DCV Simulation

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Simulation Result

- Amplitude가 1인 파장에서의 Absorption length l_0 가 0.1mm라고 됐을 때 나타난 결과

```
G4WT0 > Arrive Time : 0.00448039
G4WT0 > Arrive Time : 0.0034271
G4WT0 > Arrive Time : 0.0288629
G4WT0 > Arrive Time : 1.13042
G4WT0 > Number of Scintillation photons produced in this event : 10127
G4WT0 > Number of Cerenkov photons produced in this event : 58
G4WT0 > Number of WLS photons produced in this event : 2904
G4WT0 > 7295<- the number of photon which goes in fiber
G4WT0 > 3<- the number of photon which arrive at MPPC1
G4WT0 > 1<- the number of photon which arrive at MPPC2
```

```
*************************************
*    Row   * Wavelengt * Arrivetim *
*************************************
*        0 * 516.47849 * 0.0044803 *
*        1 * 491.21014 * 0.0034270 *
*        2 * 507.84869 * 0.0288629 *
*************************************
```

```
*************************************
*    Row   * Wavelengt * Arrivetim *
*************************************
*        0 * 478.52683 * 1.1304182 *
*************************************
```

Absorption Ratio

Critical Angle for total reflection in WLS fiber

- Refractive Index of core : 1.59
- Refractive index of cladding : 1.49

critical angle $\theta_c = \sin^{-1}(\frac{1.49}{1.59}) = 69.57°$

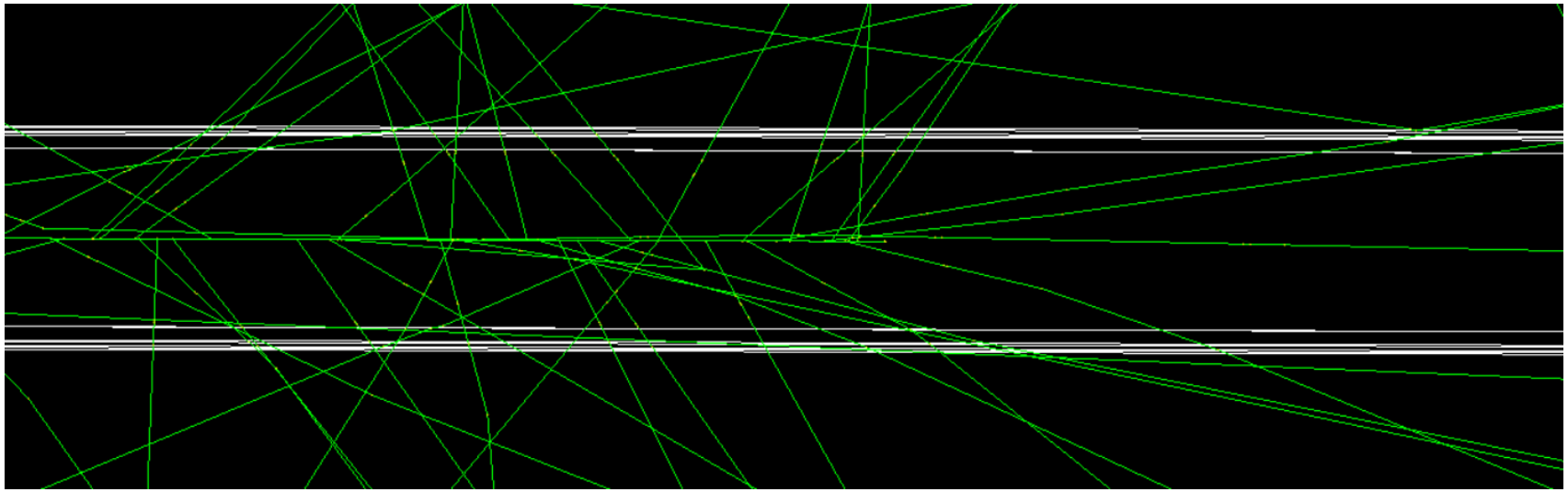
Assume that there is no attenuation and emission occurs isotropically. Probability for total reflection is

$$P = \frac{2\times\int_0^{2\pi}\int_0^{20°}\sin\theta d\theta d\phi}{\int d\Omega} = \frac{2\times 0.06}{2} = 6\%$$

- WLS Process의 수 : 2904
- MPPC에 도달한 photon 수 : 4

- WLS Process 수와 WLS fiber에서 re-emission 된 photon이 전반사로 이동할 확률을 고려했을 때, MPPC에 도달한 photon의 수는 평균 120개가 되어야 하지만 4개는 이보다 매우 작은 결과임을 알 수 있다.

