Simulation Study

WLS efficiency

WLS MEAN NUMBER PHOTONS

- A photon is wavelength shifted when the dye absorbs the photon, and the energy is transferred by non-radiative dipole – dipole interactions to excited levels of a solute, producing fluorescence. At the time, there is a probability of this non-radiative transfer.
- According to mail from Kurary, the efficiency of WLS process is around 60% or 70%.
- However there is no data for efficiency.

- In G4OpWLS, there is option named WLSMEANNUMBERPHOTONS, which allow to specify that more than one WLS photon is emitted for every primary photon.
- At the time, photon is emitted as function of Poisson.
- Reference page

http://hypernews.slac.stanford.edu/HyperNews/geant4/get/opticalphotons/443.html

Ref) Source code

```
G4int NumPhotons = 1;

if (aMaterialPropertiesTable->ConstPropertyExists("WLSMEANNUMBERPHOTONS")) {

   G4double MeanNumberOfPhotons = aMaterialPropertiesTable->
                                  GetConstProperty("WLSMEANNUMBERPHOTONS");

   NumPhotons = G4int(G4Poisson(MeanNumberOfPhotons));

   if (NumPhotons <= 0) {

      // return unchanged particle and no secondaries

      aParticleChange.SetNumberOfSecondaries(0);

      return G4VDiscreteProcess::PostStepDoIt(aTrack, aStep);

   }

}

aParticleChange.SetNumberOfSecondaries(NumPhotons);
```

Error code

```
### Run 0 start.
5<- the number of photon which arrive at MPPC1
number of event = 1 User=0.06s Real=0.08s Sys=0s
File simulate_fiber.root has been saved.
Ui manger applied
Graphics systems deleted.
Visualization Manager deleting...
G4VParticleChange::SetNumberOfSecondaries() Warning  theListOfSecondaries is not empty
```

Efficiency of WLS

- By adding the code to the right in the stacking action, we added the efficiency feature of the WLS process.

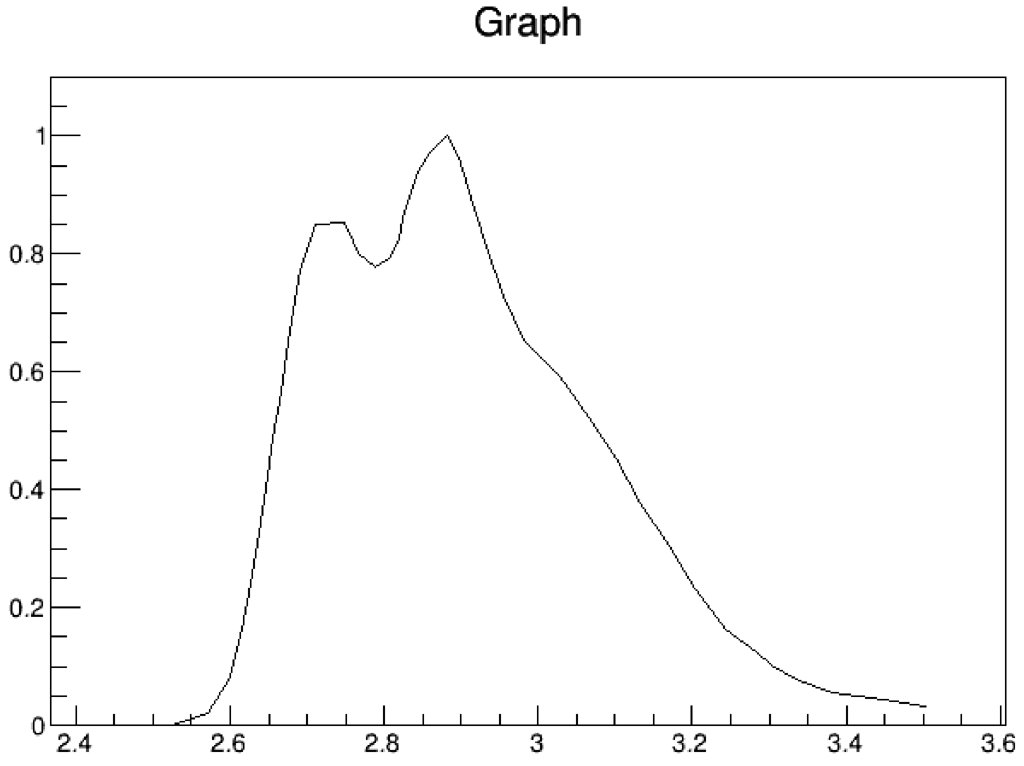
- In the similar manner, MPPC was assigned efficiency.
- For reference, The option called "EFFICIENCY" is only applicable when the photoelectric effect of gamma occurs.

```
else if (aTrack->GetCreatorProcess()->GetProcessName() == "OpWLS")
{
    random_number = G4UniformRand();

    if (random_number > 0.7)
    {
        return fKill;
    }

    else
    {
        if (fTrackID != fPreTrackID)
        {
            fWLSCounter++;

            fPreTrackID = fTrackID;
            man->AddNtupleRow(0);
            return fUrgent;
        }
    }
}
```

