# 200513

# Kuraray 사의 spectrum table

Y-11Absorption　　Y-11Emission

| Wavelength | Absorption | WaveLength | Emission |
|---|---|---|---|
| 350 | −0.03252 | 430 | 0.008955 |
| 360 | −0.04878 | 440 | 0 |
| 370 | −0.07236 | 445 | 0.010746 |
| 380 | −0.14634 | 450 | 0.023881 |
| 390 | −0.28943 | 460 | 0.20597 |
| 400 | −0.46341 | 470 | 0.728358 |
| 410 | −0.60163 | 475 | 0.987463 |
| 415 | −0.63577 | 477 | 1 |
| 420 | −0.73984 | 480 | 0.979104 |
| 428 | −0.95935 | 491 | 0.719403 |
| 430 | −1 | 496 | 0.692537 |
| 435 | −0.95935 | 505 | 0.767164 |
| 440 | −0.8374 | 507 | 0.773134 |
| 443 | −0.77642 | 510 | 0.752239 |
| 448 | −0.80081 | 520 | 0.546269 |
| 450 | −0.84553 | 526 | 0.40597 |
| 452 | −0.86179 | 530 | 0.328358 |
| 455 | −0.8813 | 533 | 0.298507 |
| 460 | −0.80488 | 536 | 0.280597 |
| 470 | −0.31707 | 540 | 0.256716 |
| 475 | −0.11382 | 550 | 0.191045 |
| 480 | −0.03252 | 560 | 0.128358 |
| 485 | −0.00813 | 570 | 0.071642 |
| 490 | 0 | 580 | 0.041791 |
| 500 | 0 | 590 | 0.026866 |
| | | 600 | 0.019104 |
| | | 610 | 0.010746 |
| | | 620 | 0.00597 |
| | | 630 | 0.002985 |
| | | 640 | 0 |

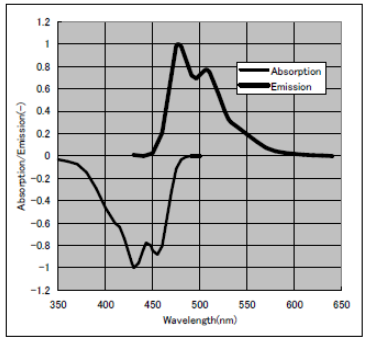



Fig.4 Absorption&Emission Spectra of Y-11

・②Absorption and Emission spectra

Please see the attached file. And Quantum efficiency of Y-11 is nearly 0.85～0.9.

If you tell me the detail of the simulation or what you want to do, I could make some advice.

(Probably, we should use trapping efficiency in addition to the Spectrum and QE.)

I think what you want to do is below(If wrong, please correct and tell me what you do).

「Final detection efficiency of the fiber?」

・Absorption Step

Depending on the wavelength of the incident light, Fiber absorb the light (Absorption spectra).

・Fluorescence Step

Many of the absorbed light change fluorescence light (QE=0.85～0.9)

・Fiber Step

A part of the fluorescence was trapped in the fiber(Trapping efficiency).

※Many fluorescence travel away from the fiber.

※Multi cladding is better than single cladding.

・Transmission Step

Depending on the fiber length and the fluorescence wavelength, the light decrease.

・Detection Step

The transmission light reach the detector which has different wavelength sensitivity.

# Code

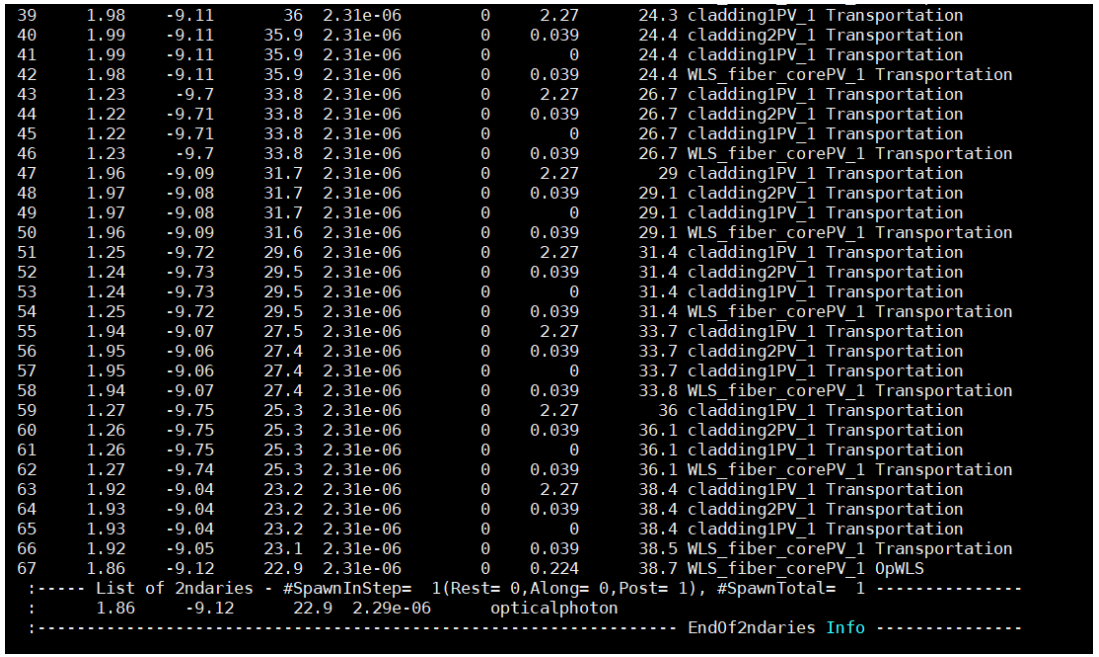
```
G4double WLS_absorption_photon_energy[] =
{
    350., 360., 370., 380., 390., 400., 410., 415., 420., 428.,
    430., 435., 440., 443., 448., 450., 452., 455., 460., 470.,
    475., 480., 485.//, 490.//, 500.
};
const G4int Entry_WLS_abs = sizeof(WLS_absorption_photon_energy) / sizeof(G4double);

for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_photon_energy[i] = (1242.1875 / WLS_absorption_photon_energy[i]) * eV;
}

G4double WLS_absorption_length[] =
{
    0.03252, 0.04878, 0.07236, 0.14634, 0.28943, 0.46341, 0.60163, 0.63577, 0.73984, 0.95935,
    1., 0.95935, 0.8374, 0.77642, 0.80081, 0.84553, 0.86179, 0.8813, 0.80488, 0.31707,
    0.11382, 0.03252, 0.00813//, 0.000000000000000001, 0.
};

G4double Parameter_k = 0.00638;
G4double Concentration = 200.;
for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_length[i] = (0.434294481903251827651128918916605082294397005803666566 / (Parameter_k * Concentration * WLS_absorption_length[i])) * mm;
}
Core_mpt->AddProperty("WLSABSLENGTH", WLS_absorption_photon_energy, WLS_absorption_length, Entry_WLS_abs);
```