Visualization



- 원인을 확인하기 위해, fiber 안에서 optical photon을 100개 정도 쏘아주었을 때 absorption과 emission이 잘 이루어지는지 확인했다.
- 그 결과 WLS Process로써 absorption과 emission은 발생한 것을 확인할 수 있었지만, emission된 모든 optical photon이 전반사 없이, fiber 밖으로 나아가 버리는 것을 확인할 수 있었다.

Solution : SetSpline(true)

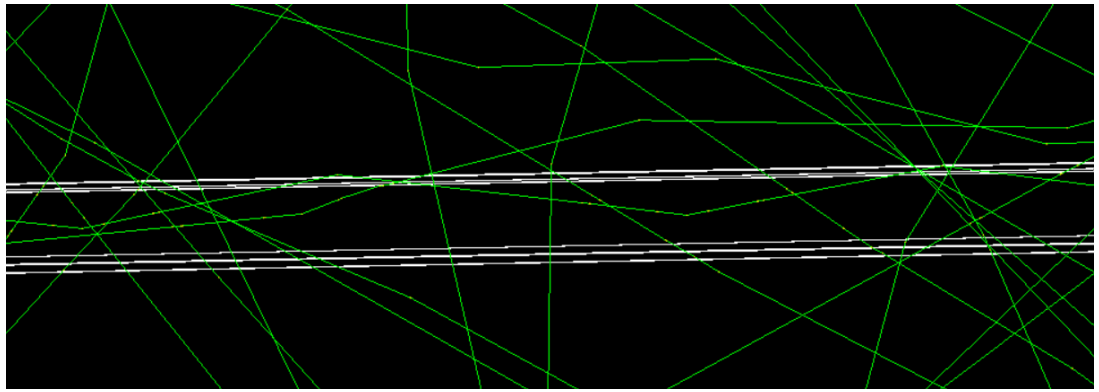
- Optical photon이 전반사가 일어나지 않는 이유가 굴절률이 모든 파장에 대해 제대로 나타나 있지 않다고 생각되었다.
- 따라서 각 물질에 굴절률을 부여하는 명령어의 맨 끝에

" -> SetSpline(true);"

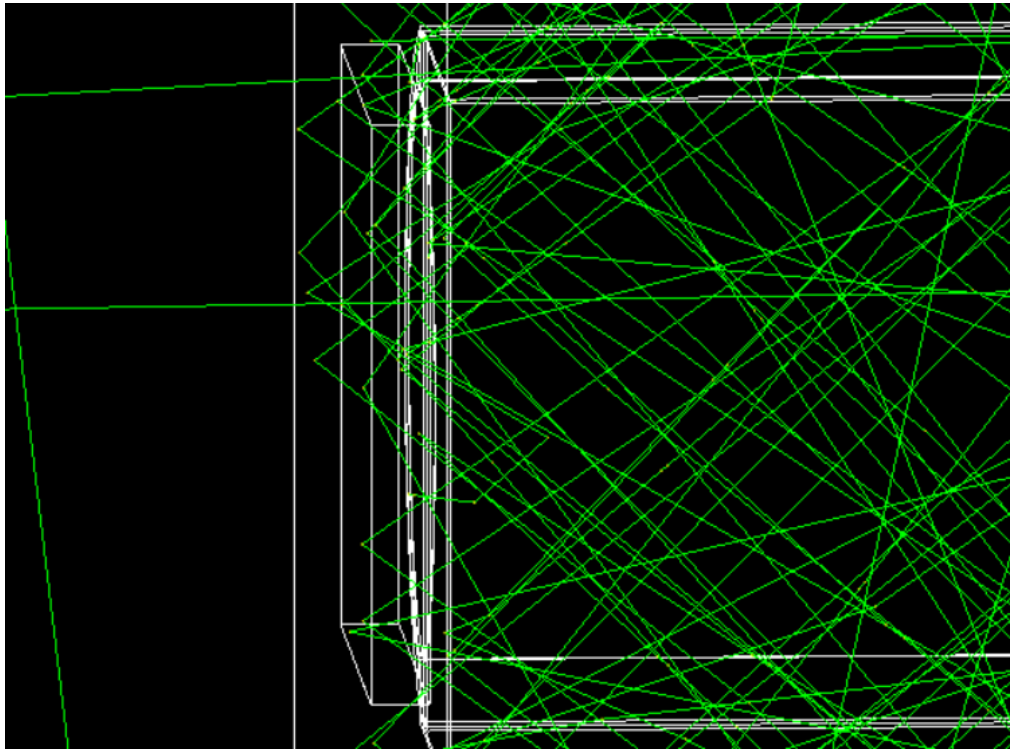
를 써 줌으로써, 해당 굴절률의 값을 연장 시켜 해결할 수 있었다.

