전북대학교

Beam commissioning of the downstream charged veto detector for the KOTO experiment at J-PARC.

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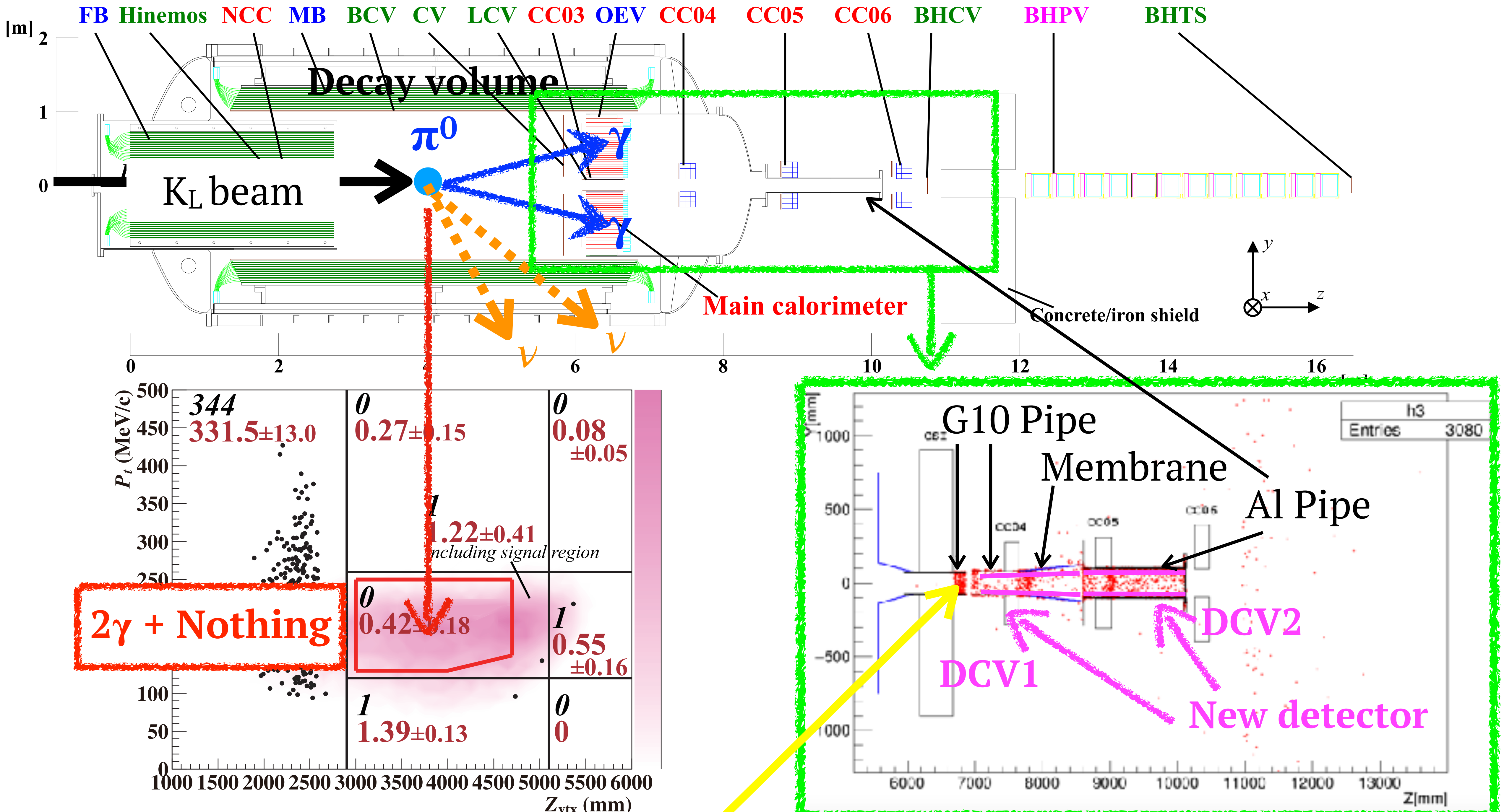
for the KOTO collaboration

2019 KPS Spring Meeting

The motivation of new detector(DCV)

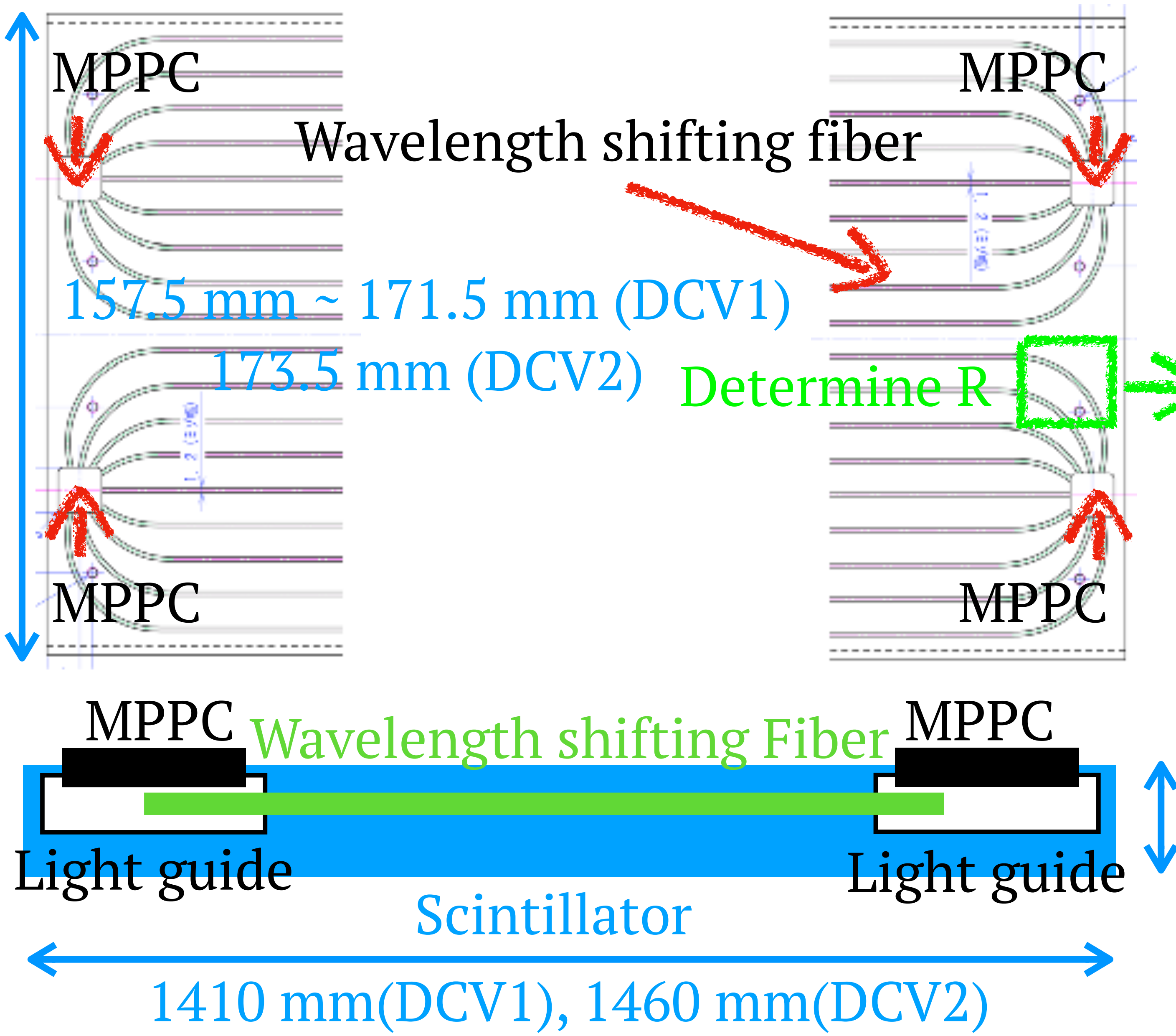


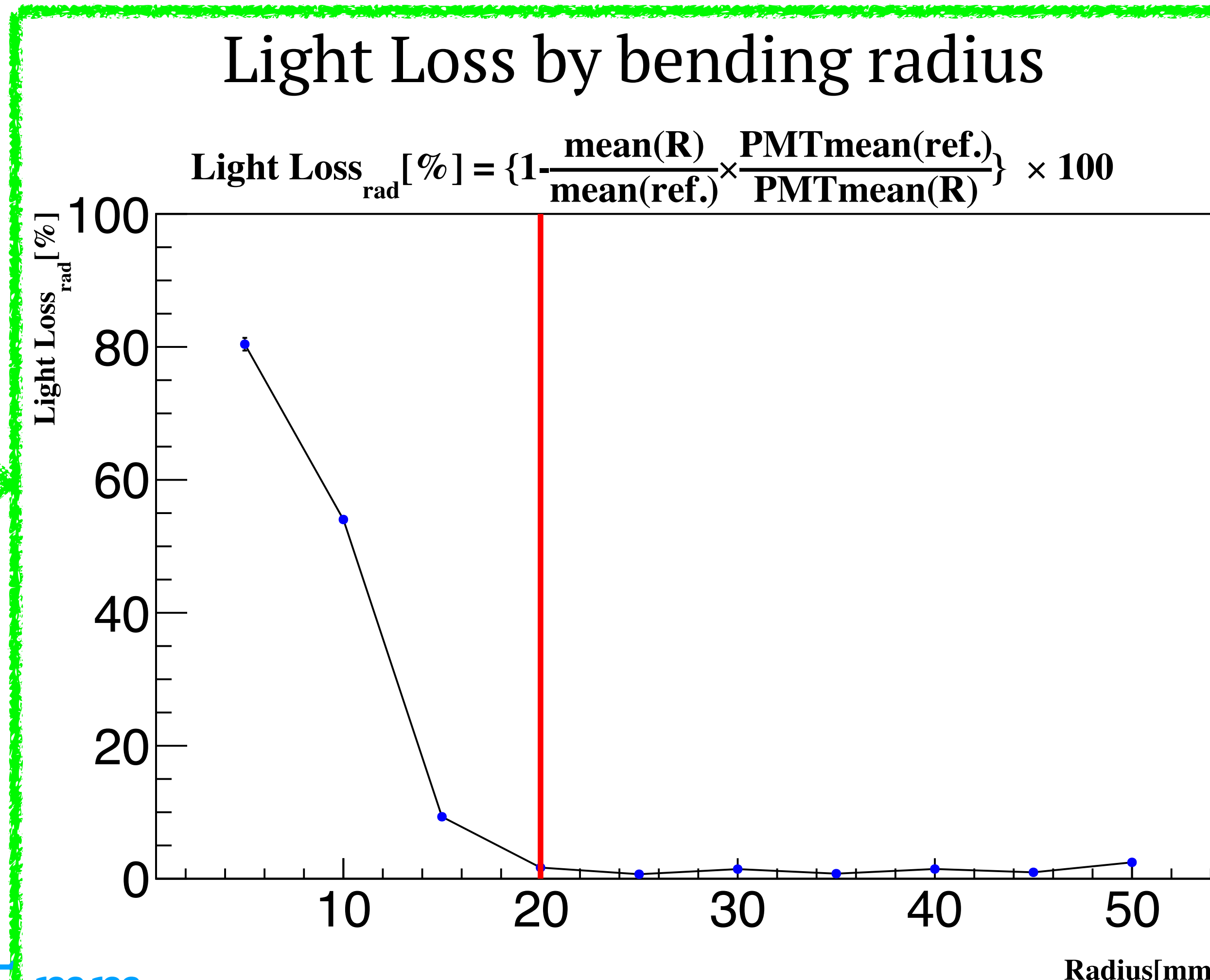
Background Estimation

source		Number of events
K_L decay	$K_L \to \pi^+\pi^-\pi^0$	0.05 ± 0.02
	$K_L \to 2\pi^0$	0.02 ± 0.02
	other K_L decays	0.03 ± 0.01
neutron-induced	hadron-cluster	0.24 ± 0.17
	upstream-π^0	0.04 ± 0.03
	CV-η	0.04 ± 0.02
total		0.42 ± 0.18

- We needed new detector before interacting with dead materials
- Due to very limited space, we are trying a new scheme of light collection.

A scheme of DCV

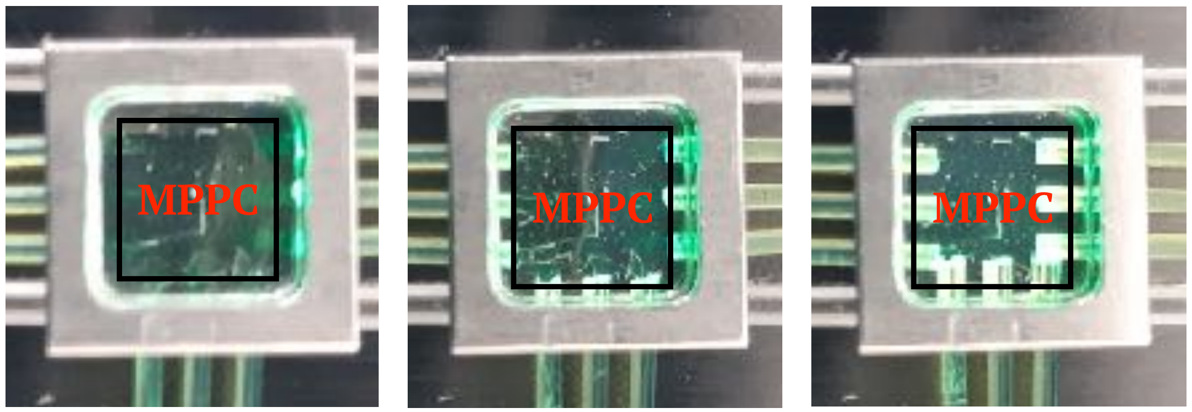




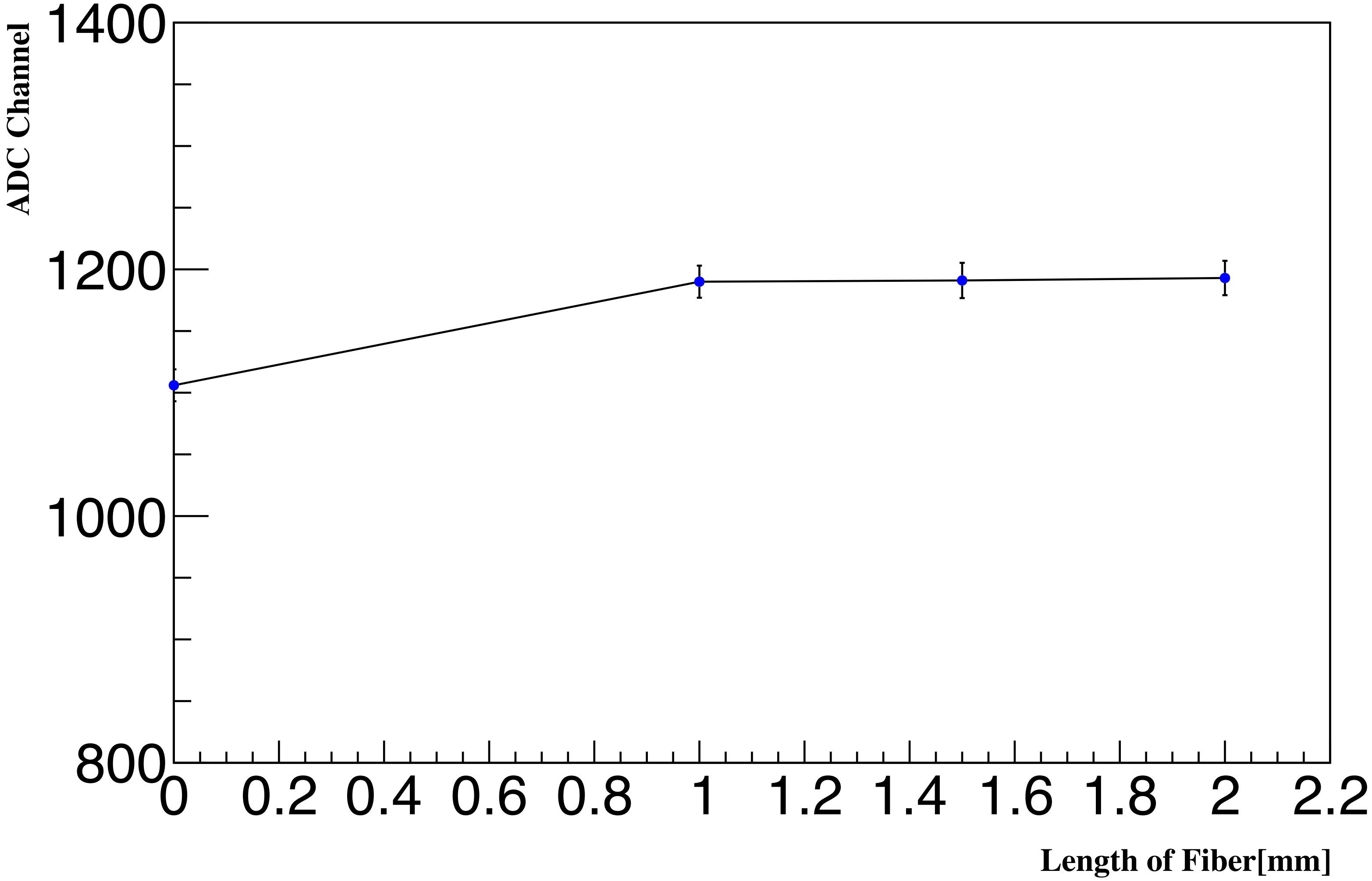
- We could bend the fiber to a minimum radius of 20 mm.

- Two pipes, total 8 sheets of scintillators.
- MPPCs are attached to the surface of the scintillator.
- The fiber goes side by side into the light guide.

Fiber Length



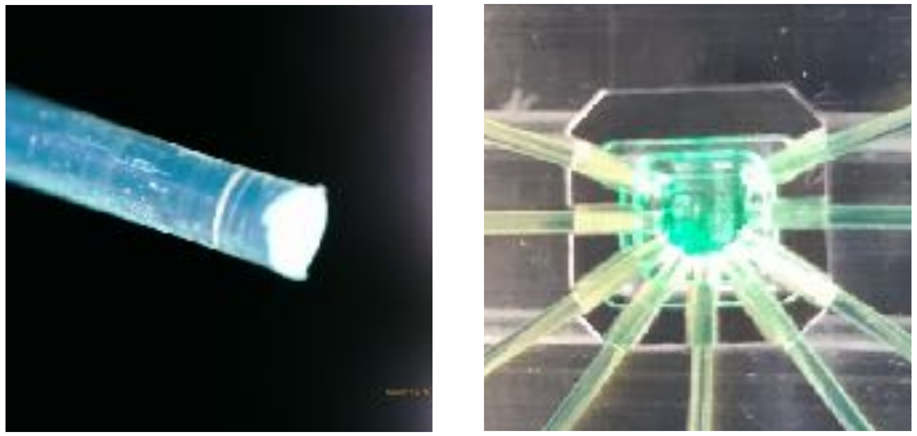
Fiber	Kuraray, Y-11, 1mm, Non S-Type
Wave length of LED	430 nm
MPPC	HAMAMATSU S13360-6050PE



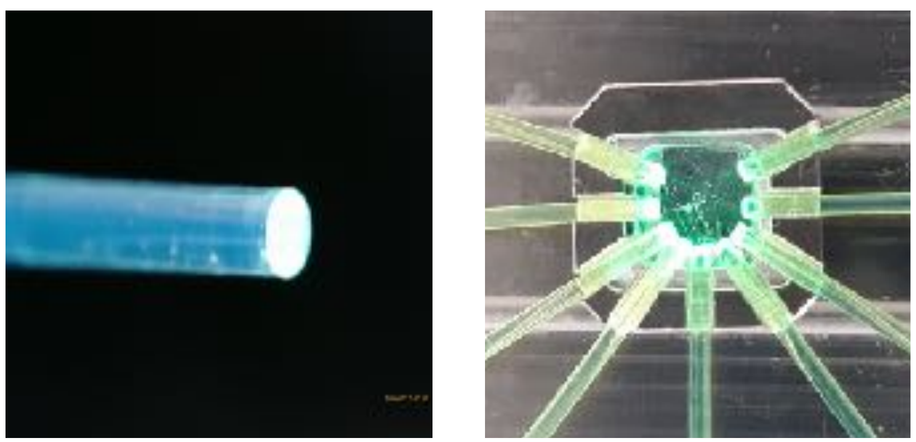
- If the length of fiber is over 2 mm in the light guide, there was the interference between fibers.
- 1 mm is adequate.

Fiber Condition

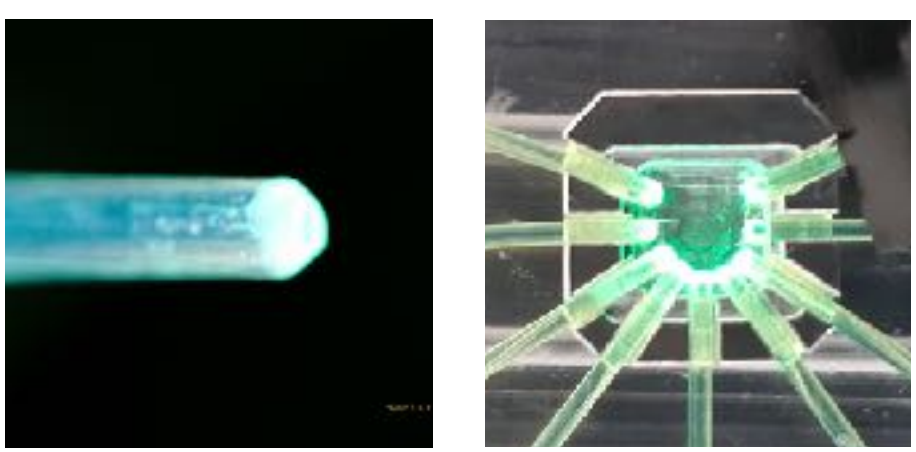
Nipper

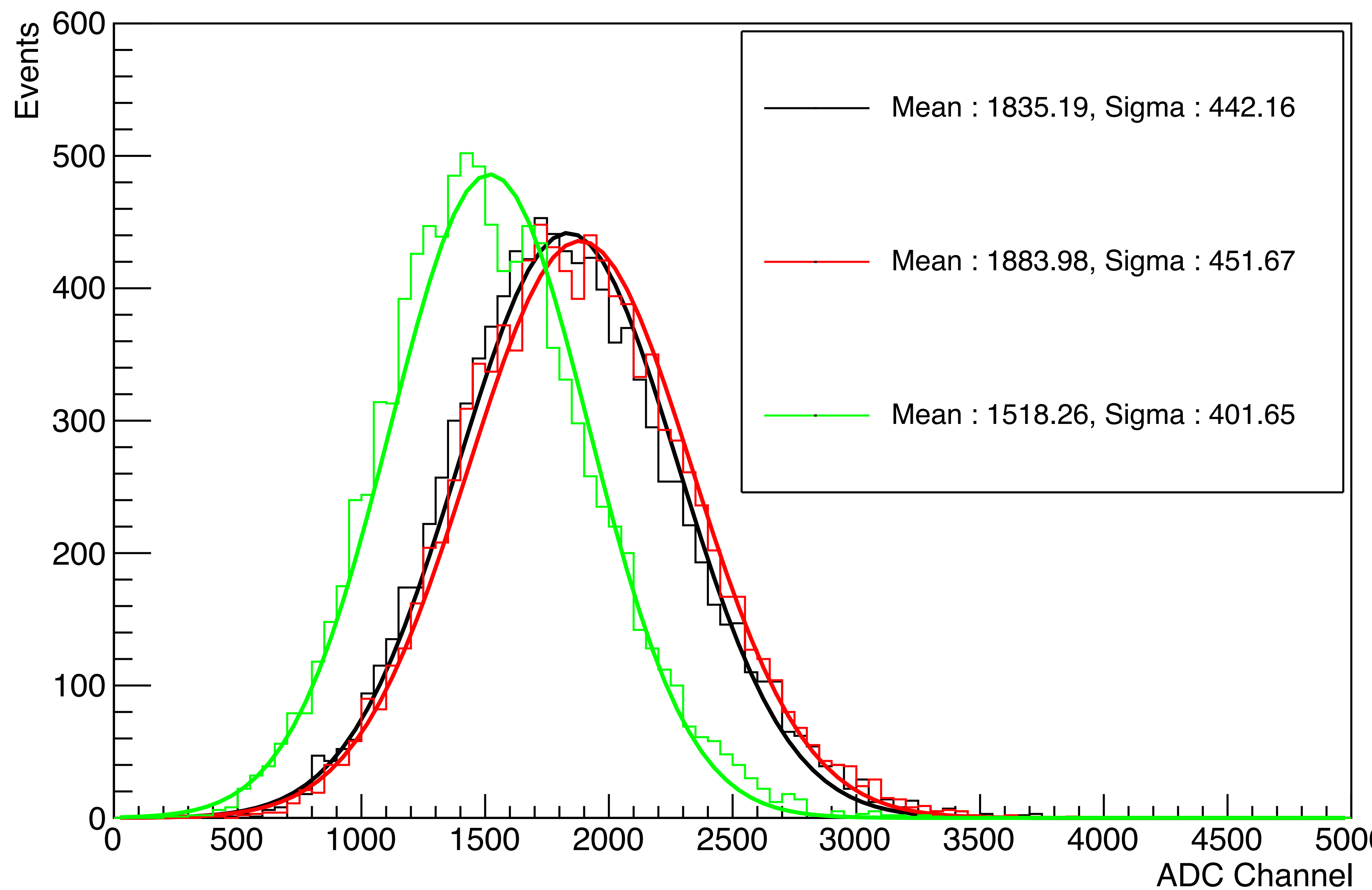


Diamond cut machine



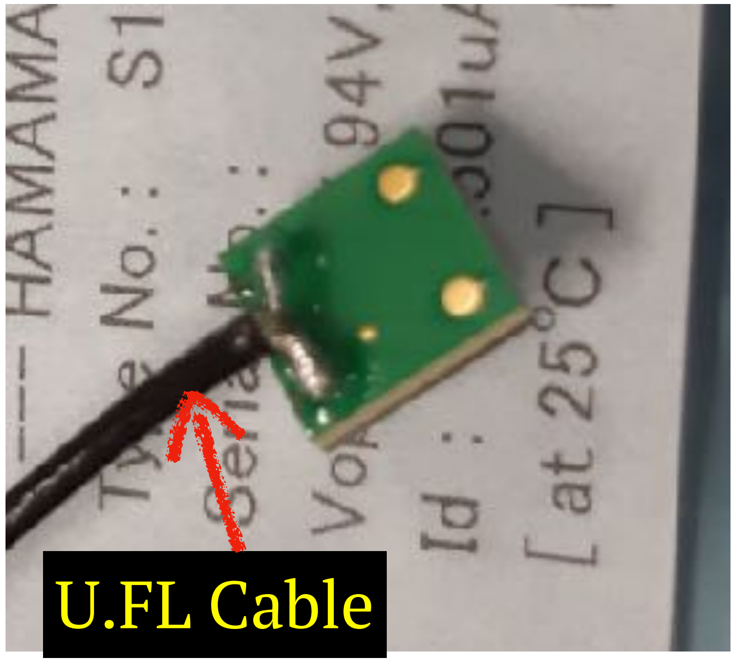
Polished the edge
(10 cycles by #1200)
after diamond cutting



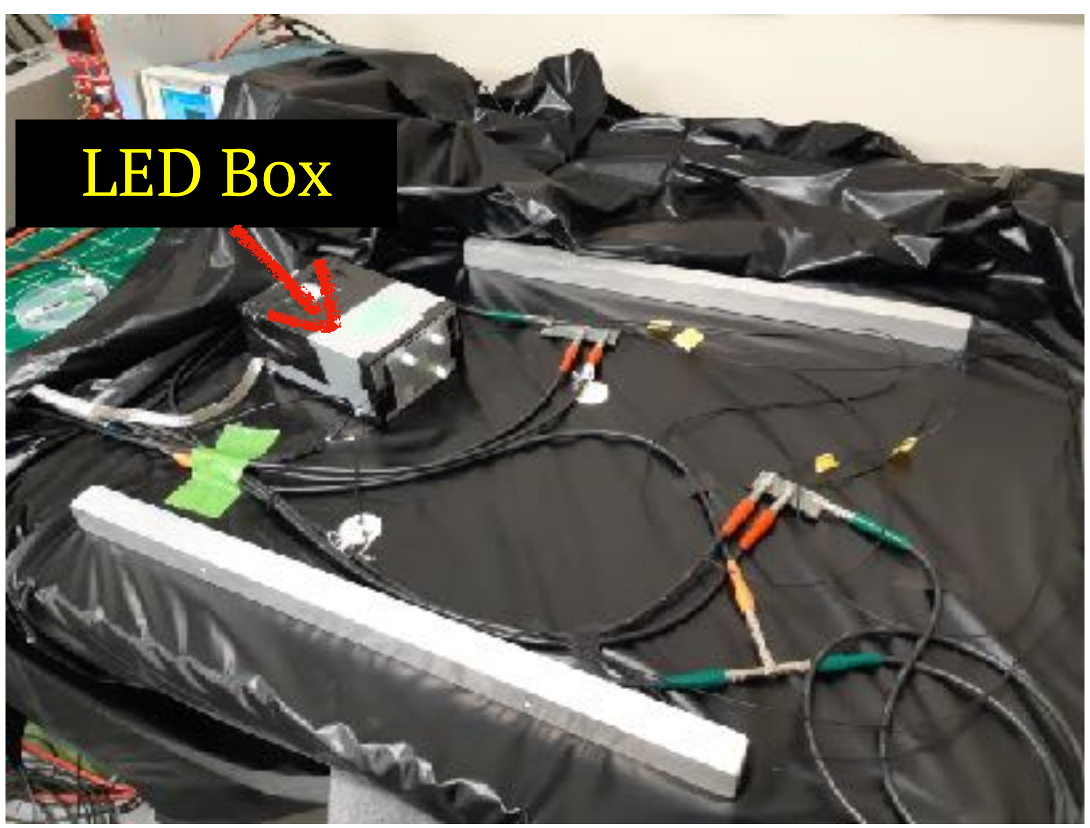


- For consistency and sufficient light yield, It is recommended to choose a diamond cut method.

