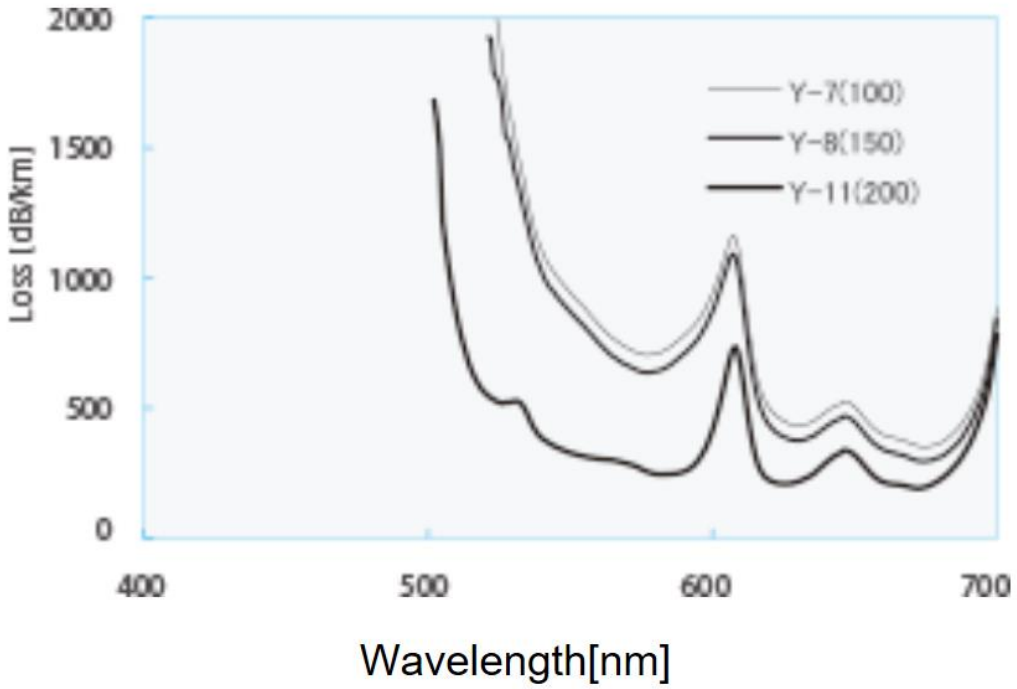
DCV Simulation

최재민

Calculate Attenuation length

- **Y-7, Y-8, Y-11**



데시벨의 정의 $dB = 10\log\frac{P}{P_0}$ 이므로,

$\frac{P}{P_0} = 10^{\frac{-\alpha_{dB/km}L}{10}}$ 이라고 쓸 수 있다.

한편, Attenuation length의 정의 $\frac{P}{P_0} = e^{-\frac{L}{l_0}}$ 에서

$l_0 = \frac{10}{\alpha_{dB/km} \times \log_e 10}$ [km] 으로 나타난다.