# Bad event

```
20     1.14    -28.1      -59  2.25e-06        0        0      17.1 WLS_fiber_corePV_5 Transportation
21     1.51    -28.7    -60.7  2.25e-06        0     1.79      18.9 cladding1PV_5 Transportation
22     1.51    -28.7    -60.7  2.25e-06        0        0      18.9 WLS_fiber_corePV_5 Transportation
23     2.08    -28.2    -62.3  2.25e-06        0     1.79      20.7 cladding1PV_5 Transportation
24     2.08    -28.2    -62.3  2.25e-06        0        0      20.7 WLS_fiber_corePV_5 Transportation
25     1.61    -27.7      -64  2.25e-06        0     1.79      22.5 cladding1PV_5 Transportation
26     1.61    -27.7      -64  2.25e-06        0        0      22.5 WLS_fiber_corePV_5 Transportation
27     1.12    -28.2    -65.6  2.25e-06        0     1.79      24.3 cladding1PV_5 Transportation
28     1.12    -28.2    -65.6  2.25e-06        0        0      24.3 WLS_fiber_corePV_5 Transportation
29     1.68    -28.7    -67.3  2.25e-06        0     1.79      26.1 cladding1PV_5 Transportation
30     1.68    -28.7    -67.3  2.25e-06        0        0      26.1 WLS_fiber_corePV_5 Transportation
31     2.07    -28.1    -68.9  2.25e-06        0     1.79      27.9 cladding1PV_5 Transportation
32     2.07    -28.1    -68.9  2.25e-06        0        0      27.9 WLS_fiber_corePV_5 Transportation
33     1.44    -27.7    -70.6  2.25e-06        0     1.79      29.7 cladding1PV_5 Transportation
34     1.44    -27.7    -70.6  2.25e-06        0        0      29.7 WLS_fiber_corePV_5 Transportation
35     1.16    -28.4    -72.2  2.25e-06        0     1.79      31.5 cladding1PV_5 Transportation
36     1.16    -28.4    -72.2  2.25e-06        0        0      31.5 WLS_fiber_corePV_5 Transportation
37     1.83    -28.6    -73.9  2.25e-06        0     1.79      33.3 cladding1PV_5 Transportation
38     1.83    -28.6    -73.9  2.25e-06        0        0      33.3 WLS_fiber_corePV_5 Transportation
39        2    -27.9    -75.5  2.25e-06        0     1.79      35.1 cladding1PV_5 Transportation
40        2    -27.9    -75.5  2.25e-06        0        0      35.1 WLS_fiber_corePV_5 Transportation
41      1.3    -27.8    -77.1  2.25e-06        0     1.79      36.9 cladding1PV_5 Transportation
42      1.3    -27.8    -77.1  2.25e-06        0        0      36.9 WLS_fiber_corePV_5 Transportation
43     1.25    -28.5    -78.8  2.25e-06        0     1.79      38.6 cladding1PV_5 Transportation
44     1.25    -28.5    -78.8  2.25e-06        0        0      38.6 WLS_fiber_corePV_5 Transportation
45     1.96    -28.5    -80.4  2.25e-06        0     1.79      40.4 cladding1PV_5 Transportation
46     1.96    -28.5    -80.4  2.25e-06        0        0      40.4 WLS_fiber_corePV_5 Transportation
47     1.88    -27.8    -82.1  2.25e-06        0     1.79      42.2 cladding1PV_5 Transportation
48     1.88    -27.8    -82.1  2.25e-06        0        0      42.2 WLS_fiber_corePV_5 Transportation
49      1.2    -27.9    -83.7  2.25e-06        0     1.75        44 WLS_fiber_corePV_5 OpWLS
 :----- List of 2ndaries - #SpawnInStep=  1(Rest= 0,Along= 0,Post= 1), #SpawnTotal=  1 --------------
 :       1.2     -27.9     -83.7   2.2e-06      opticalphoton
 :---------------------------------------------------------------- EndOf2ndaries Info --------------
```

- 광자의 에너지 = 2.25 eV
- 광자의 파장 = 약 552 nm
- 해당 파장에서 광자는 재흡수가 일어날 수 없으나, 중간에 흡수가 일어나는 경우가 발생

# Bad event



```
39     1.98    -9.11       36  2.31e-06        0     2.27      24.3 cladding1PV_1 Transportation
40     1.99    -9.11     35.9  2.31e-06        0    0.039      24.4 cladding2PV_1 Transportation
41     1.99    -9.11     35.9  2.31e-06        0        0      24.4 cladding1PV_1 Transportation
42     1.98    -9.11     35.9  2.31e-06        0    0.039      24.4 WLS_fiber_corePV_1 Transportation
43     1.23     -9.7     33.8  2.31e-06        0     2.27      26.7 cladding1PV_1 Transportation
44     1.22    -9.71     33.8  2.31e-06        0    0.039      26.7 cladding2PV_1 Transportation
45     1.22    -9.71     33.8  2.31e-06        0        0      26.7 cladding1PV_1 Transportation
46     1.23     -9.7     33.8  2.31e-06        0    0.039      26.7 WLS_fiber_corePV_1 Transportation
47     1.96    -9.09     31.7  2.31e-06        0     2.27        29 cladding1PV_1 Transportation
48     1.97    -9.08     31.7  2.31e-06        0    0.039      29.1 cladding2PV_1 Transportation
49     1.97    -9.08     31.7  2.31e-06        0        0      29.1 cladding1PV_1 Transportation
50     1.96    -9.09     31.6  2.31e-06        0    0.039      29.1 WLS_fiber_corePV_1 Transportation
51     1.25    -9.72     29.6  2.31e-06        0     2.27      31.4 cladding1PV_1 Transportation
52     1.24    -9.73     29.5  2.31e-06        0    0.039      31.4 cladding2PV_1 Transportation
53     1.24    -9.73     29.5  2.31e-06        0        0      31.4 cladding1PV_1 Transportation
54     1.25    -9.72     29.5  2.31e-06        0    0.039      31.4 WLS_fiber_corePV_1 Transportation
55     1.94    -9.07     27.5  2.31e-06        0     2.27      33.7 cladding1PV_1 Transportation
56     1.95    -9.06     27.4  2.31e-06        0    0.039      33.7 cladding2PV_1 Transportation
57     1.95    -9.06     27.4  2.31e-06        0        0      33.7 cladding1PV_1 Transportation
58     1.94    -9.07     27.4  2.31e-06        0    0.039      33.8 WLS_fiber_corePV_1 Transportation
59     1.27    -9.75     25.3  2.31e-06        0     2.27        36 cladding1PV_1 Transportation
60     1.26    -9.75     25.3  2.31e-06        0    0.039      36.1 cladding2PV_1 Transportation
61     1.26    -9.75     25.3  2.31e-06        0        0      36.1 cladding1PV_1 Transportation
62     1.27    -9.74     25.3  2.31e-06        0    0.039      36.1 WLS_fiber_corePV_1 Transportation
63     1.92    -9.04     23.2  2.31e-06        0     2.27      38.4 cladding1PV_1 Transportation
64     1.93    -9.04     23.2  2.31e-06        0    0.039      38.4 cladding2PV_1 Transportation
65     1.93    -9.04     23.2  2.31e-06        0        0      38.4 cladding1PV_1 Transportation
66     1.92    -9.05     23.1  2.31e-06        0    0.039      38.5 WLS_fiber_corePV_1 Transportation
67     1.86    -9.12     22.9  2.31e-06        0    0.224      38.7 WLS_fiber_corePV_1 OpWLS
 :----- List of 2ndaries - #SpawnInStep=  1(Rest= 0,Along= 0,Post= 1), #SpawnTotal=  1 --------------
 :      1.86     -9.12      22.9  2.29e-06      opticalphoton
 :---------------------------------------------------------------- EndOf2ndaries Info --------------
```

- 광자의 에너지 = 2.31 eV
- 광자의 파장 = 약 537 nm
- 해당 파장에서 광자는 재흡수가 일어날 수 없으나, 중간에 흡수가 일어나는 경우가 발생

# Manual for G4OpWLS

Listing 5.7: Specification of WLS properties in `DetectorConstruction`.