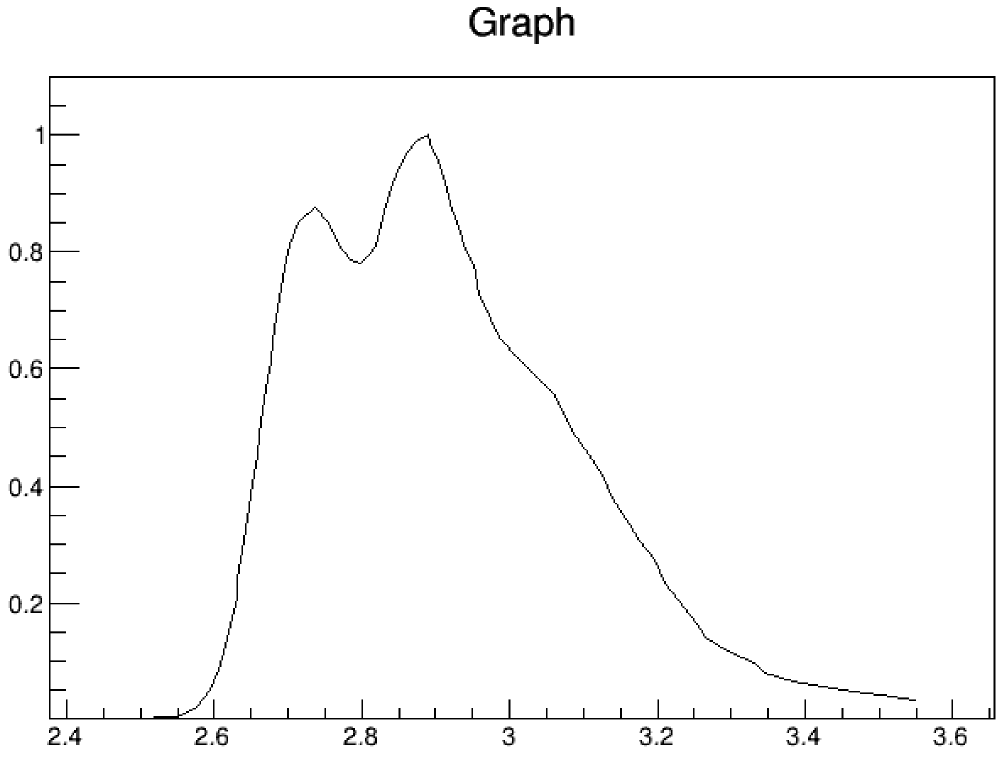
Absorption Length

Backup

Absorption spectrum used before



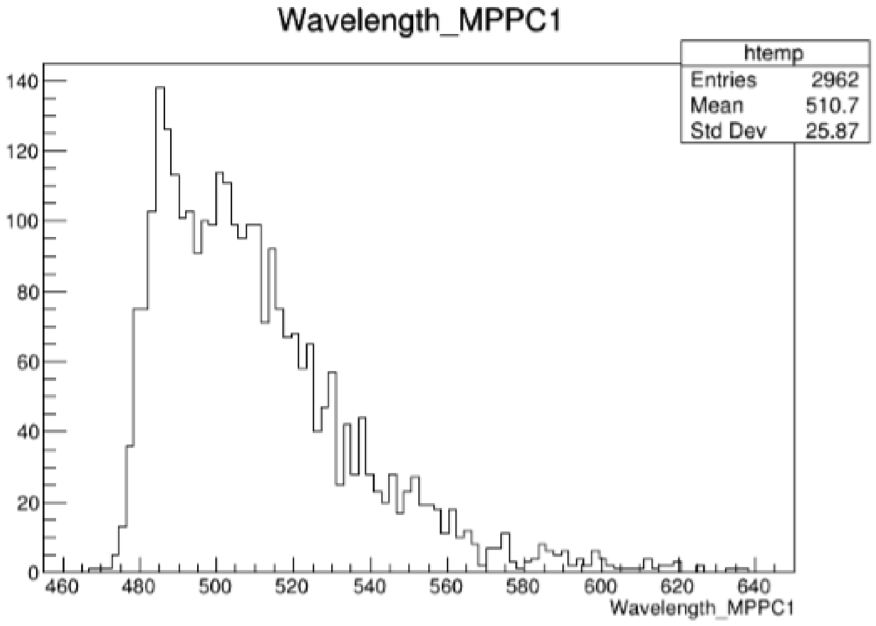
Absorption spectrum used after



Backup

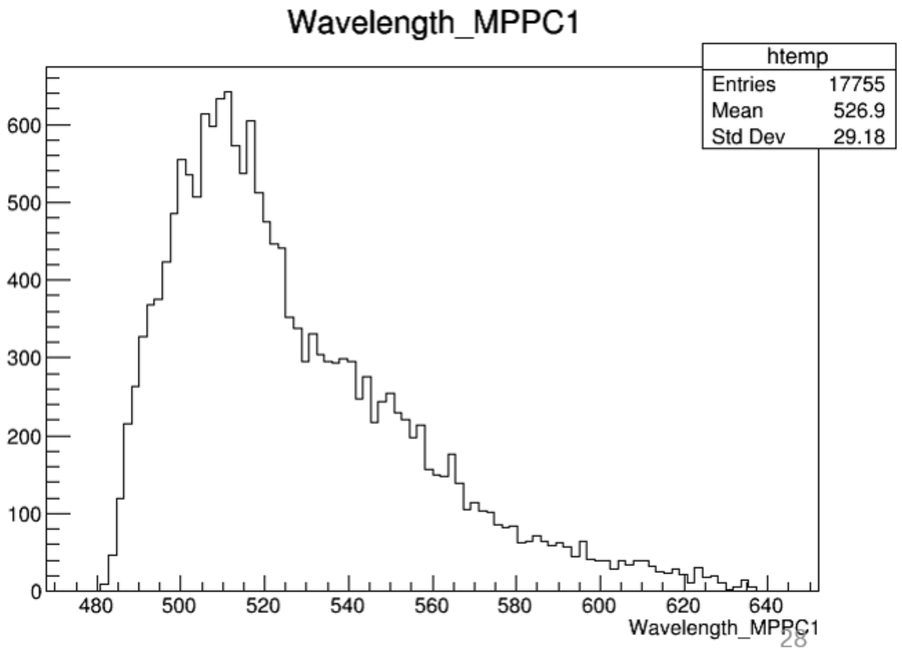
Before

For 30 cm

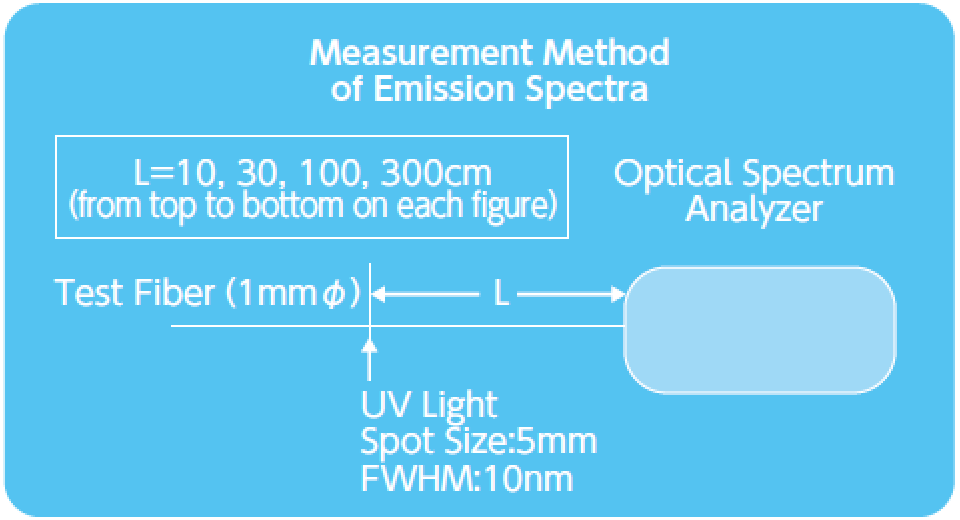