Proper Absorption Length

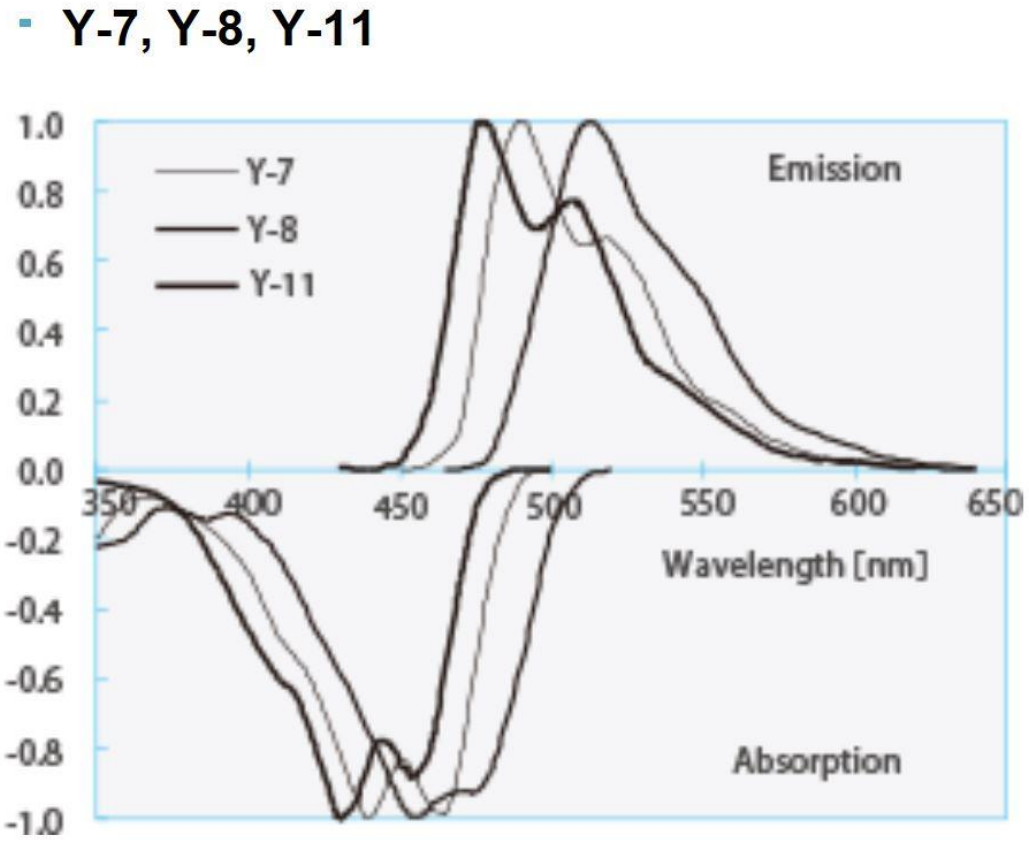
Amplitude가 1인 파장에서의 absorption length를 l_0라고 했을 때, l_0의 거리를 이동한 뒤 빛의 세기는 $\frac{1}{e}$가 된다. 따라서 흡수된 빛의 세기는 $1-\frac{1}{e}$가 된다.

Amplitude가 c인 파장에서의 absorption length를 l이라고 했을 때, 같은 거리 l_0의 거리를 이동한 뒤 흡수된 빛의 세기는 $(1-\frac{1}{e})c$ 여야 하므로 l을 구하기 위한 식은 아래와 같다.

$$1-e^{(-\frac{l}{l_0})}=(1-\frac{1}{e})c$$

따라서, 구하고자 하는 $l=-\frac{l_0}{\ln(1-c(1-\frac{1}{e}))}$ 가 된다.

- 위의 공식에 맞게 WLSABSLENGTH를 설정한 뒤, 상수 l_0을 변경시키며 실험데이터와 유사한 값을 구할 수 있다.



WLSABSLENGTH code

```
G4double WLS_absorption_length[] =
{
    0.03311, 0.04305, 0.05629, 0.07616,
    0.10265, 0.12583, 0.16225, 0.23179,
    0.30464, 0.37748, 0.45364, 0.52318,
    0.59272, 0.62252, 0.65232, 0.72848,
    0.80464, 0.88411, 0.96358, 1,
    0.97351, 0.9404, 0.86093, 0.8245,
    0.79139, 0.77815, 0.80132, 0.82119,
    0.8543, 0.85099, 0.77152, 0.64901,
    0.56623, 0.48675, 0.40397, 0.3245,
    0.24172, 0.16225, 0.08278, 0.01987,
    0.00001, 0.00000001
};

G4double Parameter_length = .01 *mm;
for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_length[i] = - Parameter_length/(TMath::Log(1.- WLS_absorption_length[i] * 0.632121));
}
WLS_fiber_core_mpt->AddProperty("WLSABSLENGTH", WLS_absorption_photon_energy, WLS_absorption_length, Entry_WLS_abs);
```