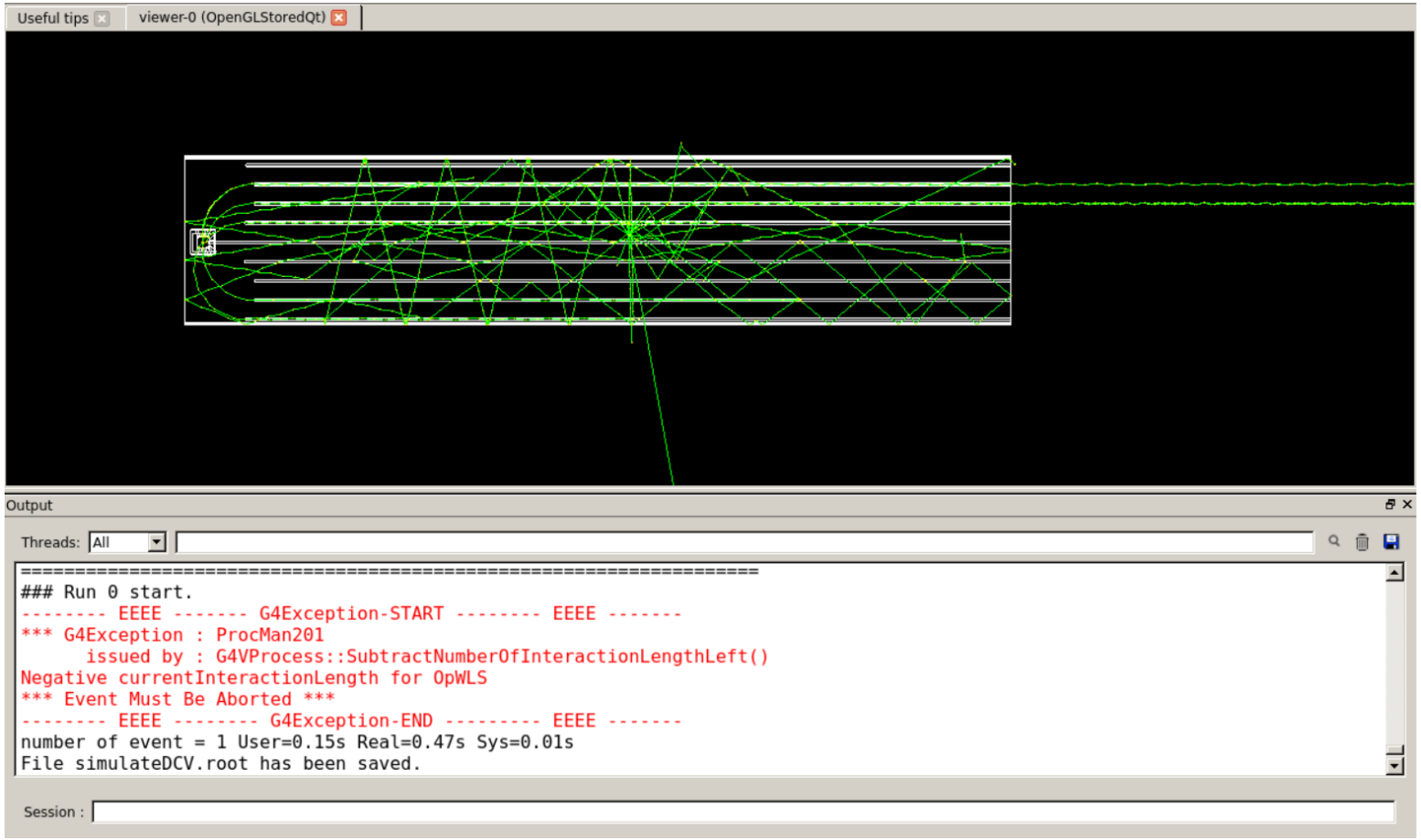
```
const G4int nEntries = 9;

G4double PhotonEnergy[nEntries] = { 6.6*eV, 6.7*eV, 6.8*eV, 6.9*eV,
                                    7.0*eV, 7.1*eV, 7.2*eV, 7.3*eV, 7.4*eV };

G4double RIndexFiber[nEntries] =
          { 1.60, 1.60, 1.60, 1.60, 1.60, 1.60, 1.60, 1.60, 1.60 };
G4double AbsFiber[nEntries] =
          {0.1*mm,0.2*mm,0.3*mm,0.4*cm,1.0*cm,10*cm,1.0*m,10.0*m,10.0*m};
G4double EmissionFiber[nEntries] =
          {0.0, 0.0, 0.0, 0.1, 0.5, 1.0, 5.0, 10.0, 10.0 };

 G4Material* WLSFiber;
 G4MaterialPropertiesTable* MPTFiber = new G4MaterialPropertiesTable();

 MPTFiber->AddProperty("RINDEX",PhotonEnergy,RIndexFiber,nEntries);
 MPTFiber->AddProperty("WLSABSLENGTH",PhotonEnergy,AbsFiber,nEntries);
 MPTFiber->AddProperty("WLSCOMPONENT",PhotonEnergy,EmissionFiber,nEntries);
 MPTFiber->AddConstProperty("WLSTIMECONSTANT", 0.5*ns);

 WLSFiber->SetMaterialPropertiesTable(MPTFiber);
```

# Code(before)

```
G4double WLS_absorption_photon_energy[] =
{
    350., 360., 370., 380., 390., 400., 410., 415., 420., 428.,
    430., 435., 440., 443., 448., 450., 452., 455., 460., 470.,
    475., 480., 485., 490.//, 500.
};
const G4int Entry_WLS_abs = sizeof(WLS_absorption_photon_energy) / sizeof(G4double);

for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_photon_energy[i] = (1242.1875 / WLS_absorption_photon_energy[i]) * eV;
}

G4double WLS_absorption_length[] =
{
    0.03252, 0.04878, 0.07236, 0.14634, 0.29843, 0.46341, 0.60163, 0.63577, 0.73984, 0.95935,
    1., 0.95935, 0.8374, 0.77642, 0.86081, 0.84553, 0.86179, 0.8813, 0.80488, 0.31707,
    0.11382, 0.03252, 0.00813, 0.//, 0.
};

G4double Parameter_k = 0.00638;
G4double Concentration = 200.;
for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_length[i] = (0.434294481903251827651128918916605082294397005803666566 / (Parameter_k * Concentration * WLS_absorption_length[i])) * mm;
}
Core_mpt->AddProperty("WLSABSLENGTH", WLS_absorption_photon_energy, WLS_absorption_length, Entry_WLS_abs);
```

