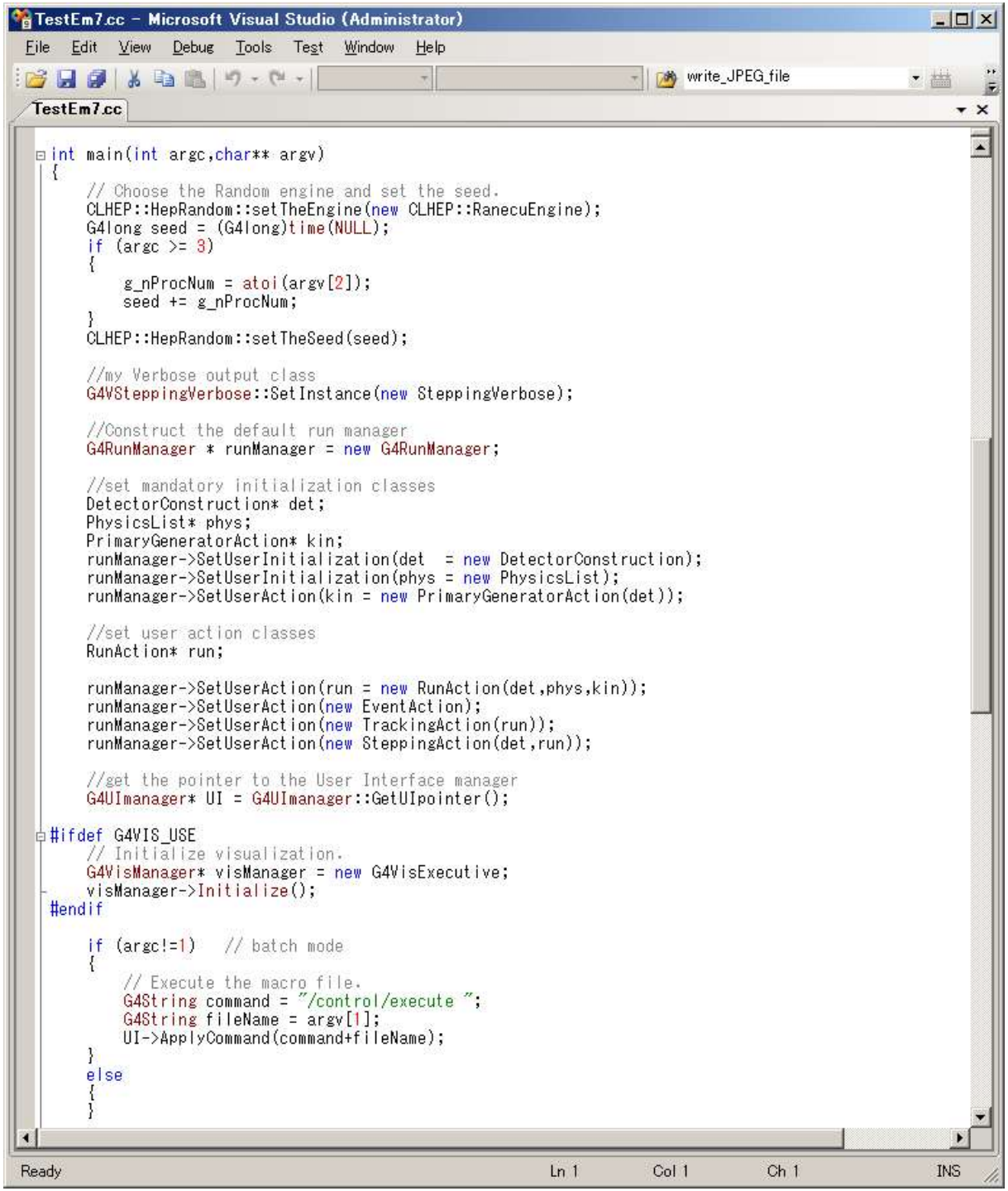
管理者: コマンド プロンプト - Release¥TestEm7.exe vis.mac

```
**********************************************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 44,   Parent ID = 1
**********************************************************************************************************

Step#       X          Y          Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0   5.52 cm   2.03 mm  -1.25 mm   88.1 keV     0 eV      0 fm      0 fm     Absorber    initStep
    1   5.53 cm   2.02 mm  -1.28 mm      0 eV   88.1 keV   116 um    116 um     Absorber       eIoni

**********************************************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 43,   Parent ID = 1
**********************************************************************************************************

Step#       X          Y          Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0    5.4 cm   1.97 mm  -1.23 mm   89.1 keV     0 eV      0 fm      0 fm     Absorber    initStep
    1    5.4 cm      2 mm  -1.22 mm      0 eV   89.1 keV   118 um    118 um     Absorber       eIoni

**********************************************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 42,   Parent ID = 1
**********************************************************************************************************

Step#       X          Y          Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0   5.37 cm   1.96 mm  -1.22 mm   85.2 keV     0 eV      0 fm      0 fm     Absorber    initStep
    1   5.37 cm   1.97 mm   -1.2 mm      0 eV   85.2 keV   109 um    109 um     Absorber       eIoni

**********************************************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 41,   Parent ID = 1
**********************************************************************************************************

Step#       X          Y          Z        KineE    dEStep   StepLeng  TrakLeng    Volume     Process
    0   5.09 cm   1.85 mm  -1.16 mm    103 keV     0 eV      0 fm      0 fm     Absorber    initStep
    1    5.1 cm   1.86 mm  -1.19 mm      0 eV    103 keV   151 um    151 um     Absorber       eIoni

**********************************************************************************************************
```

Main Program



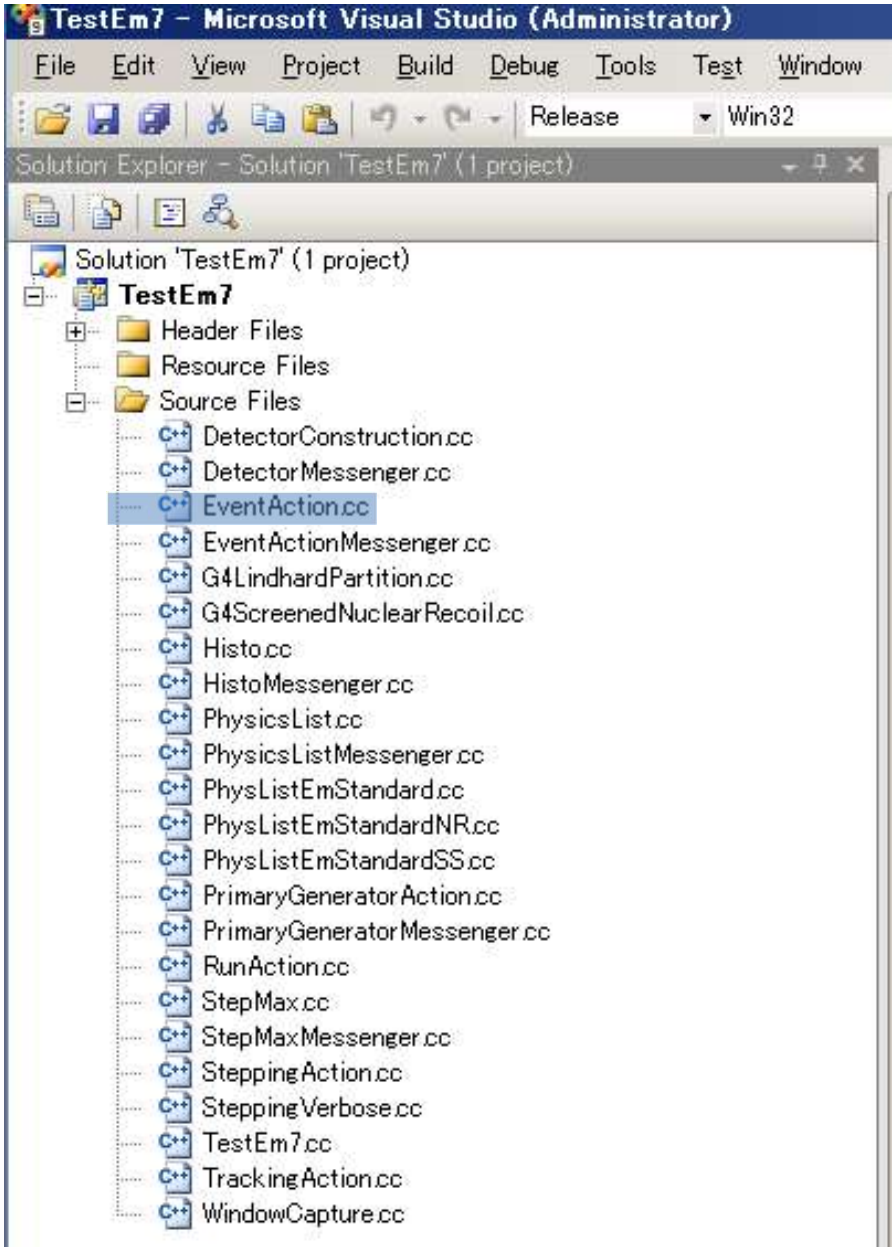
Main Program



Action Classes

- RunAction
  - BeginOfRunAction
  - EndOfRunAction
- EventAction
  - BeginOfEventAction
- SteppingAction
  - UserSteppingAction