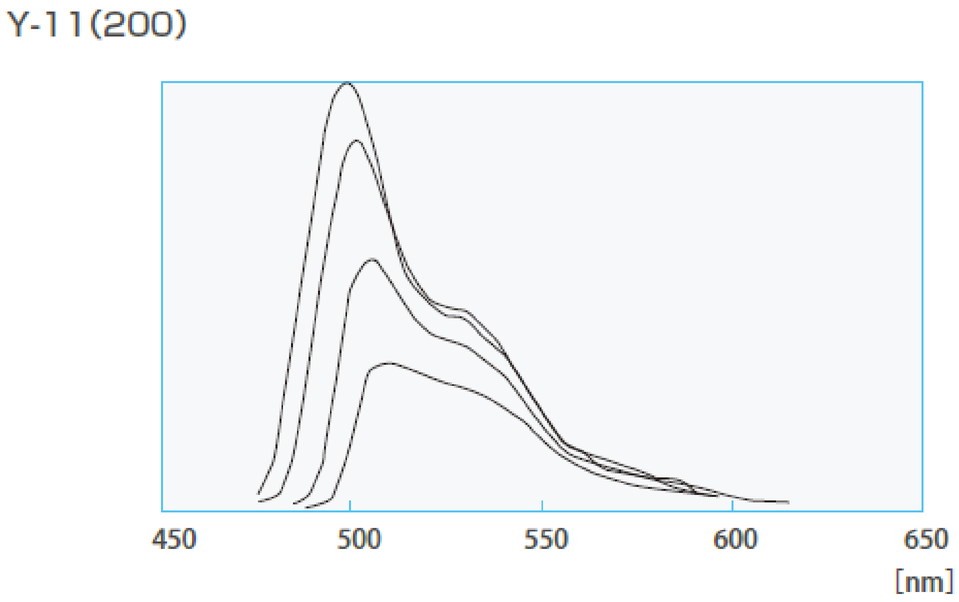
After

For 30 cm



Comparison of simulation



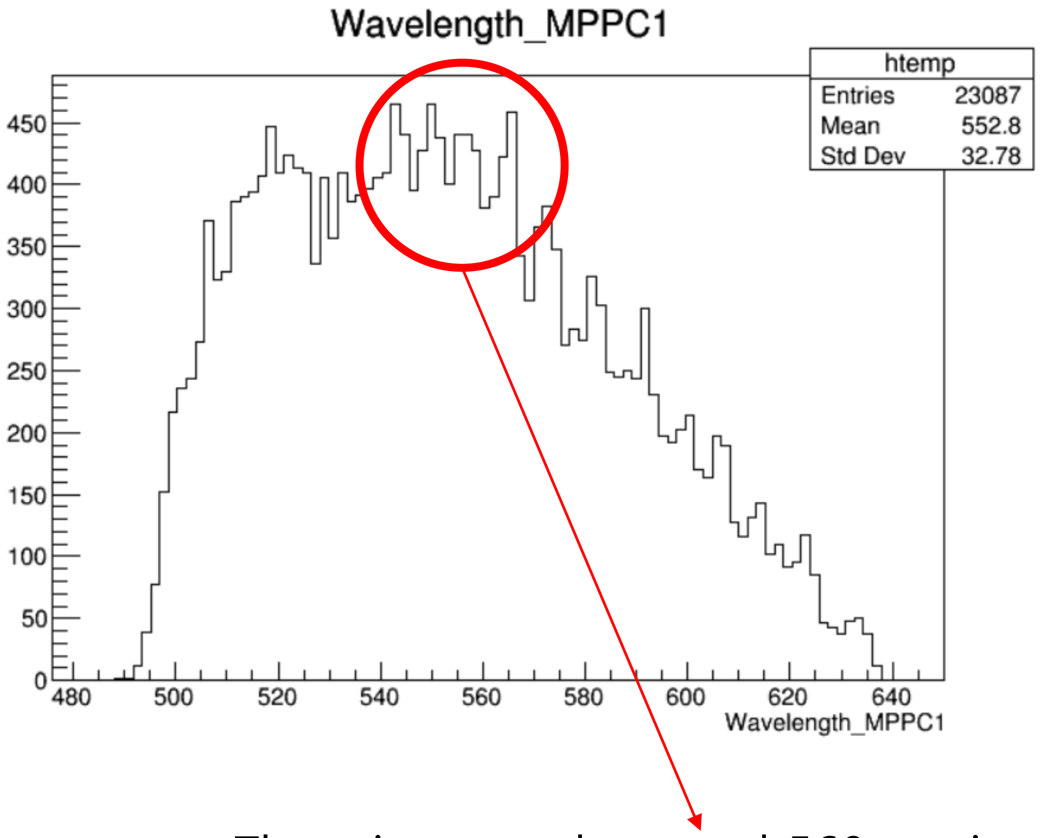


Exiting Wavelength:430nm

When photon of a wavelength of 430nm shoot in the end of fiber, the emission spectrum should be same as the right.