이 때 absorption length가 무한대로 발산

# Bad example

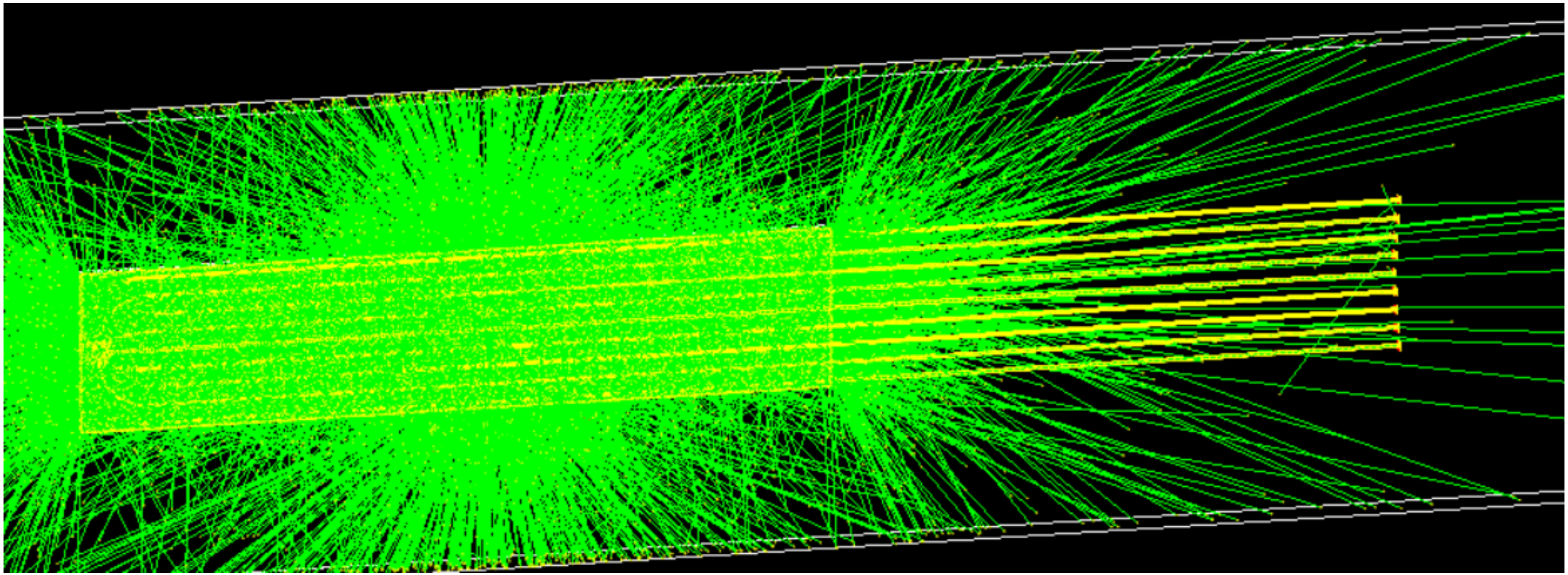

Useful tips
viewer-0 (OpenGLStoredQt)
Output
Threads: All
==========
### Run 0 start.
-------- EEEE ------- G4Exception-START -------- EEEE -------
*** G4Exception : ProcMan201
issued by : G4VProcess::SubtractNumberOfInteractionLengthLeft()
Negative currentInteractionLength for OpWLS
*** Event Must Be Aborted ***
-------- EEEE -------- G4Exception-END --------- EEEE -------
number of event = 1 User=0.15s Real=0.47s Sys=0.01s
File simulateDCV.root has been saved.
Session :

# Code

```
G4double WLS_absorption_photon_energy[] =
{
    350., 360., 370., 380., 390., 400., 410., 415., 420., 428.,
    430., 435., 440., 443., 448., 450., 452., 455., 460., 470.,
    475., 480., 485., 490.//, 500.
};
const G4int Entry_WLS_abs = sizeof(WLS_absorption_photon_energy) / sizeof(G4double);

for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_photon_energy[i] = (1242.1875 / WLS_absorption_photon_energy[i]) * eV;
}

G4double WLS_absorption_length[] =
{
    0.03252, 0.04878, 0.07236, 0.14634, 0.28943, 0.46341, 0.60163, 0.63577, 0.73984, 0.95935,
    1., 0.95935, 0.8374, 0.77642, 0.89091, 0.84553, 0.86179, 0.8813, 0.80488, 0.31707,
    0.11382, 0.03252, 0.00813, 0.0000000000000000//, 0.
};

G4double Parameter_k = 0.00638;
G4double Concentration = 200.;
for (G4int i = 0; i < Entry_WLS_abs; i++)
{
    WLS_absorption_length[i] = (0.434294481903251827651128918916605082294397005803666666 / (Parameter_k * Concentration * WLS_absorption_length[i])) * mm;
}
Core_mpt->AddProperty("WLSABSLENGTH", WLS_absorption_photon_energy, WLS_absorption_length, Entry_WLS_abs);
```

일부러 매우 작은 값을 줌으로써 absorption length를 매우 키워서 사실상 WLS absorption이 일어나는 것을 막음

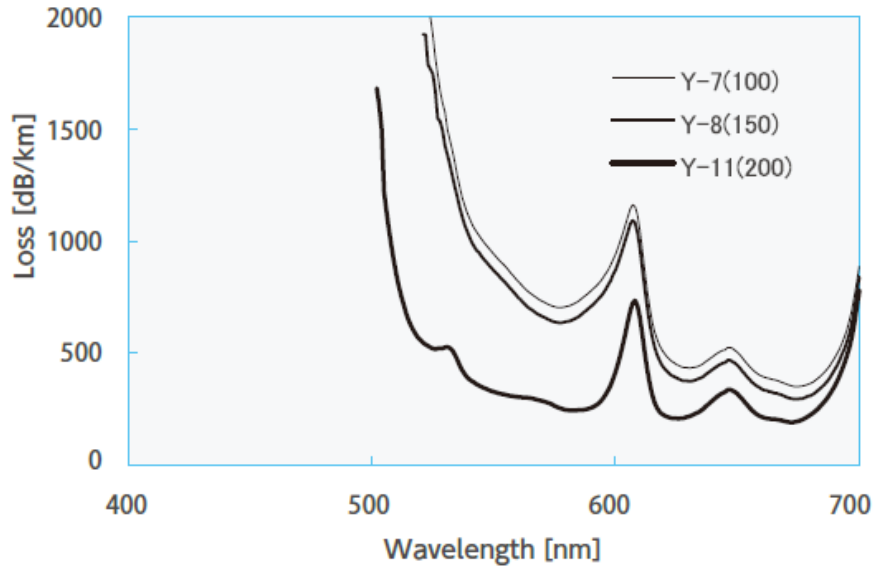
# Visualization



# Transmission loss

Transmission Loss

Y-7, Y-8, Y-11




・①Transmission Loss

I explain to use sample condition below.

・Fiber length:1m

・Transmission Loss 500dB/km

・Incident Light power $I_0$=1 W

・Detection Light power $I_1$

1st step we calculate transmission Loss of 1m fiber(=X).