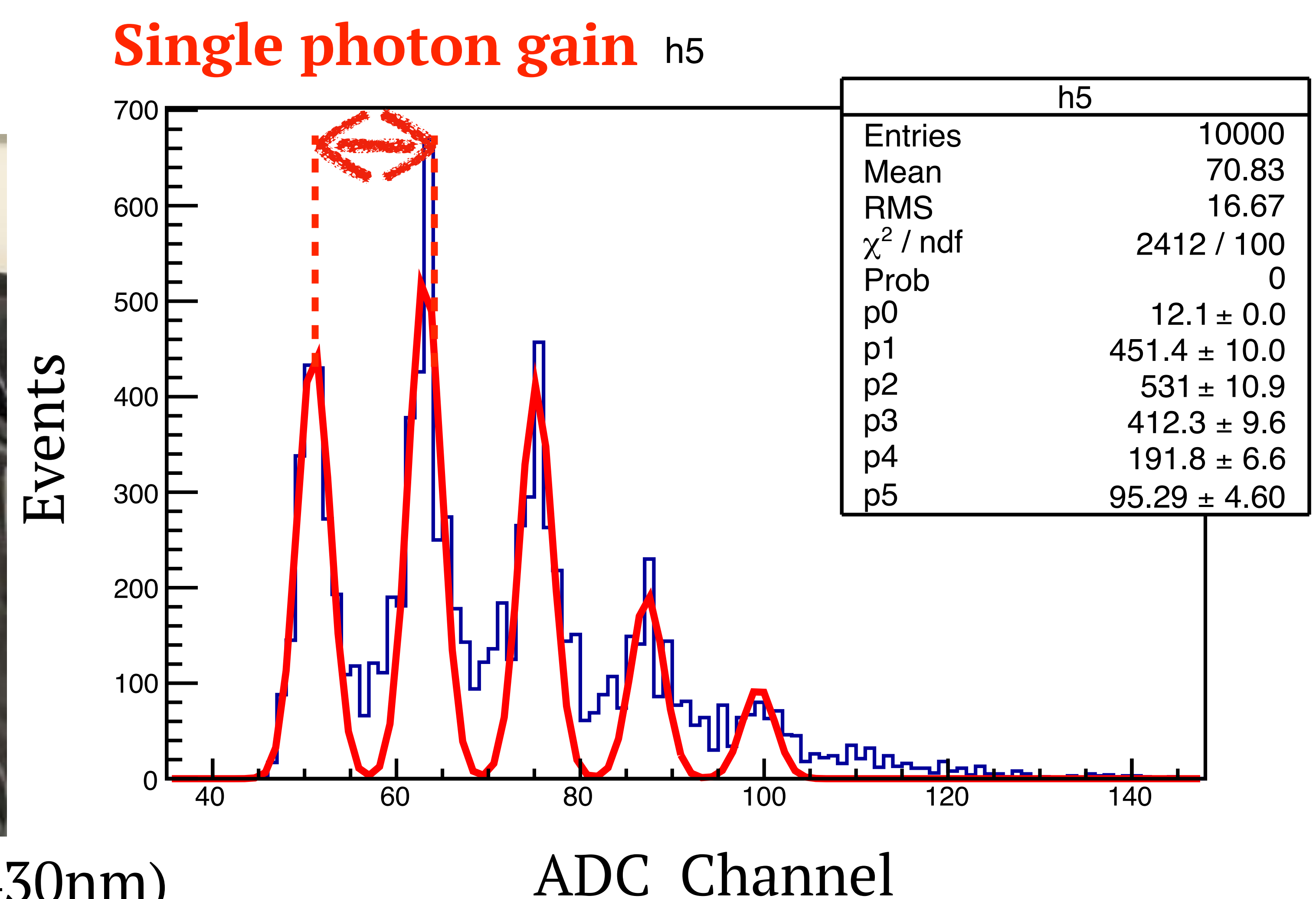
Measurement of the single photon gain



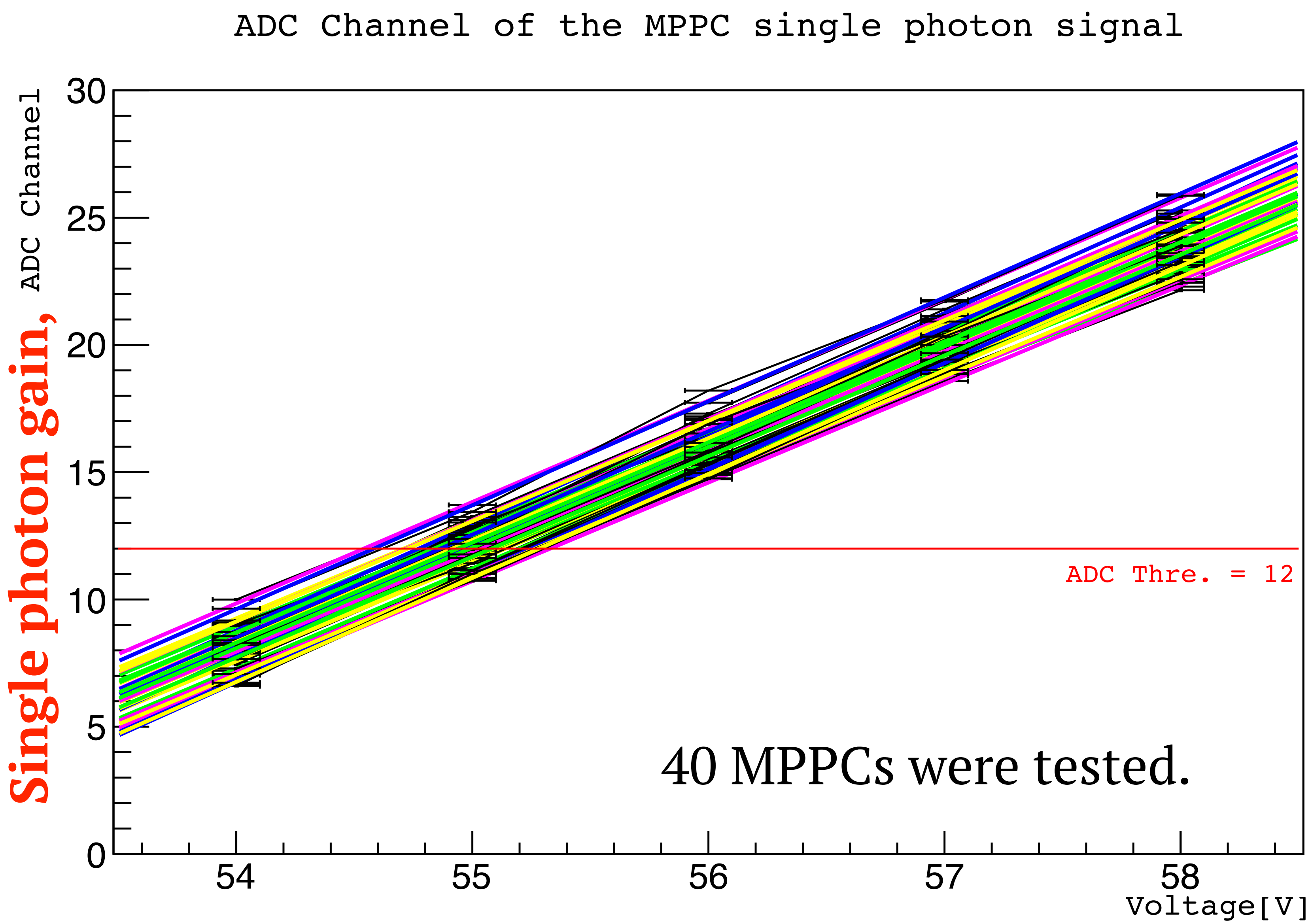
Type No.	HAMAMATSU S13360-6050PE
Effective photosensitive area	6.0 mm × 6.0 mm
Material size	7.35 mm × 6.85 mm × 1.45 mm
Spectral response range λ	320 nm ~ 900 nm



Single photon measurement by LED(430nm)



Grouping the MPPCs



ADC Channel = 12

S.N.	Voltage		
12686	54.7099	DCV1 (module 0)	54.7 V
12705	54.7202		
12685	54.7262		
12697	54.7742		
12693	54.7843	DCV1 (module 1)	54.8 V
12679	54.8381		
12692	54.8428		
12708	54.8495		

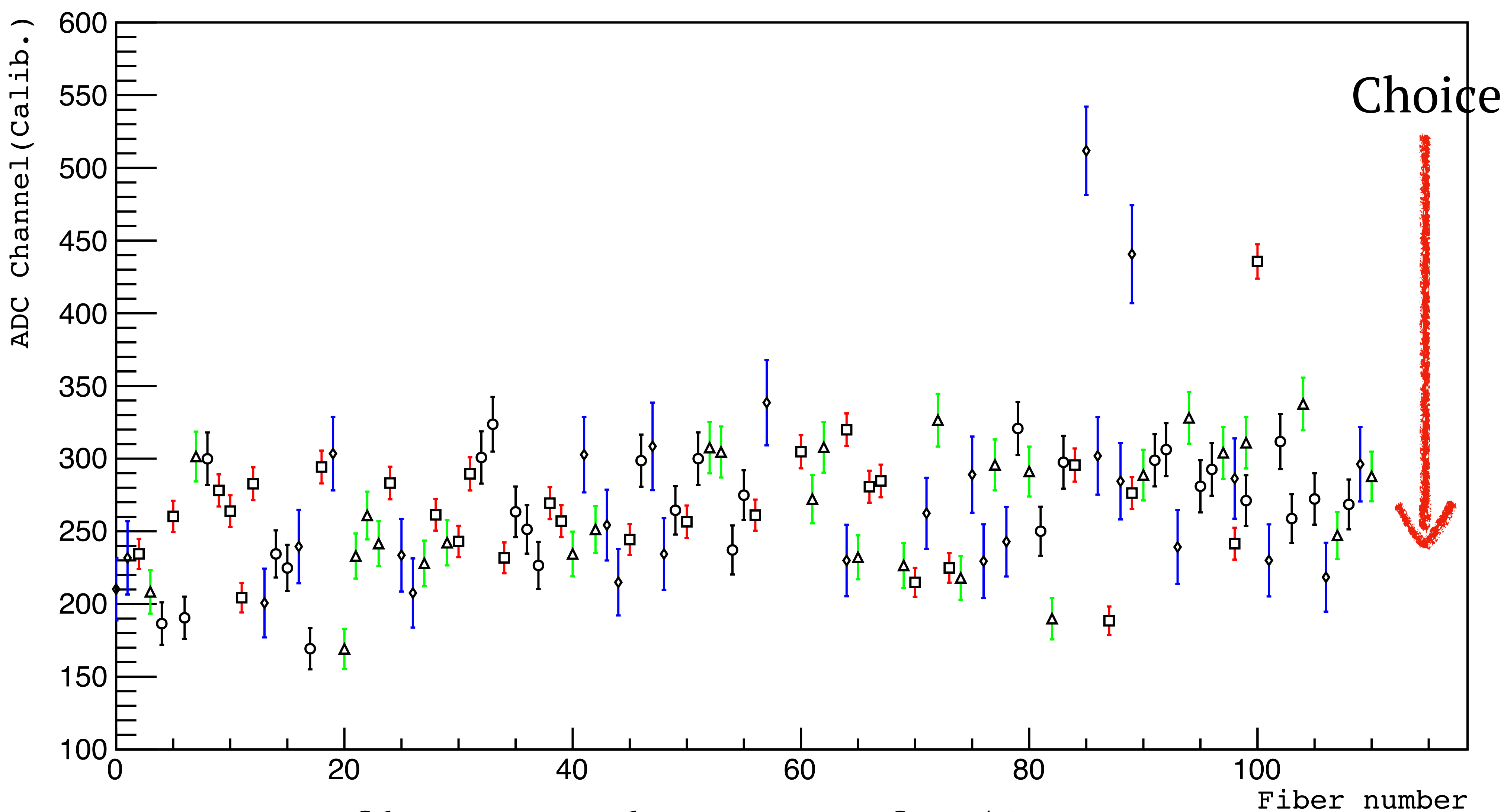
⋮

Fiber test

Test bench

Fiber Type	Kuraray, Y-11, 1mm, S-Type
Fiber Length[mm]	1600

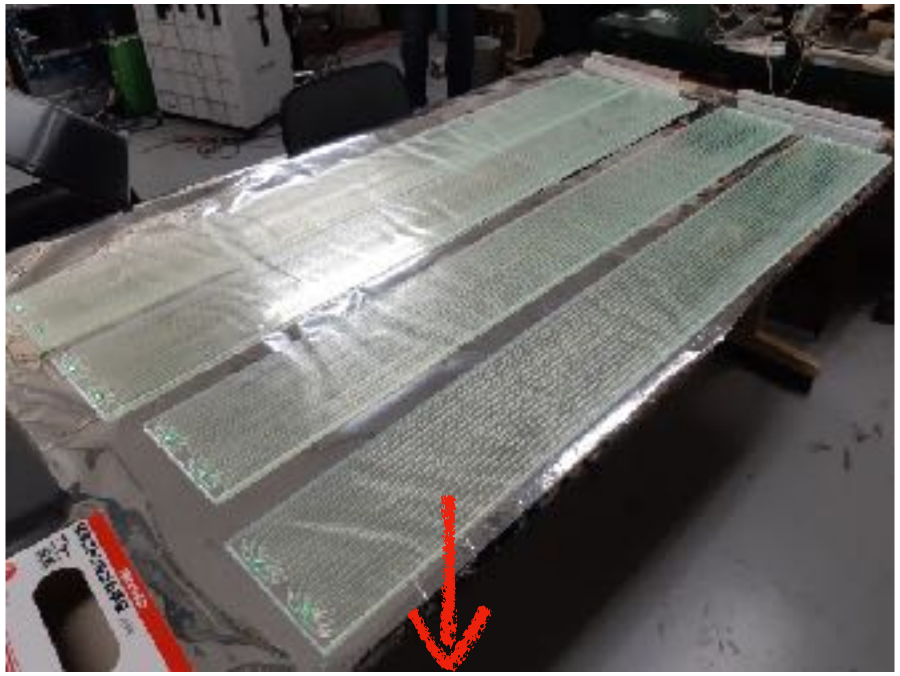
for DCV2



72 fibers were chosen out of 115 in DCV2
(72 fibers were chosen out of 94 in DCV1)