- 참고 : SetSpline이란, Linear interpolation(선형보간법, 즉 앞의 값들을 바탕으로 하여, 함수가 직선이라고 가정하여 나머지 함수값을 추정하는 방법)을 통해 정의되지 않은 구간의 값을 유추하여 넣는 명령어이다.
- 이번에 SetSpline을 사용한 것은 Refractive index로, 파장에 따라 크게 변화하지 않는다고 가정했고, 따라서 상수 함수임으로 SetSpline을 사용하여 설정할 수 있다.

```
G4double Refractive_index_cladding[] =
{
    1.49, 1.49, 1.49, 1.49,
    1.49, 1.49, 1.49, 1.49,
    1.49, 1.49, 1.49, 1.49,
    1.49, 1.49, 1.49, 1.49,
    1.49, 1.49, 1.49, 1.49,
    1.49
};
WLS_fiber_cladding_mpt->AddProperty("RINDEX", PhotonEnergy, Refractive_index_cladding, Num_entry)->SetSpline(true);
```



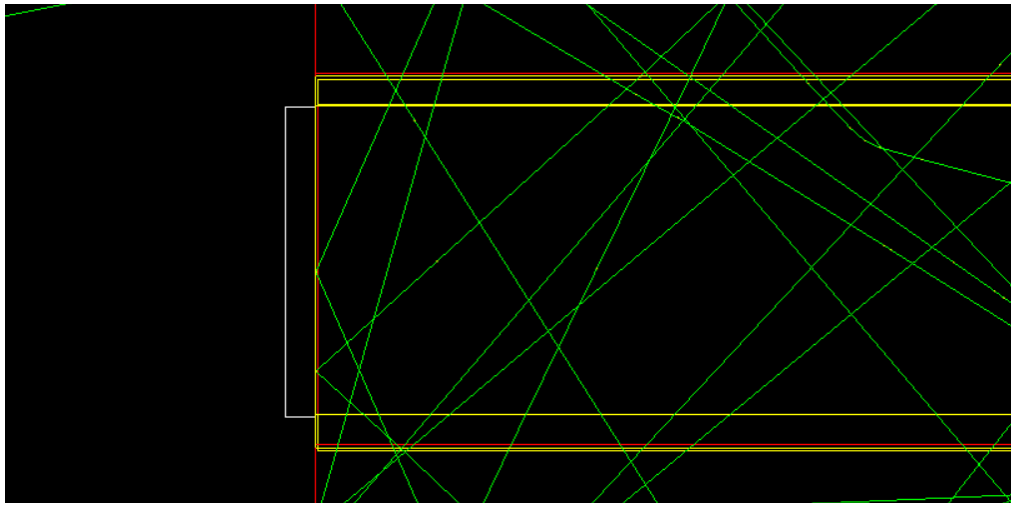
MPPC counter

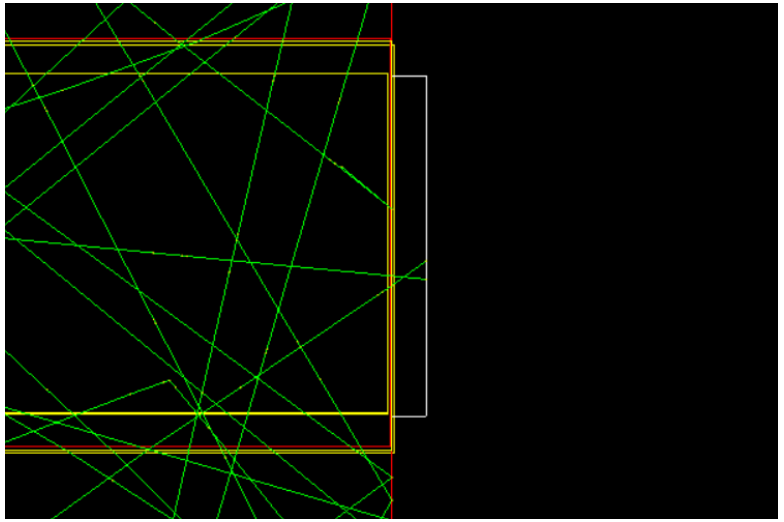


```
Arrive Time : 0.000605885
Arrive Time : 9.52315
Arrive Time : 17.874
Arrive Time : 1.36279
Number of Scintillation photons produced in this event : 8576
Number of Cerenkov photons produced in this event : 0
Number of WLS photons produced in this event : 240
2343<- the number of photon which goes in fiber
4<- the number of photon which arrive at MPPC1
0<- the number of photon which arrive at MPPC2
```