Event Action



EventAction

EventAction.cc - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

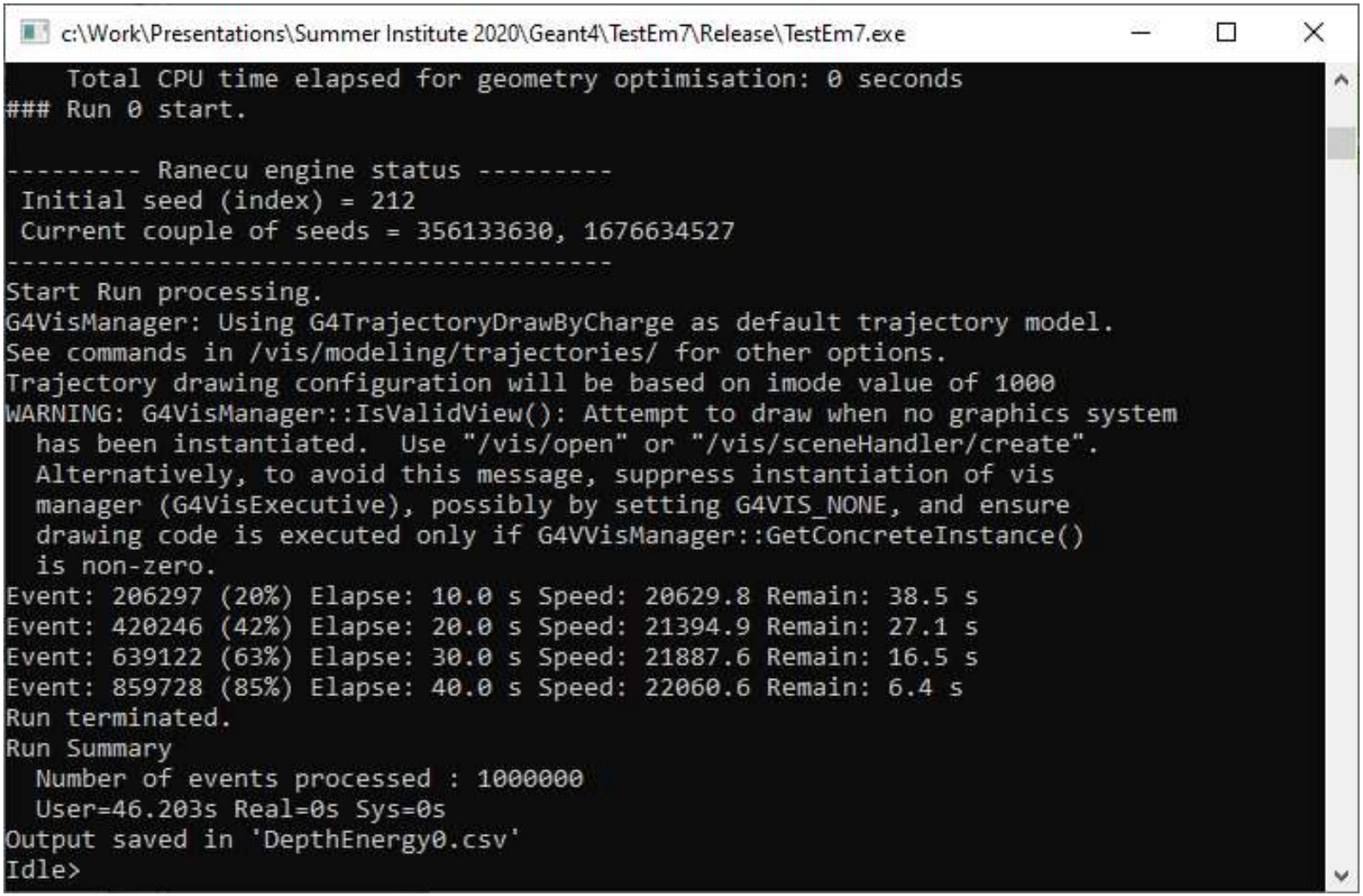
/testem/stepMax

EventAction.cc

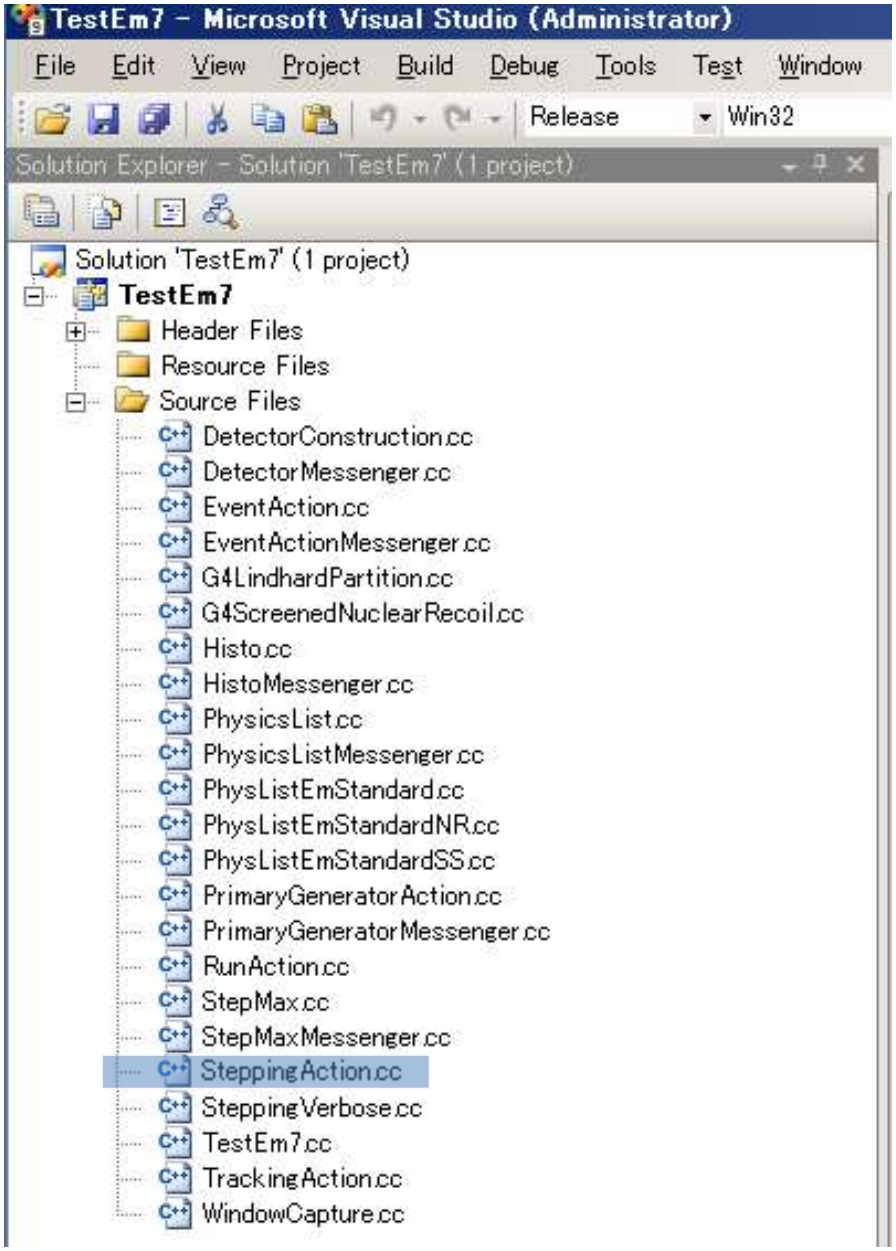
```
void EventAction::BeginOfEventAction(const G4Event* pEvent)
{
    G4int nEventID = pEvent->GetEventID();

    //printing survey
    //if (evtNb%printModulo == 0)
    //  G4cout << "¥n---> Begin of Event: " << evtNb << G4endl;

    static int nTimeStart = 0;
    static int nTimePrev = 0;
    static int nEventCount = 0;
    static int nTimeUpdate = 10;     //Update every 10 seconds

    if (nEventID == 0)
    {
        nTimeStart = (int)time(NULL);
        nTimePrev = nTimeStart;
        nEventCount = 1;
    }
    else
    {
        nEventCount++;
        int nTimeCurrent = (int)time(NULL);
        int nTimeSpan = nTimeCurrent - nTimePrev;

        // Update every 10 seconds
        if (nTimeSpan >= nTimeUpdate)
        {
            G4RunManager* pRunManager = G4RunManager::GetRunManager();
            const G4Run* pRun = pRunManager->GetCurrentRun();
            G4int nNumberOfEventToBeProcessed = pRun->GetNumberOfEventToBeProcessed();
            int nPerc = int((nEventID / (float)nNumberOfEventToBeProcessed) * 100);

            float fElapse = (float)(nTimeCurrent - nTimeStart);
            float fSpeed = 0.0;
            if (nTimeSpan > 0.0)
                fSpeed = nEventCount / (float)nTimeSpan;           // events per sec

            float fRemain = (nNumberOfEventToBeProcessed - nEventID) / fSpeed;

            //int nPercent = (100 * nEventID) / NbofEvents;

            char szElapse[16];
            char szRemain[16];
            FormatTime(fElapse, szElapse);
            FormatTime(fRemain, szRemain);

            char sz[128];
            sprintf(sz, "Event: %d (%d%%) Elapse: %s Speed: %0.1f Remain: %s",
                nEventID, nPerc, szElapse, fSpeed, szRemain);
            G4cout << sz << G4endl;

            nTimePrev = nTimeCurrent;
            nEventCount = 0;

            //if (dRemain > 60.*3)
            //  dwTimeUpdate = 60 * 1000;

            if (::GetAsyncKeyState(VK_ESCAPE) != 0)
            {
                printf("Abort run? [y/n] ");
                char c = getchar();
                if (c == 'y')
                {
                    pRunManager->AbortRun();
                }
            }
        }
    }

}
```

Ready Ln 1 Col 1 Ch 1 INS

EventAction



Stepping Action



Stepping Action

SteppingAction.cc - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

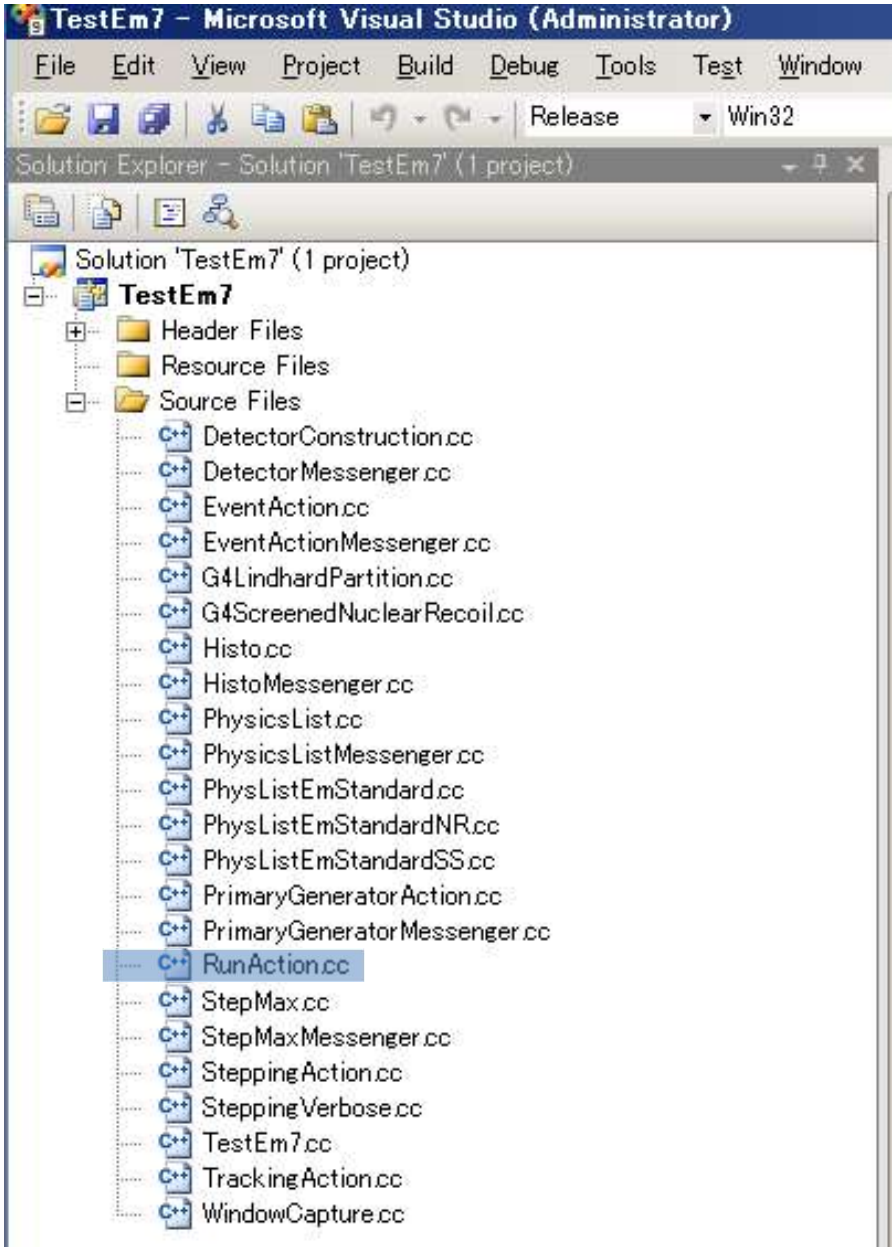
write_JPEG_file

SteppingAction.cc

```
void SteppingAction::UserSteppingAction(const G4Step* aStep)
{
  G4double edep = aStep->GetTotalEnergyDeposit();
  if (edep <= 0.) return;

  // G4cout << "edep= " << edep << "NIEL= " << aStep->GetNonIonizingEnergyDeposit()<<G4endl;

  //runAction->FillEdep(edep,aStep->GetNonIonizingEnergyDeposit());

  if(aStep->GetTrack()->GetTrackID() == 1) runAction->AddPrimaryStep();

  //Bragg curve
  //
  G4StepPoint* prePoint  = aStep->GetPreStepPoint();
  G4StepPoint* postPoint = aStep->GetPostStepPoint();

  G4double x1 = prePoint->GetPosition().x(), x2 = postPoint->GetPosition().x();
  G4double x = runAction->GetOffsetX() + x1 + G4UniformRand()*(x2-x1);
/*
  runAction->FillHisto(0, x/mm , edep);
  runAction->FillHisto(1, x/mm , edep);

  //fill tallies
  //
  G4TouchableHandle touchable = prePoint->GetTouchableHandle();
  G4LogicalVolume* lVolume = touchable->GetVolume()->GetLogicalVolume();
  if (lVolume == detector->GetLogicalTally())
    runAction->FillTallyEdep(touchable->GetCopyNumber(), edep);
*/
  runAction->SaveEnergyDeposit(x, edep);
}

//....oooOOOOOooo.......oooOOOOOooo.......oooOOOOOooo.......oooOOOOOooo.....
```

Ready Ln 1 Col 1 Ch 1 INS

Run Action


TestEm7 - Microsoft Visual Studio (Administrator)
File Edit View Project Build Debug Tools Test Window
Release
Win32
Solution Explorer - Solution 'TestEm7' (1 project)
Solution 'TestEm7' (1 project)
TestEm7
Header Files
Resource Files
Source Files
DetectorConstruction.cc
DetectorMessenger.cc
EventAction.cc
EventActionMessenger.cc
G4LindhardPartition.cc
G4ScreenedNuclearRecoil.cc
Histo.cc
HistoMessenger.cc
PhysicsList.cc
PhysicsListMessenger.cc
PhysListEmStandard.cc
PhysListEmStandardNR.cc
PhysListEmStandardSS.cc
PrimaryGeneratorAction.cc
PrimaryGeneratorMessenger.cc
RunAction.cc
StepMax.cc
StepMaxMessenger.cc
SteppingAction.cc
SteppingVerbose.cc
TestEm7.cc
TrackingAction.cc
WindowCapture.cc