1m=1/1000 km

500dB/km ×1/1000 km =0.5 dB (=X)

2nd step we calculate detection light power $I_1$ to use the relation between light power and transmission loss.

$X=-10\times \mathrm{Log10}(I_1 / I_0)$

$\Rightarrow \mathrm{Log10}(I_1 / I_0)=-X/10=-1/20$

$\Rightarrow I_1 / I_0=10^{(-1/20)}$

$\Rightarrow I_1 =0.89 \times I_0$

So in the case(Transmission Loss 500dB/km and fiber length 1m)⇒The detection light's power decrease to the 89% power of incident light.

※Caution

Transmission loss change when the wavelength of light change because the light transparency of polystyrene differs. See our catalog data(Transmission Loss graph)

# Transmission loss

- Change unit of transmission loss[dB/km] to absorption length.

$$\alpha[\frac{dB}{km}] = 10\log\frac{I}{I_0} \qquad \text{and} \qquad e^{-\frac{x}{l_0}} = \frac{I}{I_0}$$

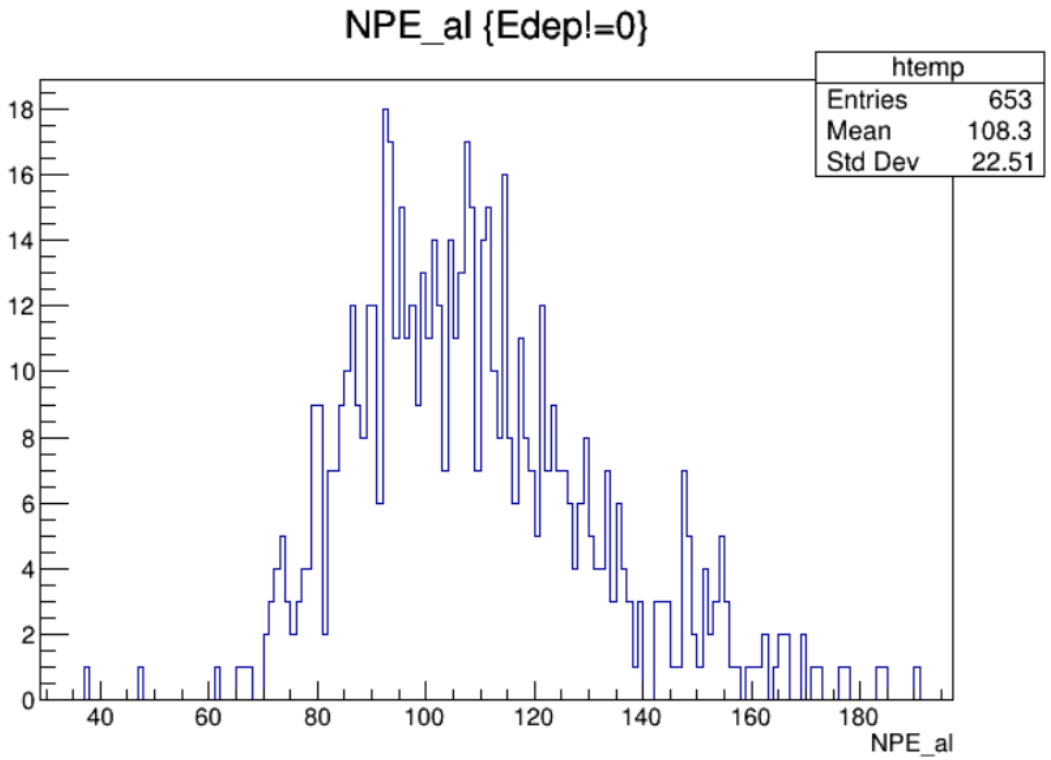
$$\text{Therfore } l_0 = \frac{10}{\alpha \ln 10}$$

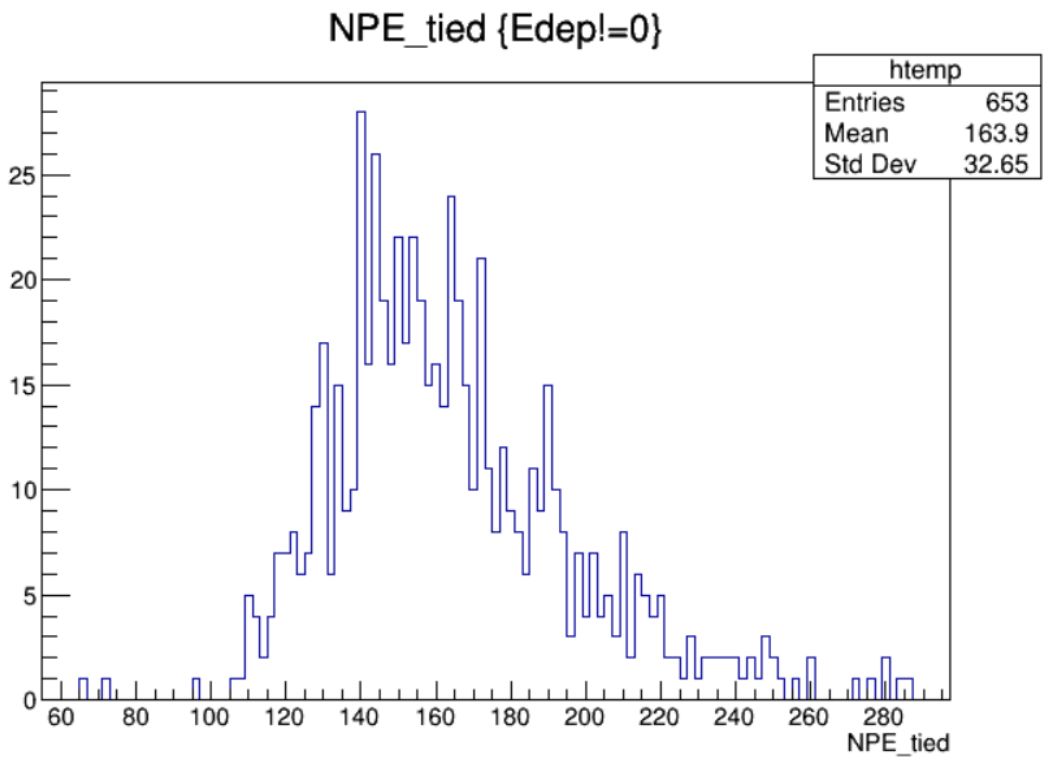
>> In this case, minimum absorption length is about 2.5 m and maximum absorption length is about 19 m. (too long)