Detector manufacturing process

Fiber gluing

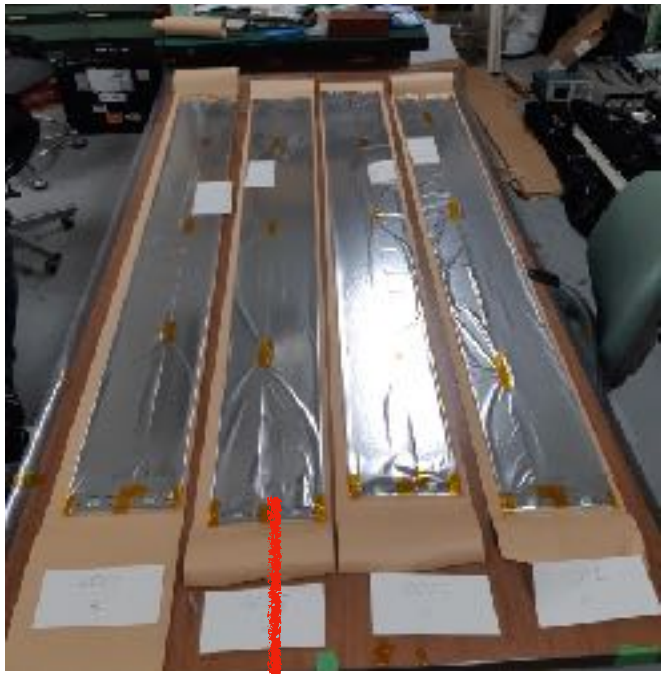


Scintillator : ELJEN EJ-200
Glue : Saint Gobain BC-600

Evacuation
by vacuum chamber

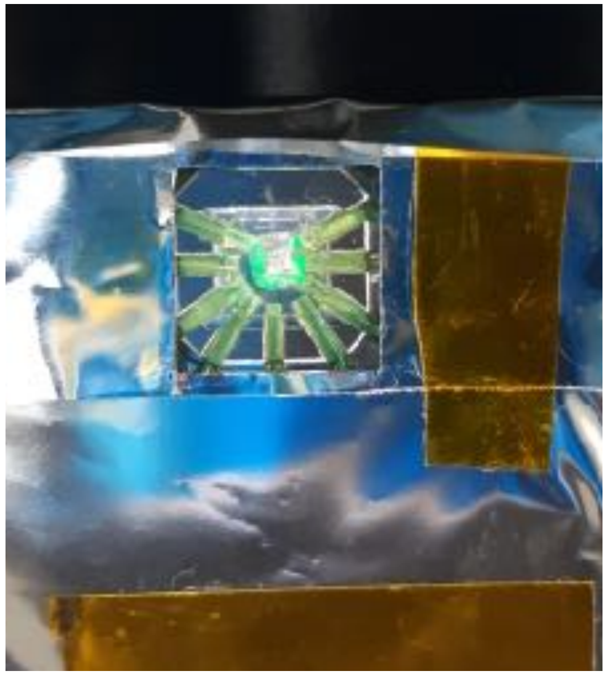
Over the 48 hr
Extracting outgas

Wrapping

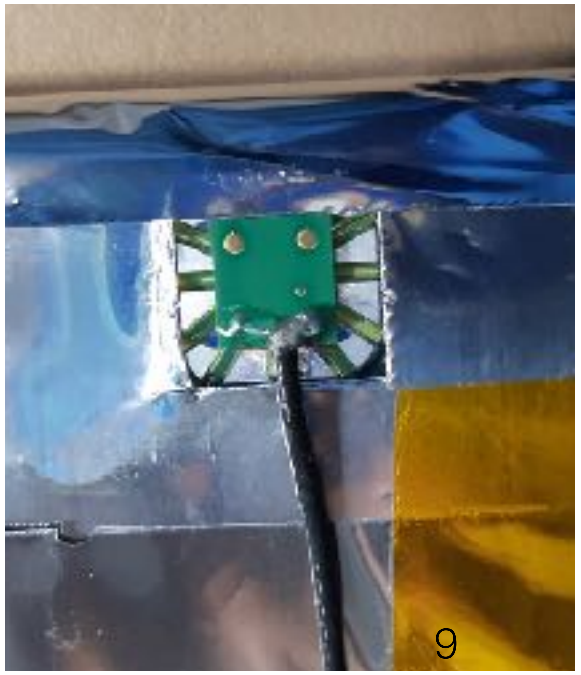


12 μm aluminized film

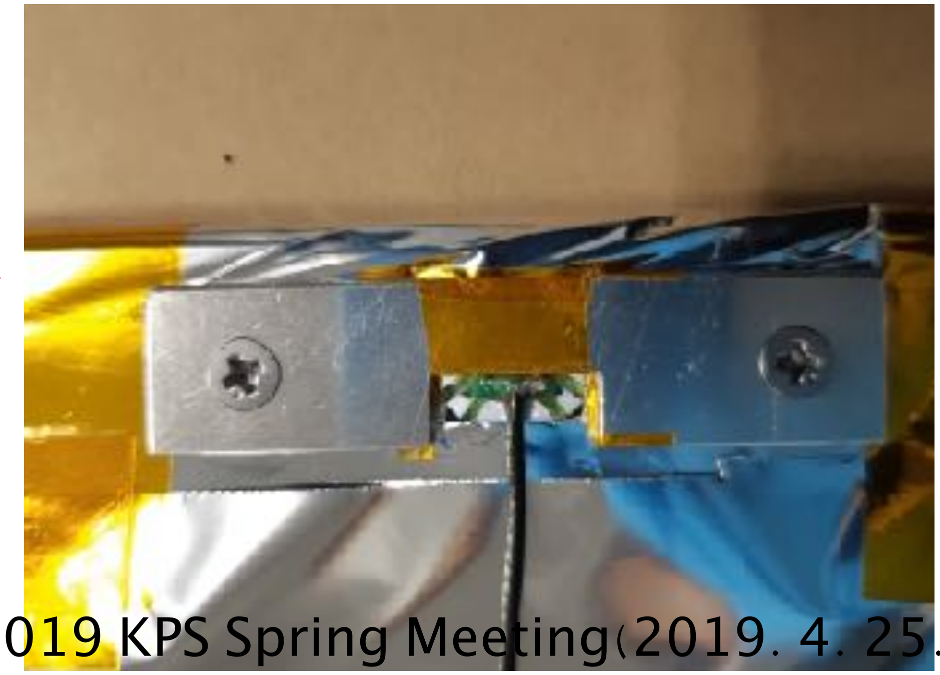
Light guide



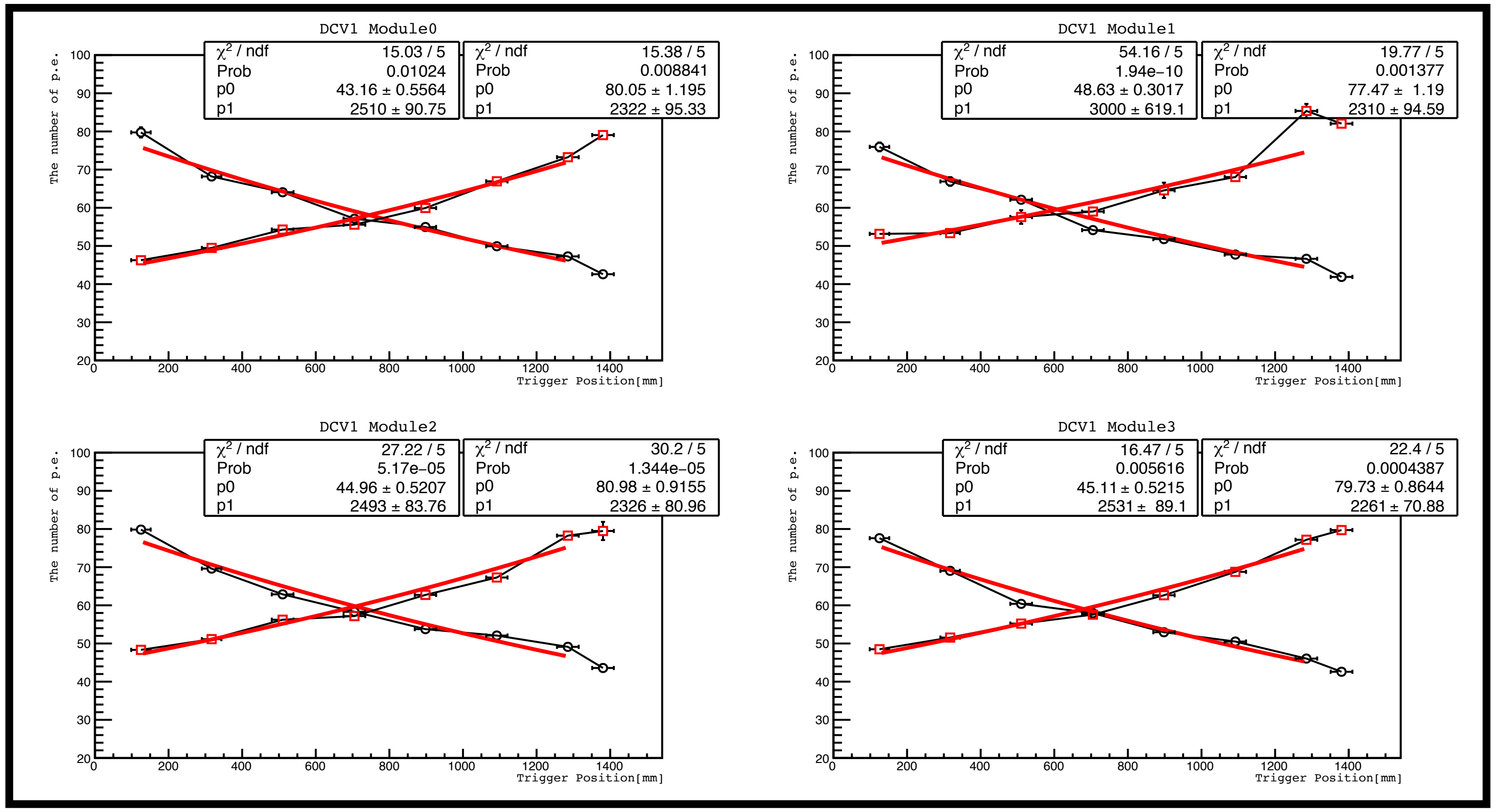
Put the MPPC

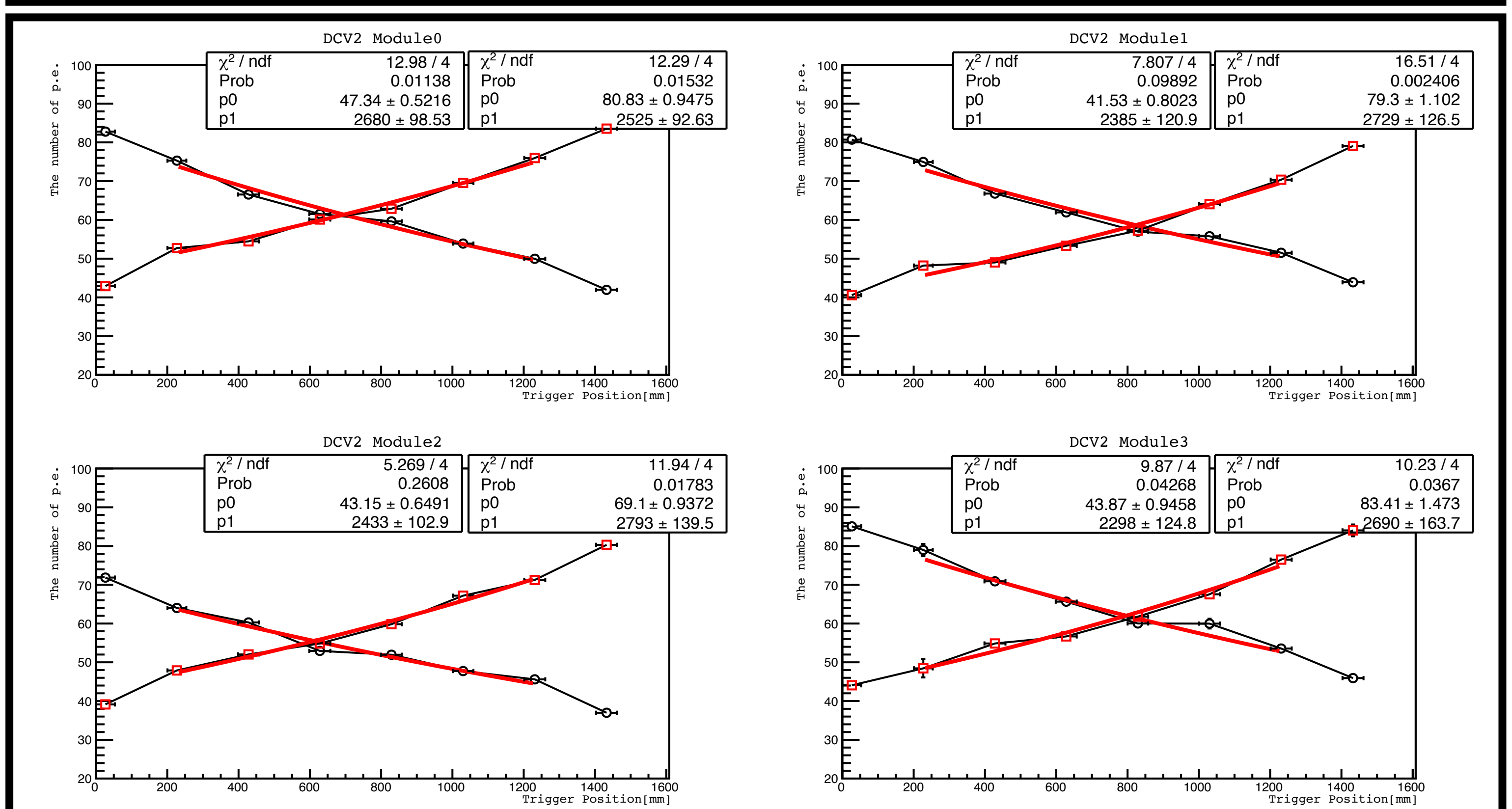


Cover the MPPC



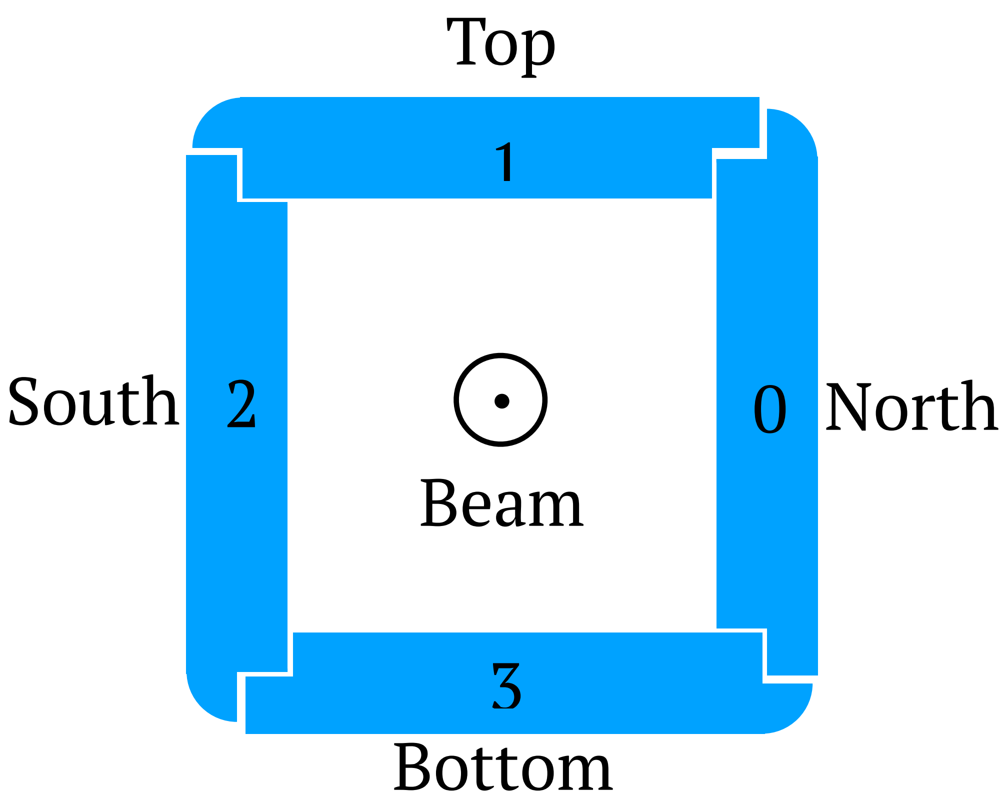
Cosmic ray test



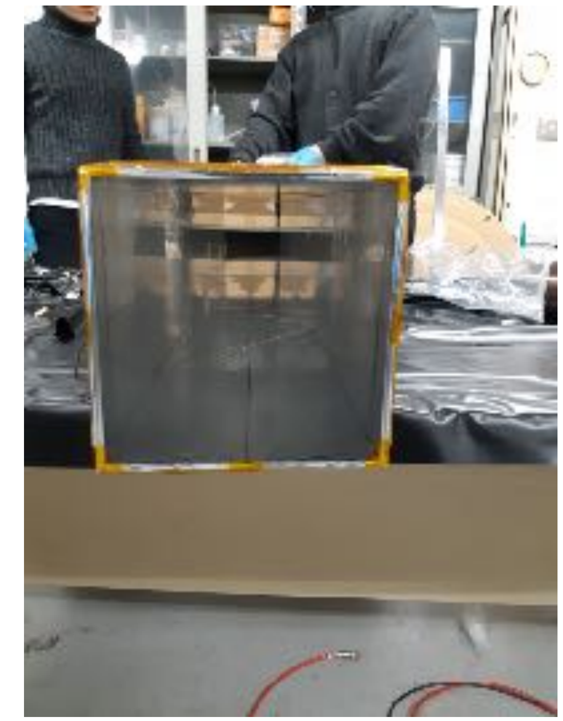


P.E. for 1 MeV	• **DCV1** **Min : 41.88 / Max : 82.05** • **DCV2** **Min : 36.98 / Max : 85.08**
Fitting Function	f(x) = [0] * exp(±x / [1])
Fitting Range	• DCV1 : 128 ~ 1285 (DCV1 Length = 1410 mm) • DCV2 : 227 ~ 1231 (DCV2 Length = 1460 mm)
Average Attenuation Length	• **DCV1 : 2469 mm** • **DCV2 : 2567 mm**