Comparison with reference

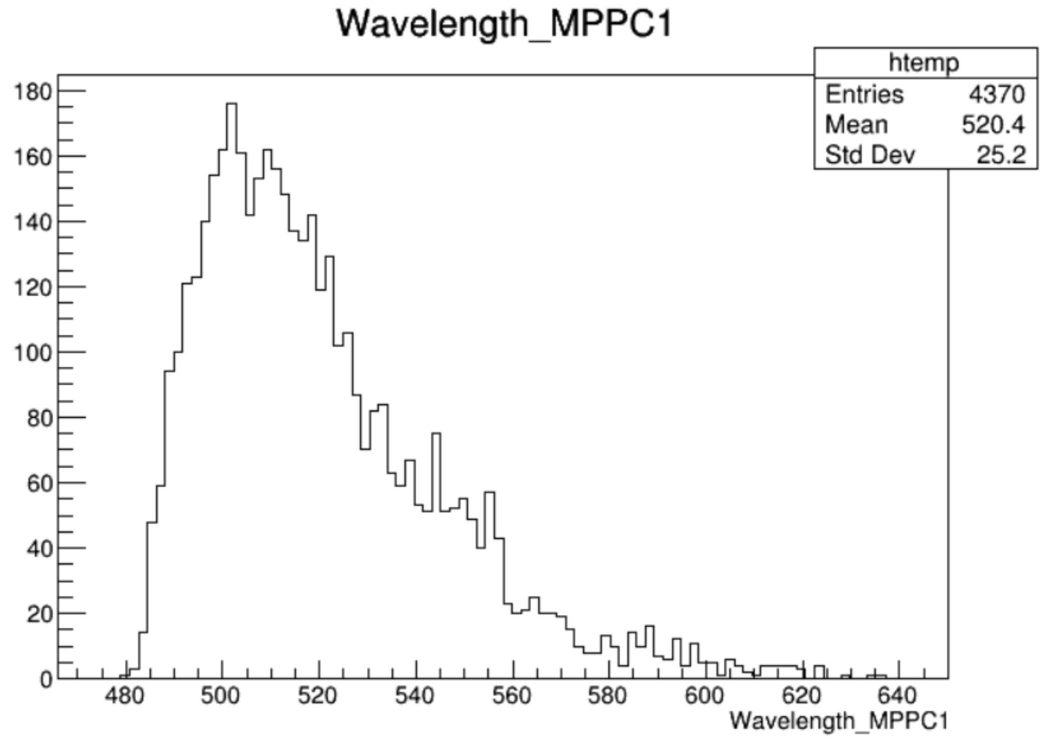
For 100 cm



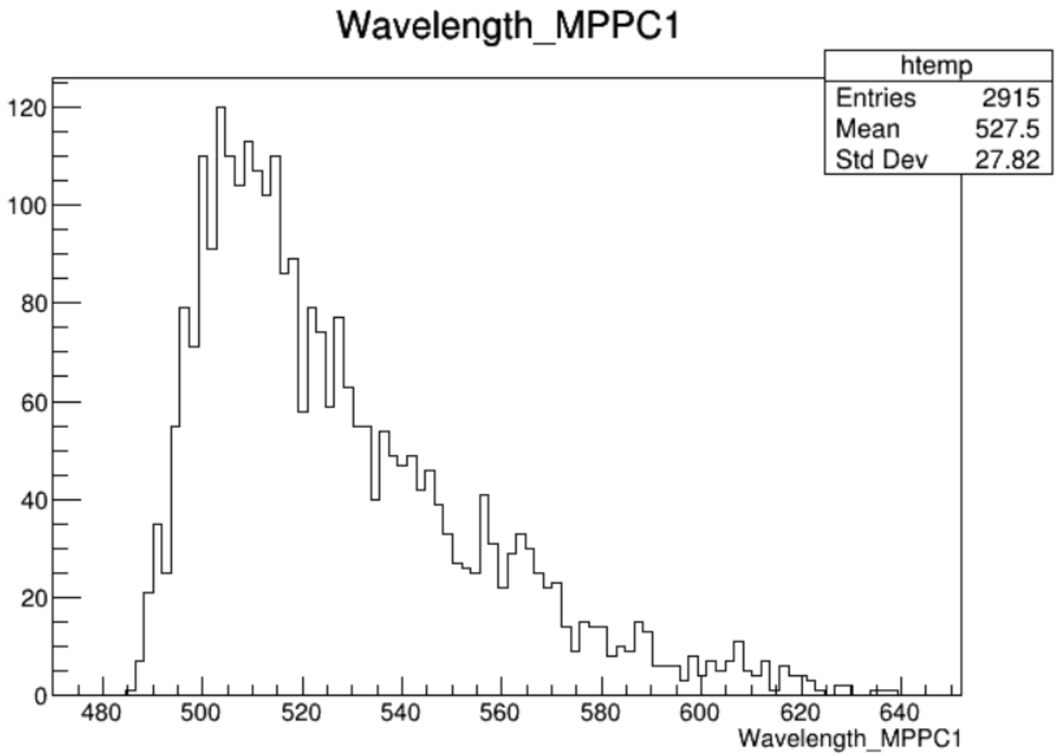
There is no peak around 560 nm in reference.