# The number of photoelectron

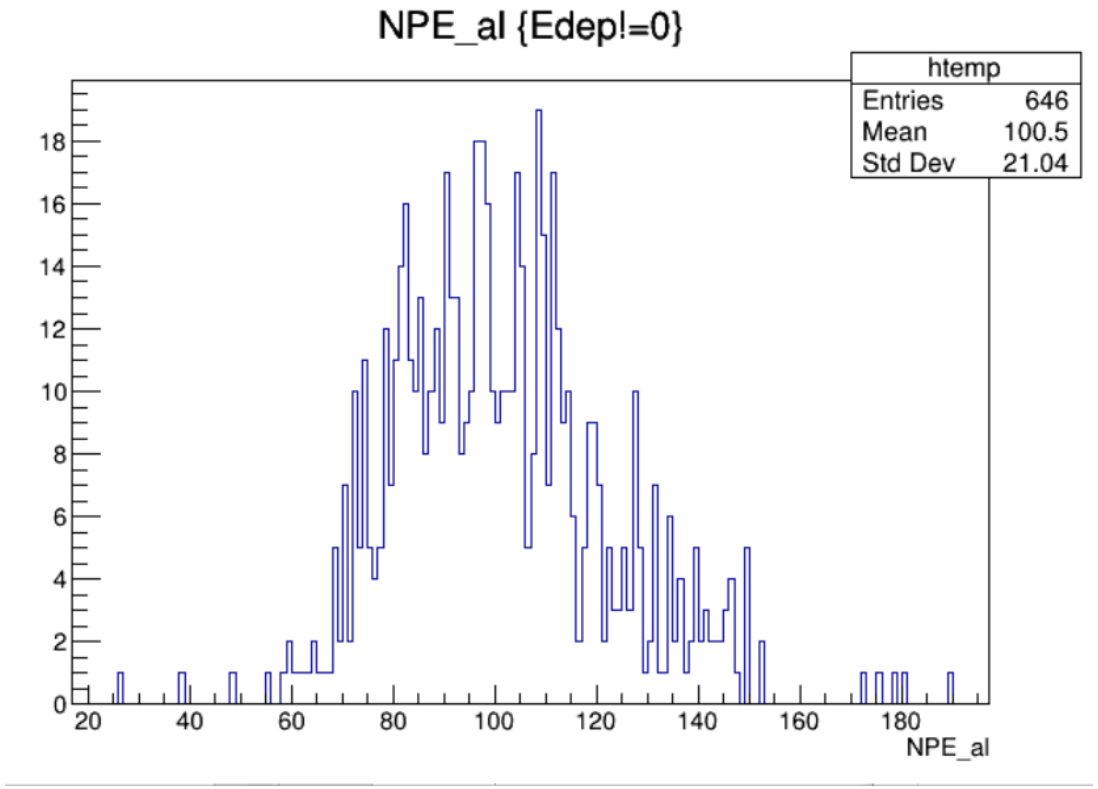
- 지금까지는 왼쪽의 Transmission loss에서 dB/km를 km 단위의 absorption length로 바꾼 뒤 사용하였다.
- 하지만 이 경우 NPE의 값이 매우 높게 나타났다.
- 이는 Geant4에서 input으로 작용하는 parameter는 bulk absorption이기 때문에 transmission loss와는 다른 개념이다.
- 따라서 NPE의 값을 설명할 수 있는 absorption length를 찾아주었다.
- 문제점: 하지만 이렇게 되면, absorption length는 파장마다 달라지게 되는데 이러한 요소를 고려하지 못하게 된다.

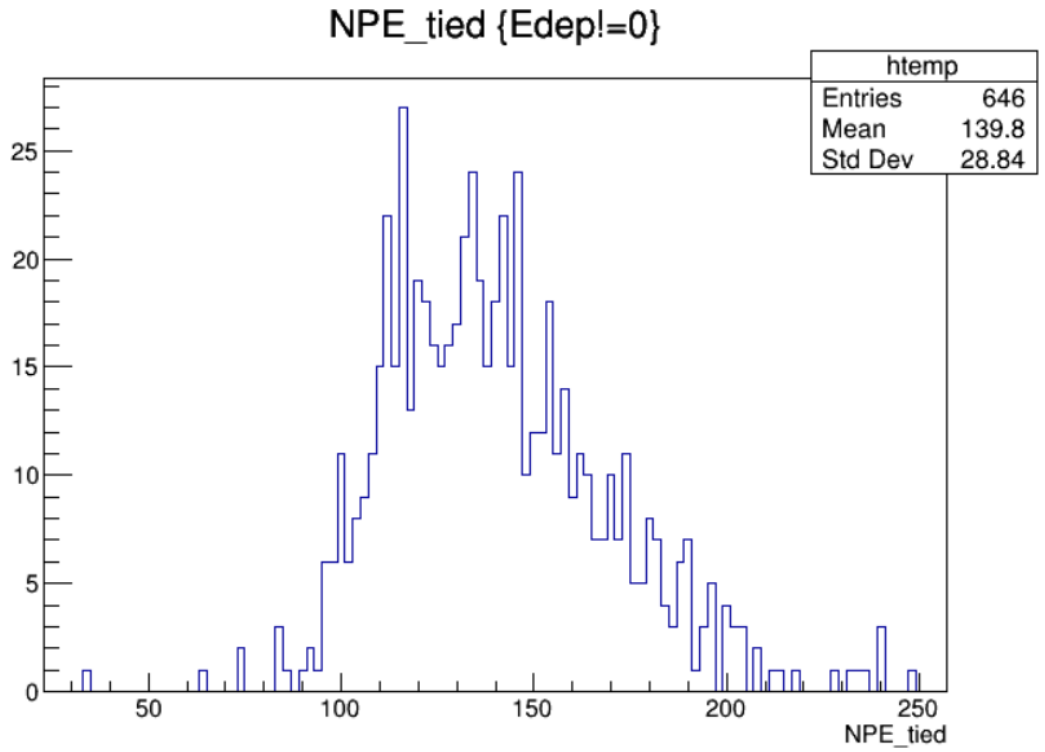
# Absorption length = 4 m (20cm 4.7mm)