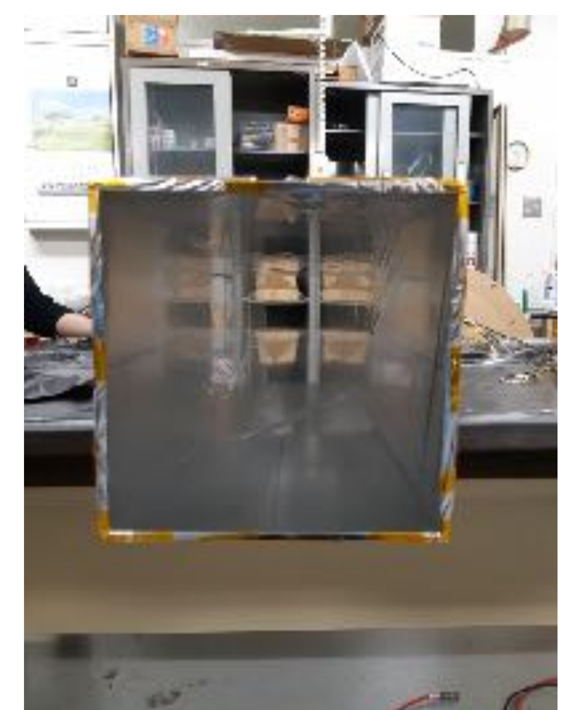
Making the scintillator pipes



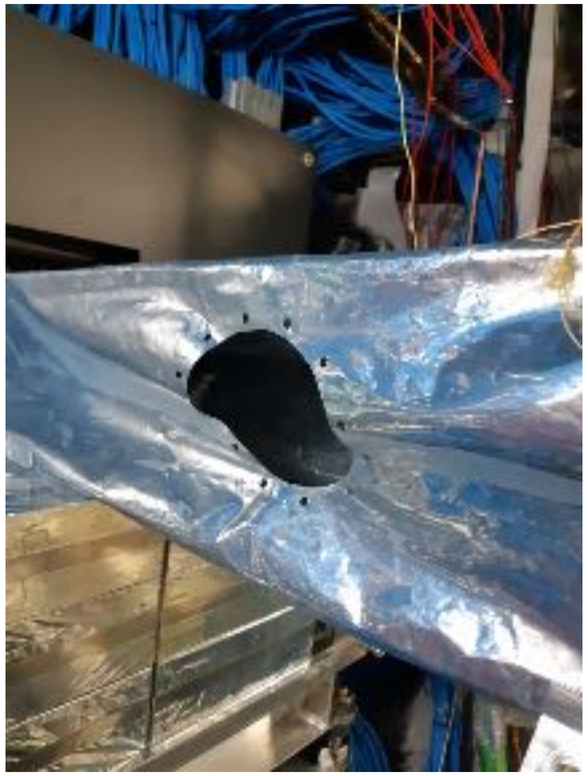
DCV1

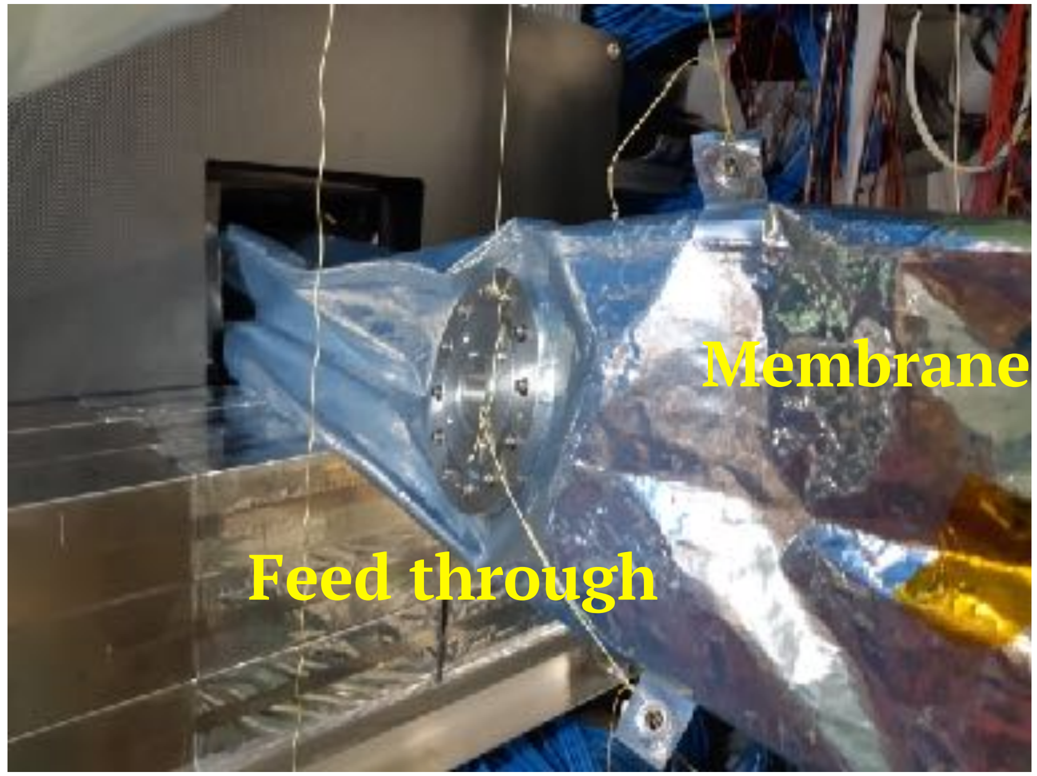



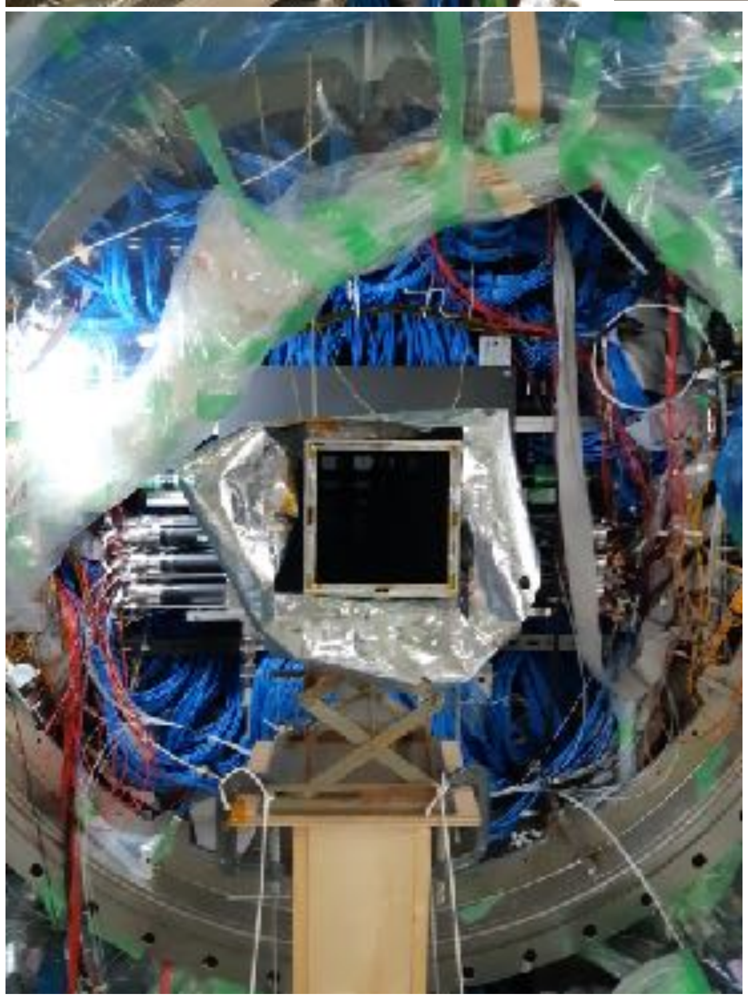
DCV2

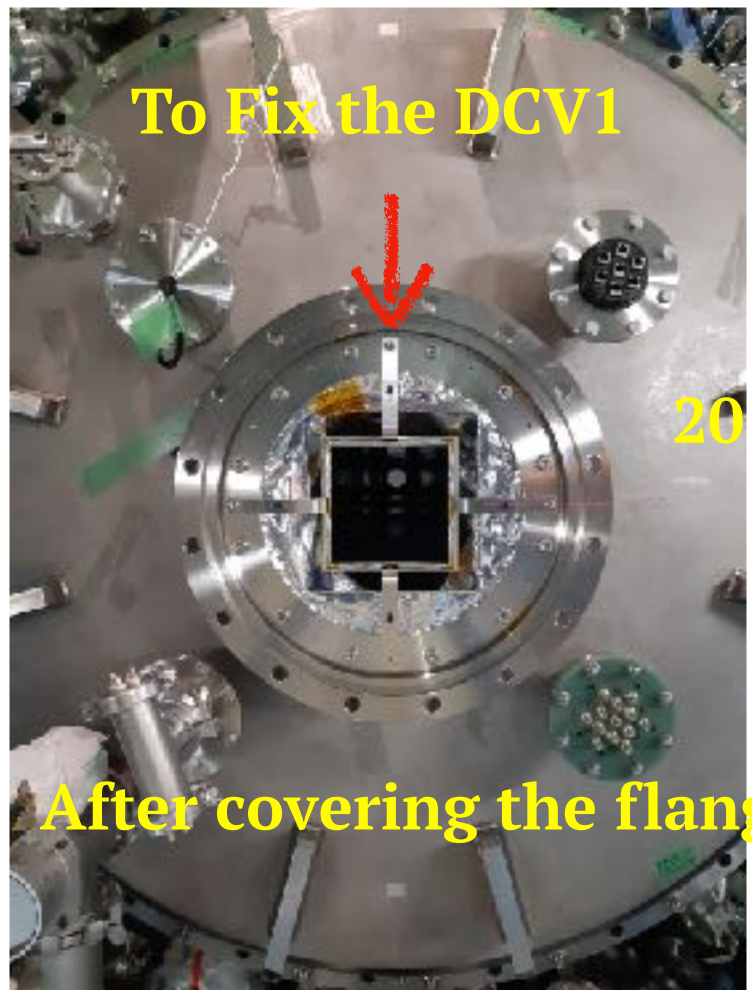



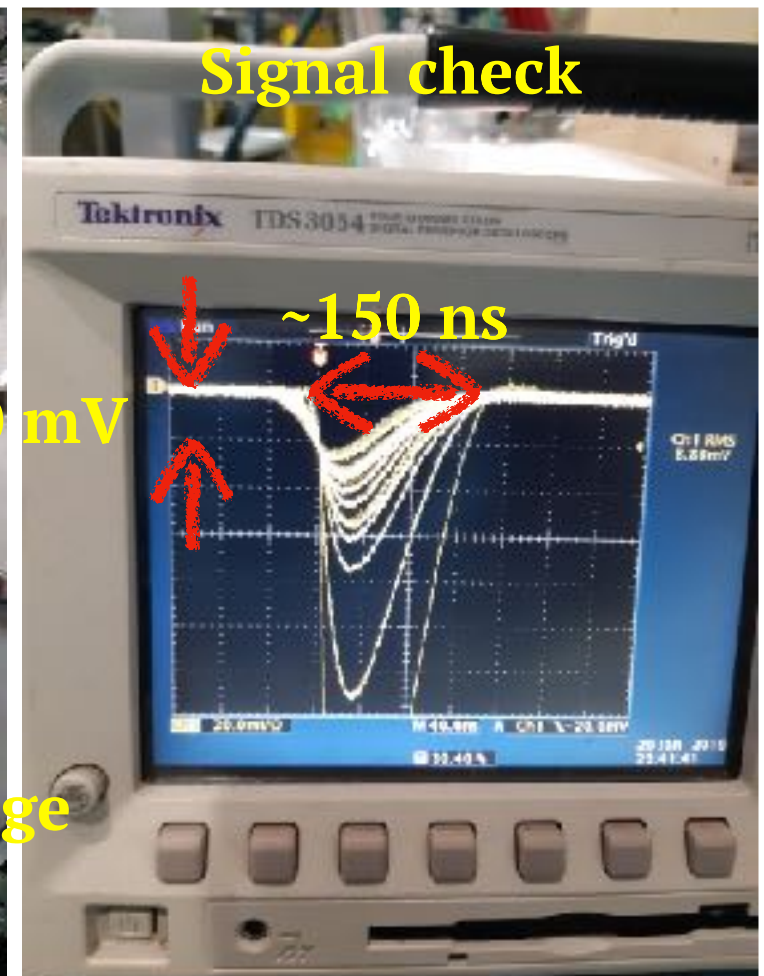
Installation of DCV1



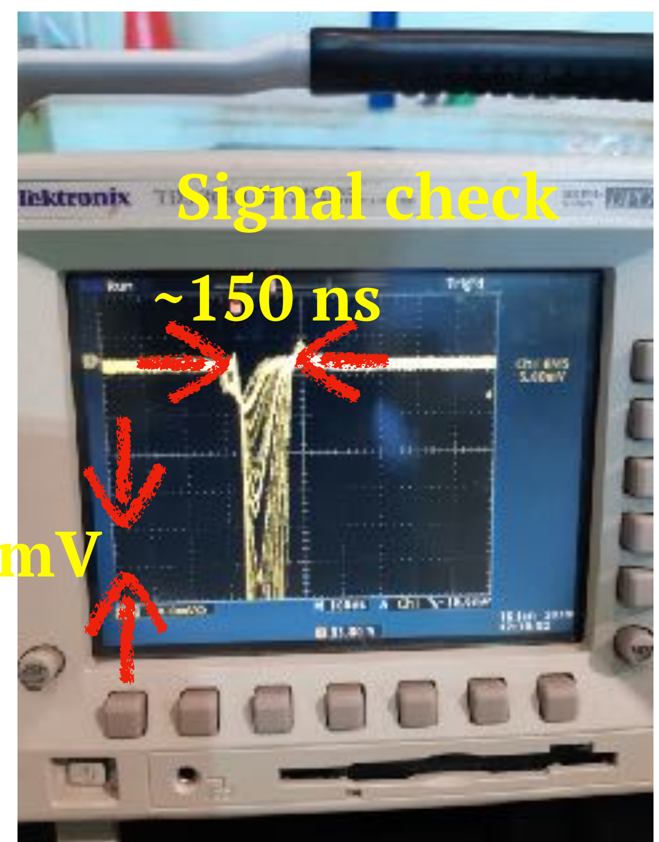




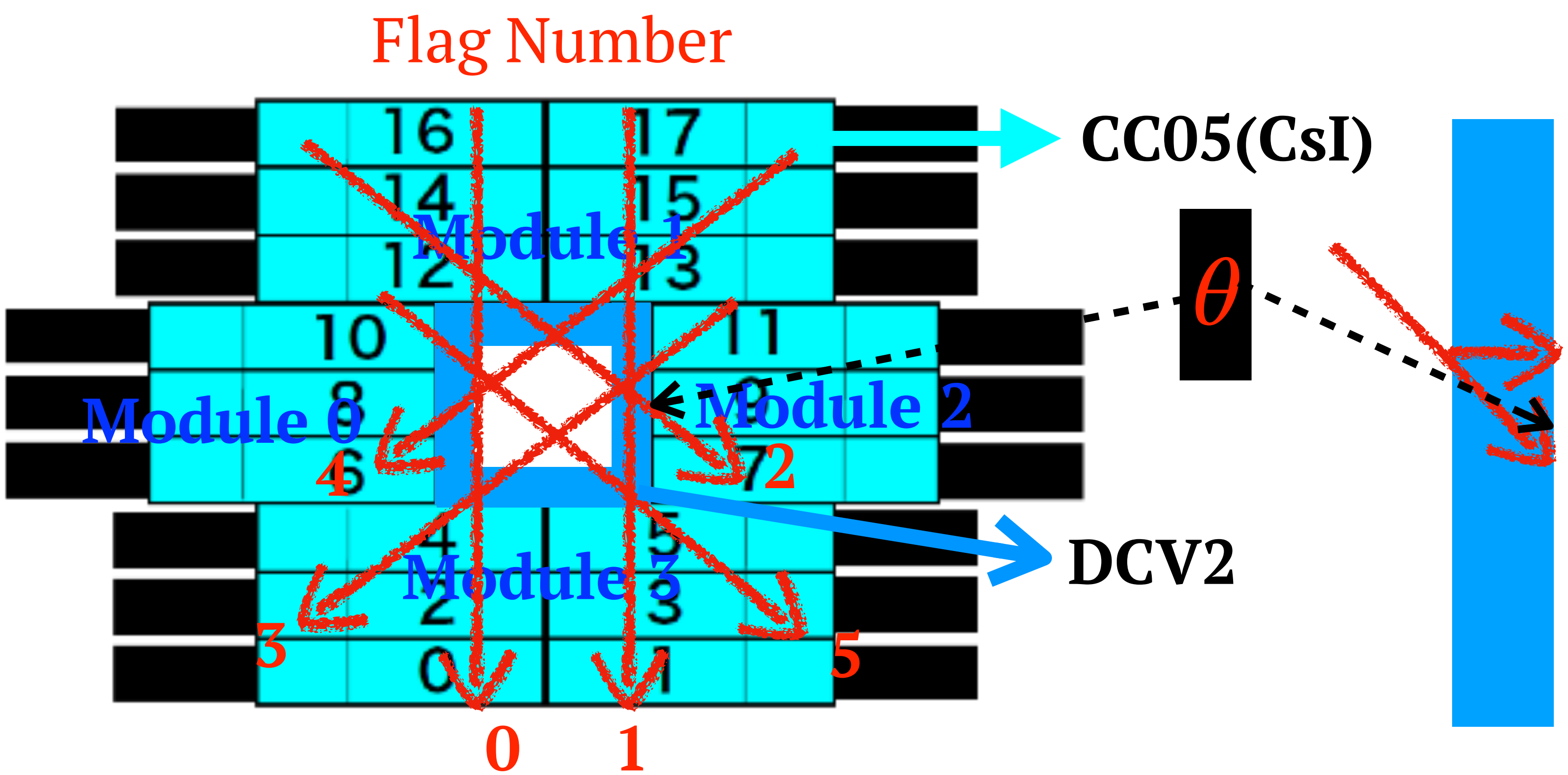




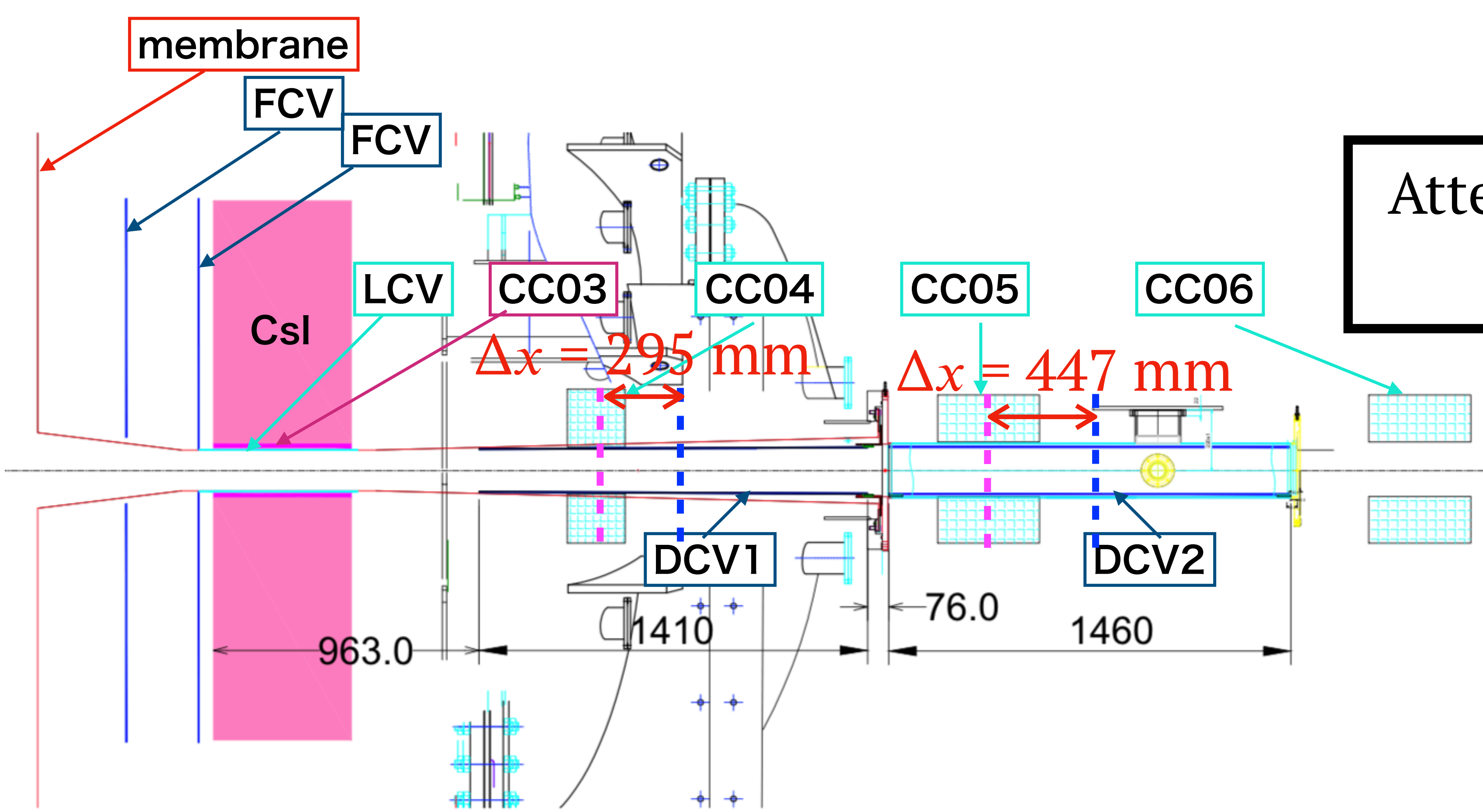
Installation of DCV2



Calibration of DCV

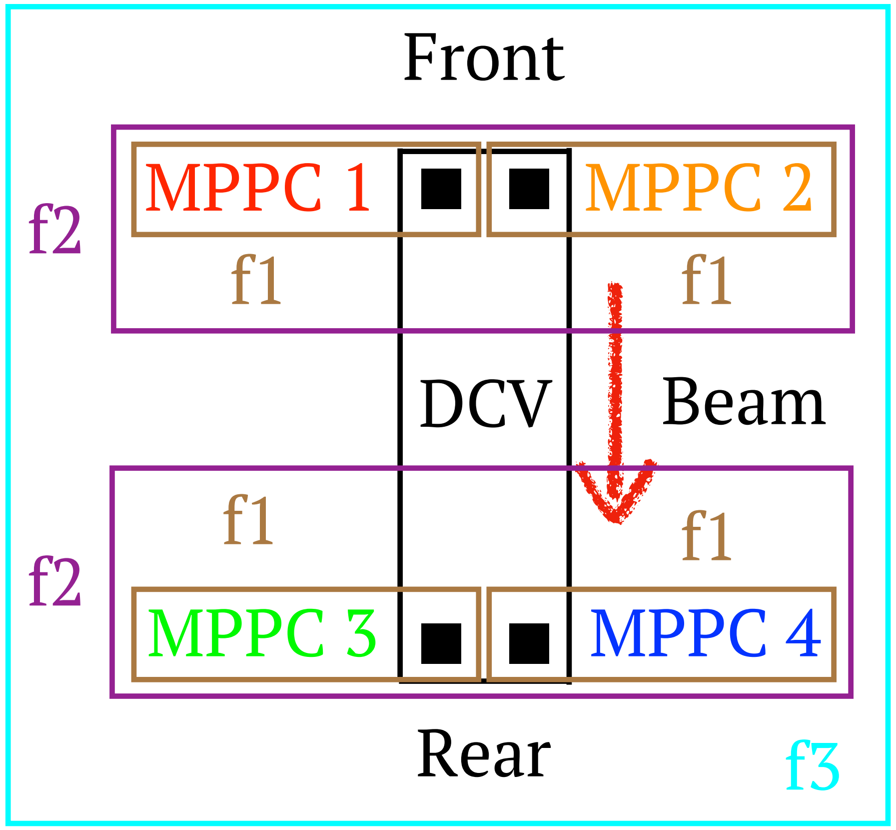


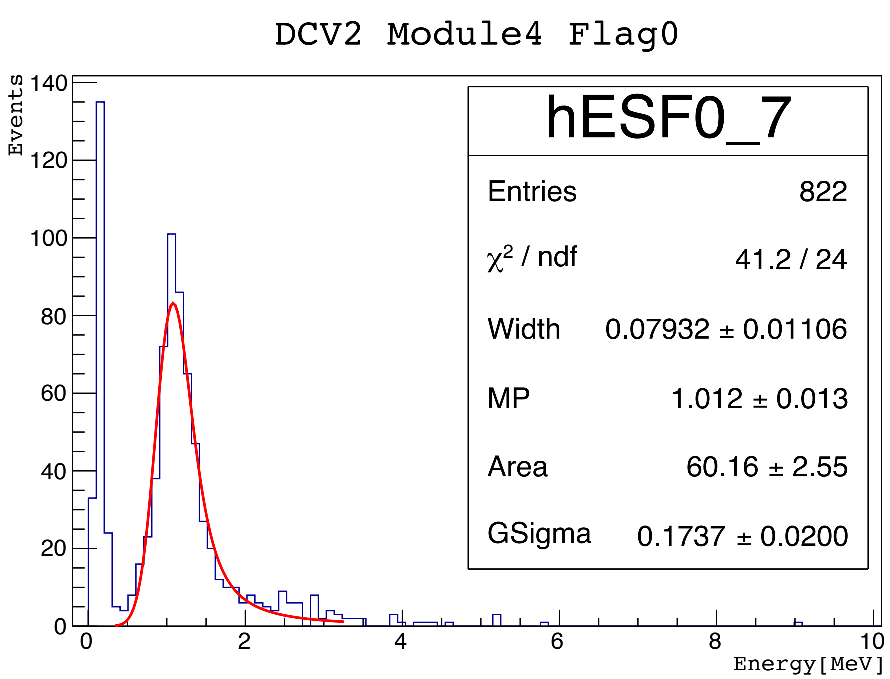
Path length correction factor
$= \sin\theta$



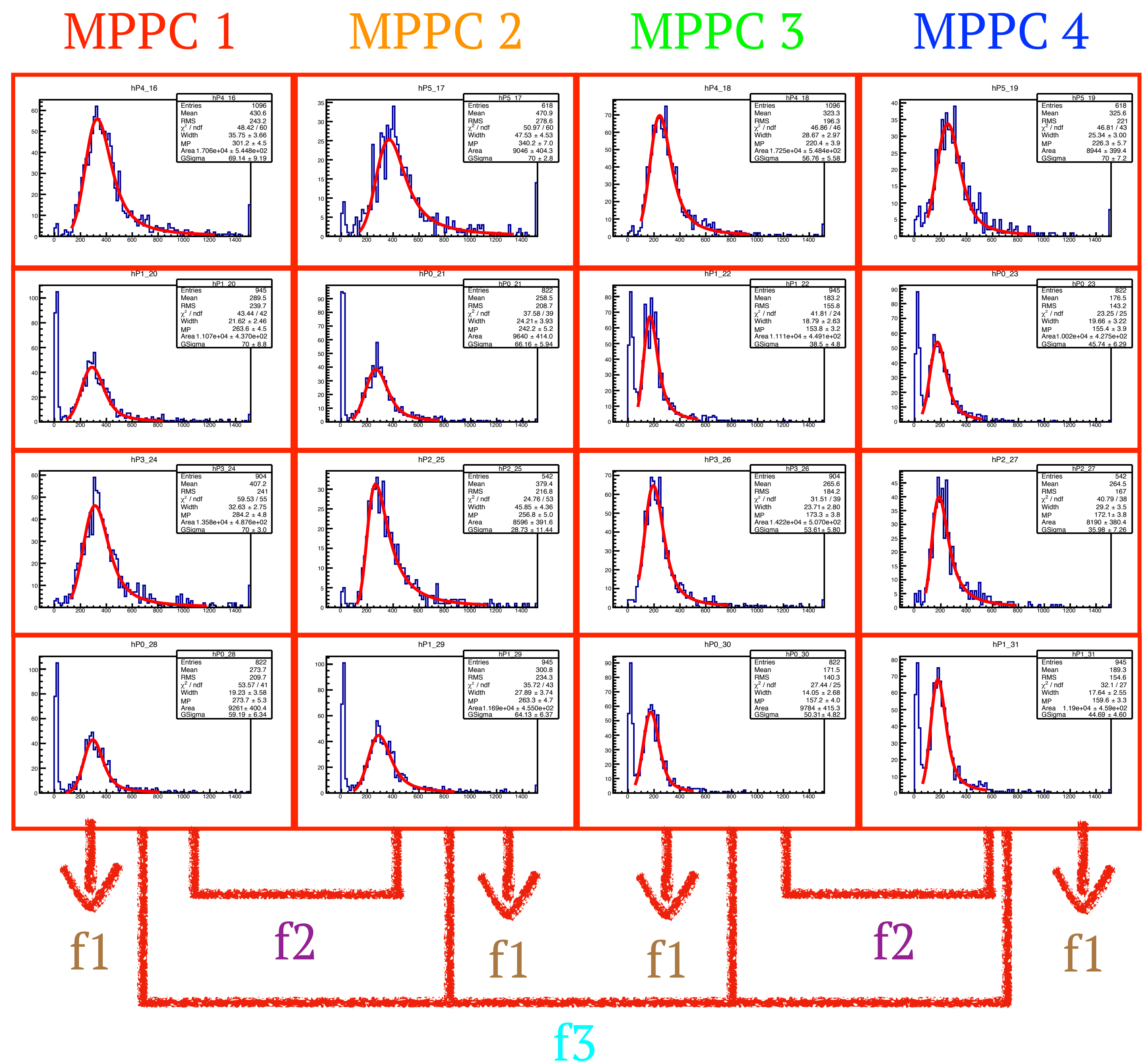
Attenuation factor = $\exp(\Delta x / \lambda)$
λ : Attenuation length

Calibration of DCV





Fitting function : Convoluted landau × gaussian



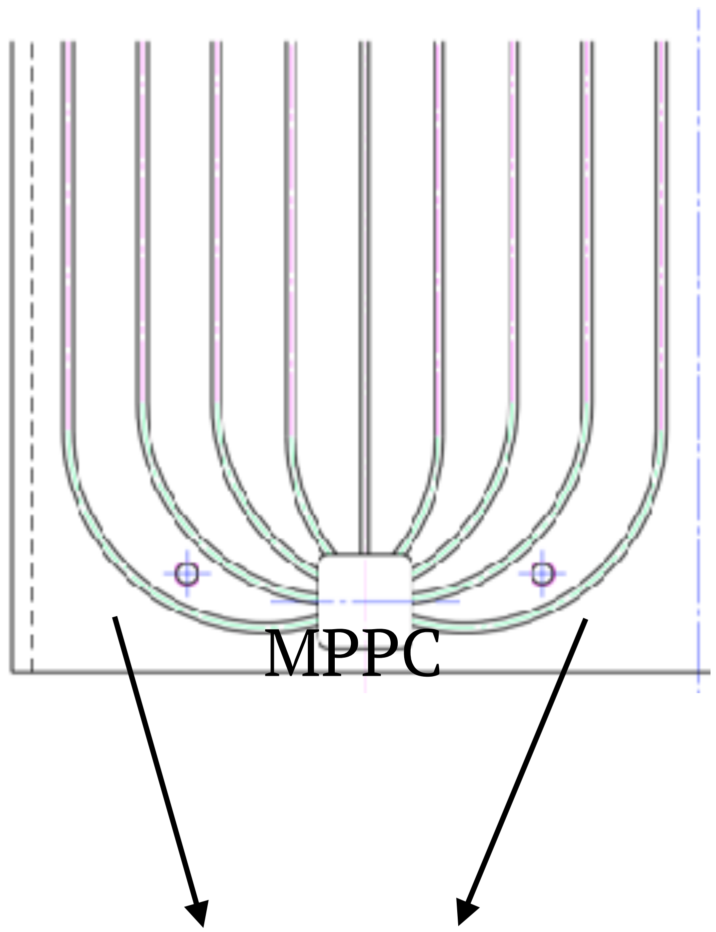
Calibration factor = Attenuation factor / (f1 × f2 × f3 × Path length correction factor)

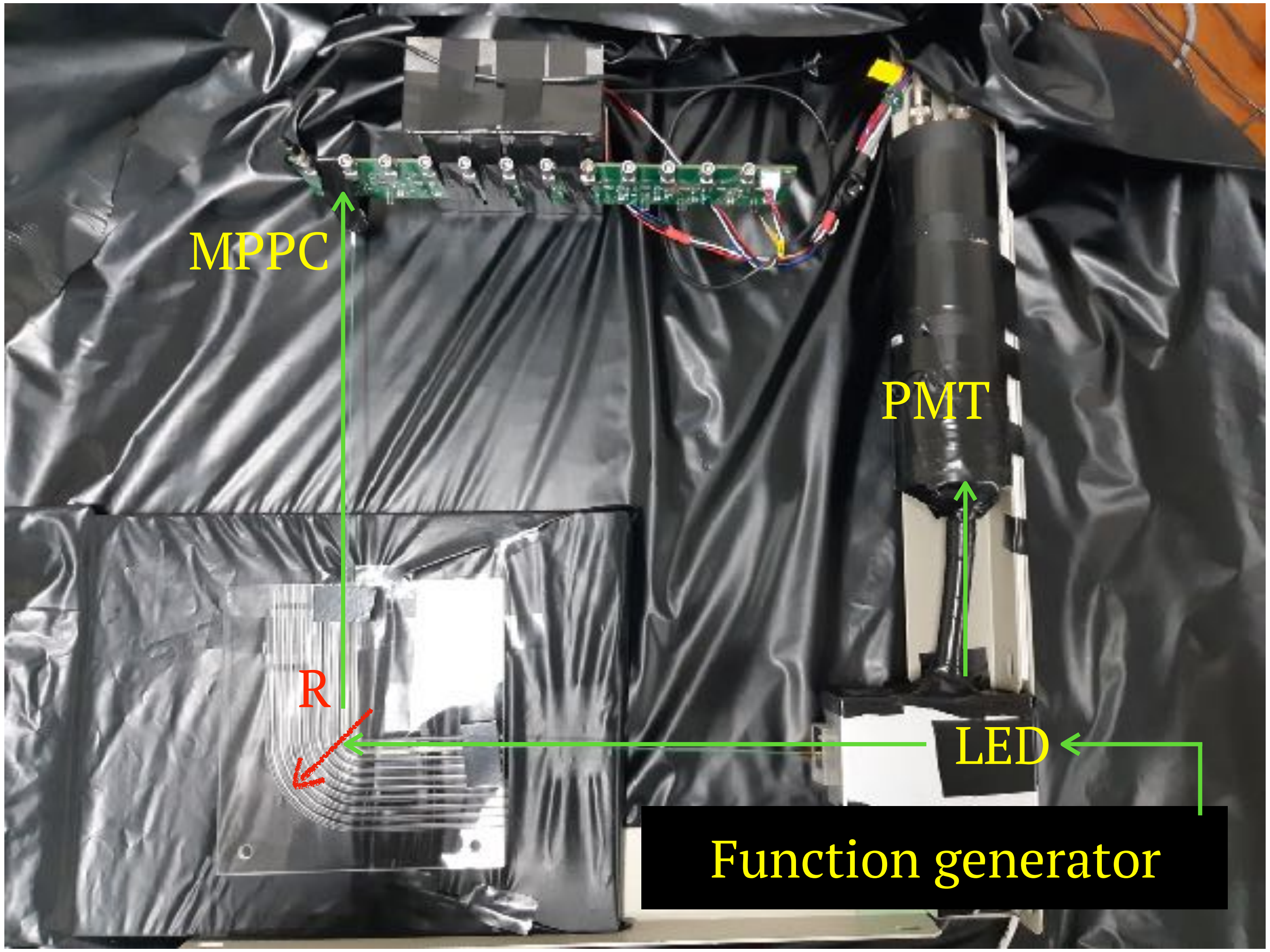
Summary

1. To reduce the background which is $K_L \rightarrow \pi^+\pi^-\pi^0$, It is necessary to install the new scintillator detectors(DCV) inside the beam pipe.
2. Due to limit space, a new type of light collection is adapted.
    1. MPPC is connected in parallel direction.
        1. WLS fiber could be bent to a radius of 20 mm.
    2. Fiber length into the light guide, Fiber condition, Shape of reflector were also concerned.
3. The result of cosmic ray data, DCV got 41.88 ~ 82.05 p.e.(DCV1) and 36.98 ~ 85.08 p.e.(DCV2).
4. DCV was well installed at KOTO beam line.
5. The calibration of DCV was completed by using the cosmic ray data.
6. DCV is now receiving the beam data at J-PARC.

BACK UP

How many difference light yield by bending radius?

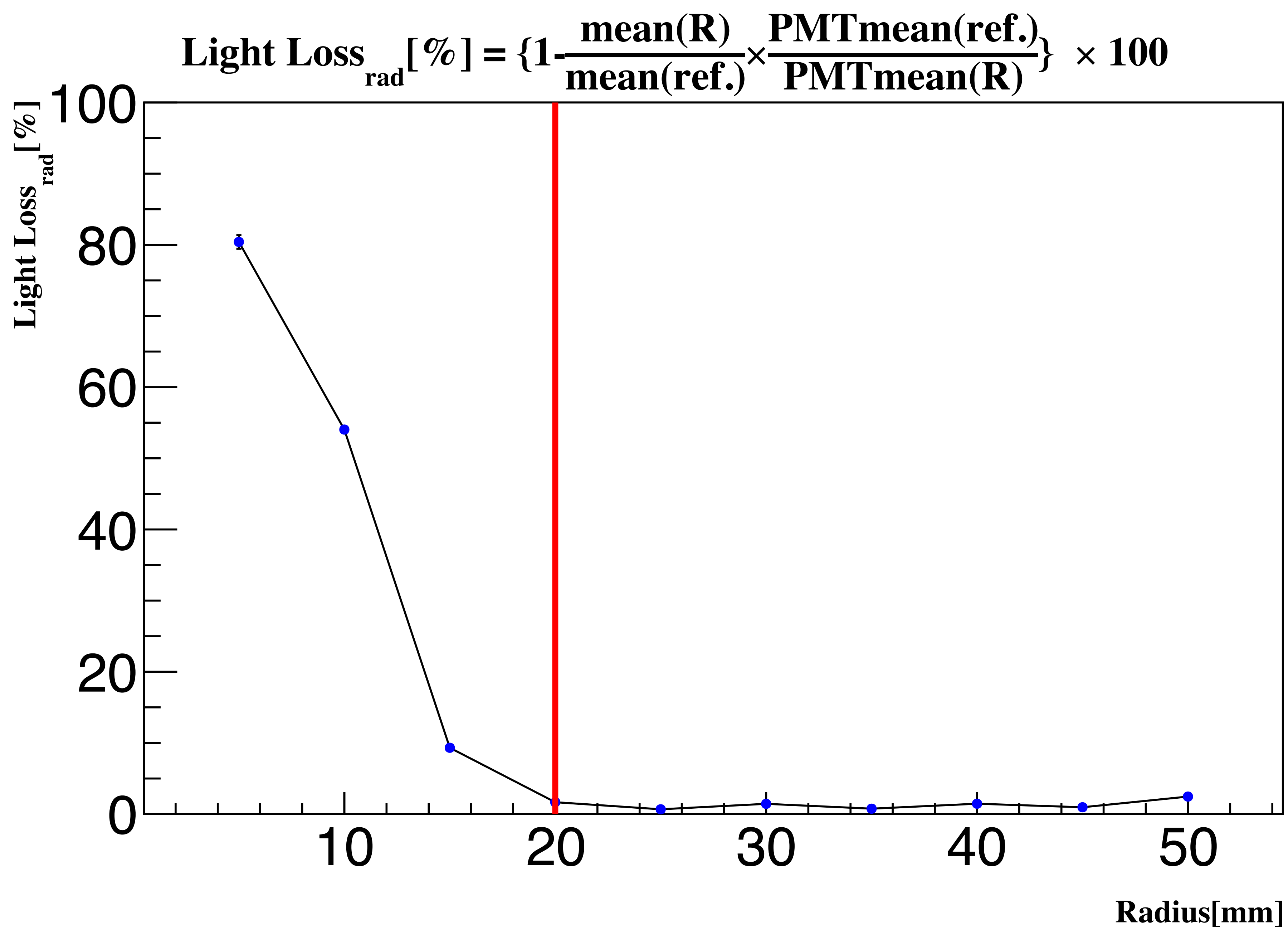




Fiber : Kuraray Y-11 1mm

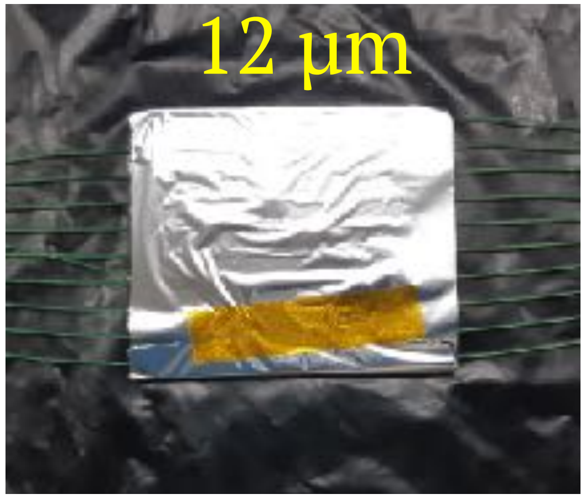
Variables	
Radius[mm]	∞(ref.), 50, 45, 40, 35, 30, 25, 20, 15, 10, 5 mm
MPPC Voltage[V]	55 V
Light intensity by Function generator width[ns]	65 ns

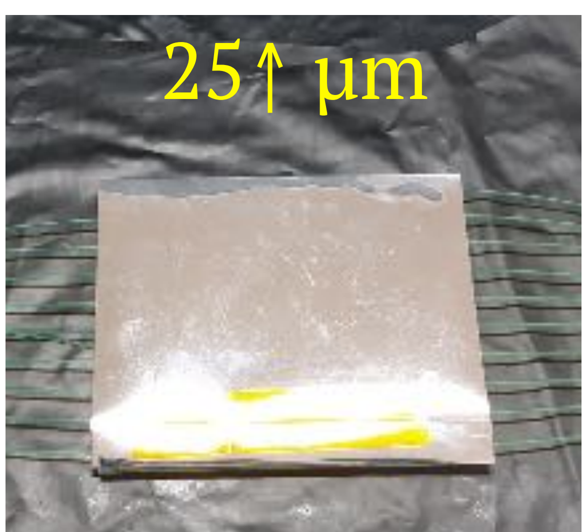
How many difference light yield by bending radius?