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

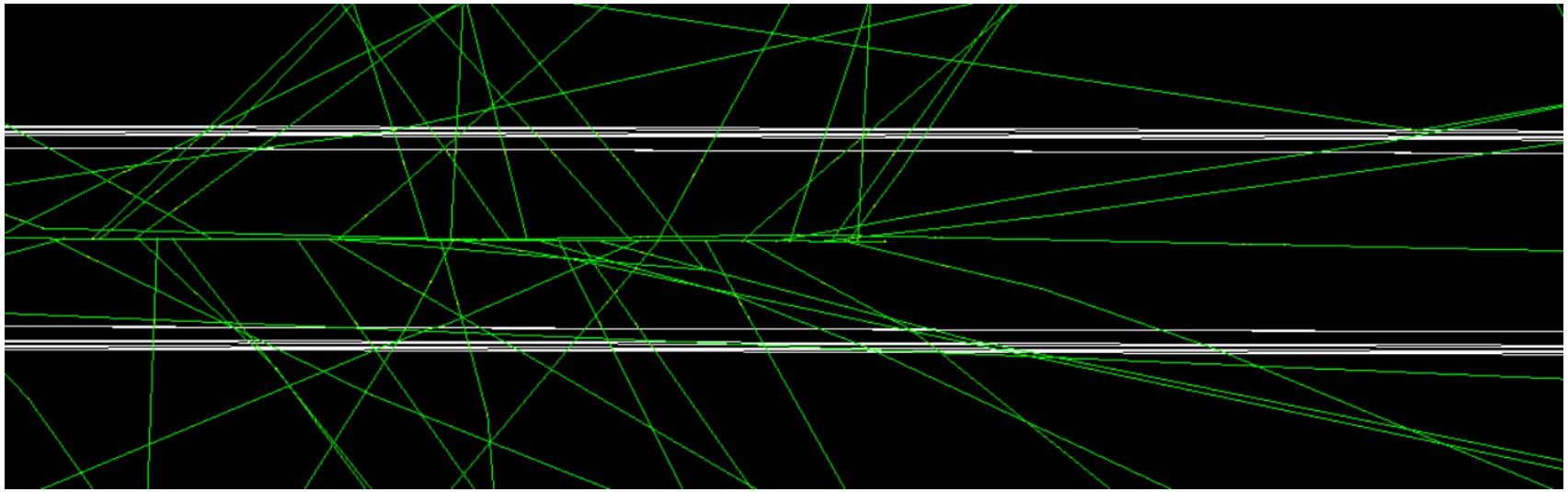
Assume that there is no attenuation and emission occurs isotropically. Probability for total reflection is

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

- 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)

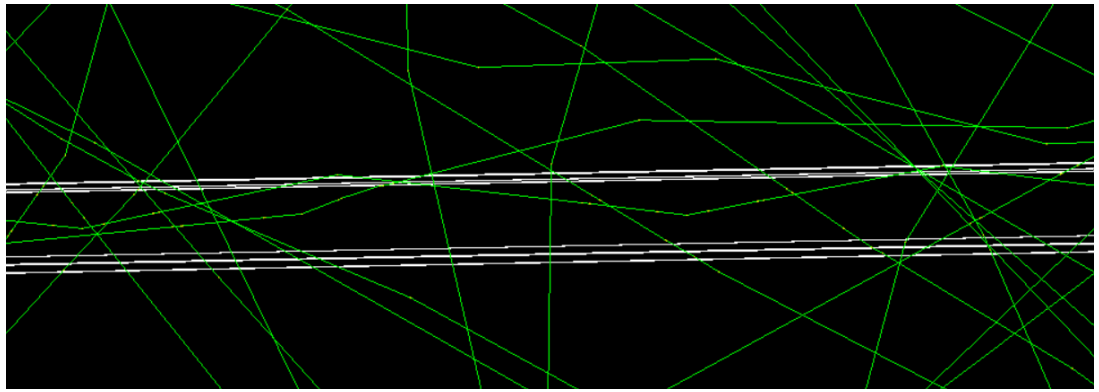
- Optical photon이 전반사가 일어나지 않는 이유가 굴절률이 모든 파장에 대해 제대로 나타나 있지 않다고 생각되었다.
- 따라서 각 물질에 굴절률을 부여하는 명령어의 맨 끝에