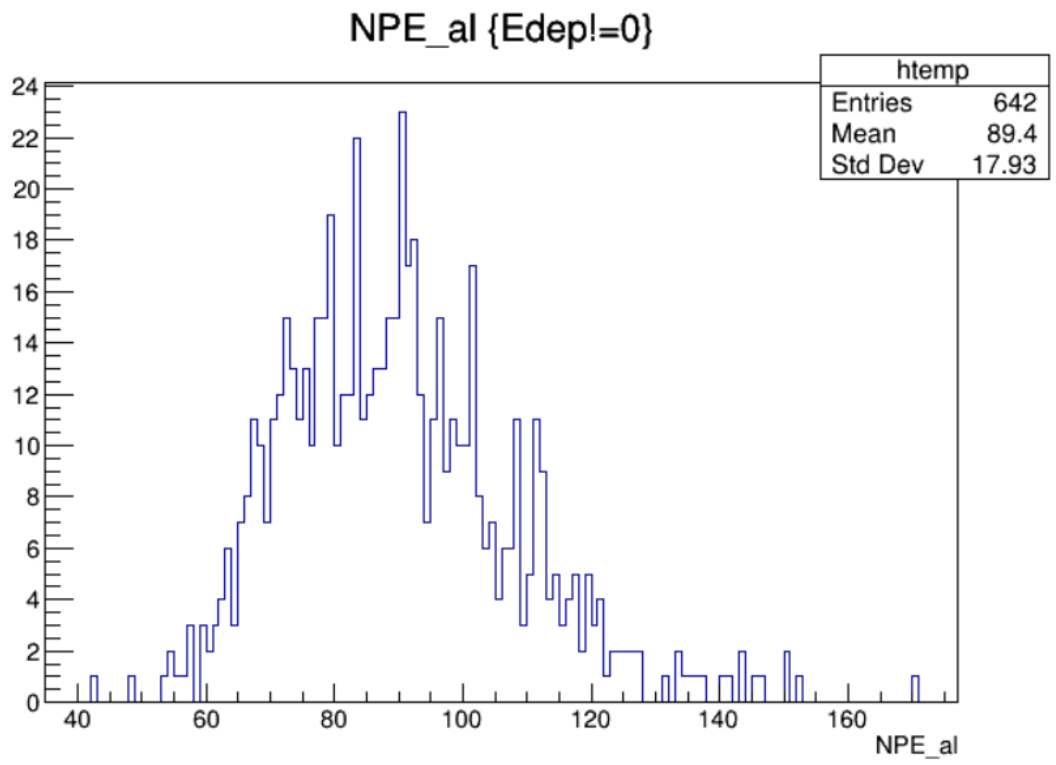



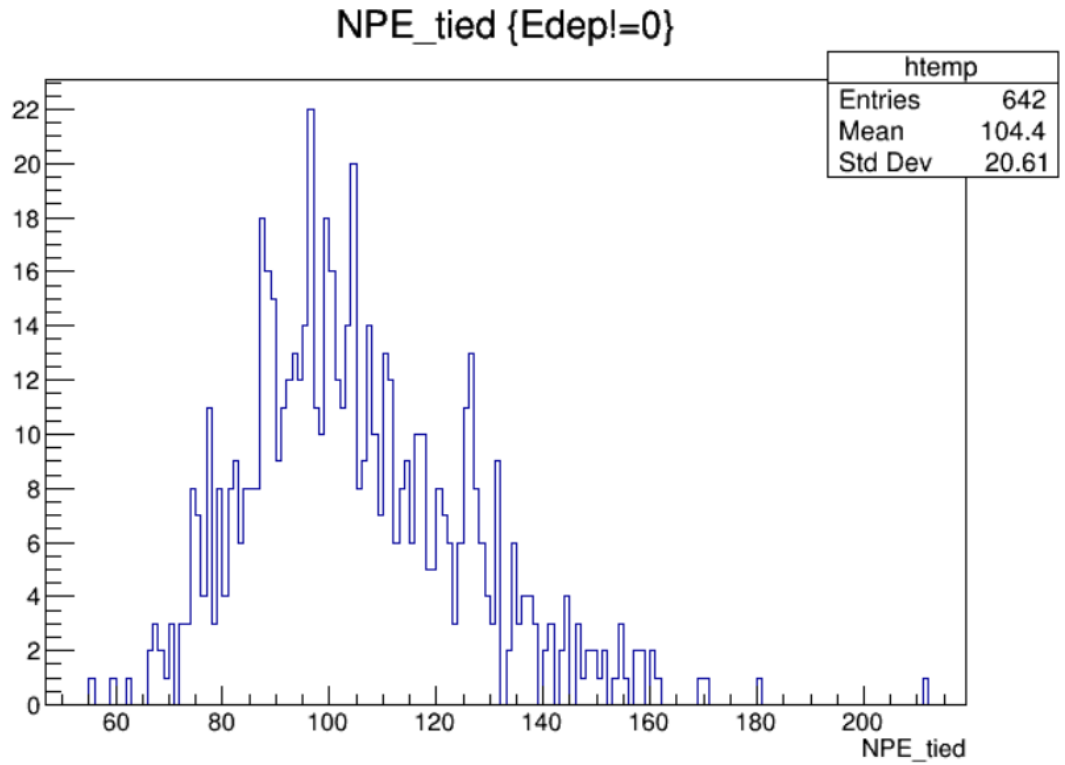
# Absorption length = 2 m



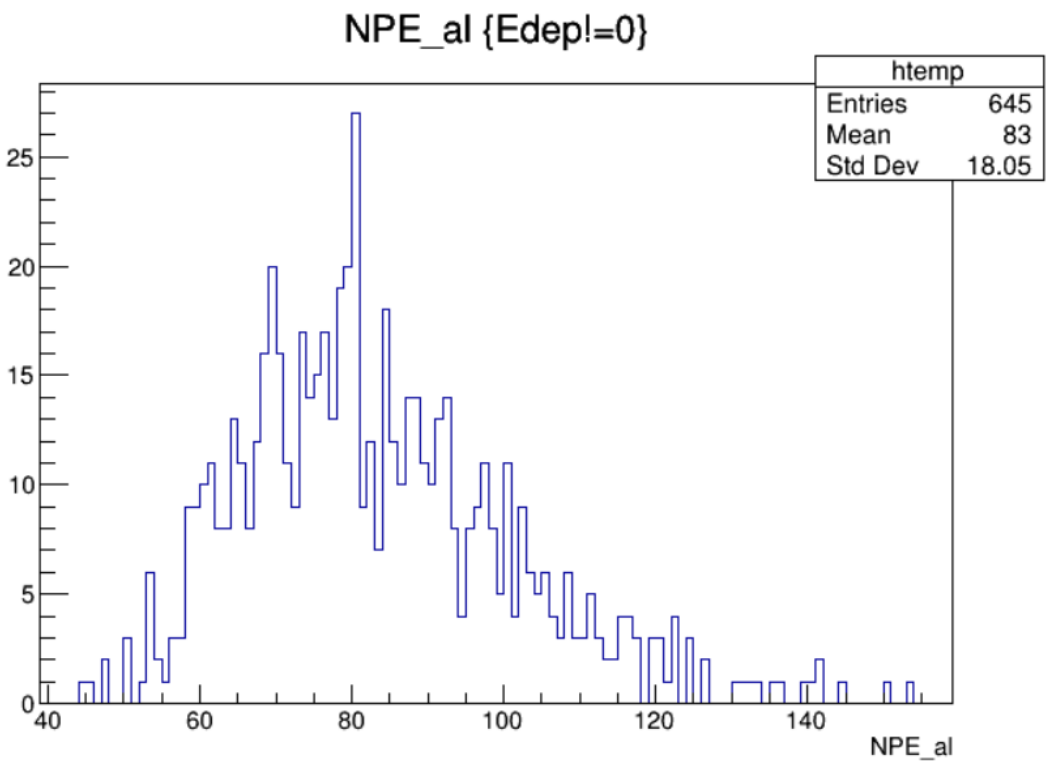



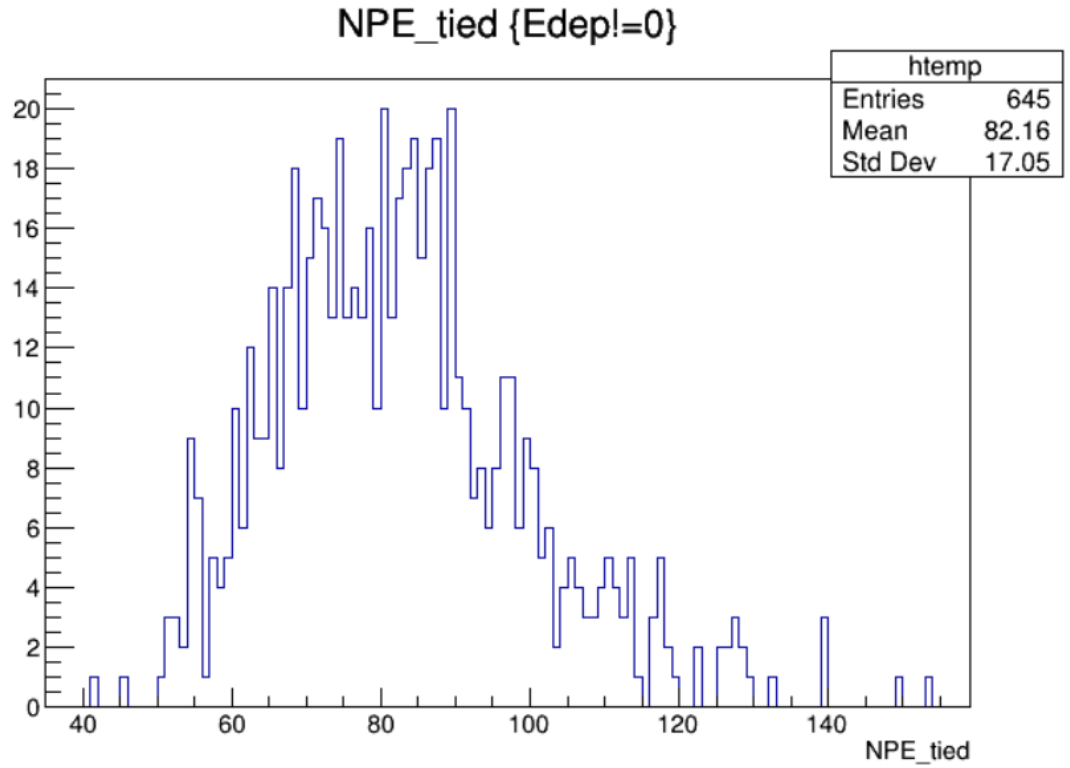