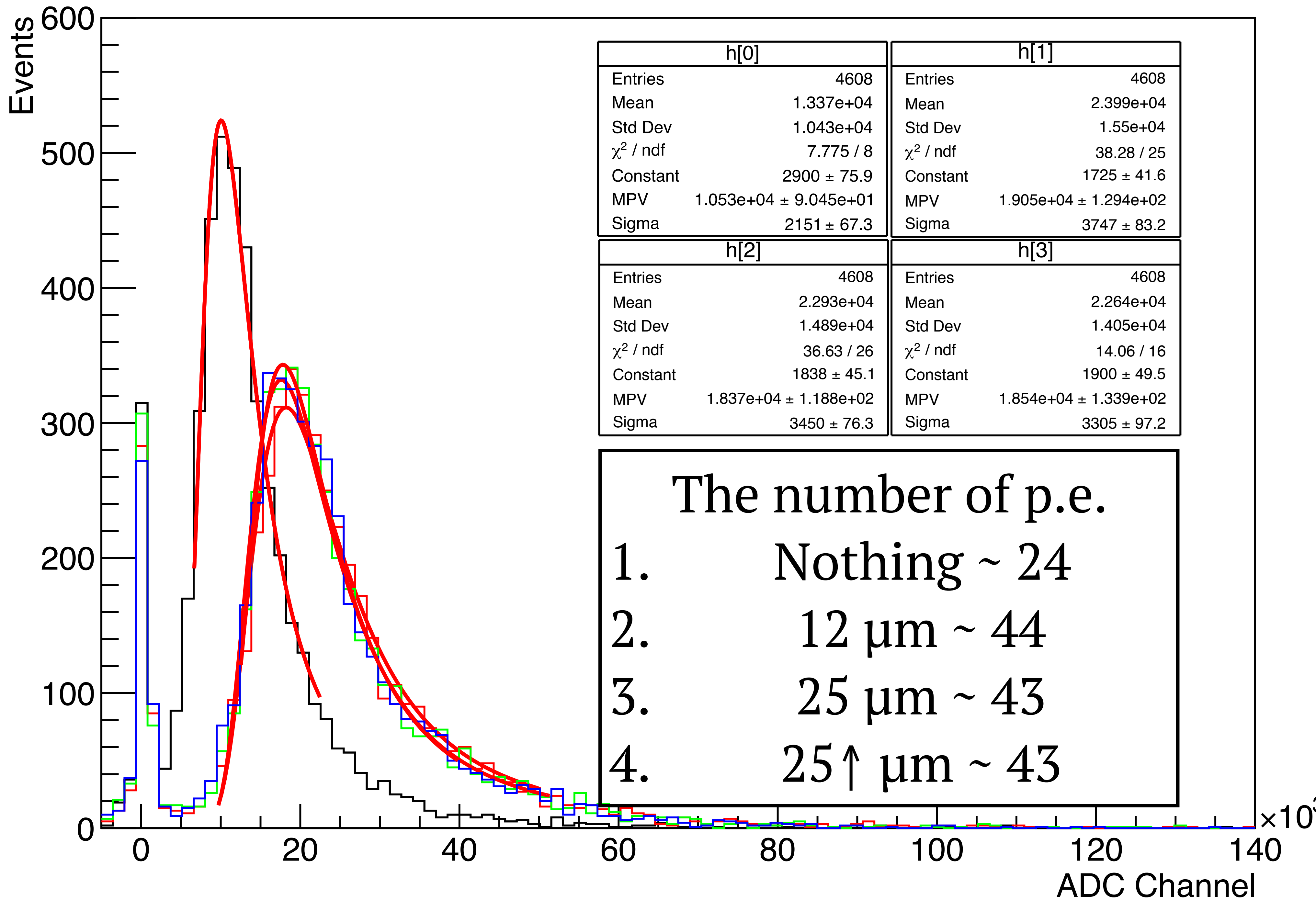


- There is a sudden loss of light under 15 mm.
- We could bend the fiber to a minimum radius of 20 mm.

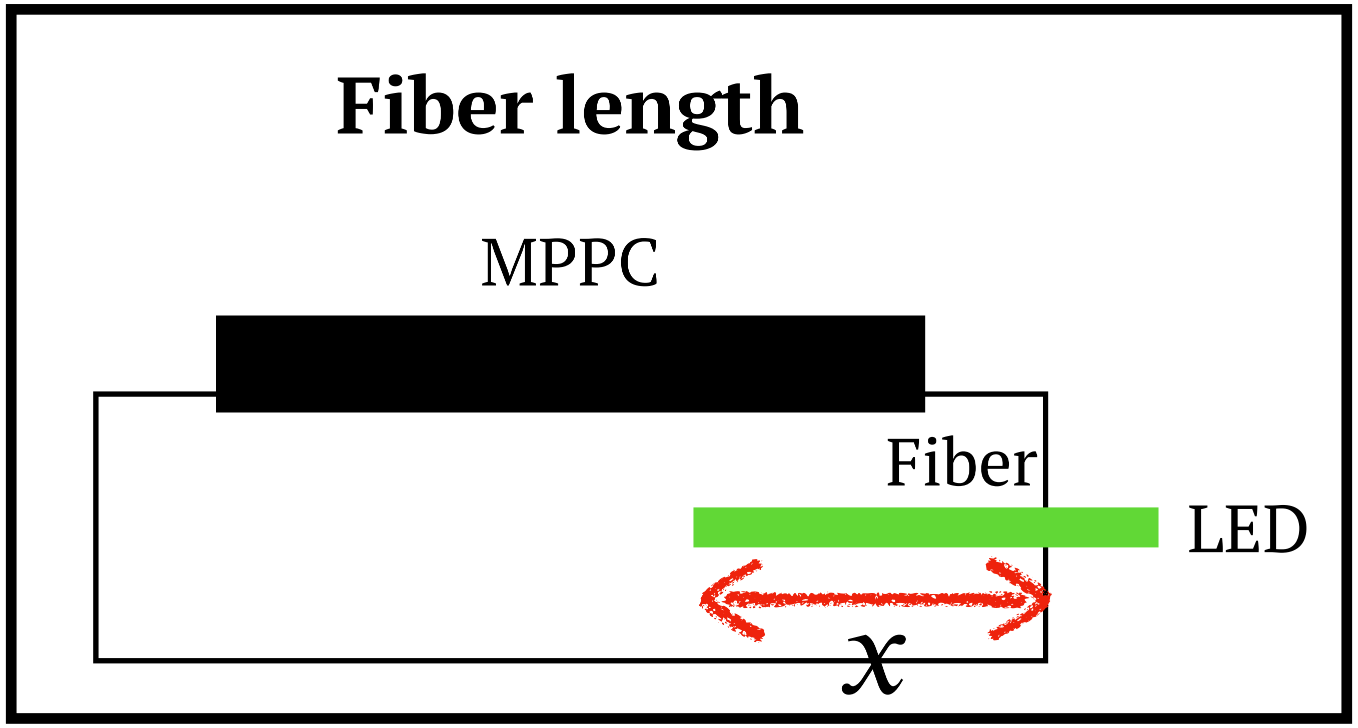
Thickness of reflector

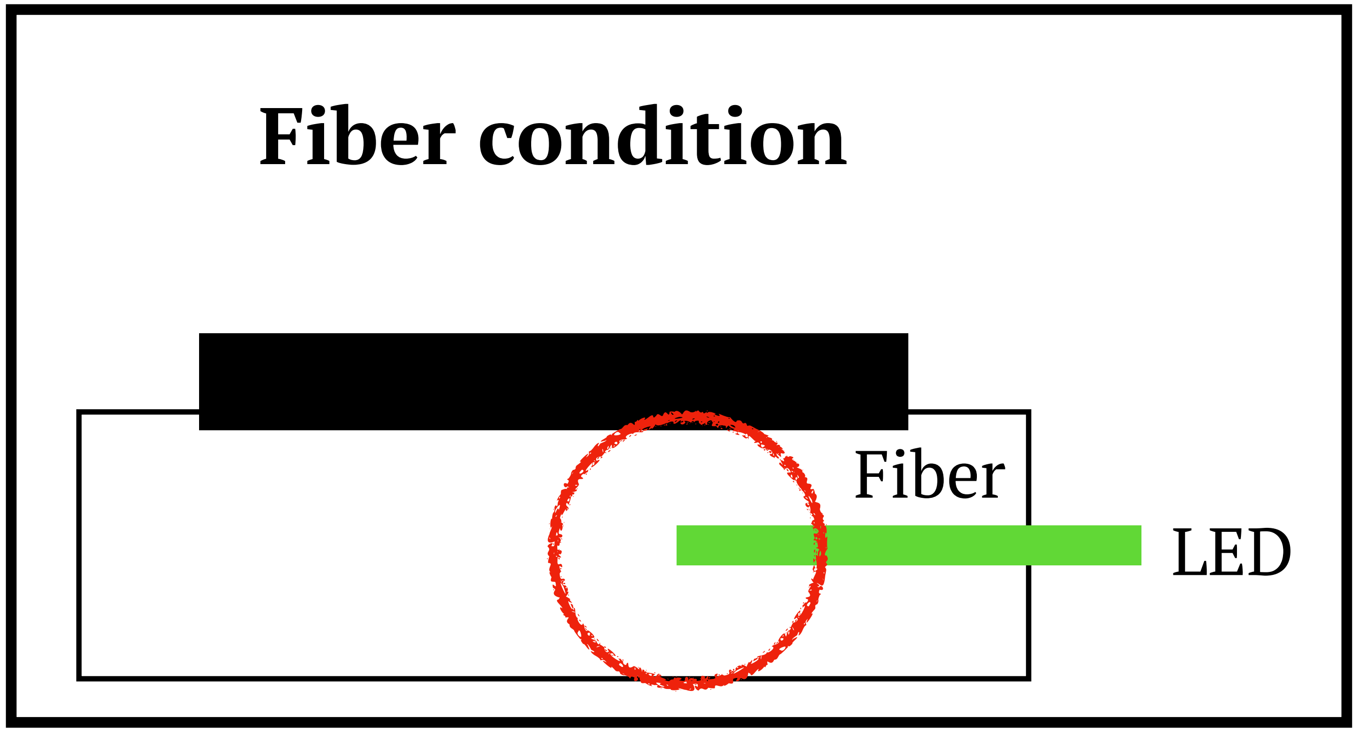


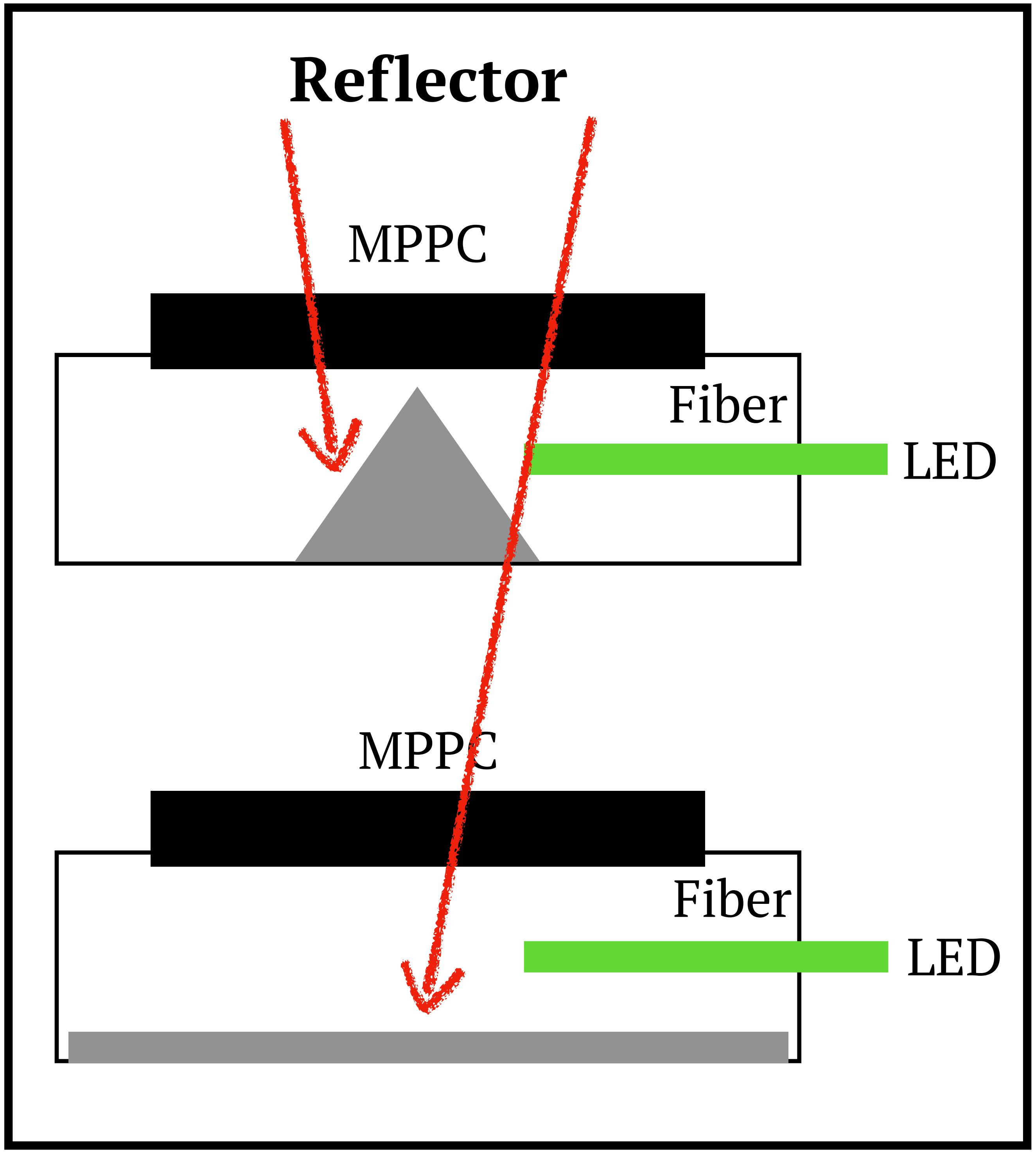




Design of Light guide





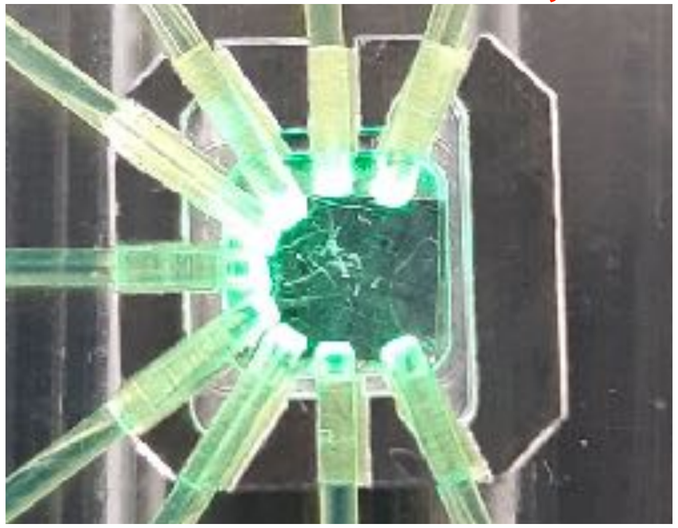


Light guide material = aluminum

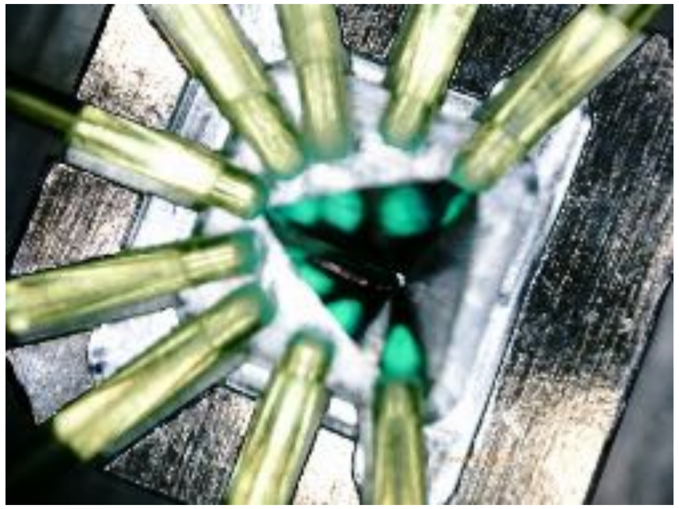
Reflector

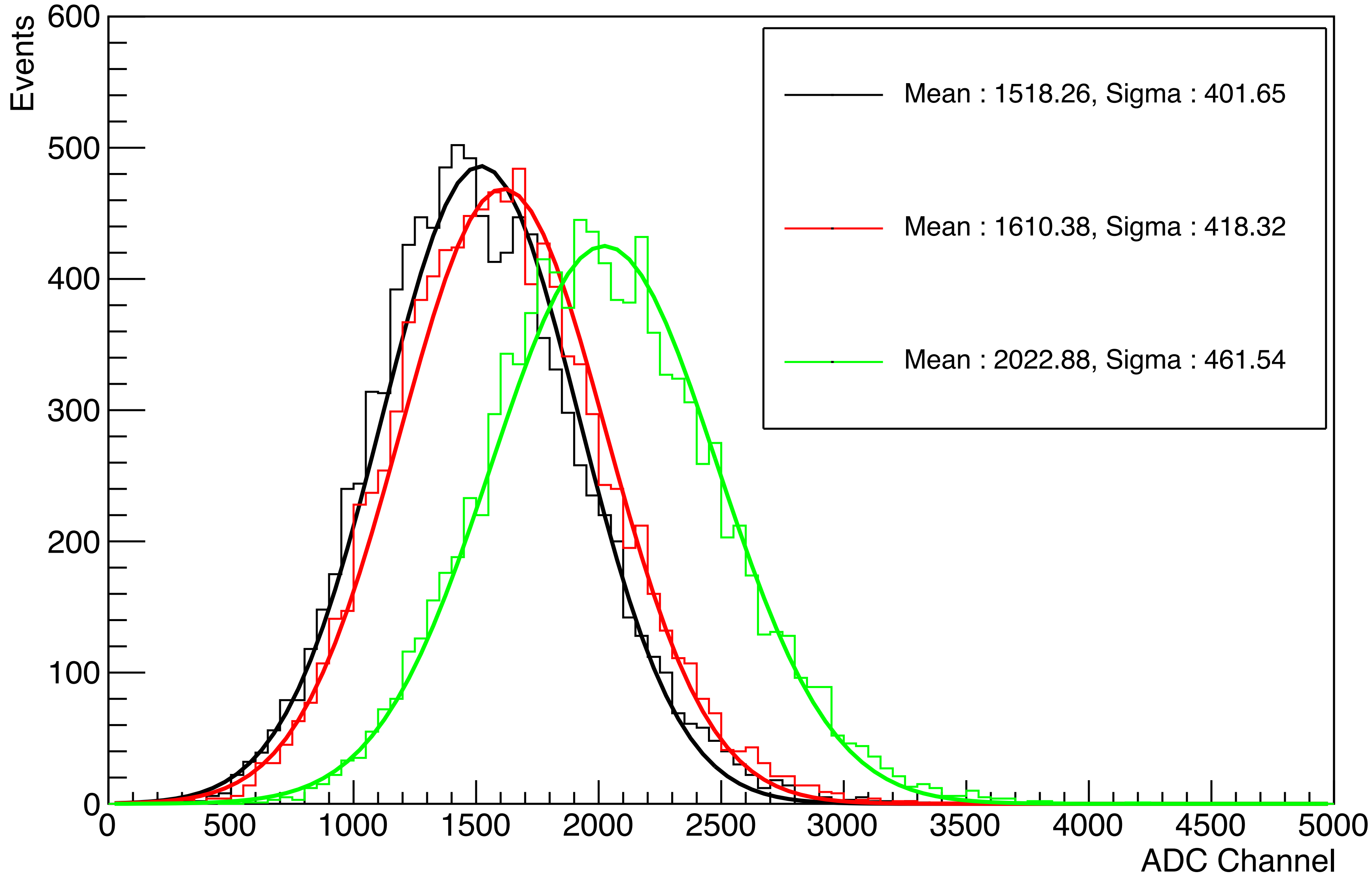
Nothing

1 sheet of
the aluminized mylar



the tetrahedron-shaped
aluminized mylar





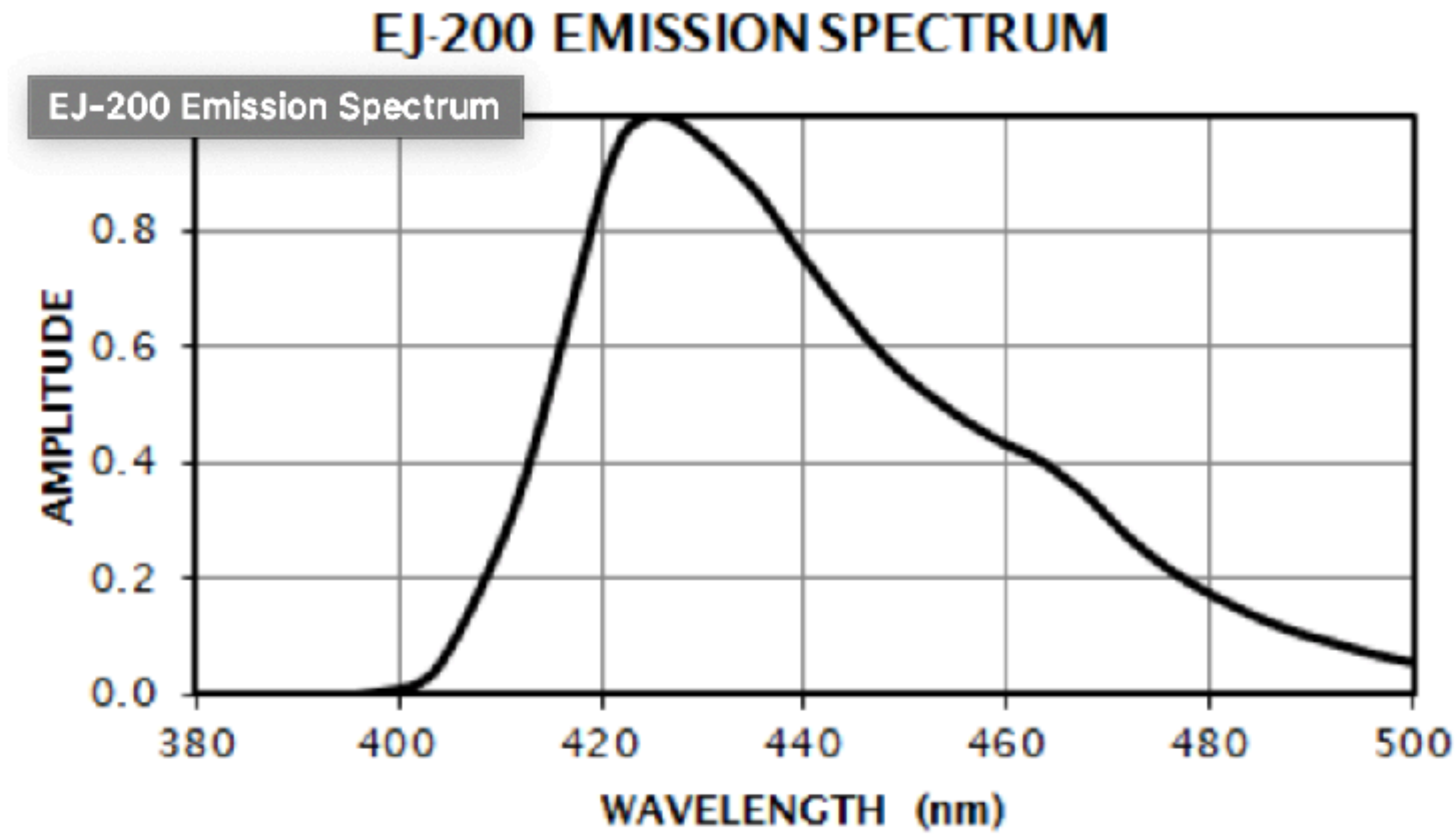
- Tetrahedron-shaped reflector increased about 30% efficiency of light yield.

- The way to create a large number of tetrahedron-shaped reflector is currently under study.