RunAction.hh

RunAction.hh - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

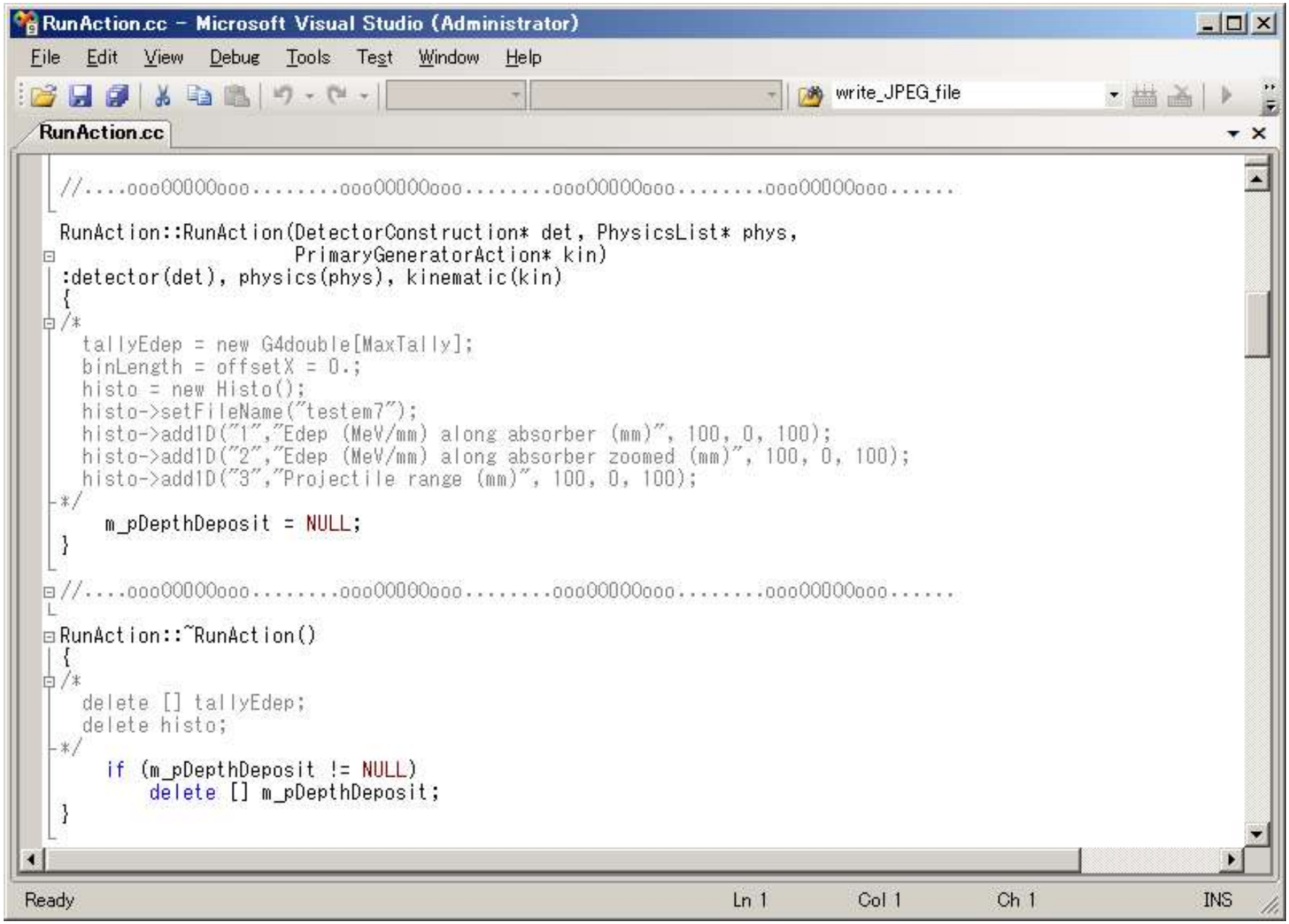
write_JPEG_file

RunAction.hh

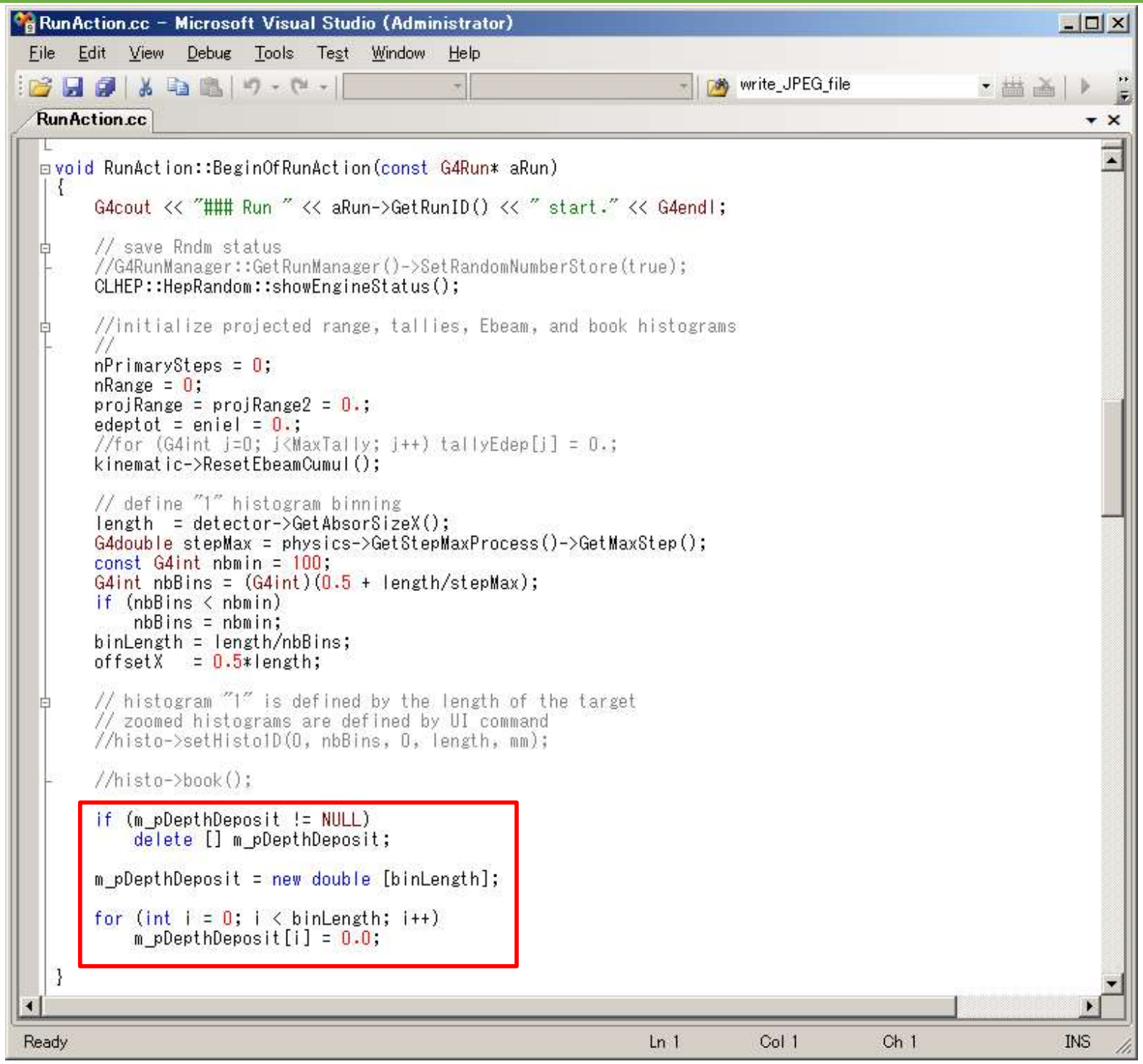
```
//....ooo00000ooo.......ooo00000ooo.......ooo00000ooo.......ooo00000ooo.....

class RunAction : public G4UserRunAction
{
public:
  RunAction(DetectorConstruction*, PhysicsList*,
        PrimaryGeneratorAction*);
  virtual ~RunAction();

  void BeginOfRunAction(const G4Run*);
  void   EndOfRunAction(const G4Run*);

  //void FillTallyEdep(G4int n, G4double e)  {tallyEdep[n] += e;};
  //void FillEdep(G4double de, G4double eni) {edeptot += de; eniel += eni;};

  G4double GetBinLength() {return binLength;};
  G4double GetLength()    {return length;};
  G4double GetOffsetX()   {return offsetX;}

  //void FillHisto(G4int id, G4double x, G4double weight = 1.0);

  void AddProjRange (G4double x)
  {projRange += x; projRange2 += x*x; nRange++;};
  void AddPrimaryStep() {nPrimarySteps++;};

    void SaveEnergyDeposit(G4double dDepth,G4double dEnergyDep);

private:

  DetectorConstruction*   detector;
  PhysicsList*            physics;
  PrimaryGeneratorAction* kinematic;
  //G4double*               tallyEdep;
  G4double                binLength;
  G4double                offsetX;
  G4double                length;
  G4double                projRange, projRange2;
  G4double                edeptot, eniel;
  G4int                   nPrimarySteps;
  G4int                   nRange;

  //Histo*                  histo;

   double* m_pDepthDeposit;
};
```

Ready Ln 1 Col 1 Ch 1 INS

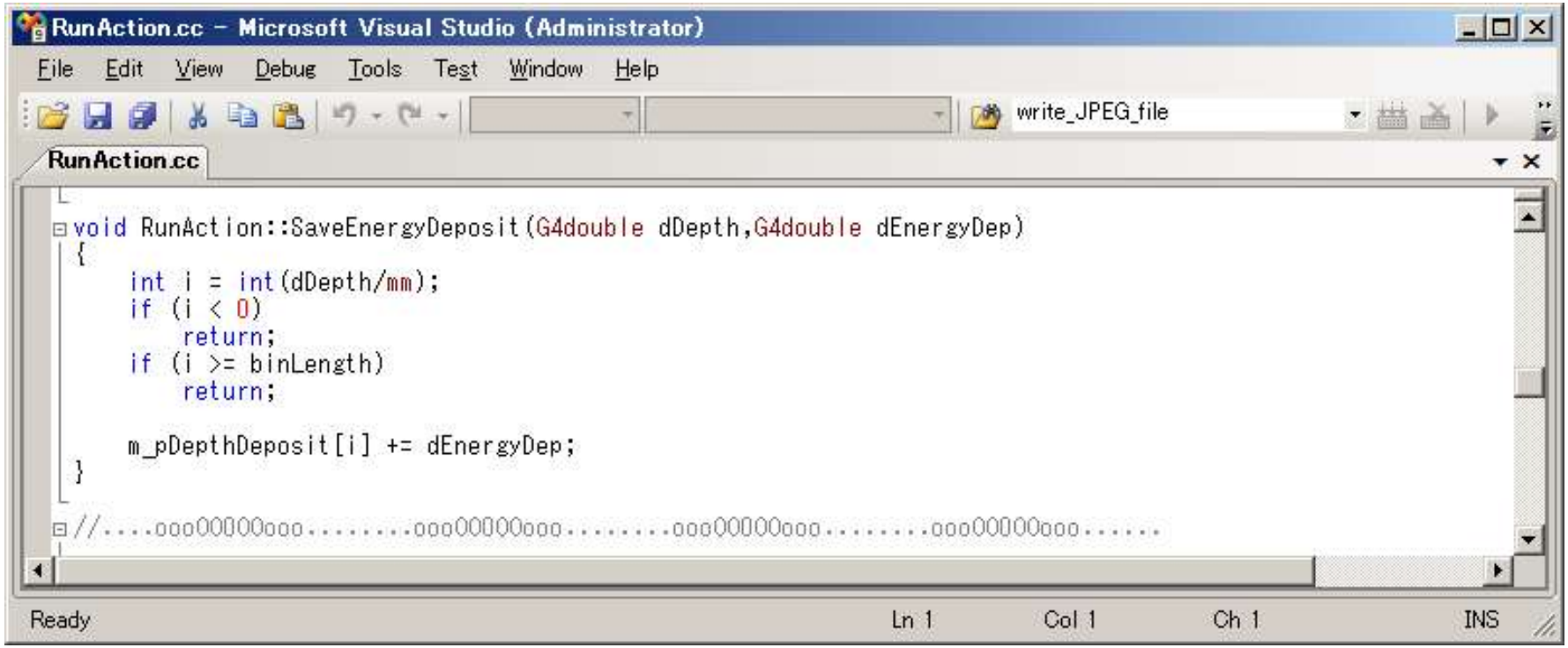
RunAction.cc – Constructor and Destructor