# Absorption length = 1 m



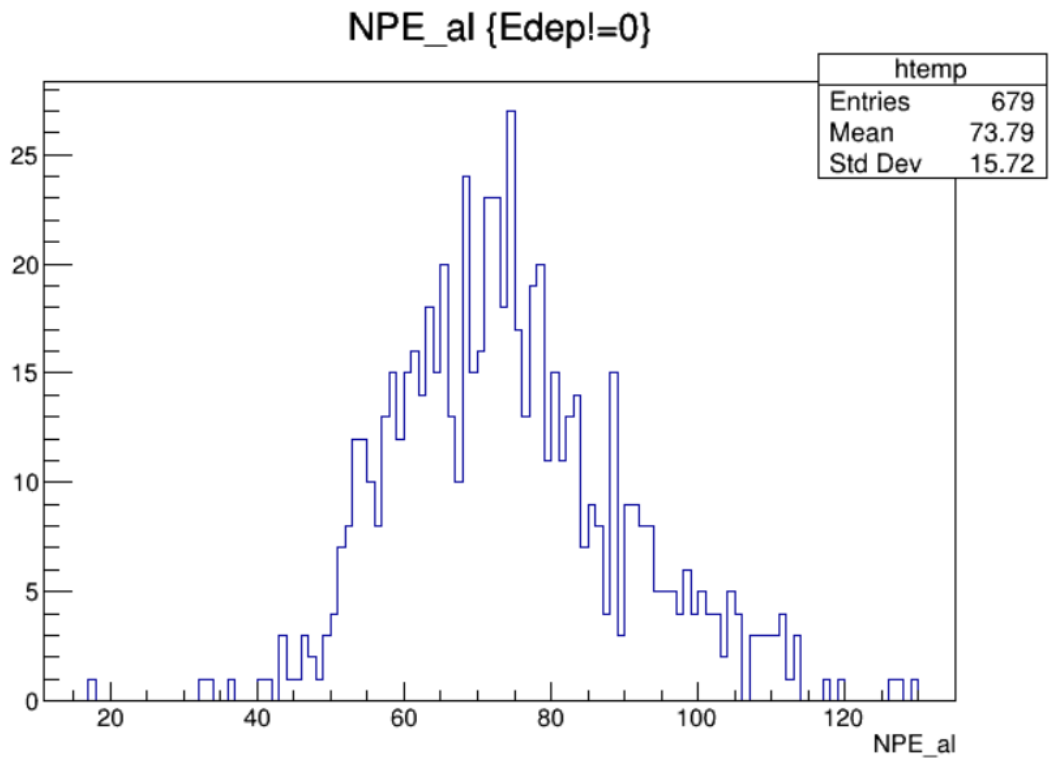



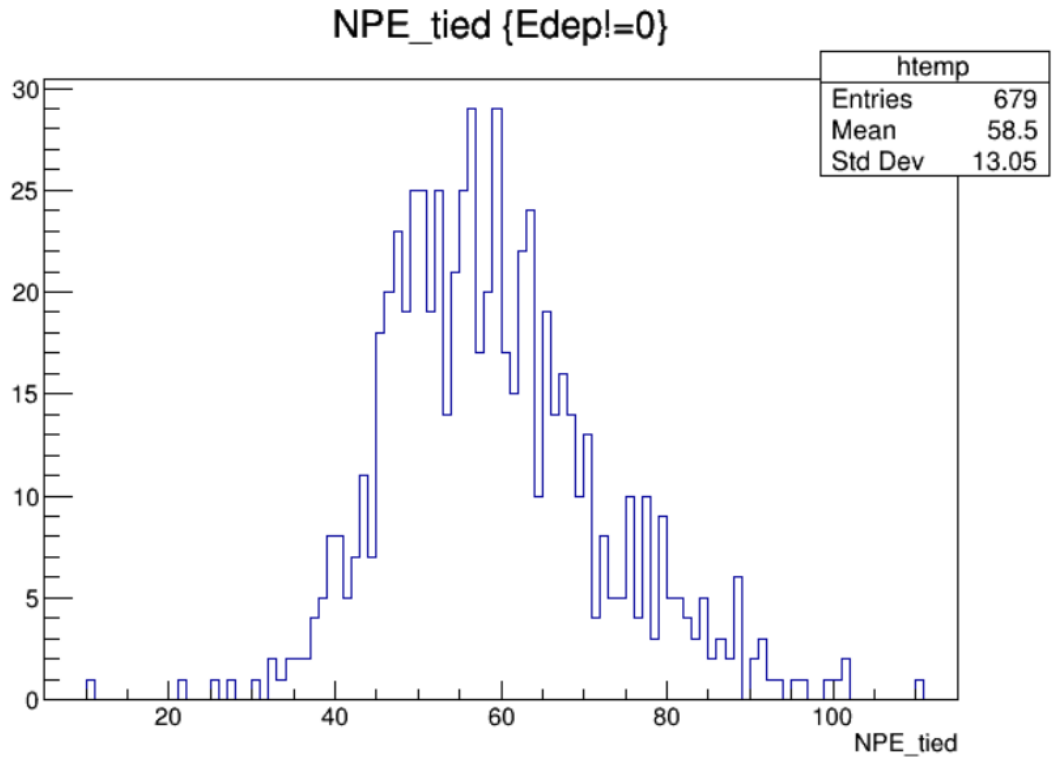
# Absorption length = 70 cm



# Absorption length = 50 cm



# Experimental data