Comparison with reference

For 10 cm

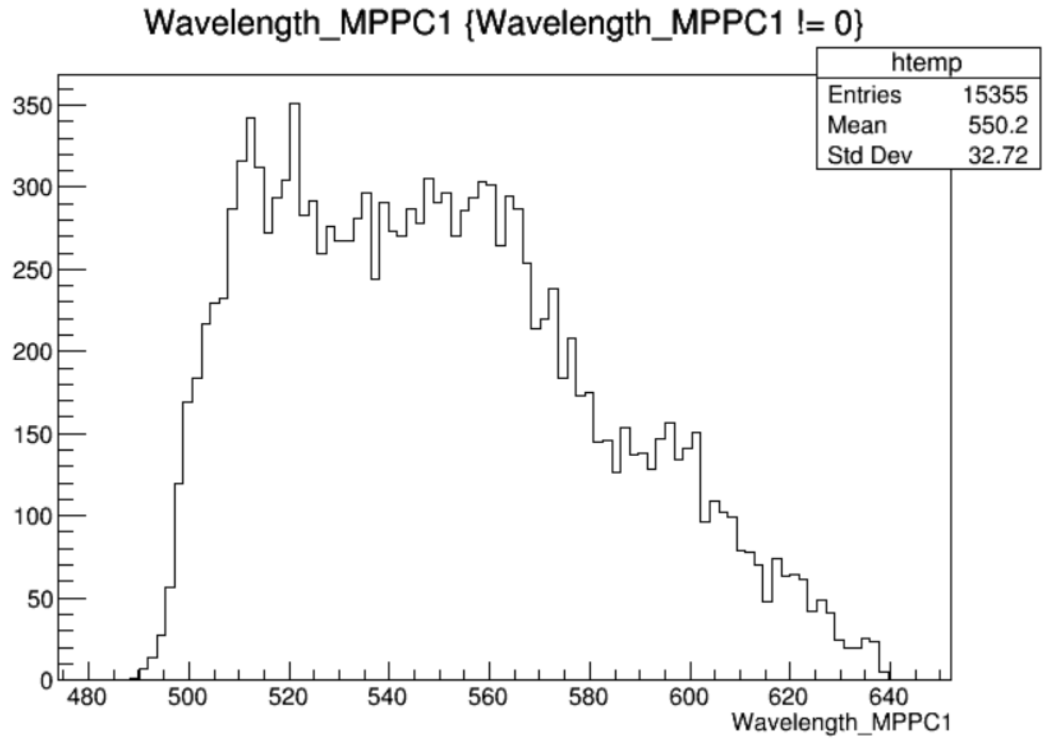


For 30 cm



Comparison with reference

For 100 cm



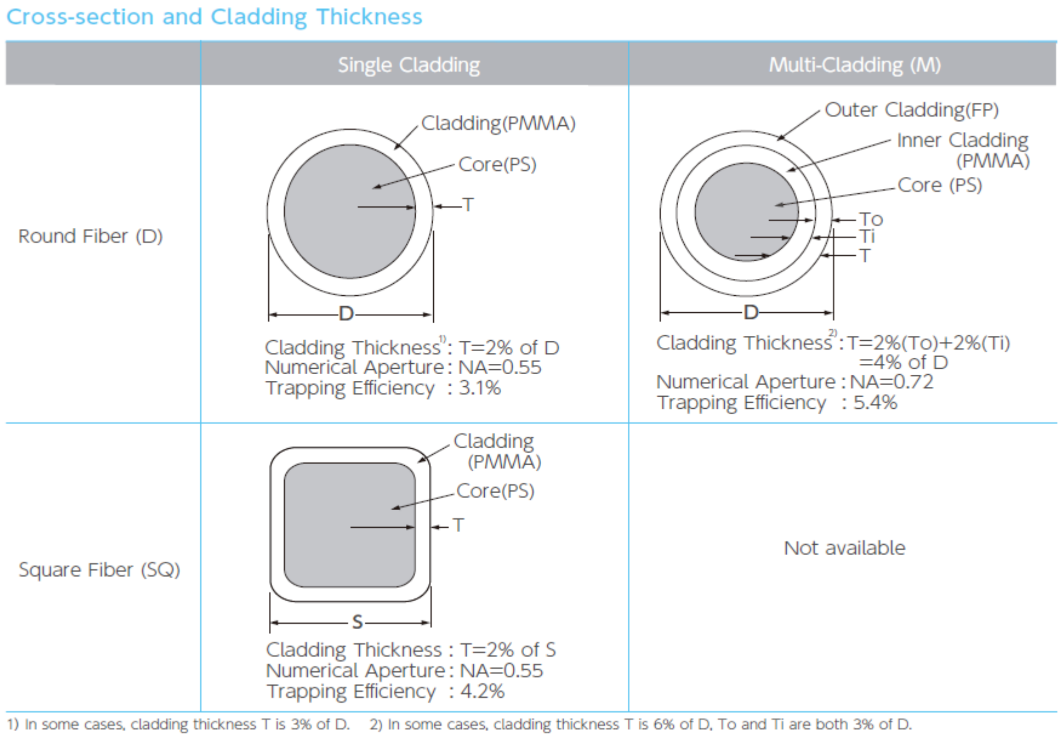
For 300 cm

Trapping efficiency difference

Between single cladding and double cladding

Definition of trapping efficiency

- Let define the trapping efficiency as the probability that the photon generated in the axis of the fiber travel in fiber by total reflection.
- In this case, the trapping efficiency can be calculated easily.



Critical angle for each layer

- Critical angle is determined by Snell's law.

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

- And when total reflection is occurred,

$$n_1 sin\theta_c = n_2$$

- Therefore

$$\theta_c = sin^{-1}\frac{n_2}{n_1}$$

Refractive index and critical angle

- Refractive index of Core(Polystylene) = 1.59
- Refractive index of 1st cladding(Polymethylmethancylate) = 1.49
- Refractive index of 2nd cladding(Flourinated polymer) = 1.42

	Core -> Cladding1	Cladding1 -> Cladding2	Cladding2 -> Air
Critical angle	$\sin^{-1}(\frac{1.49}{1.59}) \approx 69.57°$	$\sin^{-1}(\frac{1.42}{1.49}) \approx 72.37°$	$\sin^{-1}(\frac{1}{1.42}) \approx 44.77°$

Refractive index and critical angle

- For single cladding, critical angle is as below

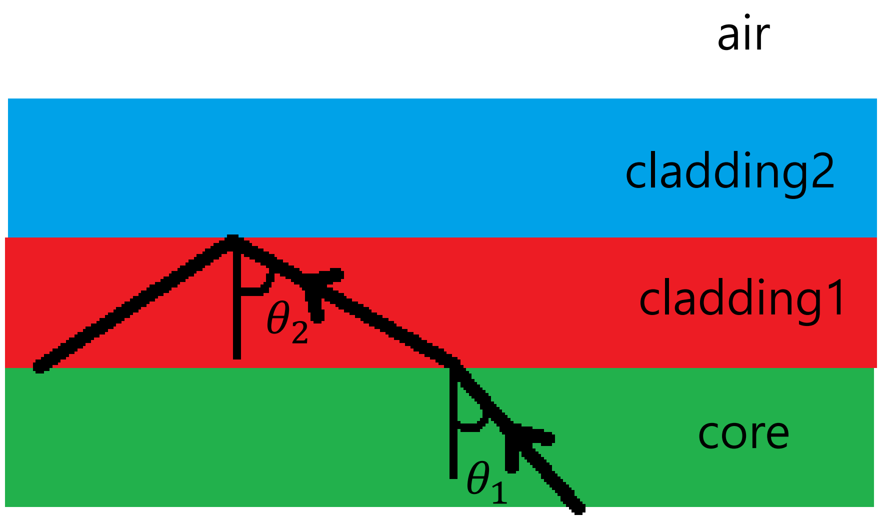
	Core -> Cladding1	Cladding1 -> Air
Critical angle	$\sin^{-1}(\frac{1.49}{1.59}) \approx 69.57°$	$\sin^{-1}(\frac{1}{1.49}) \approx 42.16°$

Refractive index and critical angle

- However, θ_2 is related with θ_1.
- By Snell's law,

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

- And when θ_2 is equal to 72.37 degree, θ_1 is equal to 63.26 degree.