RunAction.cc – BeginOfRunAction



RunAction.cc – SaveEnergyDeposit



RunAction.cc - EndOfRunAction

RunAction.cc* – Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

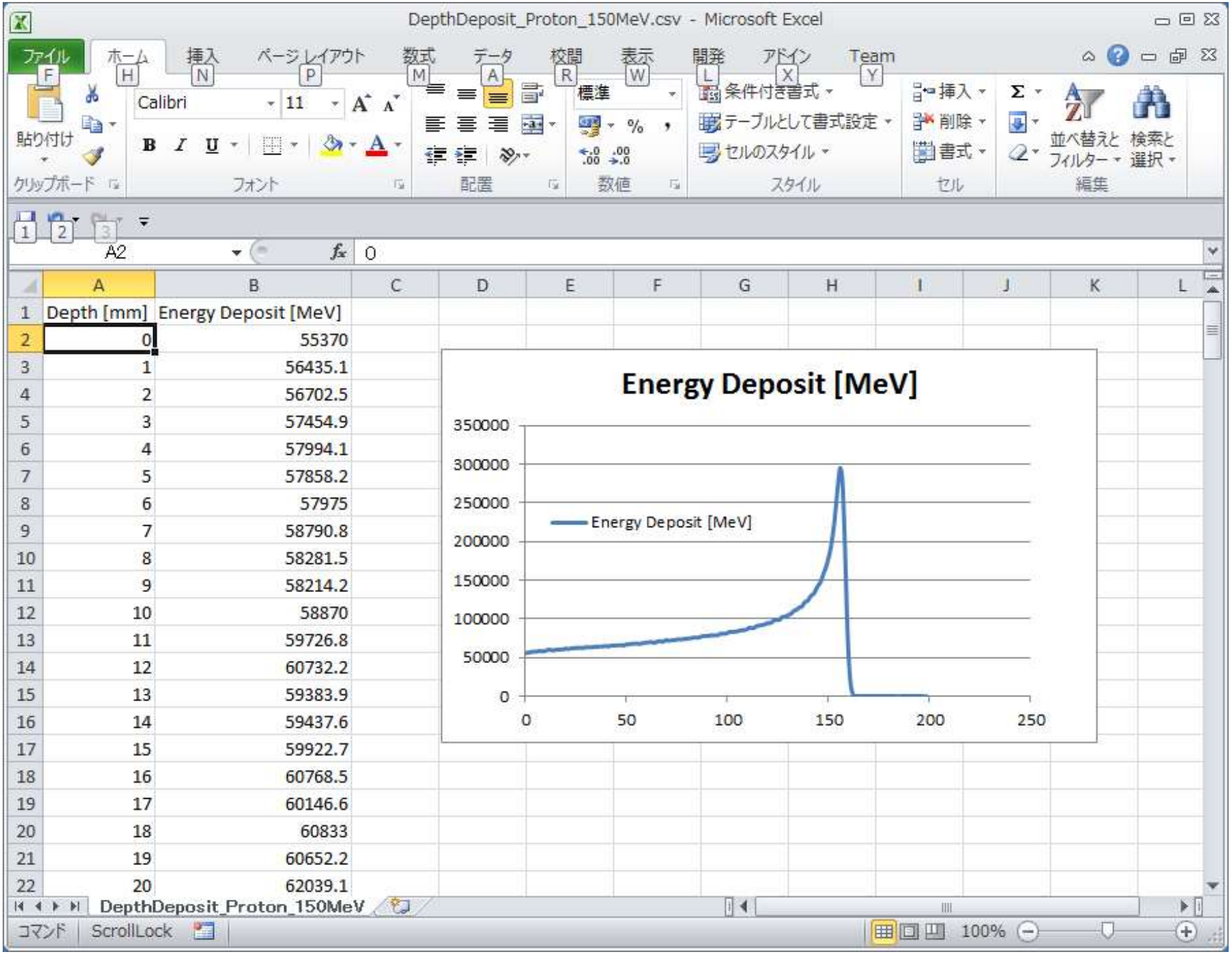
write_JPEG_file

RunAction.cc*

```
void RunAction::EndOfRunAction(const G4Run* aRun)
{
  G4int NbofEvents = aRun->GetNumberOfEvent();
  if (NbofEvents == 0) return;

    // Save the dose depth.
    FILE* fp;
    char szFileName[1024];
    extern int g_nProcNum;
    sprintf(szFileName, "DepthEnergy%d.csv", g_nProcNum);
retry:
    fp = fopen(szFileName, "wt");
    if (fp == NULL)
    {
        printf("Failed to open '%s'¥n", szFileName);
        printf("Retry? [y/n] ");
        char c = getchar();
        if (c == 'n' || c == 'N')
            return;
        goto retry;
    }


    fprintf(fp, "Depth [mm], Energy [MeV]¥n");
    for (int i = 0; i < binLength; i++)
    {
        // Normalize to MeV per incedent particle (event).
        double dDeposit = m_pDepthDeposit[i];
        dDeposit /= NbofEvents;
        fprintf(fp, "%d,%f¥n", i, dDeposit);
    }

    fclose(fp);
    printf("Output saved in '%s'¥n", szFileName);
}
```

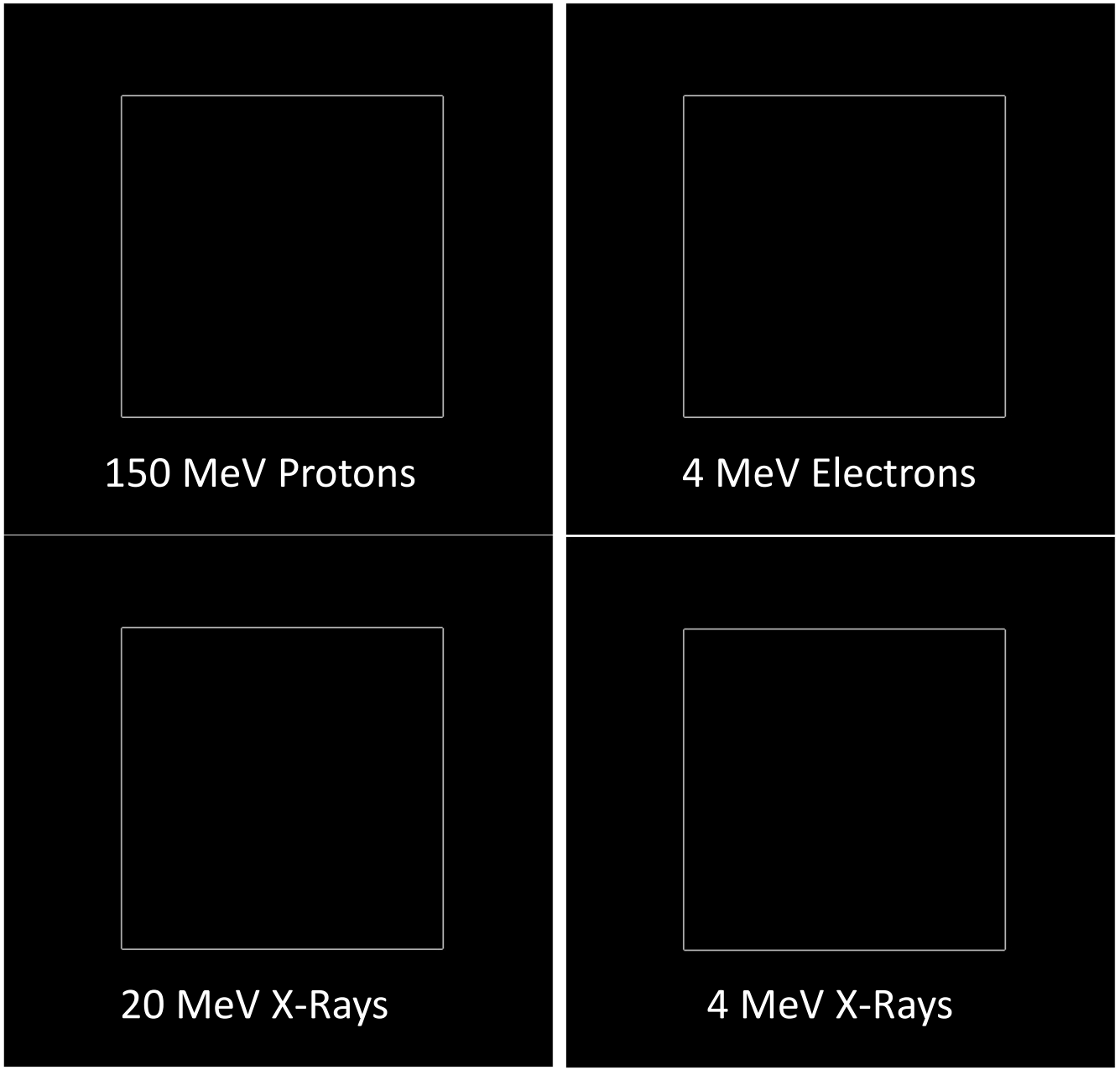
Ready Ln 177 Col 1 Ch 1 INS

Output .csv file

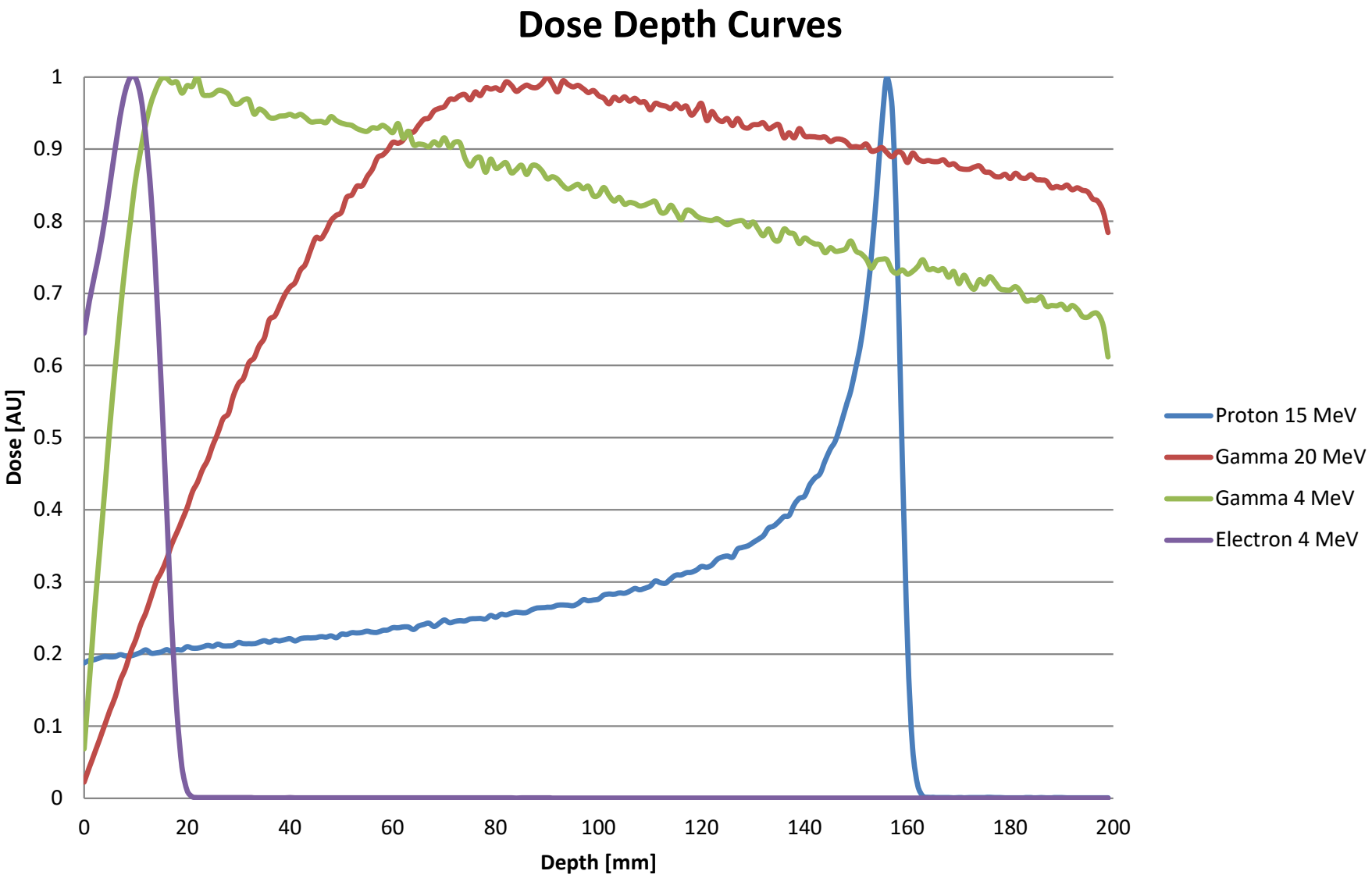


Depth [mm]	Energy Deposit [MeV]
0	55370
1	56435.1
2	56702.5
3	57454.9
4	57994.1
5	57858.2
6	57975
7	58790.8
8	58281.5
9	58214.2
10	58870
11	59726.8
12	60732.2
13	59383.9
14	59437.6
15	59922.7
16	60768.5
17	60146.6
18	60833
19	60652.2
20	62039.1