ELJEN EJ-200 Properties

PROPERTIES	EJ-200	EJ-204	EJ-208	EJ-212
Light Output (% Anthracene)	64	68	60	65
Scintillation Efficiency (photons/1 MeV e^-)	10,000	10,400	9,200	10,000
Wavelength of Maximum Emission (nm)	425	408	435	423
Light Attenuation Length (cm)	380	160	400	250
Rise Time (ns)	0.9	0.7	1.0	0.9
Decay Time (ns)	2.1	1.8	3.3	2.4
Pulse Width, FWHM (ns)	2.5	2.2	4.2	2.7
No. of H Atoms per cm^3 ($x10^{22}$)	5.17	5.15	5.17	5.17
No. of C Atoms per cm^3 ($x10^{22}$)	4.69	4.68	4.69	4.69
No. of Electrons per cm^3 ($x10^{23}$)	3.33	3.33	3.33	3.33
Density (g/cm^3)	1.023	1.023	1.023	1.023
Polymer Base	Polyvinyltoluene			
Refractive Index	1.58			
Softening Point	75°C			
Vapor Pressure	Vacuum-compatible			
Coefficient of Linear Expansion	7.8 x 10^{-5} below 67°C			
Light Output vs. Temperature	At 60°C, L.O. = 95% of that at 20°C No change from 20°C to -60°			
Temperature Range	-20°C to 60°C			

ELJEN EJ-200 Properties



SAINT-GOBAIN BC-600

KURARAY Y-11 Properties

Formulations[1]

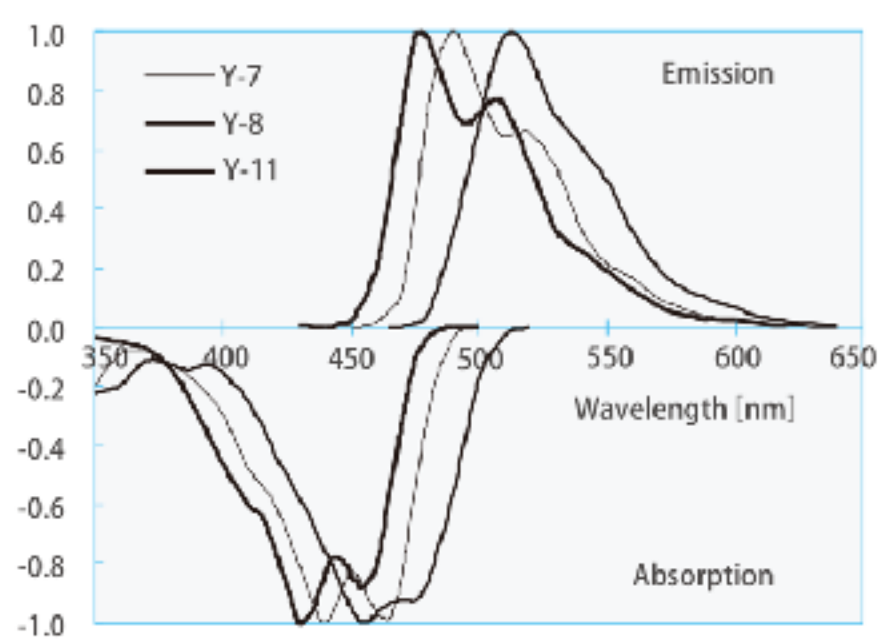
Description	Emission			Absorption Peak[nm]	Att.Leng.[2] [m]	Characteristics
	Color	Spectra	Peak[nm]			
Y-7(100)	green	See the following figure	490	439	>2.8	Blue to Green Shifter
Y-8(100)	green		511	455	>3.0	Blue to Green Shifter
Y-11(200)	green		476	430	>3.5	Blue to Green Shifter (K-27 formulation) Long Attenuation Length and High Light Yield
B-2(200)	blue		437	375	>3.5	UV to Blue shifter
B-3(200)	blue		450	351	>4.0	UV to Blue shifter
O-2(100)	orange		550	535	>1.5	Green to orange shifter
R-3(100)	red		610	577	>2.0	Green to red shifter

1) Test fibers are Non-S type, 1mmϕ.

2) Measured by using bialkali PMT.
Attenuation length measurement method is the same with scintillating fibers which can be confirmed on Page 5.

Absorption and Emission Spectra

Y-7, Y-8, Y-11



HAMAMATSU MPPC Properties

Selection guide

Type no.	Pixel pitch (μm)	Effective photosensitive area (mm)	Number of pixels	Package	Fill factor (%)
S13360-1325CS	25	1.3 × 1.3	2668	Ceramic	47
S13360-1325PE				Surface mount type	
S13360-3025CS		3.0 × 3.0	14400	Ceramic	
S13360-3025PE				Surface mount type	
S13360-6025CS		6.0 × 6.0	57600	Ceramic	
S13360-6025PE				Surface mount type	
S13360-1350CS	50	1.3 × 1.3	667	Ceramic	74
S13360-1350PE				Surface mount type	
S13360-3050CS		3.0 × 3.0	3600	Ceramic	
S13360-3050PE				Surface mount type	
S13360-6050CS		6.0 × 6.0	14400	Ceramic	
S13360-6050PE				Surface mount type	
S13360-1375CS	75	1.3 × 1.3	285	Ceramic	82
S13360-1375PE				Surface mount type	
S13360-3075CS		3.0 × 3.0	1600	Ceramic	
S13360-3075PE				Surface mount type	
S13360-6075CS		6.0 × 6.0	6400	Ceramic	
S13360-6075PE				Surface mount type	

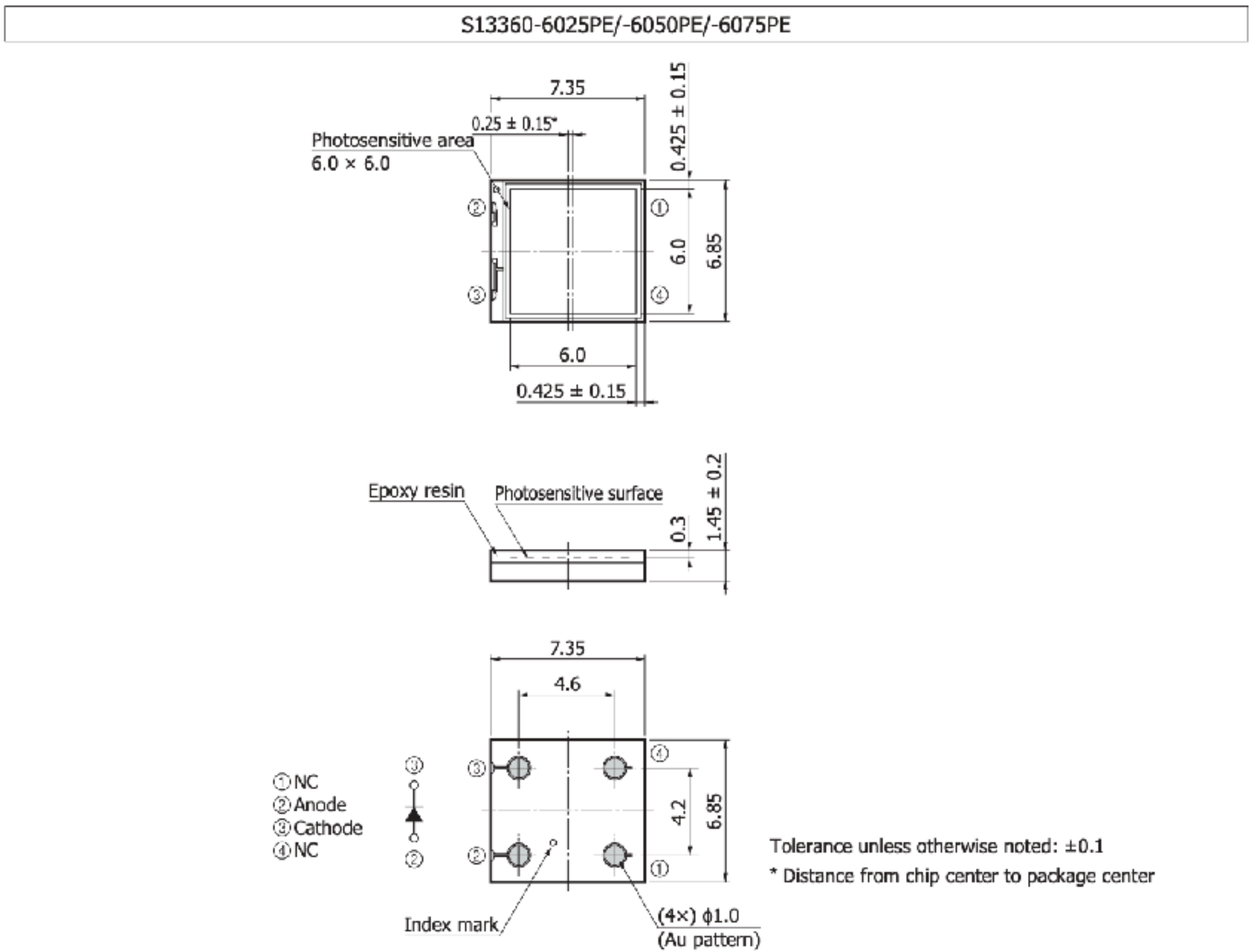
HAMAMATSU MPPC Properties

Electrical and optical characteristics (Typ. Ta=25 °C, unless otherwise noted)

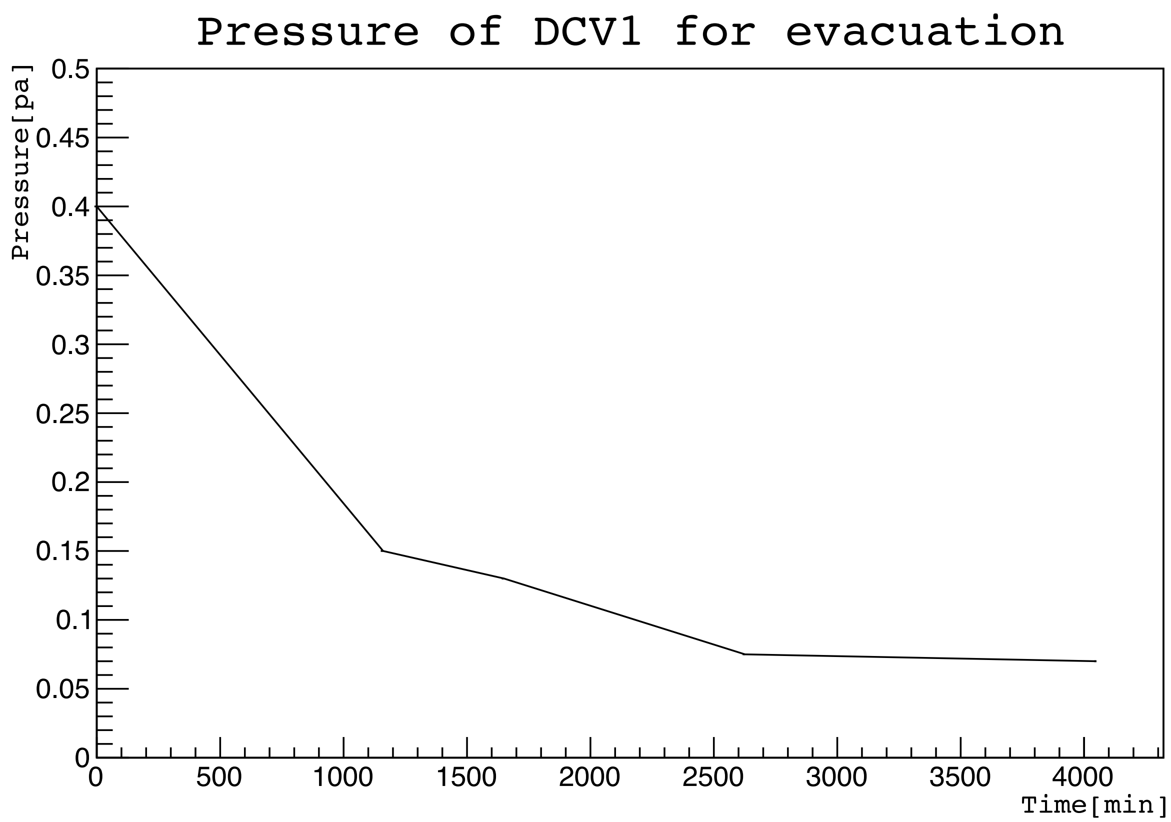
Type no.	Measurement conditions	Spectral response range λ (nm)	Peak sensitivity wavelength λp (nm)	Photon detection efficiency PDE*4 λ=λp (%)	Dark count*5 Typ. (kcps)	Dark count*5 Max. (kcps)	Terminal capacitance Ct (pF)	Gain M	Breakdown voltage VBR (V)	Crosstalk probability (%)	Recommended operating voltage Vop (V)	Temperature coefficient at recommended operating voltage ΔTVop (mV/°C)
S13360-1325CS	Vover =5 V	270 to 900	450	25	70	210	60	7.0×10^5	53 ± 5	1	VBR + 5	54
S13360-1325PE		320 to 900										
S13360-3025CS		270 to 900			400	1200	320					
S13360-3025PE		320 to 900										
S13360-6025CS		270 to 900			1600	5000	1280					
S13360-6025PE		320 to 900										
S13360-1350CS	Vover =3 V	270 to 900		40	90	270	60	1.7×10^6		3	VBR + 3	
S13360-1350PE		320 to 900										
S13360-3050CS		270 to 900			500	1500	320					
S13360-3050PE		320 to 900										
S13360-6050CS		270 to 900			2000	6000	1280					
S13360-6050PE		320 to 900										
S13360-1375CS	Vover =3 V	270 to 900		50	90	270	60	4.0×10^6		7	VBR + 3	
S13360-1375PE		320 to 900										
S13360-3075CS		270 to 900			500	1500	320					
S13360-3075PE		320 to 900										
S13360-6075CS		270 to 900			2000	6000	1280					
S13360-6075PE		320 to 900										

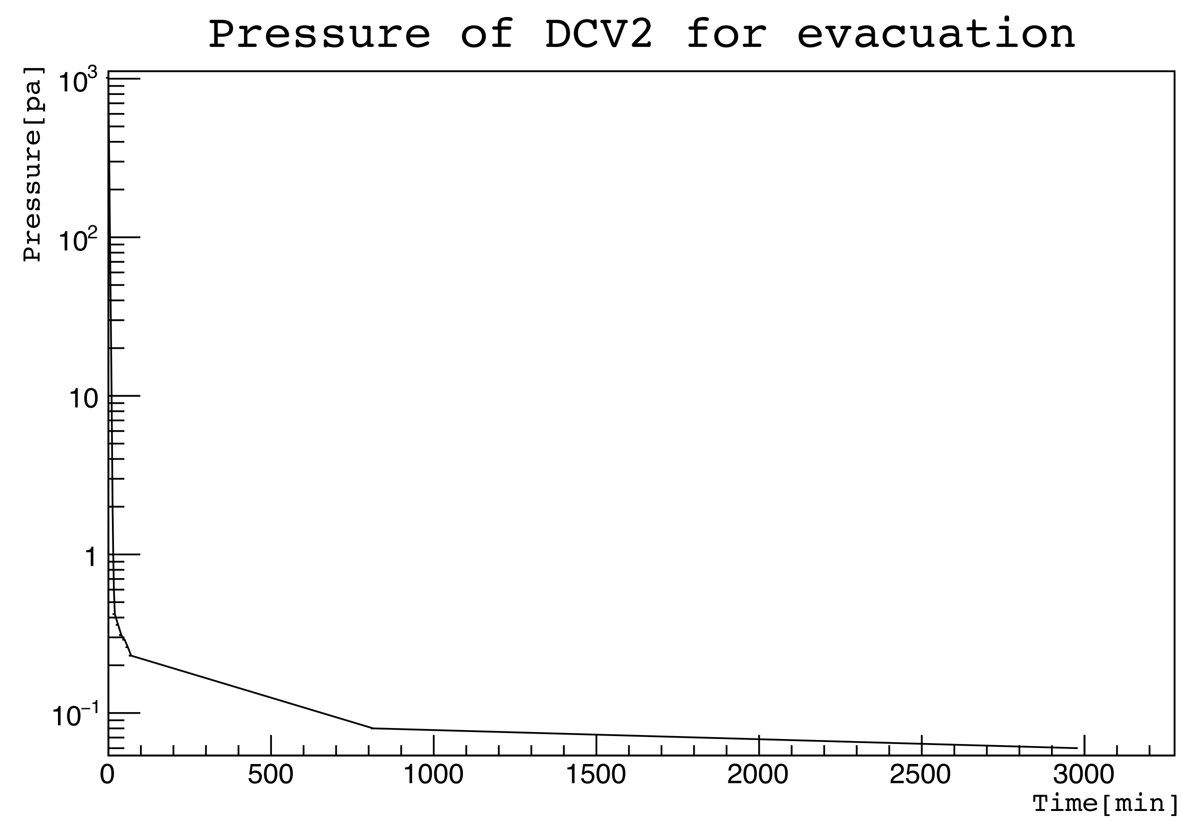
*4: Photon detection efficiency does not include crosstalk or afterpulses.
*5: Threshold=0.5 p.e.
Note: The above characteristics were measured at the operating voltage that yields the listed gain. (See the data attached to each product.)