" -> 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);
```



문제점

```
 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 -------
```

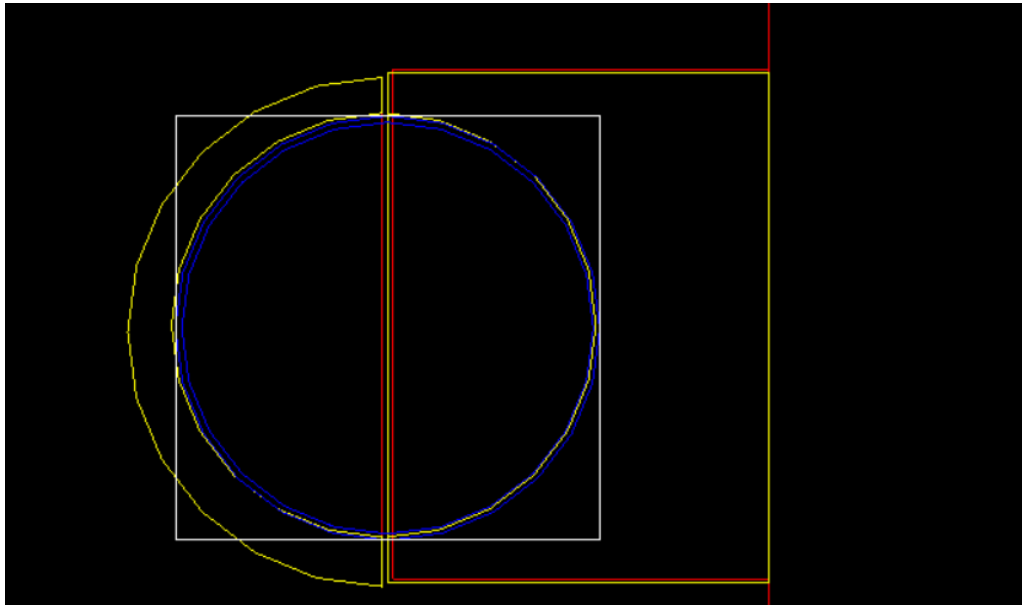
- There are some particles, that has negative true step length and negative time.
- This result is unreasonable.