Animations

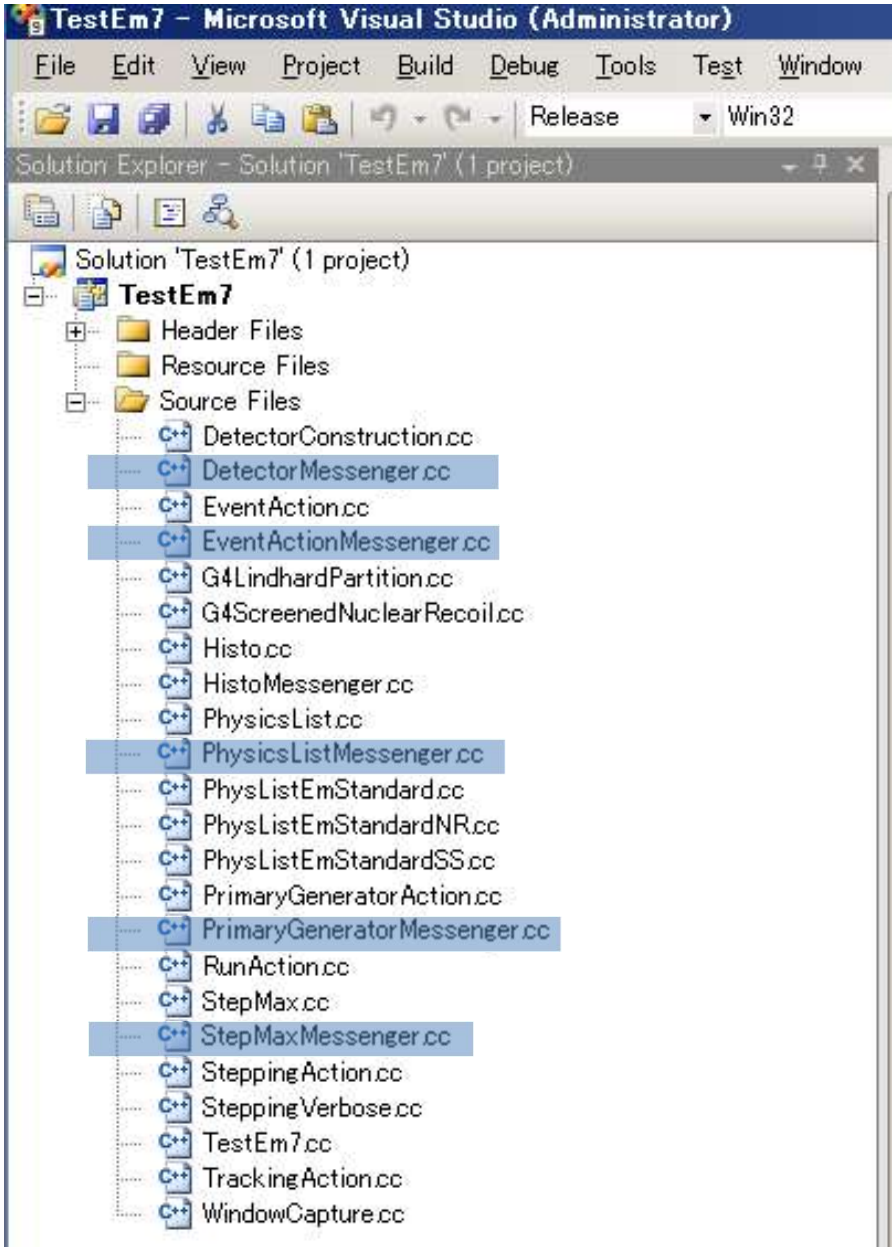


Dose Depth Curves



Geant4 Commands

Messenger Classes



StepMaxMessenger

StepMaxMessenger.cc - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

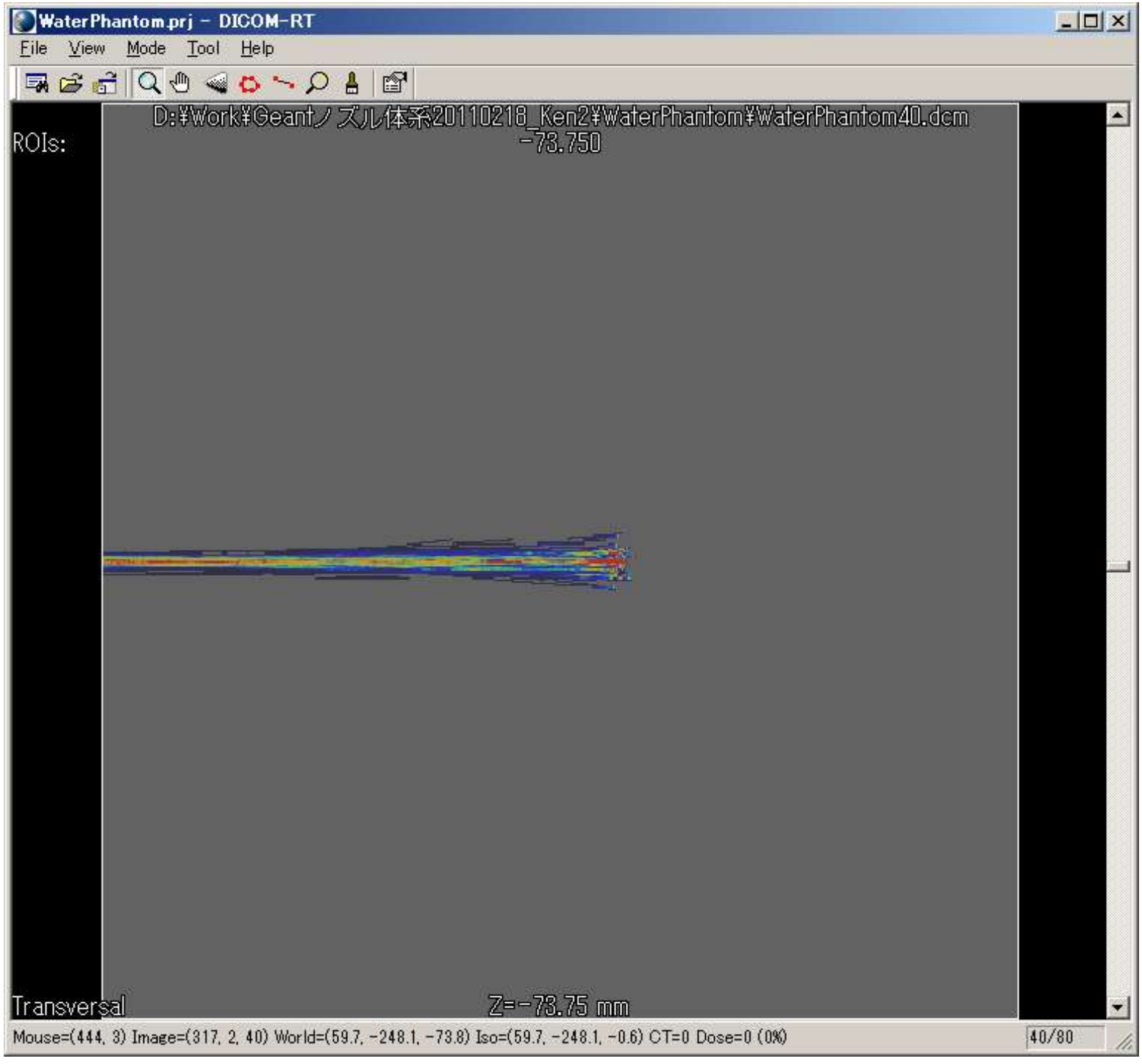
write_JPEG_file

StepMaxMessenger.cc

```
#include "StepMaxMessenger.hh"

#include "StepMax.hh"
#include "G4UIcmdWithADoubleAndUnit.hh"

//....oooOOOOOooo........oooOOOOOooo........oooOOOOOooo........oooOOOOOooo......

StepMaxMessenger::StepMaxMessenger(StepMax* stepM)
:stepMax(stepM)
{
  StepMaxCmd = new G4UIcmdWithADoubleAndUnit("/testem/stepMax",this);
  StepMaxCmd->SetGuidance("Set max allowed step length");
  StepMaxCmd->SetParameterName("mxStep",false);
  StepMaxCmd->SetRange("mxStep>0.");
  StepMaxCmd->SetUnitCategory("Length");
}

//....oooOOOOOooo........oooOOOOOooo........oooOOOOOooo........oooOOOOOooo......

StepMaxMessenger::~StepMaxMessenger()
{
  delete StepMaxCmd;
}

//....oooOOOOOooo........oooOOOOOooo........oooOOOOOooo........oooOOOOOooo......

void StepMaxMessenger::SetNewValue(G4UIcommand* command, G4String newValue)
{
  if (command == StepMaxCmd)
    { stepMax->SetMaxStep(StepMaxCmd->GetNewDoubleValue(newValue));}
}

//....oooOOOOOooo........oooOOOOOooo........oooOOOOOooo........oooOOOOOooo......
```

Ready Ln 1 Col 1 Ch 1 INS

3D Water Phantom



CT Density Table

CT scanner table

Material	Mass Density	Rel. Electron Density	GE LightSpeed	Siemens	Toshiba
Air	0.000	0.000	-991.5	-969.8	-970.3
Lung 300	0.290	0.278	-729.2	-712.9	-720.8
Lung 450	0.450	0.443	-541.8	-536.5	-543.3
Adipose	0.943	0.926	-92.8	-95.6	-67.2
Breast	0.985	0.962	-33.0	-45.6	-36.4
Solid Water	1.016	0.987	3.7	-1.9	-5.5
Water	1.000	1.000	-2.9	-5.6	-5.1
Brain	1.052	1.048	28.7	25.7	16.8
Liver	1.089	1.058	64.9	65.6	65.8
Inner Bone	1.145	1.098	212.7	207.5	211.0
B-200	1.159	1.111	227.4	220.7	229.6
CB2 30%	1.335	1.280	442.0	429.9	464.4
CB2 50%	1.560	1.470	791.2	775.3	831.1
Cortical Bone	1.823	1.695	1191.8	1173.7	1256.2

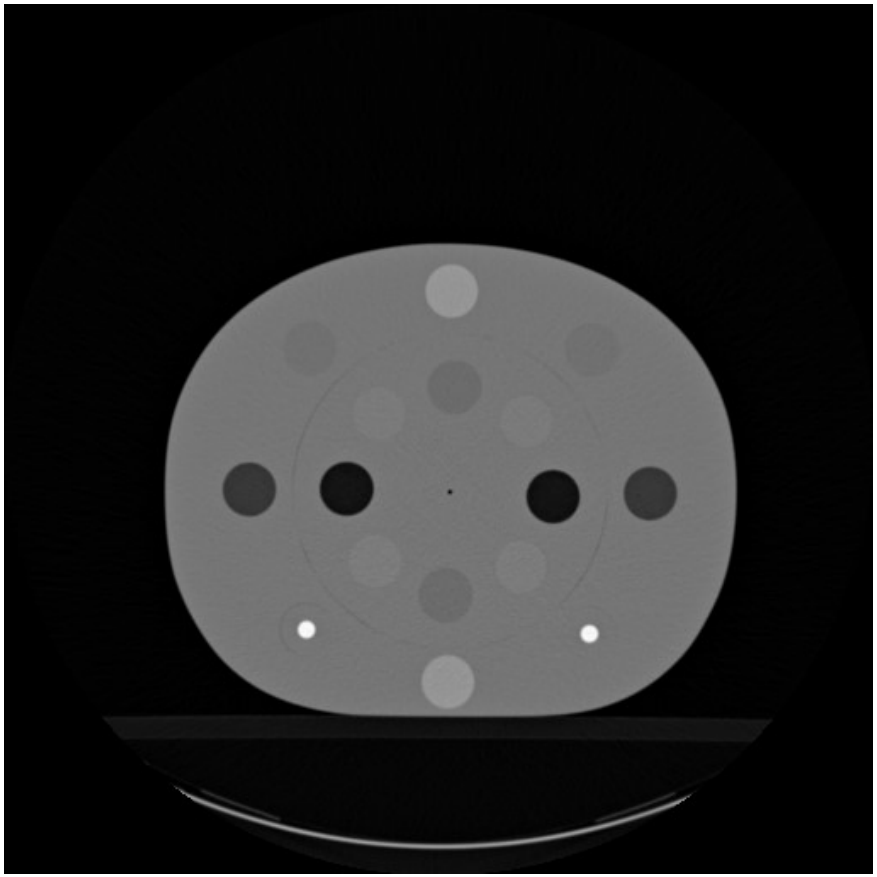
Data | Mass Density | Relative Electron Density

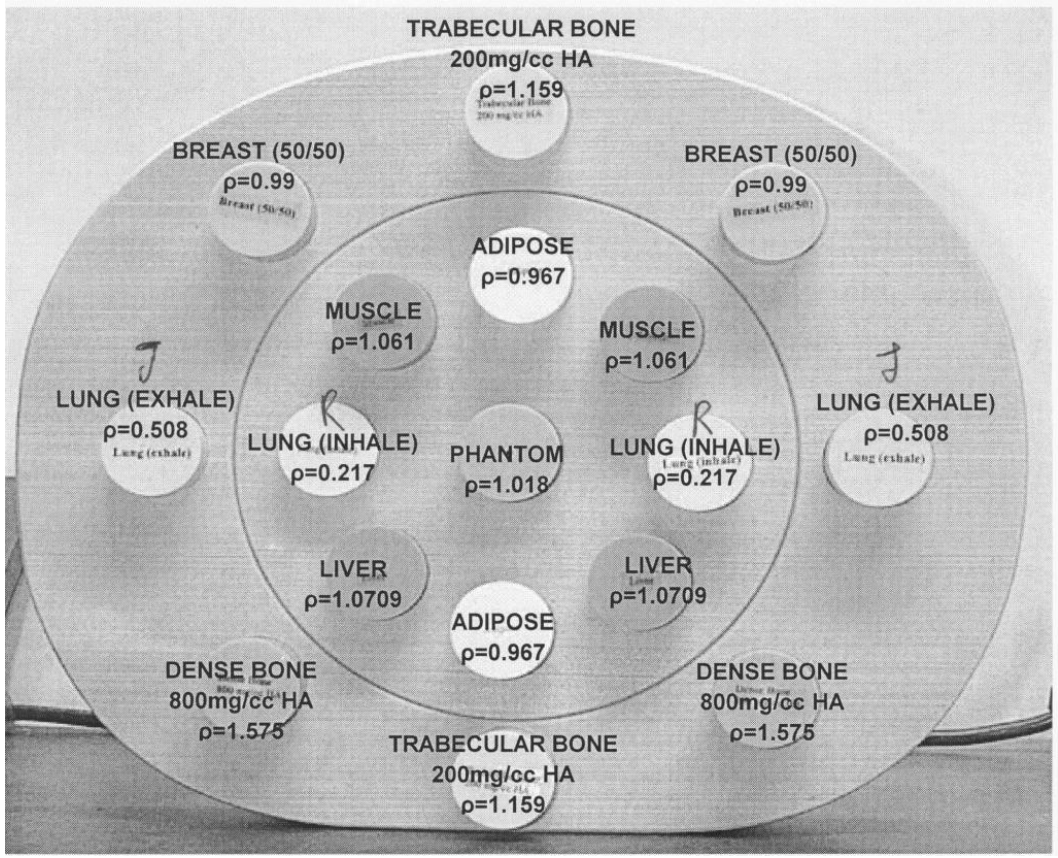
Correlation between CT numbers and tissue parameters