- 더 많은 Optical photon이 MPPC에 도달했지만, MPPC counter가 제대로 작동하지 않았다.

MPPC counter





- MPPC와 Fiber 사이에 작은 틈이 있어서, Air 와 Fiber 사이의 굴절률 차이에 의해 Total reflection이 많이 발생하였으므로, MPPC를 Fiber에 완전히 붙였다.

```
Number of Scintillation photons produced in this event : 8684
Number of Cerenkov photons produced in this event : 0
Number of WLS photons produced in this event : 59
357<- the number of photon which goes in fiber
0<- the number of photon which arrive at MPPC1
3<- the number of photon which arrive at MPPC2
```

Results

```
1.25976<- time that photon goes in MPPC
4.88798<- time that photon goes in MPPC
2.81158<- time that photon goes in MPPC
8.5031<- time that photon goes in MPPC
30.0082<- time that photon goes in MPPC
14.6006<- time that photon goes in MPPC
16.1231<- time that photon goes in MPPC
13.5008<- time that photon goes in MPPC
12.9967<- time that photon goes in MPPC
1.14974<- time that photon goes in MPPC
11.0966<- time that photon goes in MPPC
1.53321<- time that photon goes in MPPC
4.25131<- time that photon goes in MPPC
Number of Scintillation photons produced in this event : 11732
Number of Cerenkov photons produced in this event : 0
Number of WLS photons produced in this event : 559
3828<- the number of photon which goes in fiber
13<- the number of photon which arrive at MPPC1
10<- the number of photon which arrive at MPPC2
```

- Event1

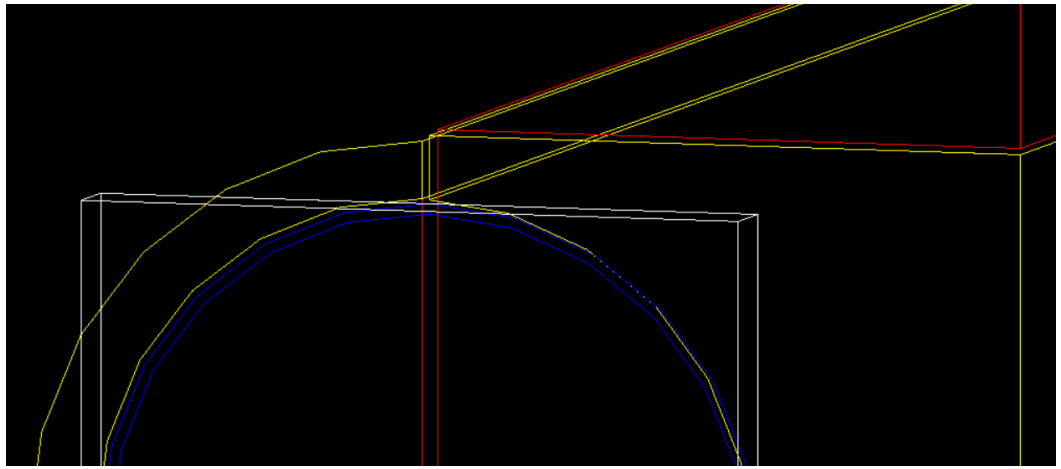
```
Number of Scintillation photons produced in this event : 7813
Number of Cerenkov photons produced in this event : 0
Number of WLS photons produced in this event : 138
896<- the number of photon which goes in fiber
2<- the number of photon which arrive at MPPC1
5<- the number of photon which arrive at MPPC2
```

- Event2

- Fiber와 MPPC 사이의 간격을 없애주면 다음과 같이 기존의 결과보다 많은 photon이 MPPC에 도달함을 알 수 있다.
- 하지만, 여전히 Absorption 후 re-emission 되는 photo의 수가 Fiber를 따라 이동할 확률 6%의 값에는 미치지 못함을 확인할 수 있다.