HAMAMATSU MPPC Properties



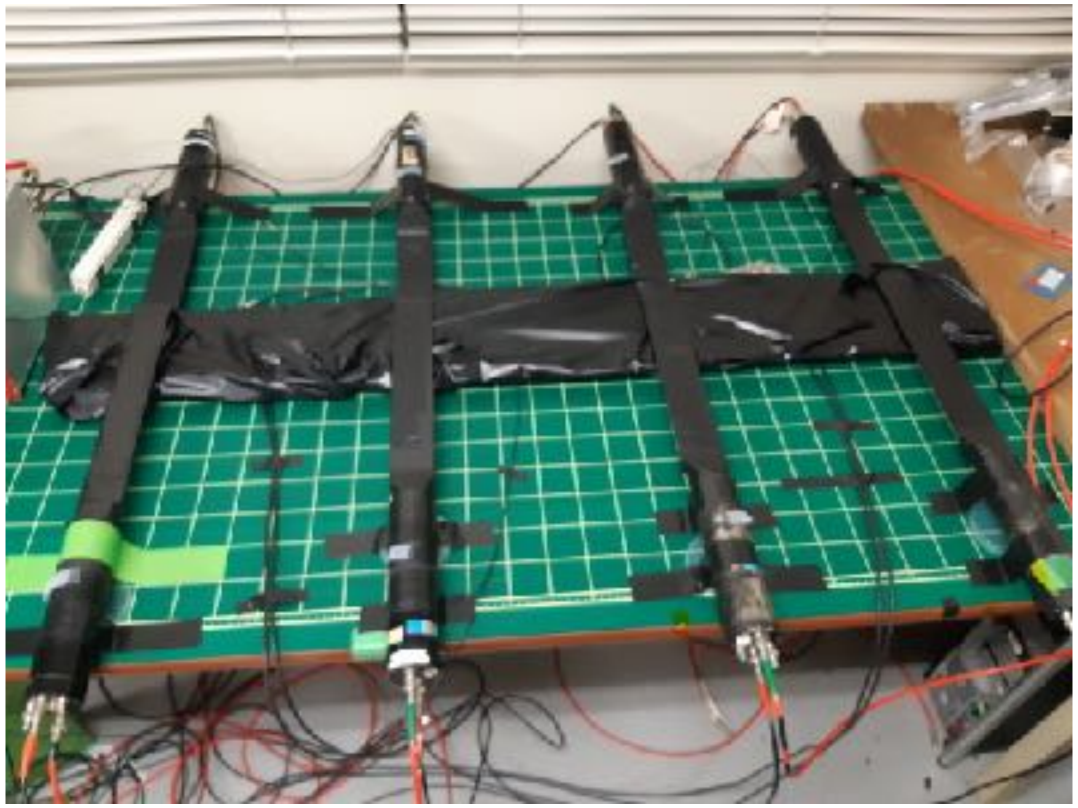
Pressure of DCV for evacuation



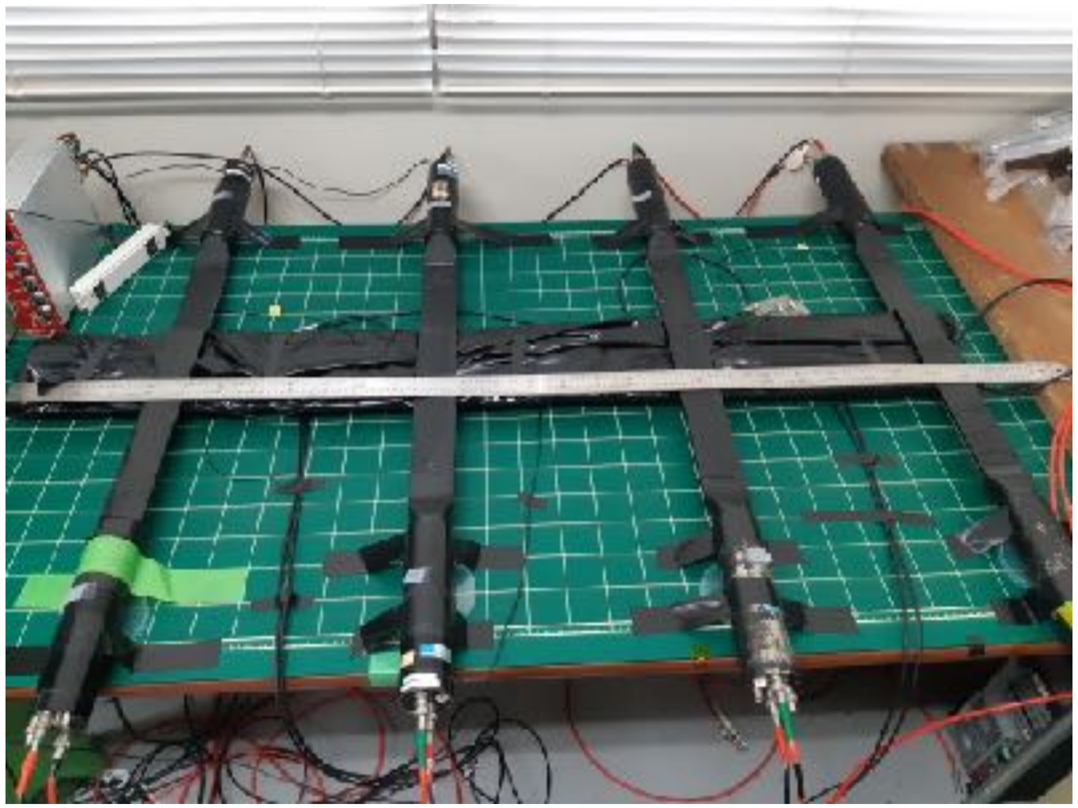


Cosmic ray test

Position1 = 125,510,898,1285

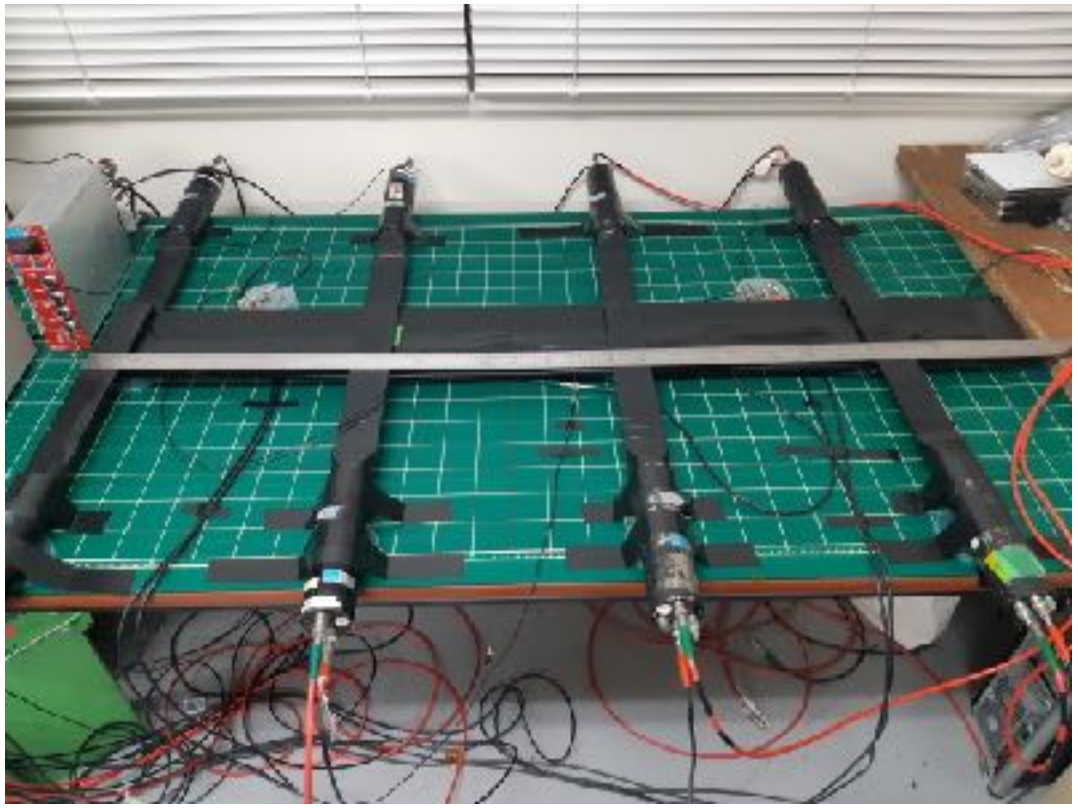


Position2 = 317,705,1092,1380.5



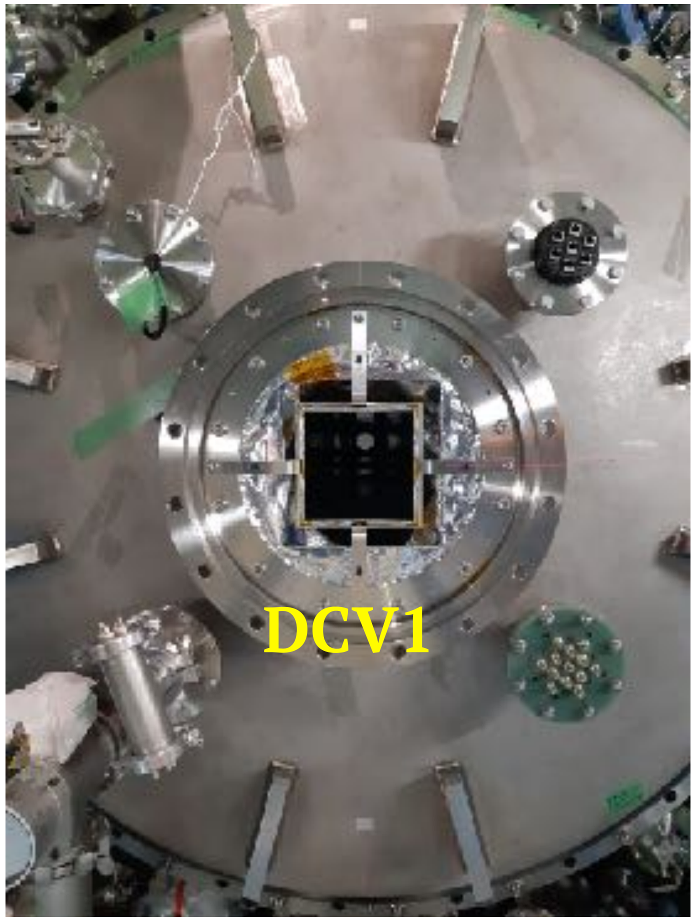
DCV 1

Position1 = 26.5,428,829,1231

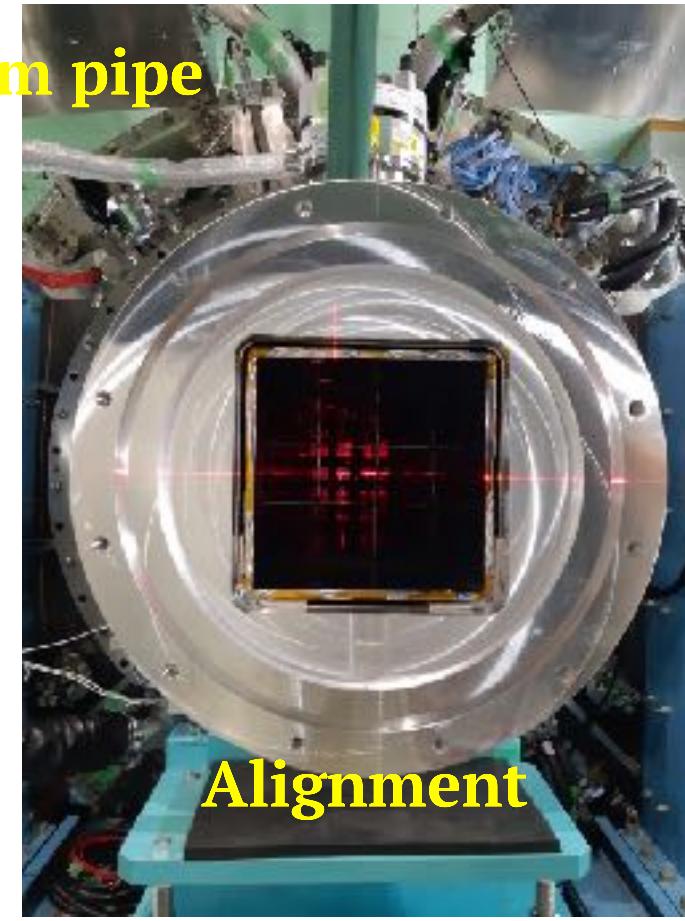


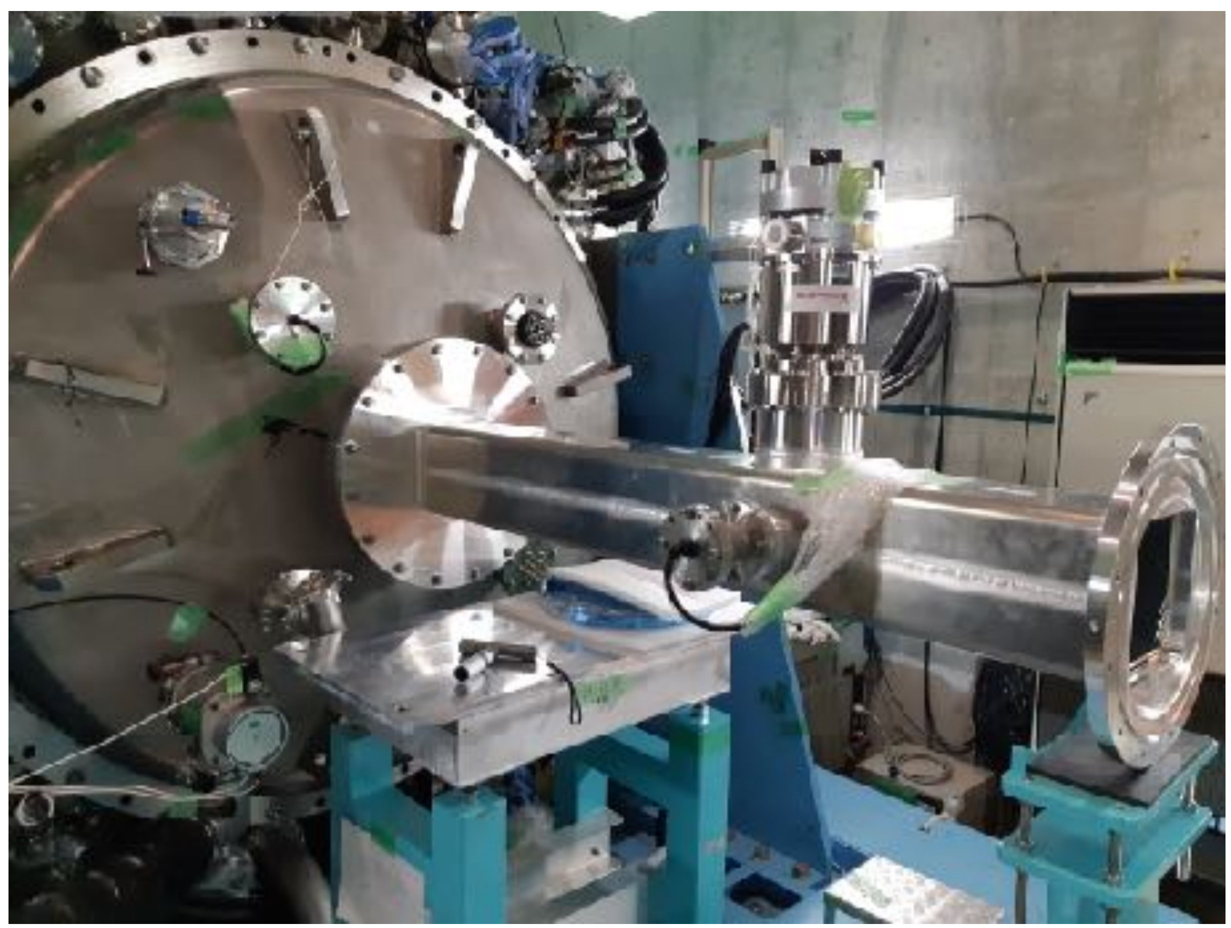
Position2 = 227,628,1030,1432.5

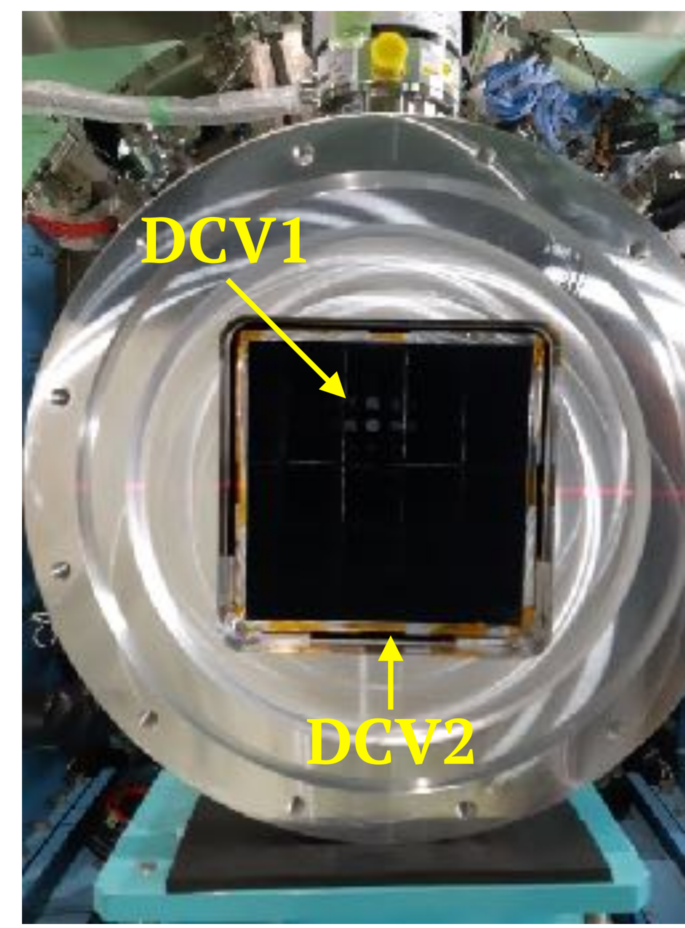
DCV2


DCV1


Combine the downstream square beam pipe

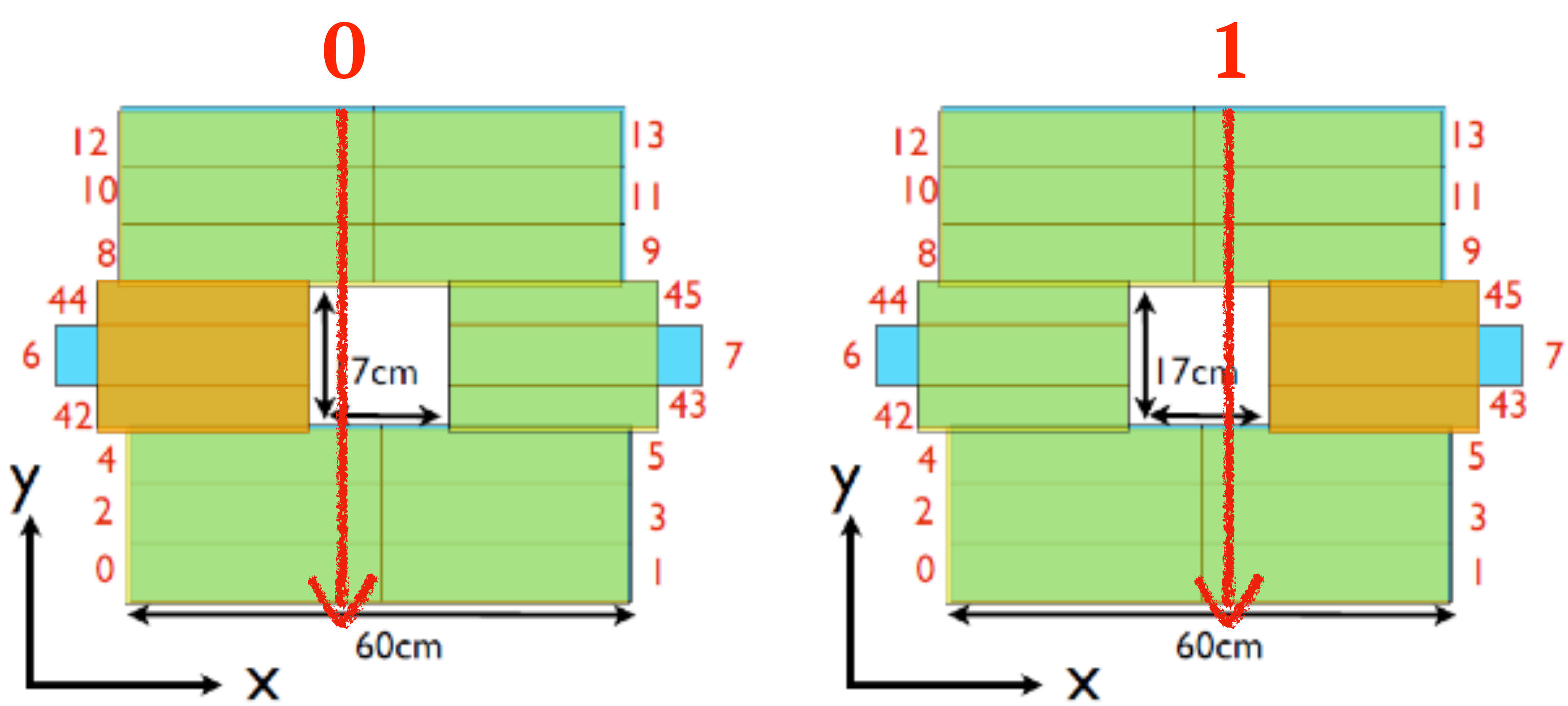

Alignment




DCV1
DCV2

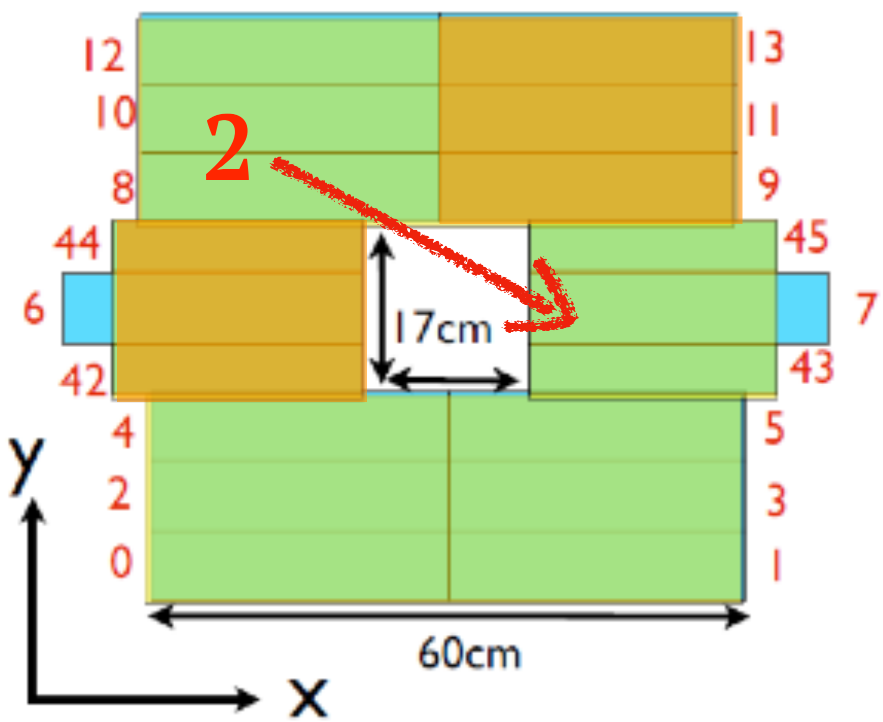
Assign the flag number for tracking the cosmic ray

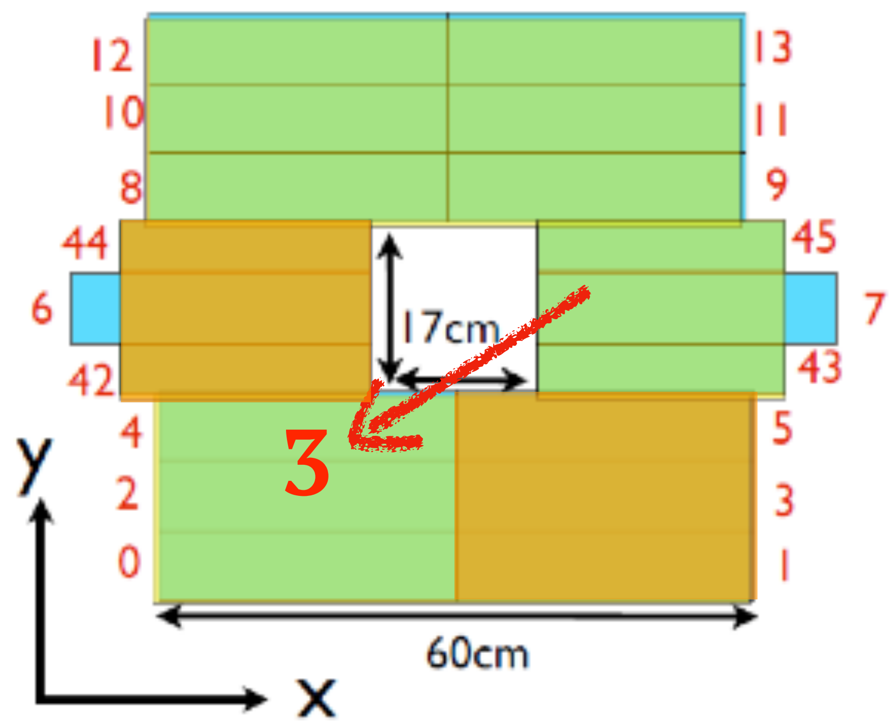
Veto

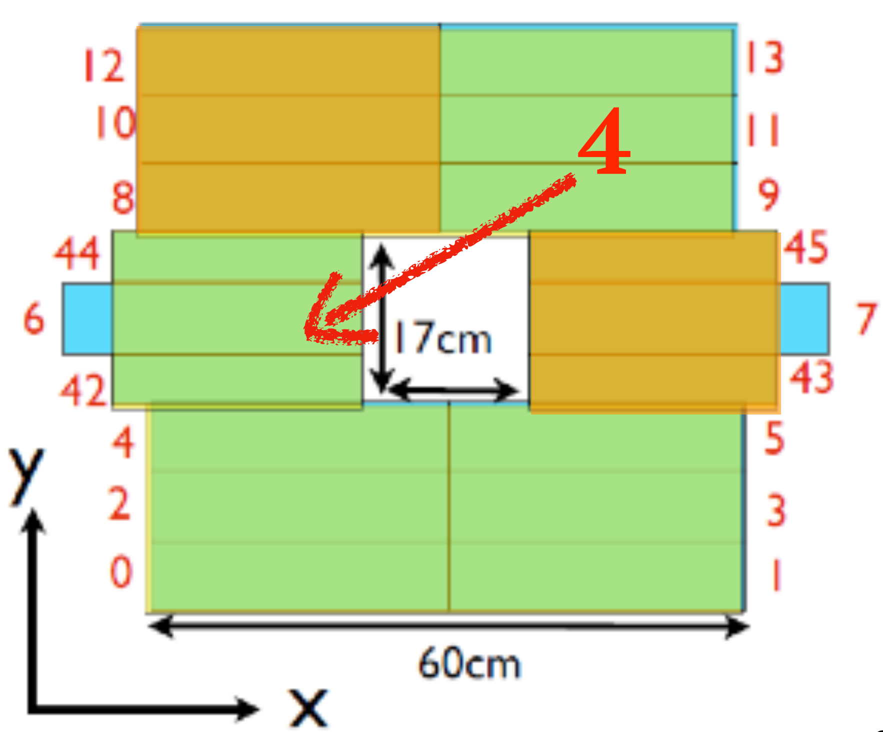


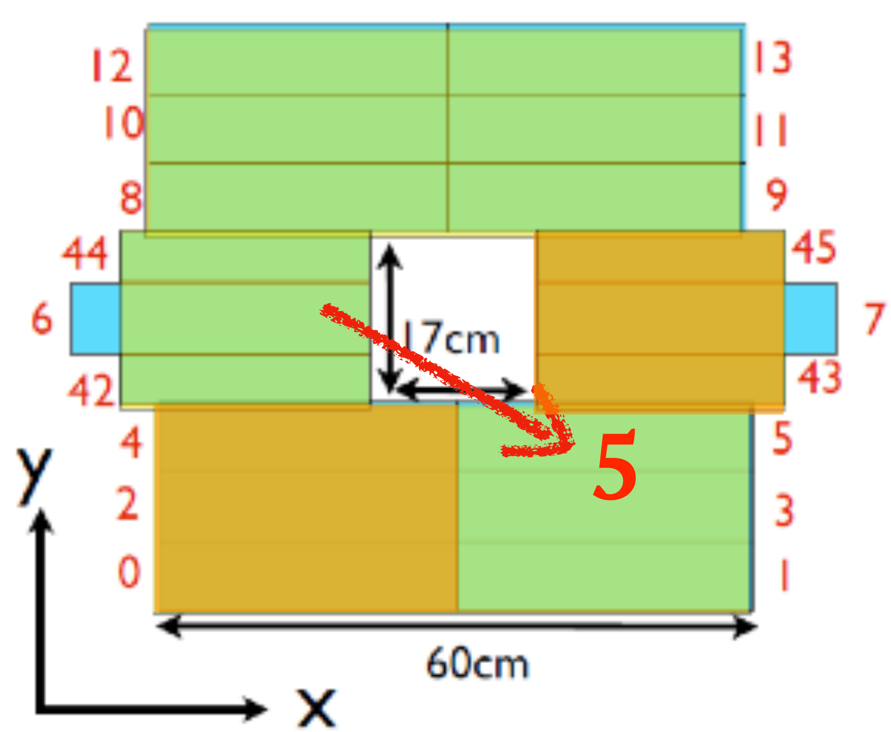
Assign the flag number for tracking the cosmic ray

Veto



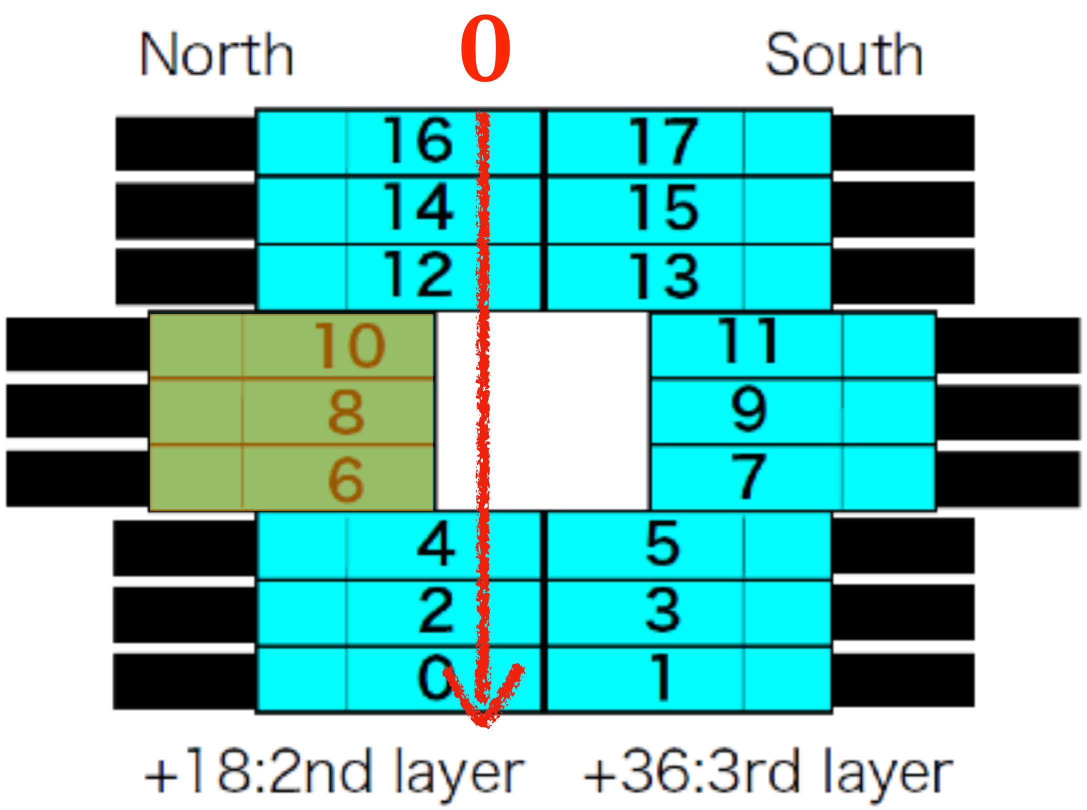


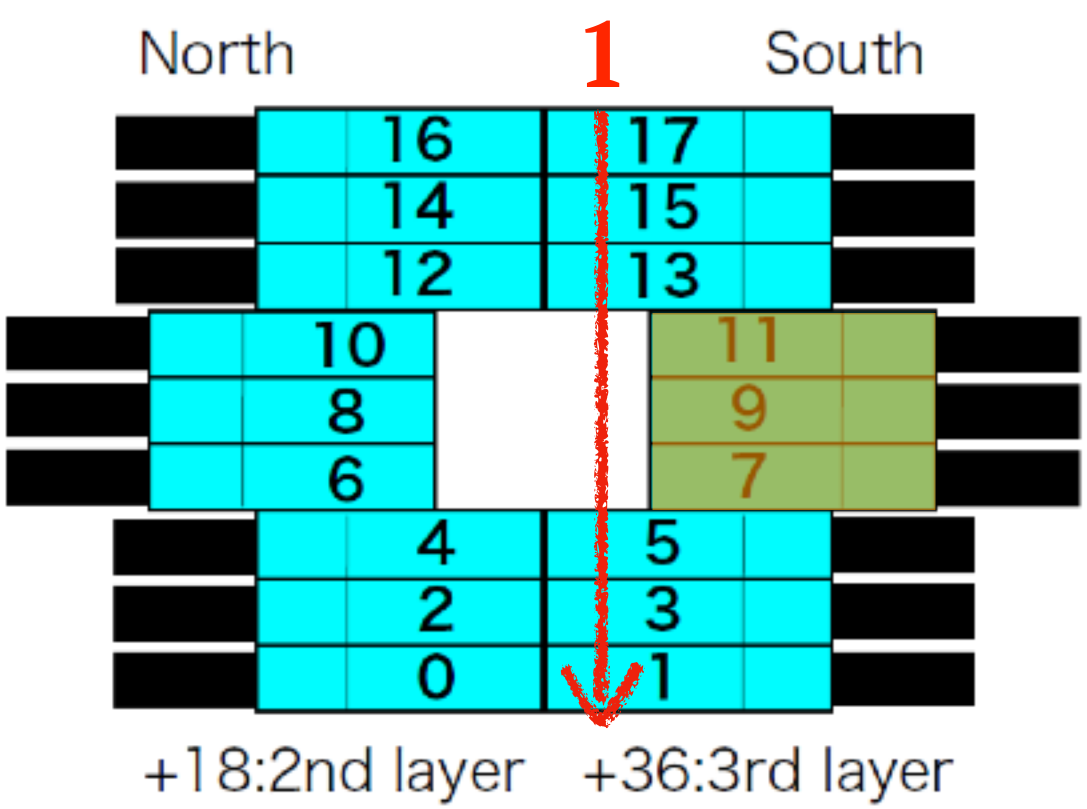




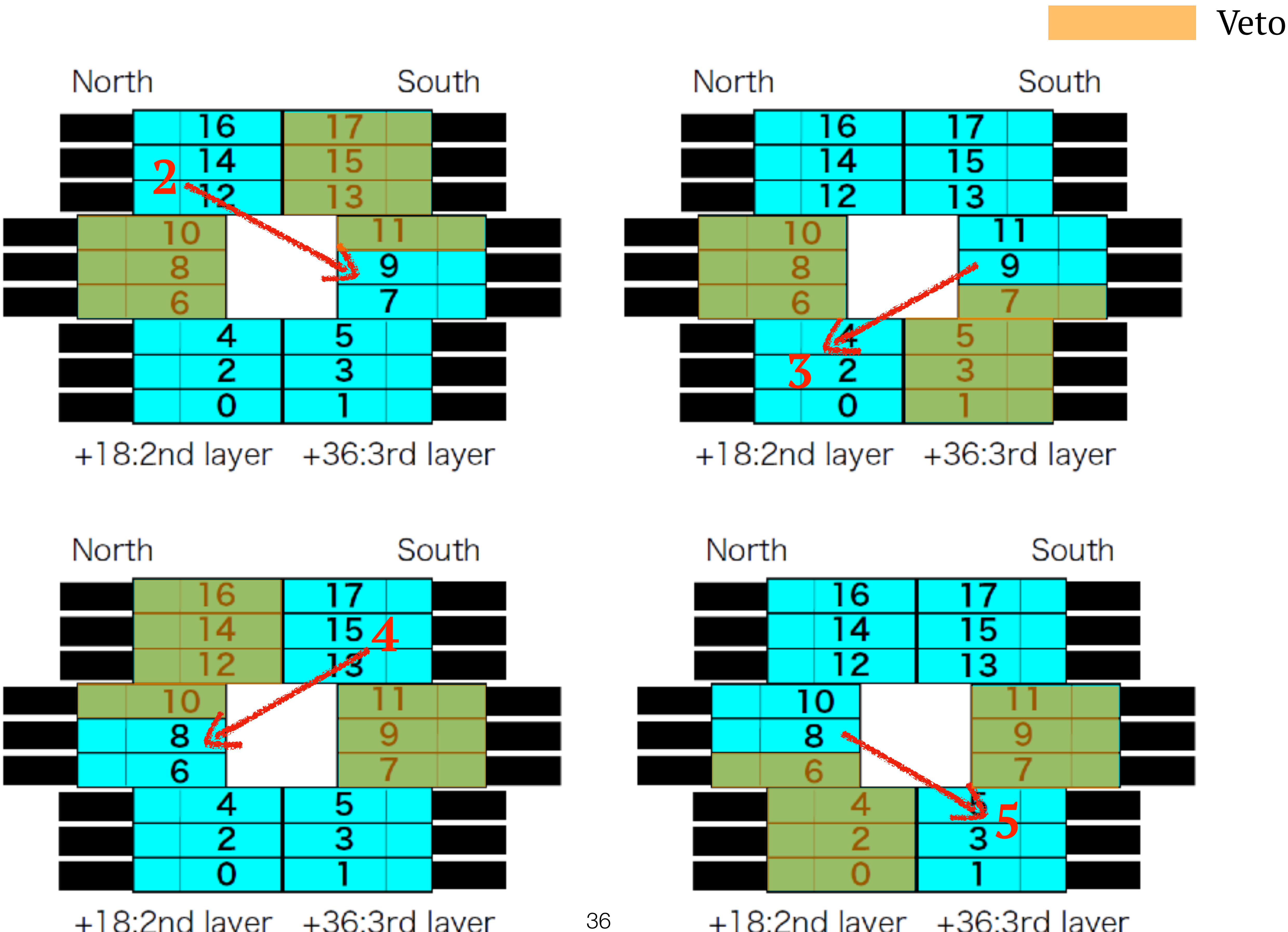
Assign the flag number for tracking the cosmic ray