	w_i (pp)											
H	H	C	N	O	Na	Mg	P	S	Cl	Ar	K	Ca
−1000–−950			75.5	23.2						1.3		
−950–−120	10.3	10.5	3.1	74.9	0.2		0.2	0.3	0.3		0.2	
−120–−83	11.6	68.1	0.2	19.8	0.1			0.1	0.1			
−82–−53	11.3	56.7	0.9	30.8	0.1			0.1	0.1			
−52–−23	11.0	45.8	1.5	41.1	0.1		0.1	0.2	0.2			
−22–7	10.8	35.6	2.2	50.9			0.1	0.2	0.2			
8–18	10.6	28.4	2.6	57.8			0.1	0.2	0.2		0.1	
19–80	10.3	13.4	3.0	72.3	0.2		0.2	0.2	0.2		0.2	
80–120	9.4	20.7	6.2	62.2	0.6			0.6	0.3			
120–200	9.5	45.5	2.5	35.5	0.1		2.1	0.1	0.1		0.1	4.5
200–300	8.9	42.3	2.7	36.3	0.1		3.0	0.1	0.1		0.1	6.4
300–400	8.2	39.1	2.9	37.2	0.1		3.9	0.1	0.1		0.1	8.3
400–500	7.6	36.1	3.0	38.0	0.1	0.1	4.7	0.2	0.1			10.1
500–600	7.1	33.5	3.2	38.7	0.1	0.1	5.4	0.2				11.7
600–700	6.6	31.0	3.3	39.4	0.1	0.1	6.1	0.2				13.2
700–800	6.1	28.7	3.5	40.0	0.1	0.1	6.7	0.2				14.6
800–900	5.6	26.5	3.6	40.5	0.1	0.2	7.3	0.3				15.9
900–1000	5.2	24.6	3.7	41.1	0.1	0.2	7.8	0.3				17.0
1000–1100	4.9	22.7	3.8	41.6	0.1	0.2	8.3	0.3				18.1
1100–1200	4.5	21.0	3.9	42.0	0.1	0.2	8.8	0.3				19.2
1200–1300	4.2	19.4	4.0	42.5	0.1	0.2	9.2	0.3				20.1
1300–1400	3.9	17.9	4.1	42.9	0.1	0.2	9.6	0.3				21.0
1400–1500	3.6	16.5	4.2	43.2	0.1	0.2	10.0	0.3				21.9
1500–1600	3.4	15.5	4.2	43.5	0.1	0.2	10.3	0.3				22.5

W. Schneider, T. Bortfeld and W. Schlegel, Phys. Med. Biol. 45, 459 (2000).

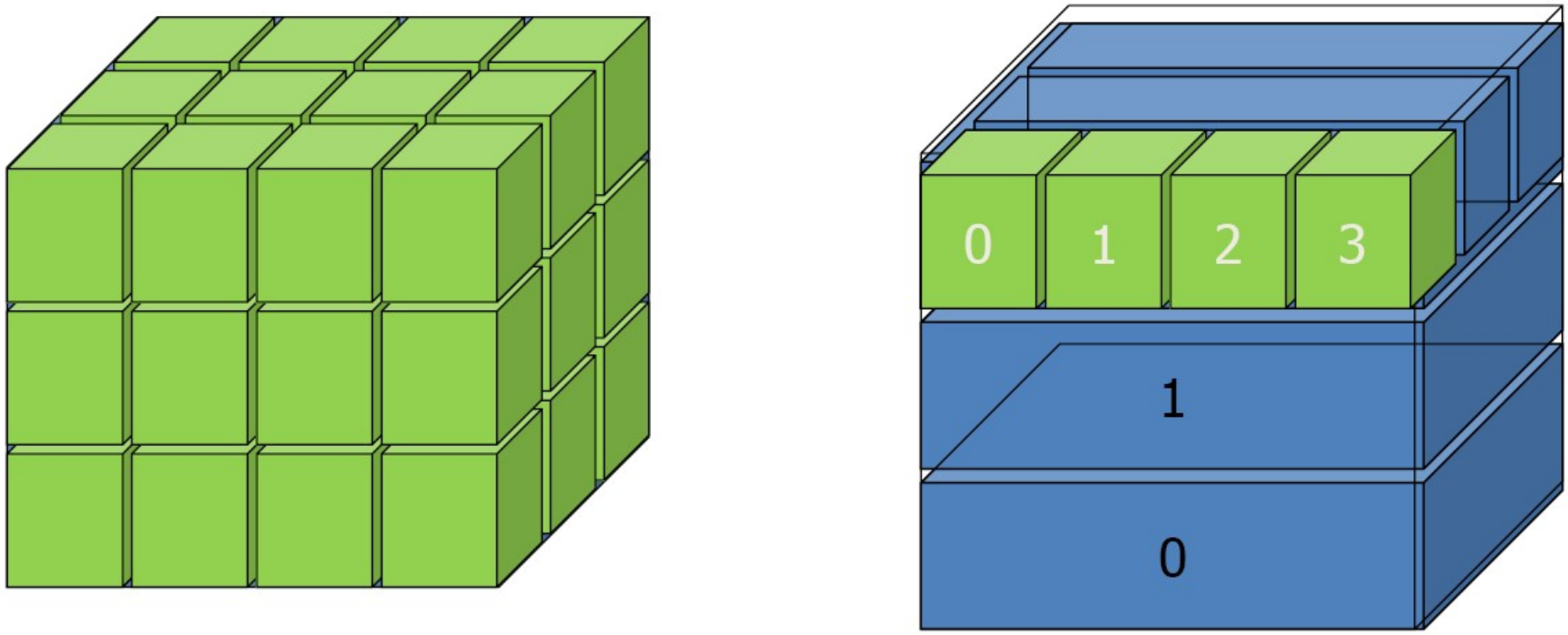
Geant4 DICOM example





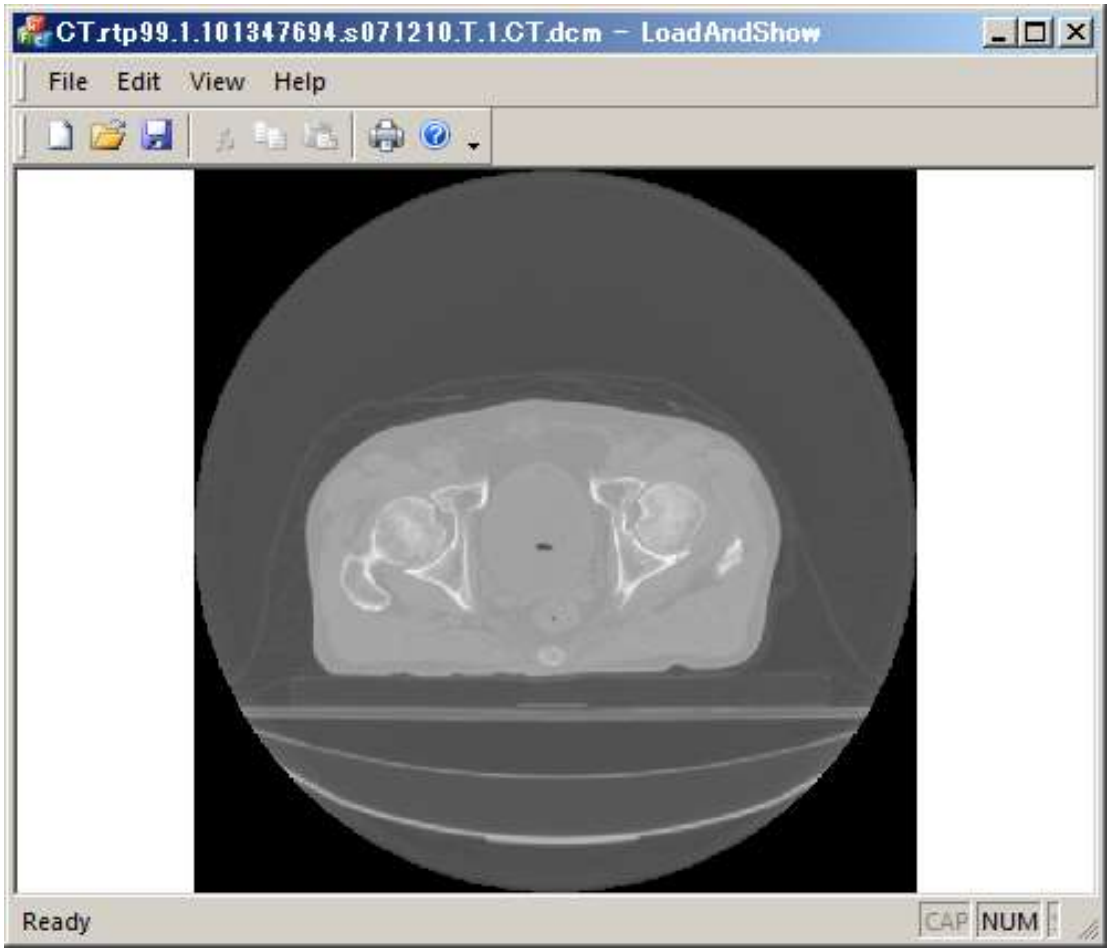
- Use a "Nested Parameterization" to store CT voxels.
- Voxels can be accessed via a "copy number".

Nested Parameterization



- The voxels are regularly placed and only differ in material.
- It requires much less memory for geometry optimization and gives much faster navigation for ultra-large number of voxels.
- A typical CT scan requires 512 x 512 x 100 = over 25 million voxels

- DCMTK – DICOM Toolkit
  - http://dicom.offis.de/dcmtk.php.en



DICOM Dump

dcmdump.txt - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
# Dicom-File-Format

# Dicom-Meta-Information-Header
# Used TransferSyntax: Little Endian Explicit
(0002,0000) UL 198                                      #   4, 1 MetaElementGroupLength
(0002,0001) OB 00¥01                                    #   2, 1 FileMetaInformationVersion
(0002,0002) UI =RTDoseStorage                           #  30, 1 MediaStorageSOPClassUID
(0002,0003) UI [1.2.276.0.7230010.3.1.4.2110234930.7728.1383032589.1] #  52, 1 MediaStorageSOPInstanceUID
(0002,0010) UI =LittleEndianImplicit                    #  18, 1 TransferSyntaxUID
(0002,0012) UI [1.2.276.0.7230010.3.0.3.5.4]            #  28, 1 ImplementationClassUID
(0002,0013) SH [OFFIS_DCMTK_354]                        #  16, 1 ImplementationVersionName