Probability for total reflection

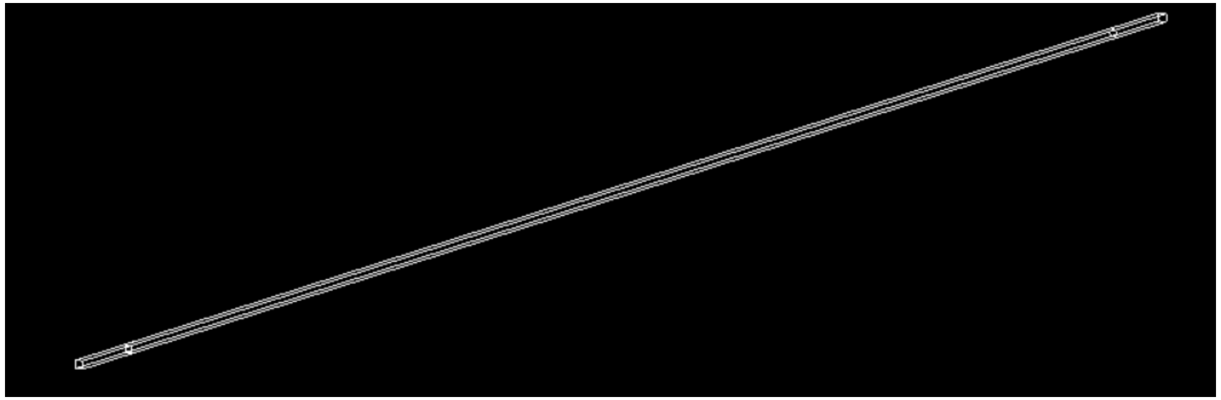
- Probability for total reflection is

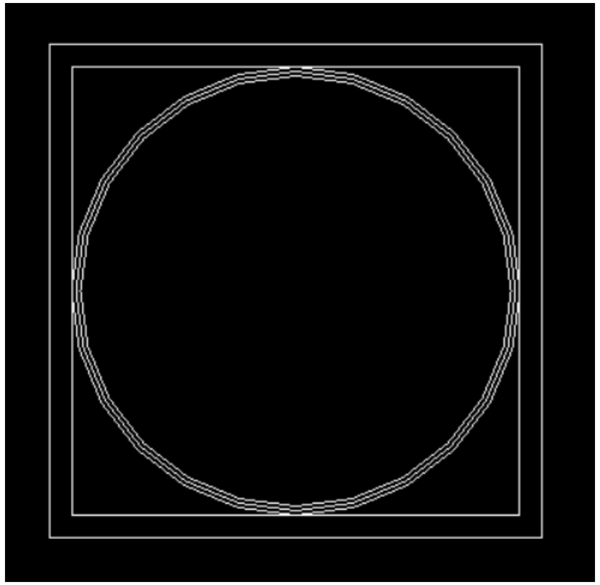
$$P = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi-\theta_0} \sin\theta d\theta d\phi$$

- Therefore, for single cladding, P = 0.03145 and for double cladding, P = 0.05347.

Simulation Condition

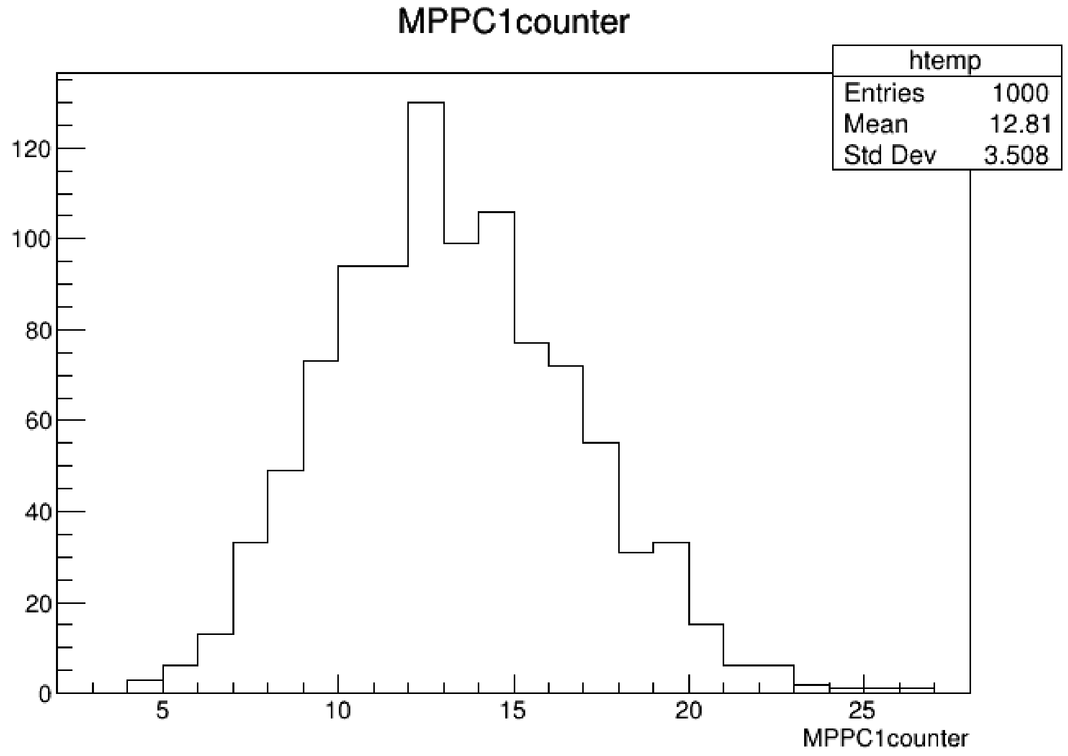
- To simulate probability, we use materials below.
- Material for world is air.
- Material for core is polystylene with dyne, which causes the WLS process.
- 1st cladding is polymethylmethancylate(PMMA) and 2nd cladding is flourinated polymer(FP).
- The wavelength of optical photon was used at 430nm, the highest absorption rate.
- Optical photon were shot in the axial direction of the fiber.
- The length of fiber is 10cm.