```
 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
```

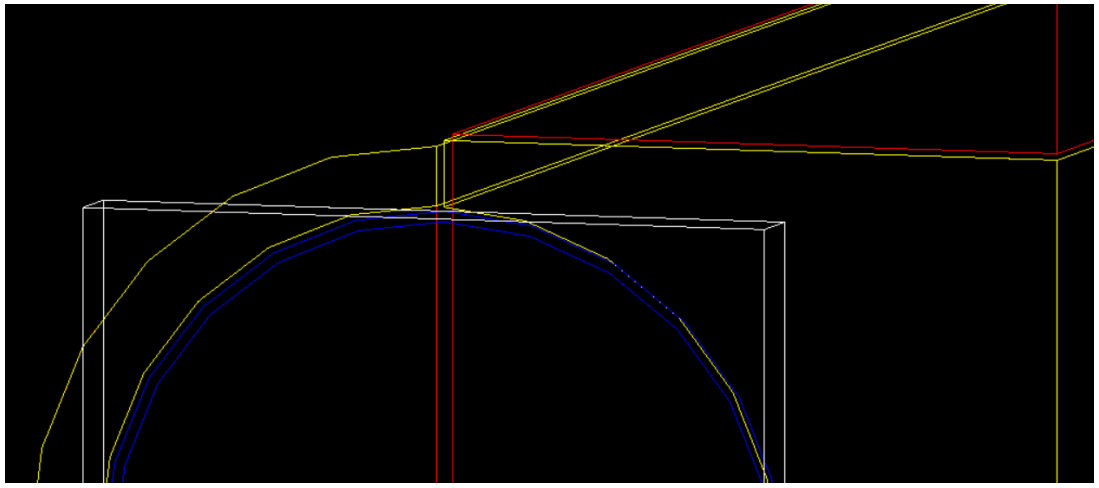
Solution

- The solution for negative true step length and negative time is not to put '->SetSpline(true)' on absorption length and attenuation length.
- Actually, absorption length and attenuation length is not linear function. Therefore it is not reasonable to extend by making use of '->SetSpline(true)'

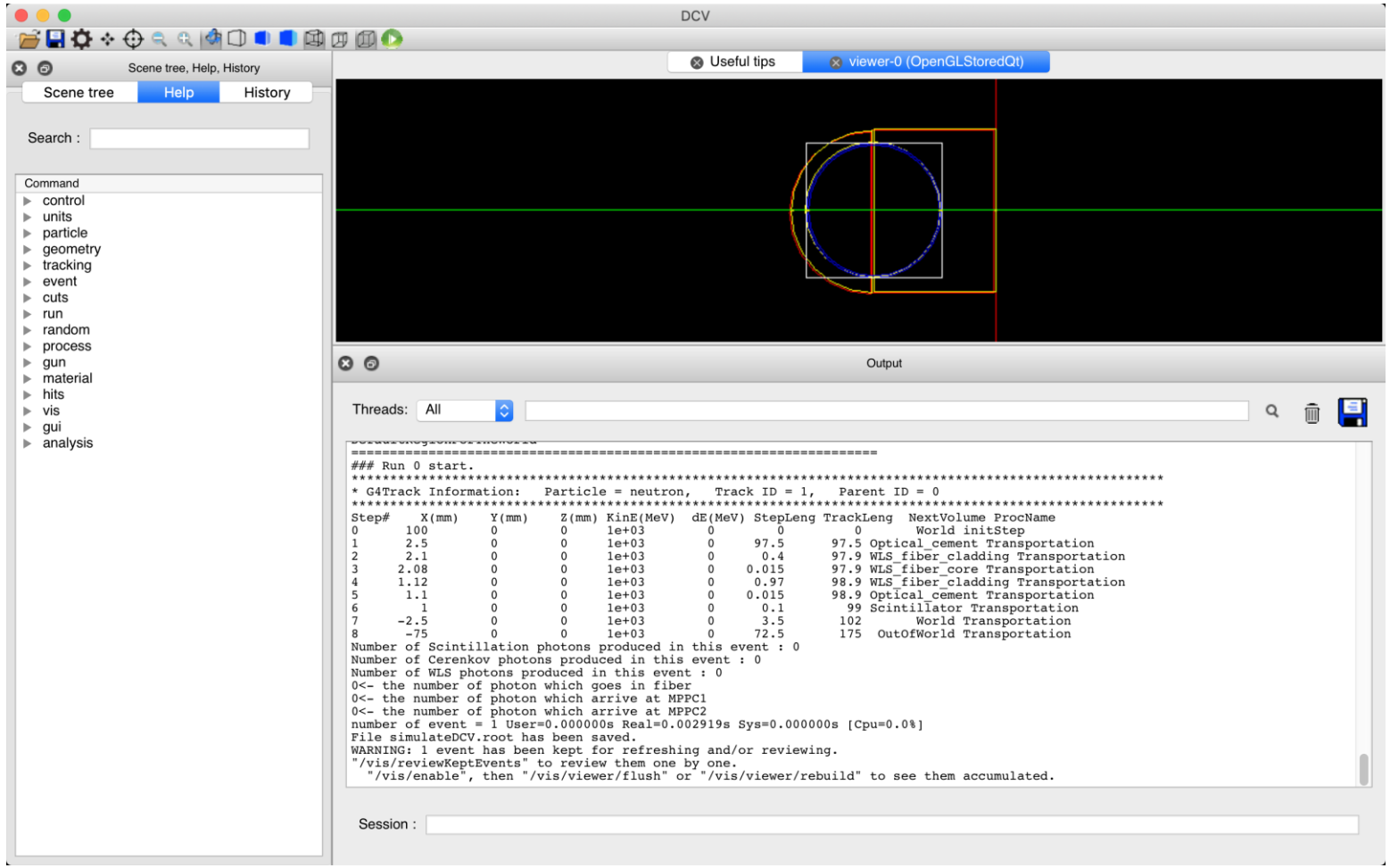
Problem in Visualization



- In visualization, it can be seen that there is a gap between two slide, tub and box which are drawn in yellow color

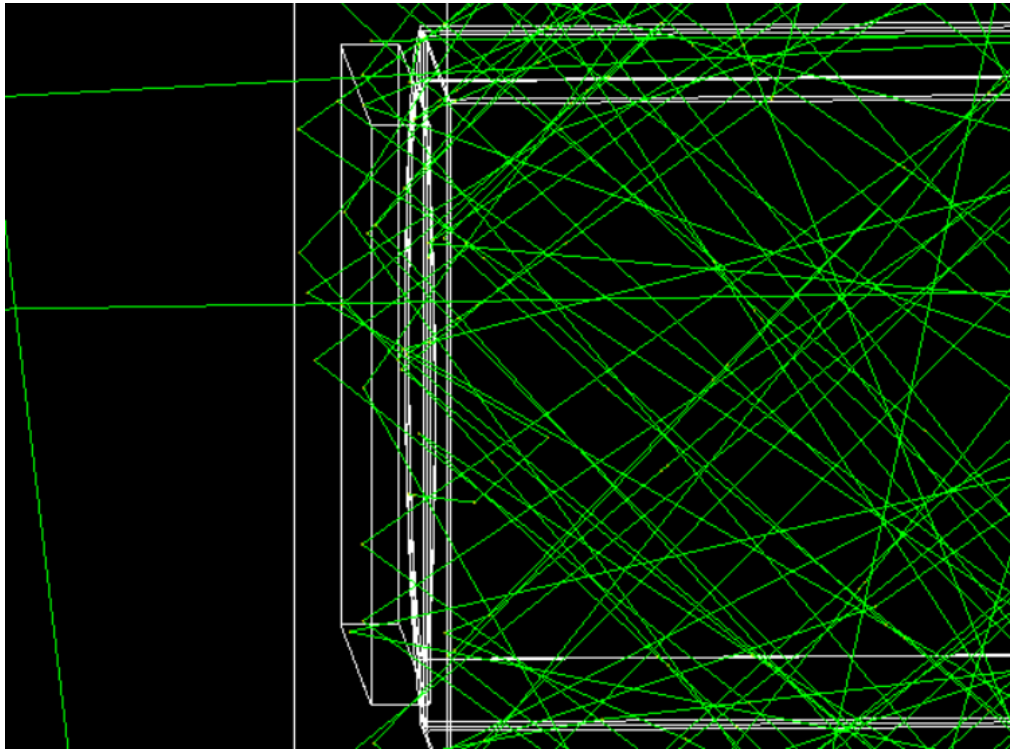


Check gap