# Dicom-Data-Set
# Used TransferSyntax: Little Endian Implicit
(0008,0005) CS [ISO_IR 100]                             #  10, 1 SpecificCharacterSet
(0008,0016) UI =RTDoseStorage                           #  30, 1 SOPClassUID
(0008,0018) UI [1.2.276.0.7230010.3.1.4.2110234930.7728.1383032589.1] #  52, 1 SOPInstanceUID
(0008,0020) DA (no value available)                     #   0, 0 StudyDate
(0008,0030) TM (no value available)                     #   0, 0 StudyTime
(0008,0050) SH (no value available)                     #   0, 0 AccessionNumber
(0008,0060) CS [RTDOSE]                                 #   6, 1 Modality
(0008,0070) LO [Hokudai]                                #   8, 1 Manufacturer
(0008,0090) PN (no value available)                     #   0, 0 ReferringPhysiciansName
(0008,1090) LO (no value available)                     #   0, 0 ManufacturersModelName
(0010,0010) PN [PHANTOM]                                #   8, 1 PatientsName
(0010,0020) LO [123456789]                              #  10, 1 PatientID
(0010,0030) DA (no value available)                     #   0, 0 PatientsBirthDate
(0010,0040) CS [F]                                      #   2, 1 PatientsSex
(0018,0050) DS (no value available)                     #   0, 0 SliceThickness
(0018,1020) LO [1.0]                                    #   4, 1 SoftwareVersions
(0020,000d) UI [1.2.276.0.7230010.3.1.4.2110234930.7728.1383032589.2] #  52, 1 StudyInstanceUID
(0020,000e) UI [1.2.276.0.7230010.3.1.4.2110234930.7728.1383032589.3] #  52, 1 SeriesInstanceUID
(0020,0010) SH [S0000001]                               #   8, 1 StudyID
(0020,0011) IS (no value available)                     #   0, 0 SeriesNumber
(0020,0013) IS [1]                                      #   2, 1 InstanceNumber
(0020,0032) DS [-250.000000¥-250.000000¥-122.500000]    #  36, 3 ImagePositionPatient
(0020,0037) DS [1¥0¥0¥0¥1¥0]                            #  12, 6 ImageOrientationPatient
(0020,0052) UI [1.2.276.0.7230010.3.1.4.2110234930.7728.1383032589.4] #  52, 1 FrameOfReferenceUID
(0020,1040) LO (no value available)                     #   0, 0 PositionReferenceIndicator
(0028,0002) US 1                                        #   2, 1 SamplesPerPixel
(0028,0004) CS [MONOCHROME2]                            #  12, 1 PhotometricInterpretation
(0028,0008) IS [80]                                     #   2, 1 NumberOfFrames
(0028,0010) US 512                                      #   2, 1 Rows
(0028,0011) US 512                                      #   2, 1 Columns
(0028,0030) DS [0.976562¥0.976562]                      #  18, 2 PixelSpacing
(0028,0100) US 16                                       #   2, 1 BitsAllocated
(0028,0101) US 16                                       #   2, 1 BitsStored
(0028,0102) US 15                                       #   2, 1 HighBit
(0028,0103) US 0                                        #   2, 1 PixelRepresentation
(0028,0106) US 0                                        #   2, 1 SmallestImagePixelValue
(0028,0107) US 65535                                    #   2, 1 LargestImagePixelValue
(3004,0002) CS [GY]                                     #   2, 1 DoseUnits
(3004,0004) CS [PHYSICAL]                               #   8, 1 DoseType
(3004,000a) CS [PLAN]                                   #   4, 1 DoseSummationType
(3004,000c) DS [0.00¥1.25¥2.50¥3.75¥5.00¥6.25¥7.50¥8.75¥10.00¥11.25¥12.50¥13.75¥15... # 472,80 GridFrameOffsetVector
(3004,000e) DS [1.281758e-003]                          #  14, 1 DoseGridScaling
(300c,0002) SQ (Sequence with undefined length #=1)     # u/l, 1 ReferencedRTPlanSequence
  (fffe,e000) na (Item with undefined length #=2)         # u/l, 1 Item
    (0008,1150) UI =RTPlanStorage                           #  30, 1 ReferencedSOPClassUID
    (0008,1155) UI (no value available)                     #   0, 0 ReferencedSOPInstanceUID
  (fffe,e00d) na (ItemDelimitationItem)                   #   0, 0 ItemDelimitationItem
(fffe,e0dd) na (SequenceDelimitationItem)               #   0, 0 SequenceDelimitationItem
(7fe0,0010) OW 0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000¥0000... # 41943040, 1 PixelData
```

DICOM-RT Dose File

NzRunAction.cc* - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

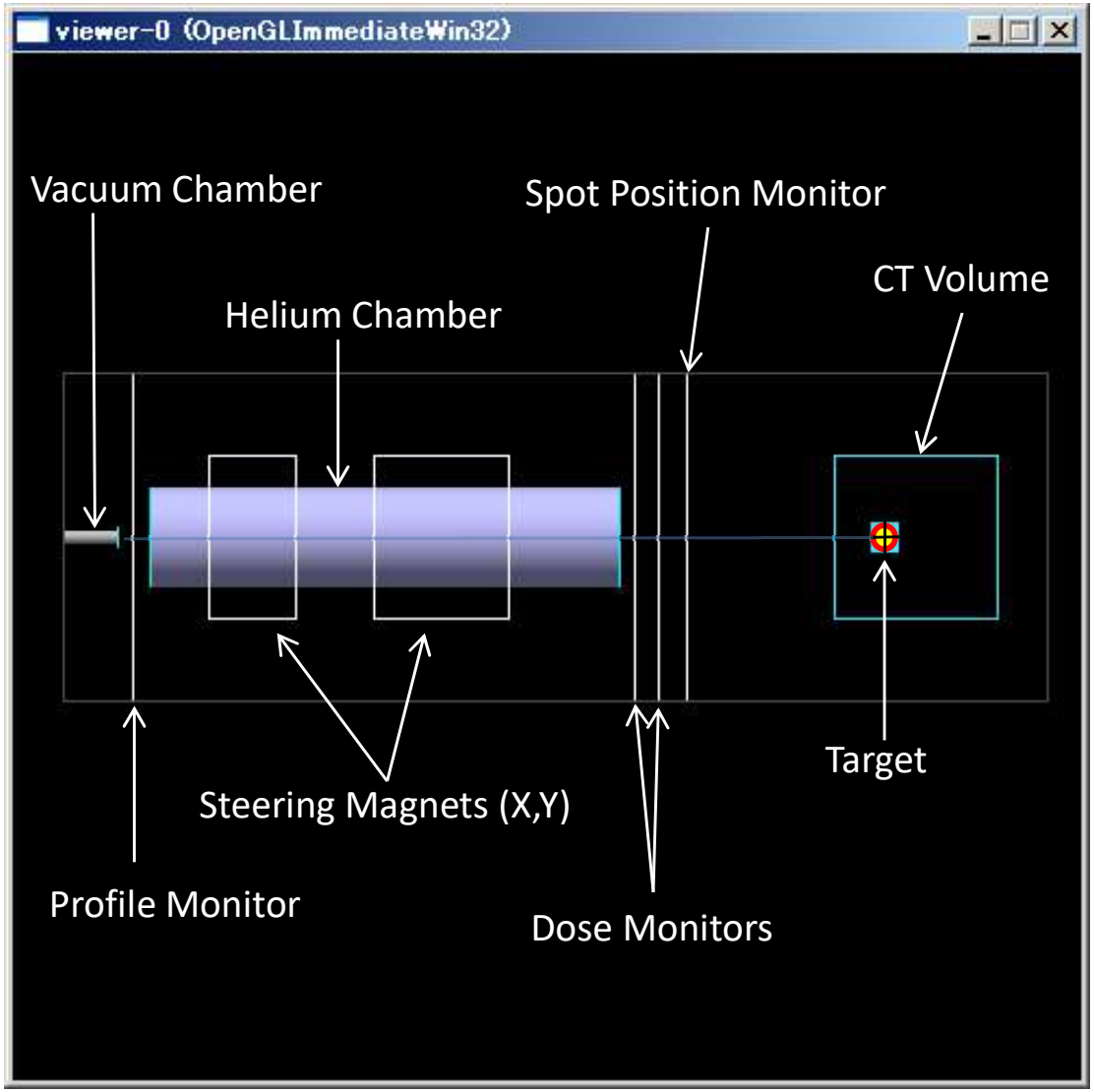
/testem/stepMax

NzRunAction.cc*

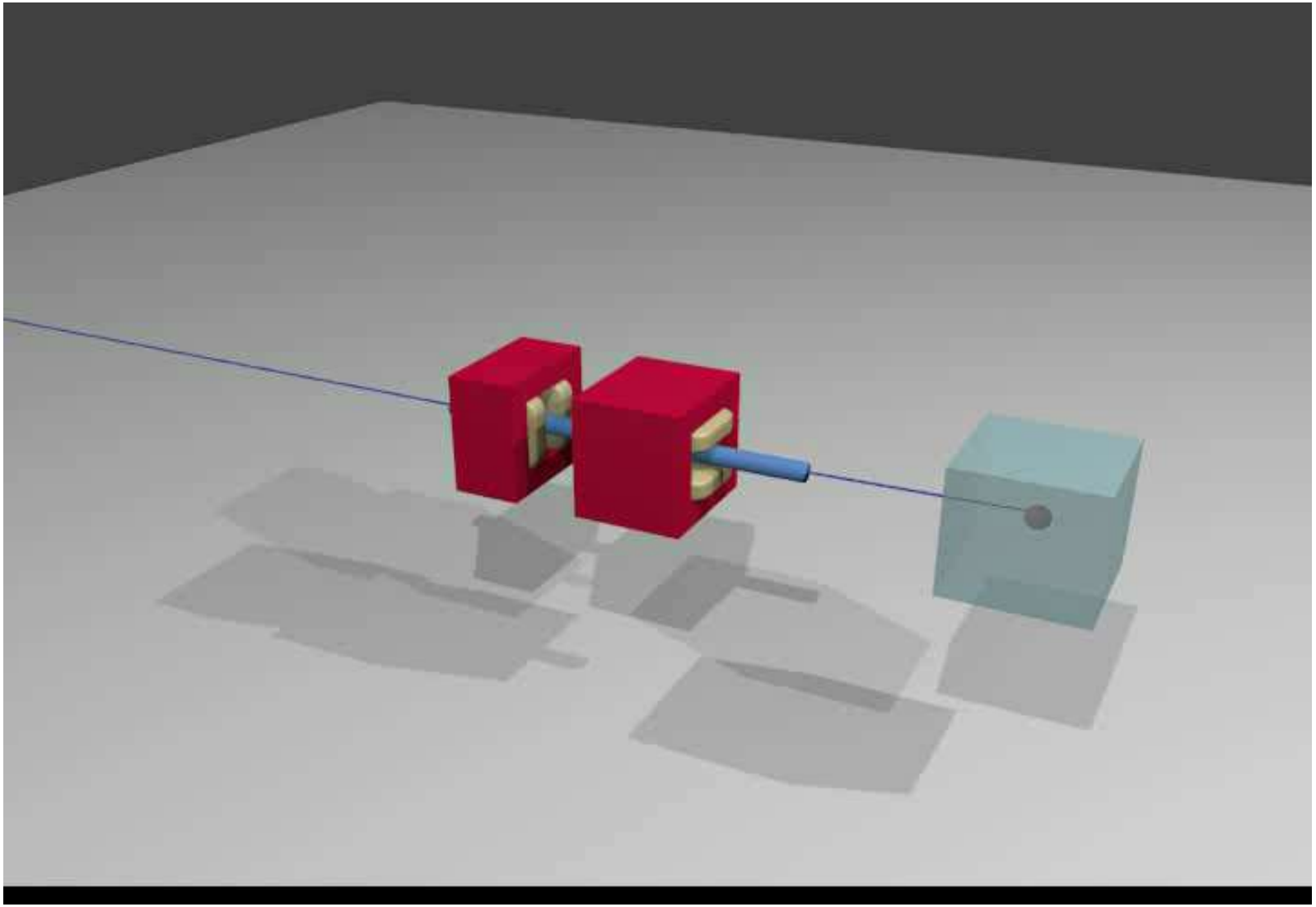
```
    // Create the DICOM-RT Dose object.
    DcmFileFormat dcmFileFormat;
    DcmDataset* pDcmDataset = dcmFileFormat.getDataset();

    pDcmDataset->putAndInsertString(DCM_SpecificCharacterSet, "ISO_IR 100");
    pDcmDataset->putAndInsertString(DCM_SOPClassUID, UID_RTDoseStorage);
    pDcmDataset->putAndInsertString(DCM_SOPInstanceUID, dcmGenerateUniqueIdentifier(sz, SITE_INSTANCE_UID_ROOT));
    pDcmDataset->putAndInsertString(DCM_StudyDate, "");
    pDcmDataset->putAndInsertString(DCM_StudyTime, "");
    pDcmDataset->putAndInsertString(DCM_AccessionNumber, "");
    pDcmDataset->putAndInsertString(DCM_Modality, "RTDOSE");
    pDcmDataset->putAndInsertString(DCM_Manufacturer, "Hokudai");
    pDcmDataset->putAndInsertString(DCM_ReferringPhysiciansName, "");
    pDcmDataset->putAndInsertString(DCM_ManufacturersModelName, "");
    pDcmDataset->putAndInsertString(DCM_PatientsName, "PHANTOM");
    pDcmDataset->putAndInsertString(DCM_PatientID, "123456789");
    pDcmDataset->putAndInsertString(DCM_PatientsBirthDate, "");
    pDcmDataset->putAndInsertString(DCM_PatientsSex, "F");
    pDcmDataset->putAndInsertString(DCM_SliceThickness, "");
    pDcmDataset->putAndInsertString(DCM_SoftwareVersions, "1.0");
    pDcmDataset->putAndInsertString(DCM_StudyInstanceUID, dcmGenerateUniqueIdentifier(sz, SITE_INSTANCE_UID_ROOT));
    pDcmDataset->putAndInsertString(DCM_SeriesInstanceUID, dcmGenerateUniqueIdentifier(sz, SITE_INSTANCE_UID_ROOT));
    pDcmDataset->putAndInsertString(DCM_StudyID, "S0000001");
    pDcmDataset->putAndInsertString(DCM_SeriesNumber, "");
    pDcmDataset->putAndInsertString(DCM_InstanceNumber, "1");

    double dPositionX = m_dImagePositionX;
    double dPositionY = m_dImagePositionY;
    double dPositionZ = m_dImagePositionZ;
    sprintf(sz, "%f¥¥%f¥¥%f", dPositionX, dPositionY, dPositionZ);
    pDcmDataset->putAndInsertString(DCM_ImagePositionPatient, sz);