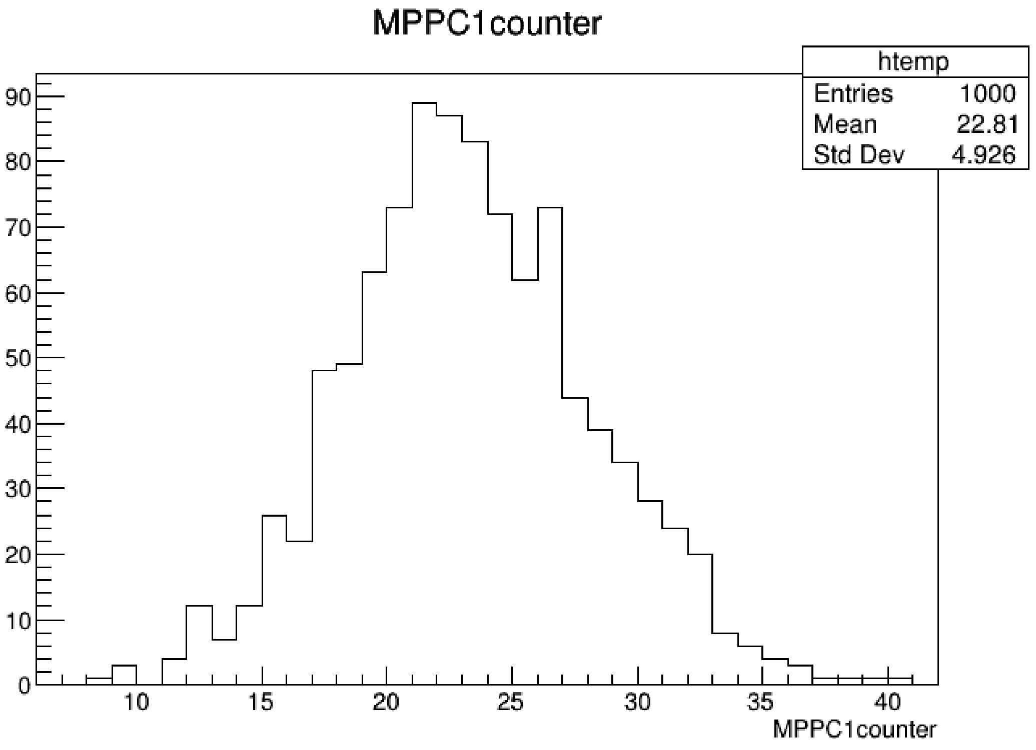


Results

Single cladding



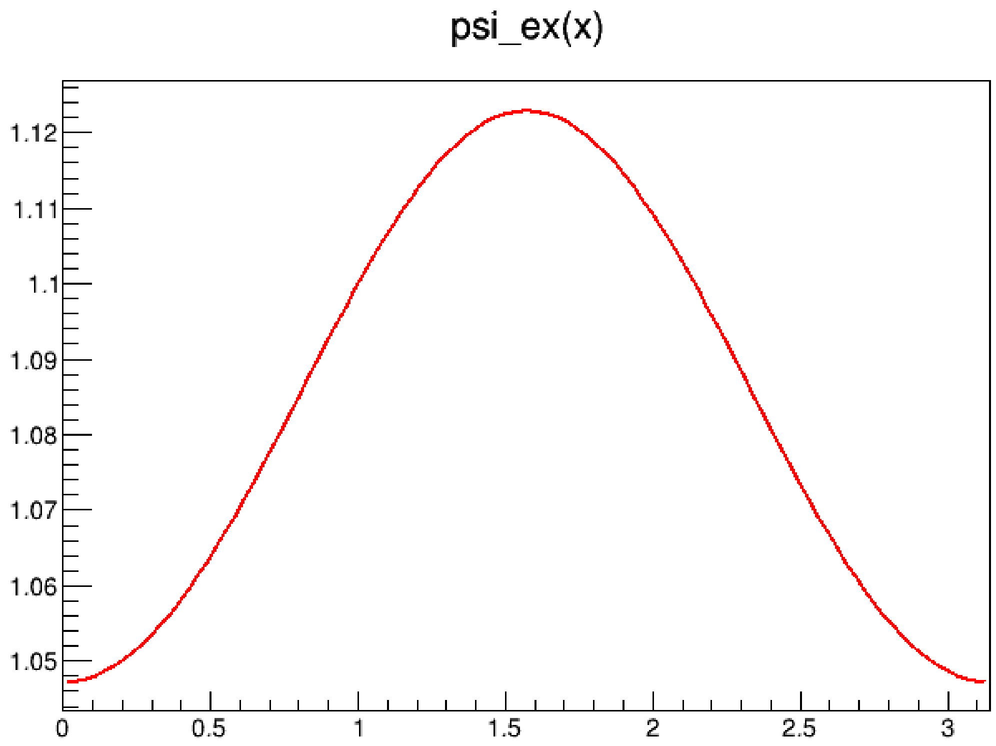
Double cladding



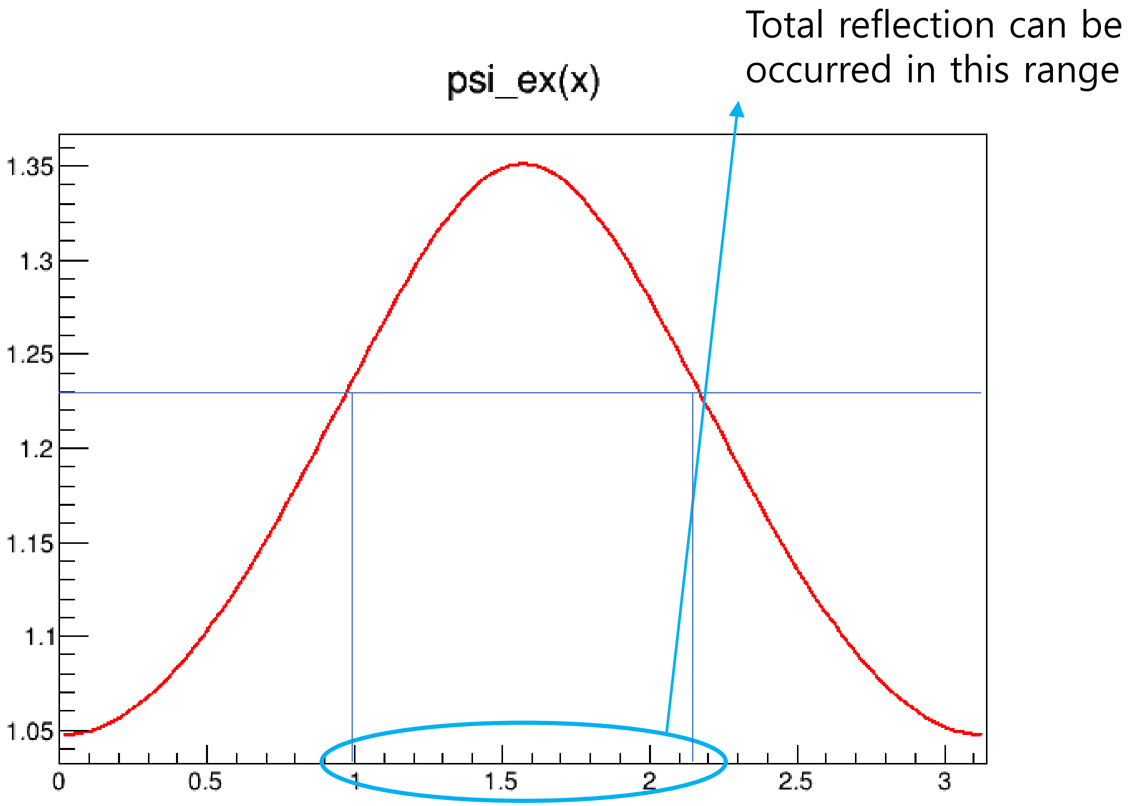
Formula for incident angle

$$\psi = \cos^{-1}\left[\sin\theta \times \frac{\left(1 - \frac{a}{R} sin^2\phi\right) - a\cos\phi\sqrt{1 - \left(\frac{a}{r}\right)^2 \sin^2\phi}}{-\frac{a}{R} cos\phi + \sqrt{1 - \left(\frac{a}{R}\right)^2 \sin^2\phi}}\right]$$