- By shooting neutron, we can see where the neutron passes.
- And we can confirm that there is no gap between the two solids.

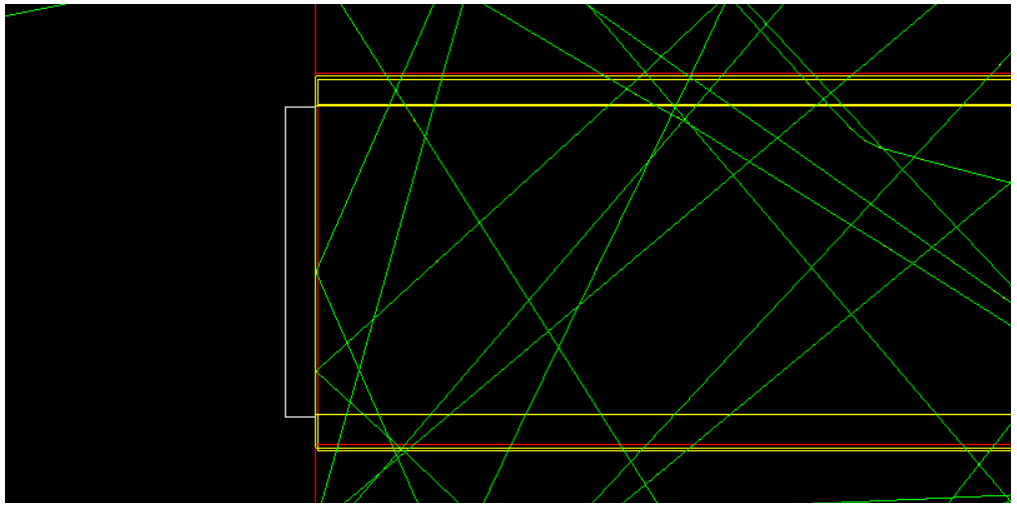
MPPC counter

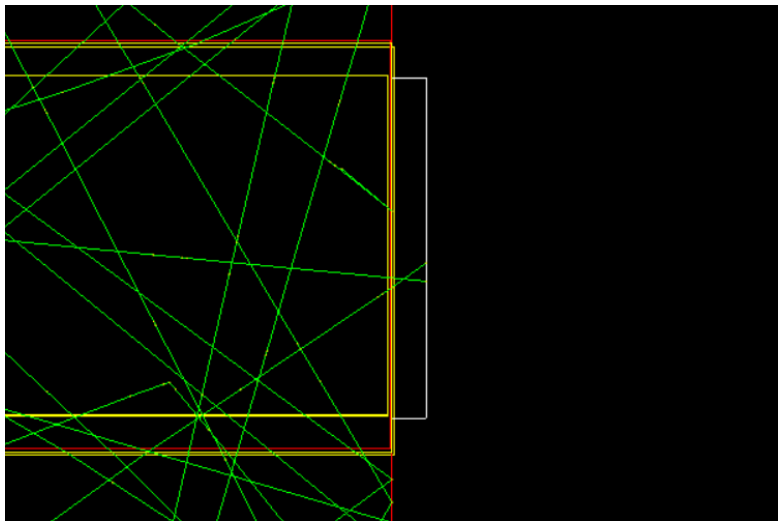


```
Arrive Time : 0.000605885
Arrive Time : 9.52315
Arrive Time : 17.874
Arrive Time : 1.36279
Number of Scintillation photons produced in this event : 8576
Number of Cerenkov photons produced in this event : 0
Number of WLS photons produced in this event : 240
2343<- the number of photon which goes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

- Even though more optical photons arrived, however, the MPPC counter did not work.

MPPC counter





- Because there was a small gap between MPPC and fiber, the total reflection was caused by the refractive index difference between air and fiber.
- For this reason, MPPC was completely attached to the fiber.

```
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

- The number of events increased and the result was as shown on the left.
- And we can see that more photons reach the MPPC than the results before, as a result of eliminating the interval between fiber and MPPC.
- However compared with the calculation results 6% in the ideal situation, the number of photons which arrived at MPPC is insufficient.