    pDcmDataset->putAndInsertString(DCM_ImageOrientationPatient, "1¥¥0¥¥0¥¥0¥¥1¥¥0");
    pDcmDataset->putAndInsertString(DCM_FrameOfReferenceUID, dcmGenerateUniqueIdentifier(sz, SITE_INSTANCE_UID_ROOT));
    pDcmDataset->putAndInsertString(DCM_PositionReferenceIndicator, "");
    pDcmDataset->putAndInsertUint16(DCM_SamplesPerPixel, 1);
    pDcmDataset->putAndInsertString(DCM_PhotometricInterpretation, "MONOCHROME2");
    // itoa(m_nBufSizeZ, sz, 10)
    sprintf(sz, "%d", m_nBufSizeZ);
    pDcmDataset->putAndInsertString(DCM_NumberOfFrames, sz);
    pDcmDataset->putAndInsertUint32(DCM_FrameIncrementPointer, 0x3004000c); // TODO: Fix this!
    pDcmDataset->putAndInsertUint16(DCM_Columns, m_nBufSizeX);  // Width  X
    pDcmDataset->putAndInsertUint16(DCM_Rows, m_nBufSizeY);     // Height Y
    sprintf(sz, "%f¥¥%f", m_dVoxelSizeX, m_dVoxelSizeY);
    pDcmDataset->putAndInsertString(DCM_PixelSpacing, sz);
    pDcmDataset->putAndInsertUint16(DCM_BitsAllocated, 16);
    pDcmDataset->putAndInsertUint16(DCM_BitsStored, 16);
    pDcmDataset->putAndInsertUint16(DCM_HighBit, 15);
    pDcmDataset->putAndInsertUint16(DCM_PixelRepresentation, 0);
    pDcmDataset->putAndInsertUint16(DCM_SmallestImagePixelValue, 0);
    pDcmDataset->putAndInsertUint16(DCM_LargestImagePixelValue, (unsigned short)dMaxData);
    pDcmDataset->putAndInsertString(DCM_DoseUnits, "GY");
    pDcmDataset->putAndInsertString(DCM_DoseType, "PHYSICAL");
    pDcmDataset->putAndInsertString(DCM_DoseSummationType, "PLAN");
```

Ready Ln 719 Col 1 Ch 1 INS

Hitachi Spot Scanning Nozzle

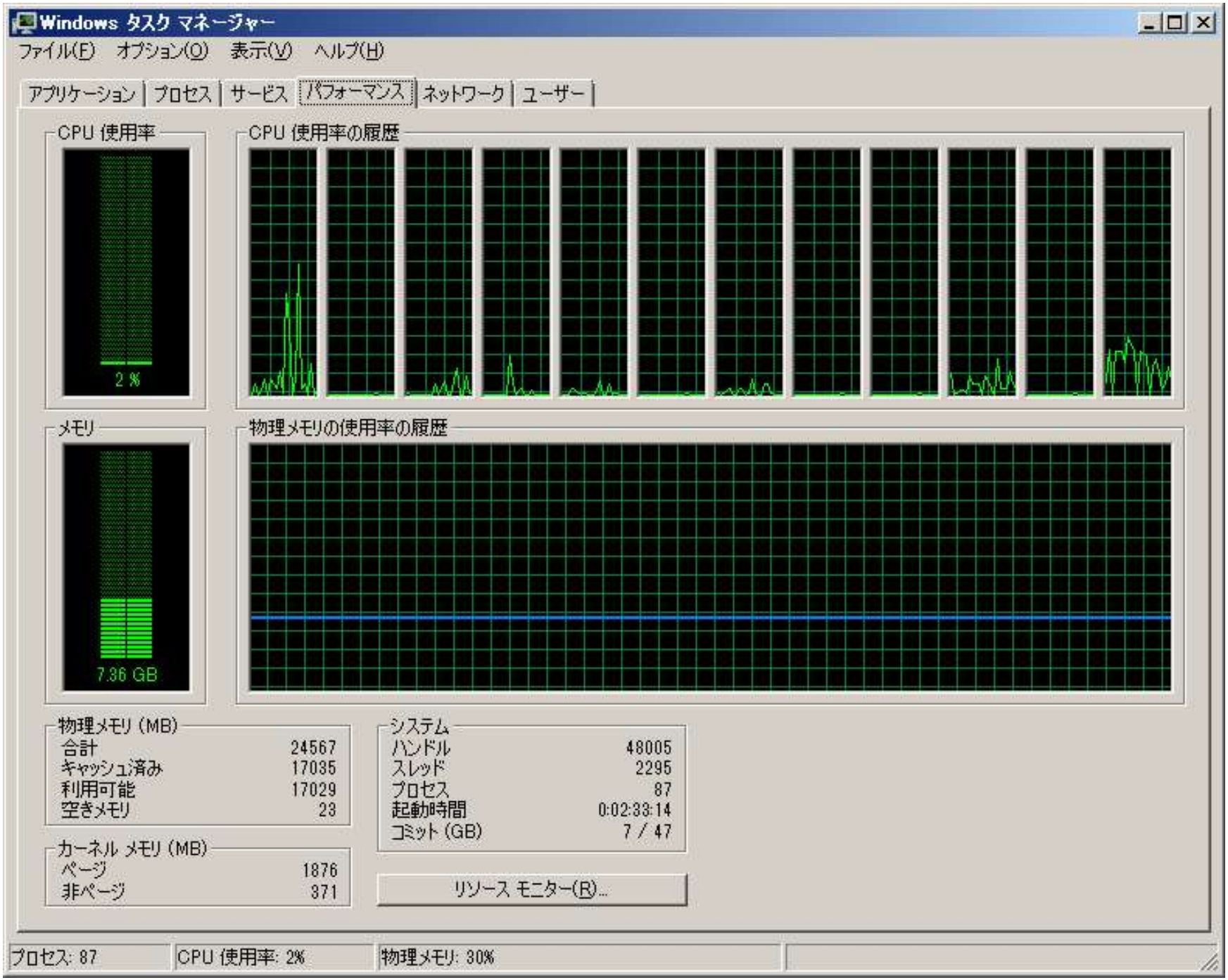


Hitachi Spot Scanning Nozzle (Blender)

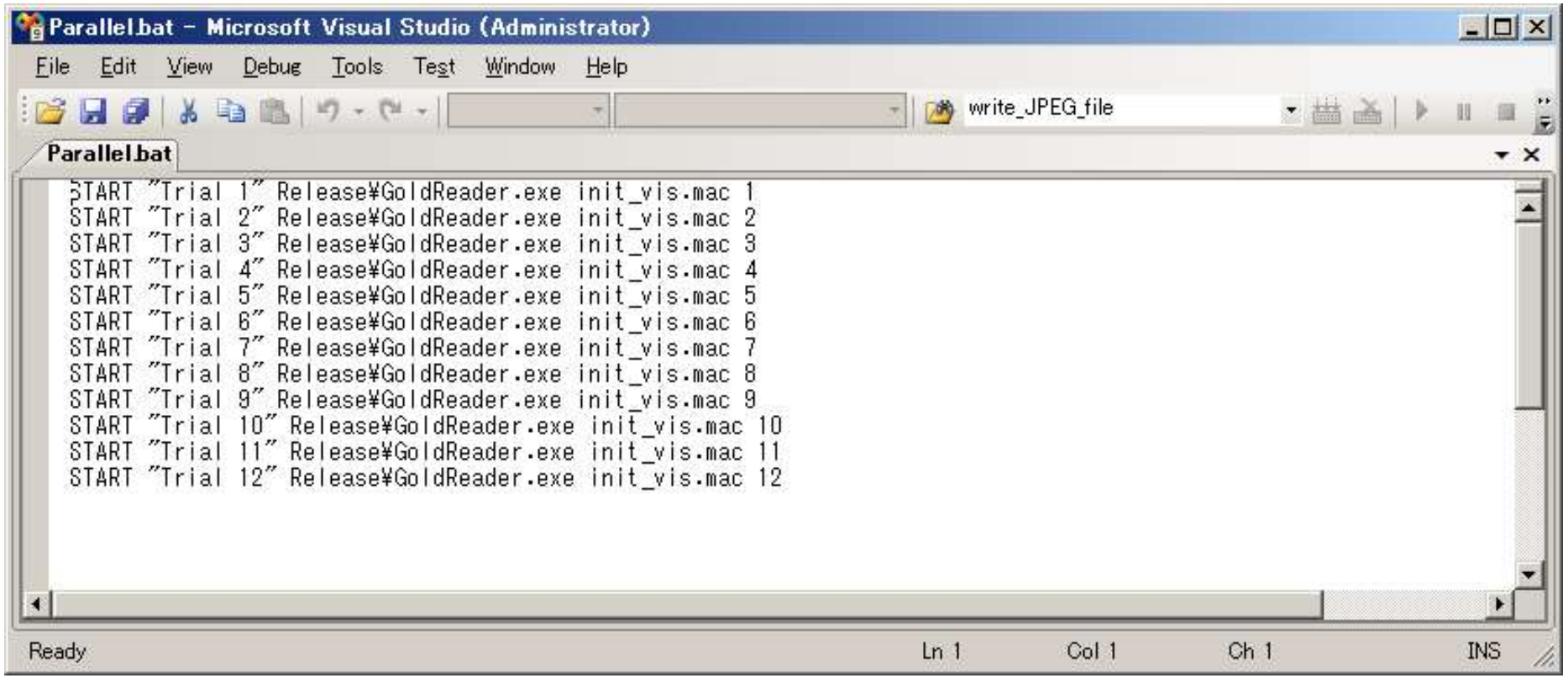


Spot Scanning – VQA Plan Data

Running in Parallel



Batch (shell script)



Main Program

TestEm7.cc - Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

write_JPEG_file

TestEm7.cc

```
int main(int argc,char** argv)
{
    // Choose the Random engine and set the seed.
    CLHEP::HepRandom::setTheEngine(new CLHEP::RanecuEngine);
    G4long seed = (G4long)time(NULL);
    if (argc >= 3)
    {
        g_nProcNum = atoi(argv[2]);
        seed += g_nProcNum;
    }
    CLHEP::HepRandom::setTheSeed(seed);

    //my Verbose output class
    G4VSteppingVerbose::SetInstance(new SteppingVerbose);

    //Construct the default run manager
    G4RunManager * runManager = new G4RunManager;

    //set mandatory initialization classes
    DetectorConstruction* det;
    PhysicsList* phys;
    PrimaryGeneratorAction* kin;
    runManager->SetUserInitialization(det  = new DetectorConstruction);
    runManager->SetUserInitialization(phys = new PhysicsList);
    runManager->SetUserAction(kin = new PrimaryGeneratorAction(det));

    //set user action classes
    RunAction* run;

    runManager->SetUserAction(run = new RunAction(det,phys,kin));
    runManager->SetUserAction(new EventAction);
    runManager->SetUserAction(new TrackingAction(run));
    runManager->SetUserAction(new SteppingAction(det,run));

    //get the pointer to the User Interface manager
    G4UImanager* UI = G4UImanager::GetUIpointer();

#ifdef G4VIS_USE
    // Initialize visualization.
    G4VisManager* visManager = new G4VisExecutive;
    visManager->Initialize();
#endif

    if (argc!=1)   // batch mode
    {
        // Execute the macro file.
        G4String command = "/control/execute ";
        G4String fileName = argv[1];
        UI->ApplyCommand(command+fileName);
    }
    else
    {
    }
```

Ready Ln 1 Col 1 Ch 1 INS

RunAction.cc - EndOfRunAction

RunAction.cc* – Microsoft Visual Studio (Administrator)

File Edit View Debug Tools Test Window Help

write_JPEG_file

RunAction.cc*

```
void RunAction::EndOfRunAction(const G4Run* aRun)
{
  G4int NbofEvents = aRun->GetNumberOfEvent();
  if (NbofEvents == 0) return;

    // Save the dose depth.
    FILE* fp;
    char szFileName[1024];
    extern int g_nProcNum;
    sprintf(szFileName, "DepthEnergy%d.csv", g_nProcNum);
retry:
    fp = fopen(szFileName, "wt");
    if (fp == NULL)
    {
        printf("Failed to open '%s'¥n", szFileName);
        printf("Retry? [y/n] ");
        char c = getchar();
        if (c == 'n' || c == 'N')
            return;
        goto retry;
    }


    fprintf(fp, "Depth [mm], Energy [MeV]¥n");
    for (int i = 0; i < binLength; i++)
    {
        // Normalize to MeV per incedent particle (event).
        double dDeposit = m_pDepthDeposit[i];
        dDeposit /= NbofEvents;
        fprintf(fp, "%d,%f¥n", i, dDeposit);
    }

    fclose(fp);
    printf("Output saved in '%s'¥n", szFileName);
}
```

Ready Ln 177 Col 1 Ch 1 INS

Debugging a Geant4 program in VC

- Select “Release” build
- In project property pages
  - C++/General/Debug Information Format/Program Database (/Zi)
  - C++/Optimization/Optimization/Disabled (/Od)
  - Linker/Debugging/Generate Debug Info/Yes (/DEBUG)
- You should now be able to set a break point and step through your program

Geant4 Tips

- Use “/vis/open OGLIWin32” to check your geometry
- Use “/tracking/verbose 1” to make sure the particle is behaving correctly
- Estimate total execution time in G4UserEventAction::BeginOfEventAction
- Set the random seed with the current time
- When running in parallel, make sure random seeds are unique
- Make sure it works with one process before running in parallel