Angle with normal vector of cylinder



When a = 0.5R, θ = 30*deg



When a = 0.9R, θ = 30*deg

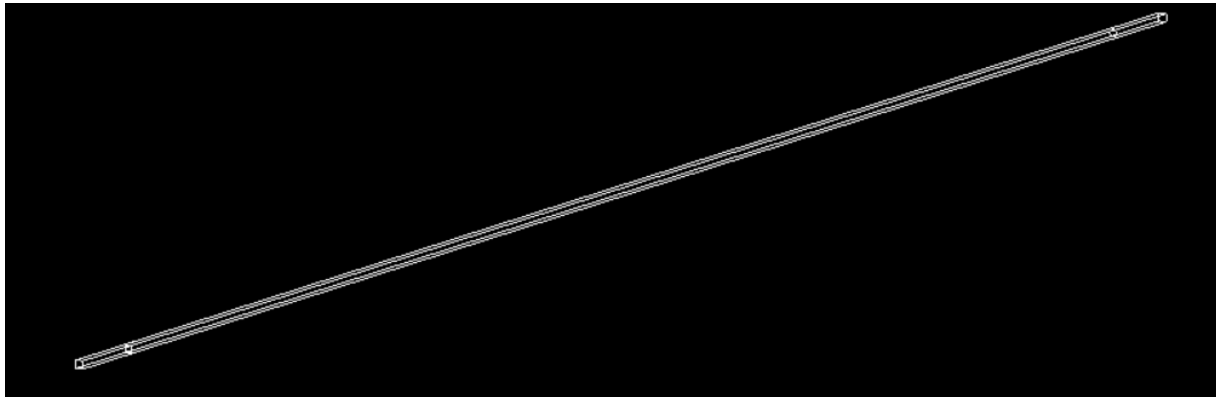
Even if the polar angle is the same, incident angle is changed depending on the position a.
For reference, critical angle is about 1.2217.

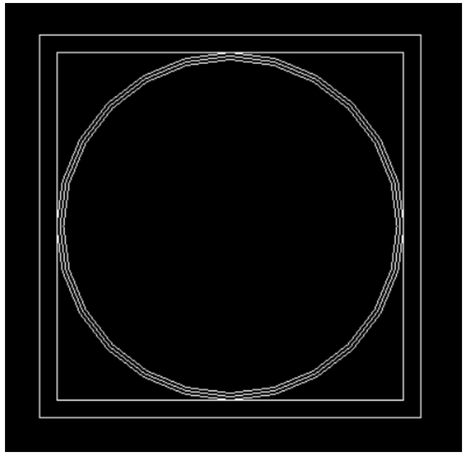
Limitation of trapping efficiency.

- According to previous slide, incident angle can be changed by emission point and solid angle.
- Since the probability that the emitted photon at the center is reflected is the smallest, trapping efficiency is different from the probability of actually seeing the light at the end of the fiber.

Simulation Condition

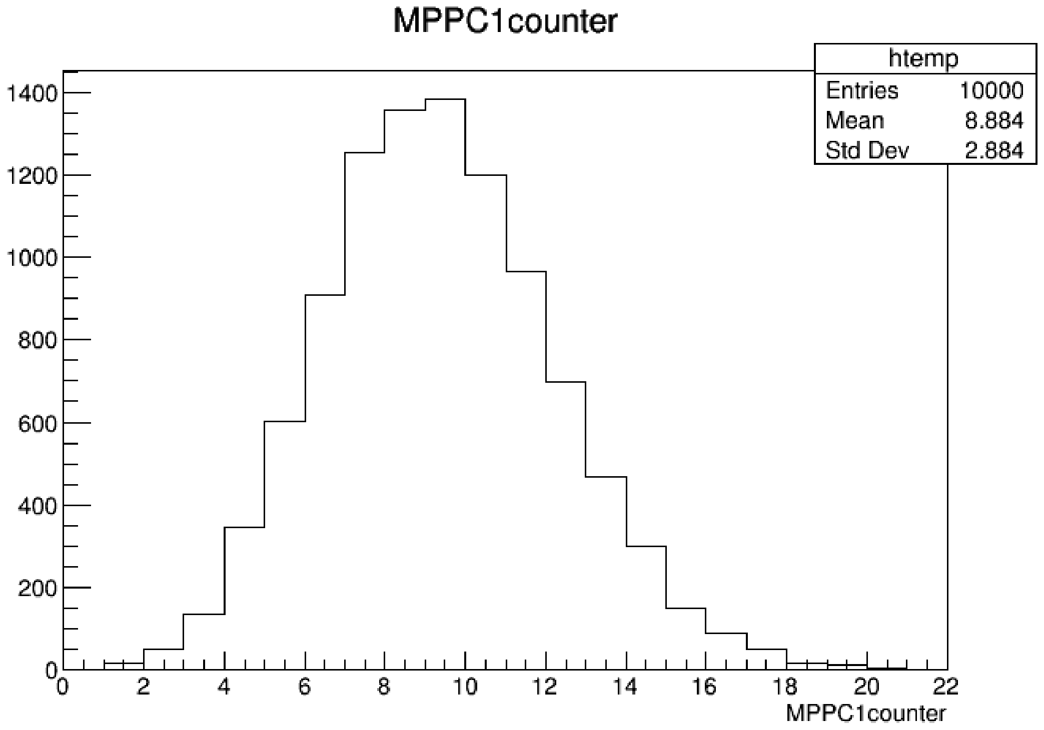
- To simulate probability, we use materials below.
- The wavelength of optical photon was used at 430nm, the highest absorption rate.
- Optical photon were shot in the radial direction of the fiber.





Results for 10cm

Axial incidence



Radial incidence