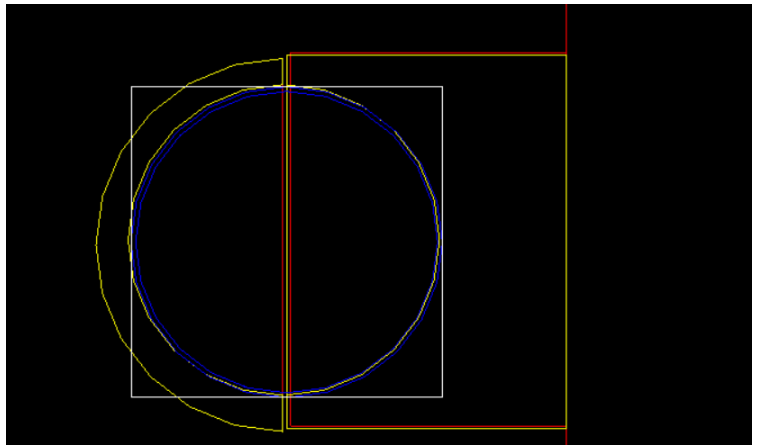
문제점

```
 G4ParticleChange::CheckIt    : the local time goes back  !!  Difference:  0.000123218[ns]
opticalphoton E=2.99741e-06 pos=0.00115728, 0.000275556, 0.2 global time=14.8983 local time=13.8234 proper time=0
      -----------------------------------------------
       G4ParticleChange Information
      -----------------------------------------------
       # of 2ndaries       :                  0
      -----------------------------------------------
       Energy Deposit (MeV):                  0
       Non-ionizing Energy Deposit (MeV):                  0
       Track Status        :               Alive
       True Path Length (mm) :              -0.0237
       Stepping Control      :                   0
       Mass (GeV)   :                  0
       Charge (eplus)   :                  0
       MagneticMoment   :                  0
              : =                 0*[e hbar]/[2 m]
       Position - x (mm)   :                1.15
       Position - y (mm)   :               0.259
       Position - z (mm)   :                 200
       Time (ns)           :                13.8
       Proper Time (ns)    :                   0
       Momentum Direct - x :               0.185
       Momentum Direct - y :               0.695
       Momentum Direct - z :               0.695
       Kinetic Energy (MeV):               3e-06
       Velocity  (/c):               0.641
       Polarization - x    :               0.571
       Polarization - y    :              -0.651
       Polarization - z    :                 0.5
       Touchable (pointer) :      0x7fffd28fba90
```



```
 G4VParticleChange::CheckIt    : the true step length is negative  !!  Difference:  0.0236793[MeV]
opticalphoton E=2.99741e-06 pos=0.00115291, 0.000259102, 0.199984
      -----------------------------------------------
       G4ParticleChange Information
      -----------------------------------------------
       # of 2ndaries       :                  0
      -----------------------------------------------
       Energy Deposit (MeV):               3e-06
       Non-ionizing Energy Deposit (MeV):                  0
       Track Status        :          StopAndKill
       True Path Length (mm) :              -0.0237
       Stepping Control      :                   0
    First Step In the voulme  :
       Mass (GeV)   :                  0
       Charge (eplus)   :                  0
       MagneticMoment   :                  0
              : =                 0*[e hbar]/[2 m]
       Position - x (mm)   :                1.15
       Position - y (mm)   :               0.259
       Position - z (mm)   :                 200
       Time (ns)           :                13.8
       Proper Time (ns)    :                   0
       Momentum Direct - x :               0.185
       Momentum Direct - y :               0.695
       Momentum Direct - z :               0.695
       Kinetic Energy (MeV):               3e-06
       Velocity  (/c):               0.641
       Polarization - x    :               0.571
       Polarization - y    :              -0.651
       Polarization - z    :                 0.5

-------- EEEE ------- G4Exception-START -------- EEEE -------
*** G4Exception : TRACK001
      issued by : G4VParticleChange::CheckIt
Step length and/or energy deposit was illegal
*** Event Must Be Aborted ***
-------- EEEE -------- G4Exception-END --------- EEEE -------
```



Code

```
G4Box* Scintillator_origin = new G4Box("Scintillator_origin", Scintillator_height / 2, Scintillator_width / 2, Scintillator_length / 2);

G4Box* Groove1 = new G4Box("Groove1", Groove_height / 2, Groove_radius, (Scintillator_length) / 2);
G4Tubs* Groove2 = new G4Tubs("Groove2", 0, Groove_radius, (Scintillator_length) / 2, 90 * deg, 180 * deg);
G4UnionSolid* Groove = new G4UnionSolid("Groove", Groove1, Groove2, 0, G4ThreeVector(-(Groove_height/2), 0., 0.));
G4SubtractionSolid* ScintillatorS = new G4SubtractionSolid("ScintillationS",Scintillator_origin, Groove, noRotation, G4ThreeVector((Scintillator_height - Groove_height) / 2, 0., 0.));
G4LogicalVolume* ScintillatorLV =   new G4LogicalVolume(ScintillatorS,scintillator,"ScintillatorLV");
new G4PVPlacement(0,G4ThreeVector(), ScintillatorLV,"Scintillator", WorldLV,  false,  0, checkOverlaps);

////////////////////////////////// Optical Cement ////////////////////////////////////////////////////////
G4Tubs* WLS_totalS = new G4Tubs("WLS_totalS", 0, WLS_radius, Scintillator_length / 2, 0 * deg, 360 * deg);
G4SubtractionSolid* Optical_cementS = new G4SubtractionSolid("Optical_cementS", Groove, WLS_totalS, noRotation, G4ThreeVector(-(Groove_height / 2), 0, 0));
G4LogicalVolume* Optical_cementLV = new G4LogicalVolume(Optical_cementS, optical_cement, "Optical_cementLV");
new G4PVPlacement(0, G4ThreeVector(Scintillator_height / 2 - Groove_height / 2, 0, 0), Optical_cementLV, "Optical_cement", WorldLV, false, 0, checkOverlaps);

//////////////////////////////// WLS_CORE ////////////////////////////////////////////
G4Tubs* WLS_fiber_coreS = new G4Tubs("WLS_fiber_coreS", 0, WLS_radius*0.97, Scintillator_length / 2, 0 * deg, 360 * deg);
G4LogicalVolume* WLS_fiber_coreLV = new G4LogicalVolume(WLS_fiber_coreS, WLS_fiber_core, "WLS_fiber_coreLV");
G4VPhysicalVolume* WLS_fiber_corePV = new G4PVPlacement(0, G4ThreeVector(Scintillator_height / 2 - Groove_height, 0, 0), WLS_fiber_coreLV, "WLS_fiber_core", WorldLV, false, 0, checkOverlaps);

//////////////////////////////// WLS_cladding ////////////////////////////////////////
G4Tubs* WLS_fiber_claddingS = new G4Tubs("WLS_fiber_claddingS", WLS_radius*0.97, WLS_radius, Scintillator_length / 2, 0 * deg, 360 * deg);
G4LogicalVolume* WLS_fiber_claddingLV = new G4LogicalVolume(WLS_fiber_claddingS, WLS_fiber_cladding, "WLS_fiber_claddingLV");
G4VPhysicalVolume* WLS_fiber_claddingPV = new G4PVPlacement(0, G4ThreeVector(Scintillator_height / 2 - Groove_height, 0, 0), WLS_fiber_claddingLV, "WLS_fiber_cladding", WorldLV, false
```

```
G4double Groove_radius = 0.6*mm;
G4double WLS_radius = 0.5*mm;
G4double Groove_height = 0.9*mm;

G4double World_length = 0.5*m;
//G4double World_lenght = 2.*m;
G4double World_width = 180.*mm;
G4double World_height = 150.*mm;

G4double Scintillator_length = 400.*mm; //z
//G4double Scintillator_length = 1410.*mm;  //z
G4double Scintillator_width = 173.5*mm; //y
G4double Scintillator_height = 5.*mm;   //x

G4Box* WorldS = new G4Box("WorldS", World_height/2, World_width/2, World_length/2);

G4LogicalVolume* WorldLV = new G4LogicalVolume(WorldS, Air,"WorldLV");

G4VPhysicalVolume* WorldPV = new G4PVPlacement(0,                    //no rotation
        G4ThreeVector(),      //at (0,0,0)
        WorldLV,            //its logical volume
        "World",              //its name
        0,                    //its mother  volume
        false,                //no boolean operation
        0,                    //copy number
        checkOverlaps);       //overlaps checking
```