Veto

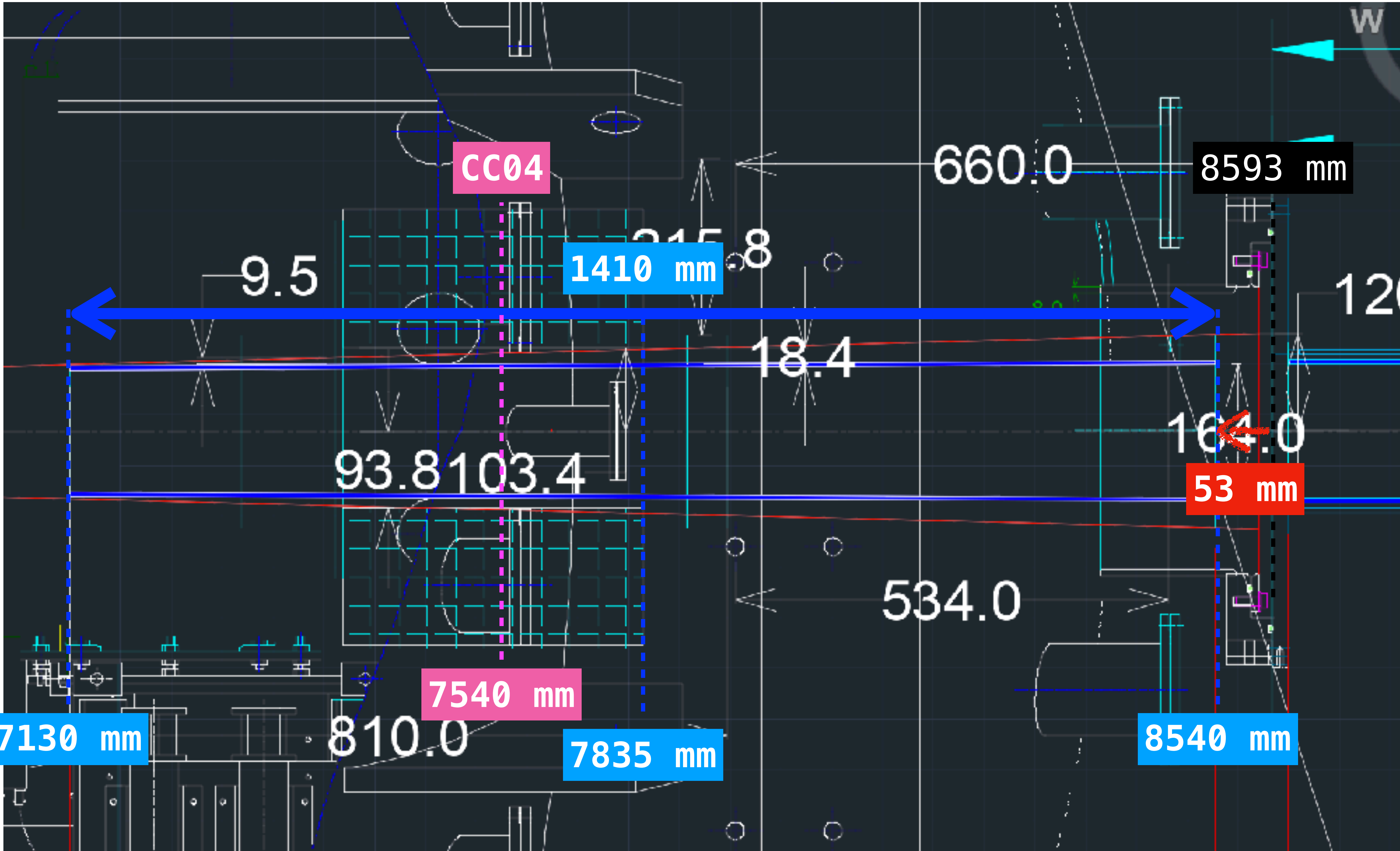


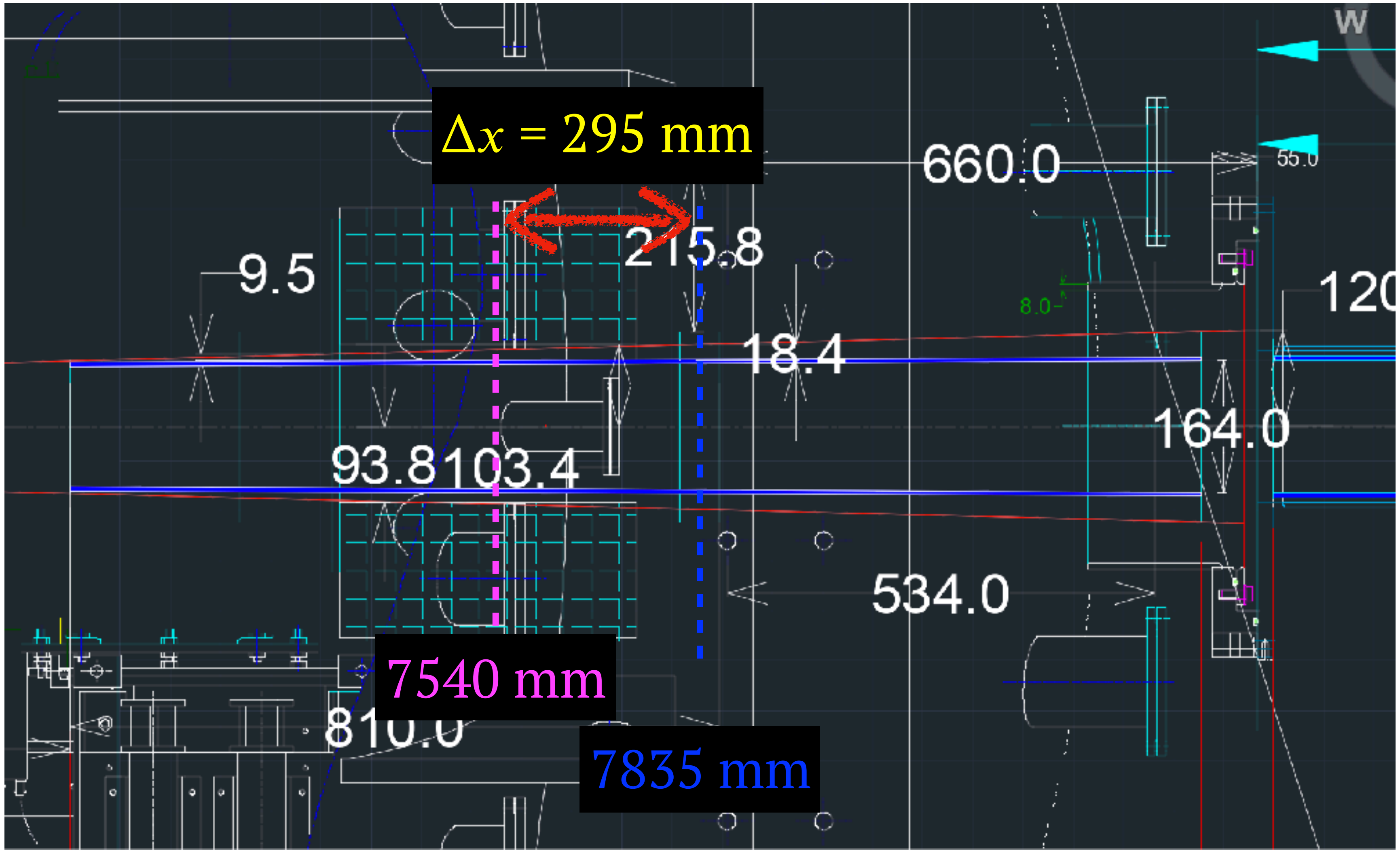


Assign the flag number for tracking the cosmic ray



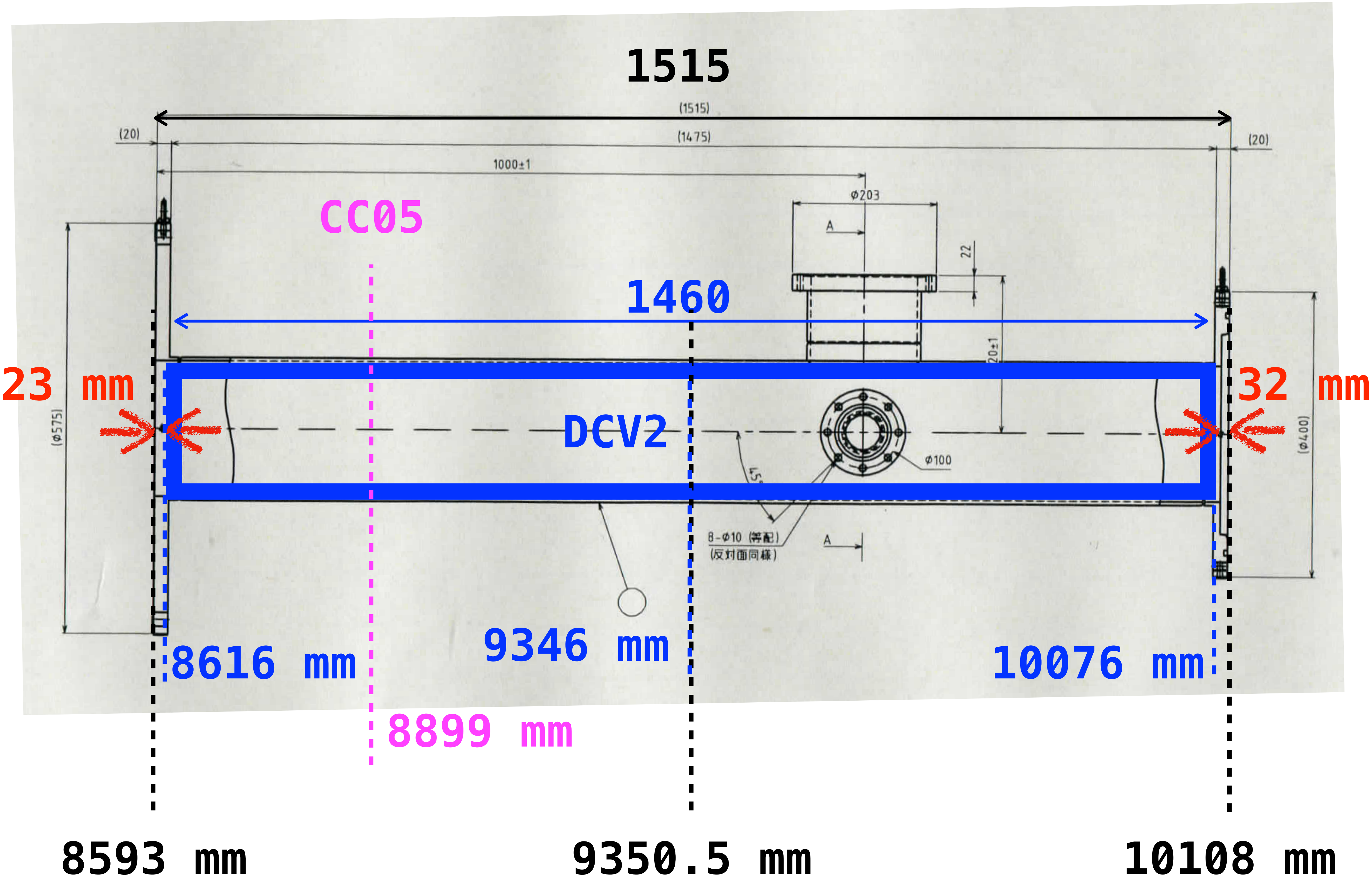
DCV1 Position

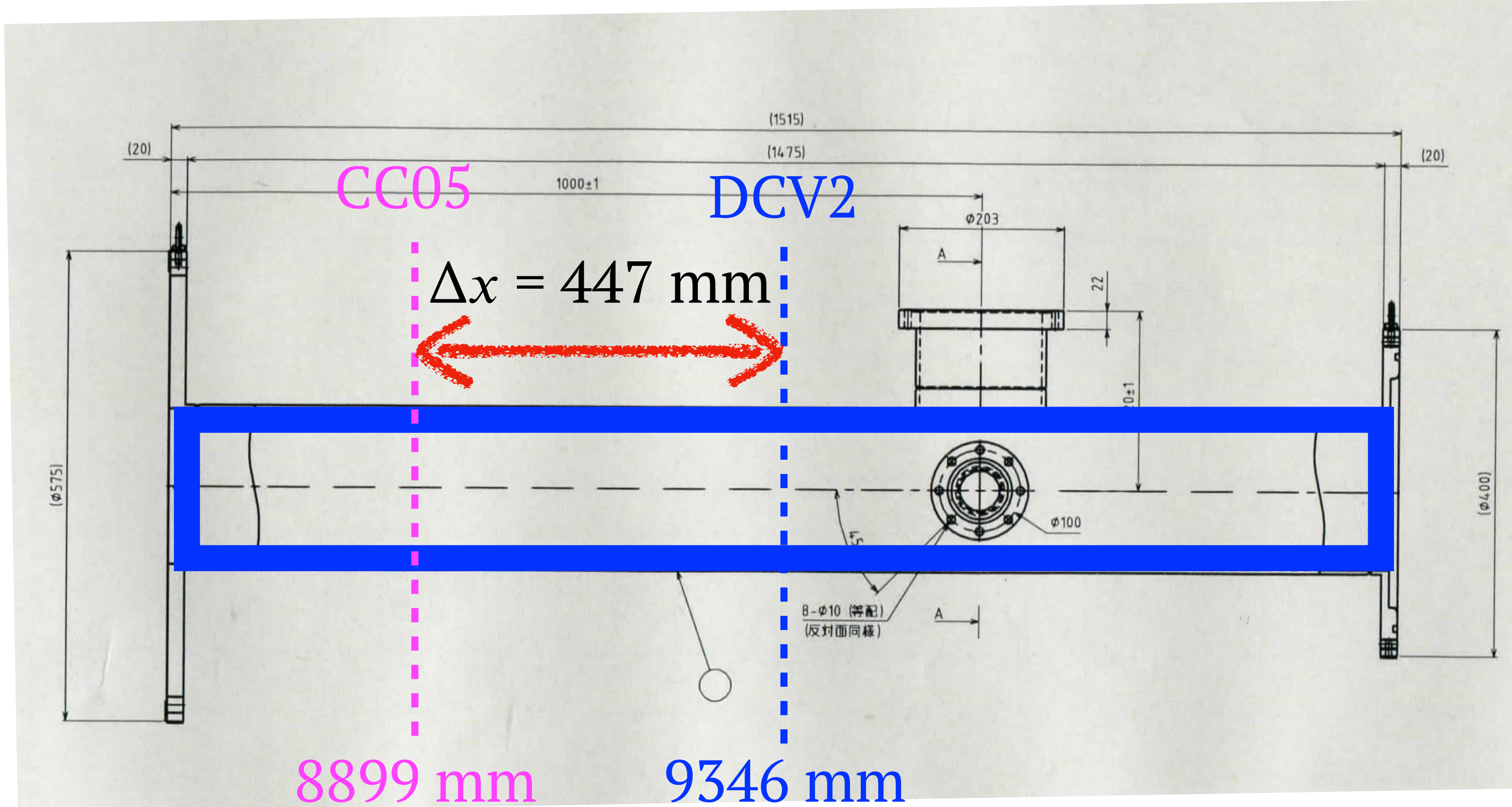





```
float lambda_dcv1 = 2469; // Attenuation Length of DCV1
float pos_DCV1 = 7835; // Center position of DCV1
float pos_CC04 = 7540; // Center position of CC04
float att1_f = exp((pos_DCV1 - pos_CC04)/lambda_dcv1);
float att1_r = exp(-(pos_DCV1 - pos_CC04)/lambda_dcv1);

float att[32] = {att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r };
```

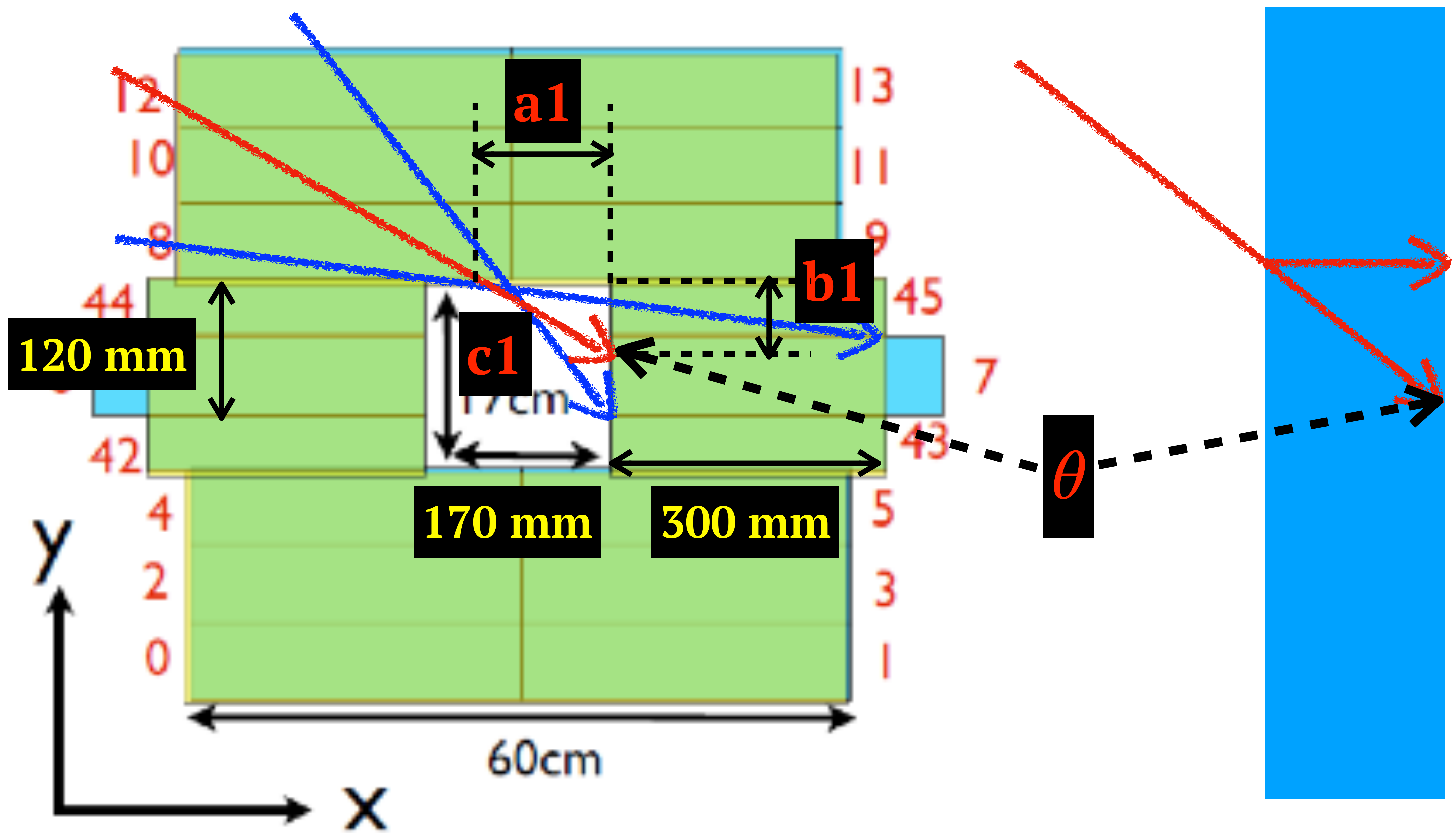
DCV2 Position





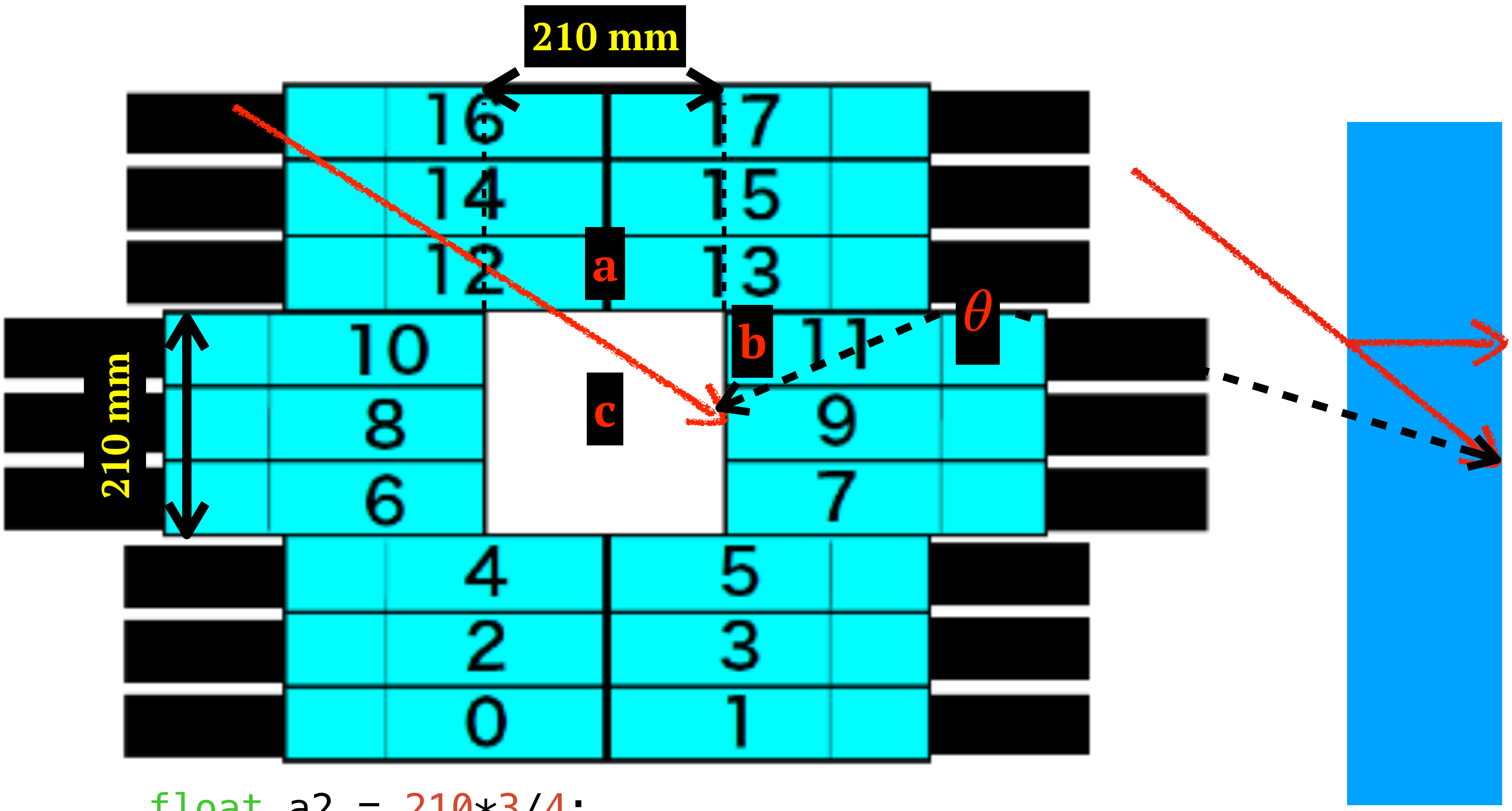

```
float lambda_dcv2 = 2567; // Attenuation Length of DCV2
float pos_DCV2 = 9346; // Center position of DCV2
float pos_CC05 = 8899; // Center position of CC05
float att2_f = exp((pos_DCV2 - pos_CC05)/lambda_dcv2);
float att2_r = exp(-(pos_DCV2 - pos_CC05)/lambda_dcv2);

float att[32] = {att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r };
```

Path length(DCV1)




```
float a1 = 170*3/4;
float x = 5*17/317;
float b1 = (x+120)/2;
float c1 = sqrt((a1*a1)+(b1*b1));
float sin1 = a1/c1;
```

Path length(DCV2)




```
float a2 = 210*3/4;
float b2 = 210/2;
float c2 = sqrt((a2*a2)+(b2*b2));

float sin2 = a/c;
```

Total calculation the calibration factors including path length

/home/had/hmkim/work/hmkim/run81/final_cal/out_cal/make_calib_factor.C

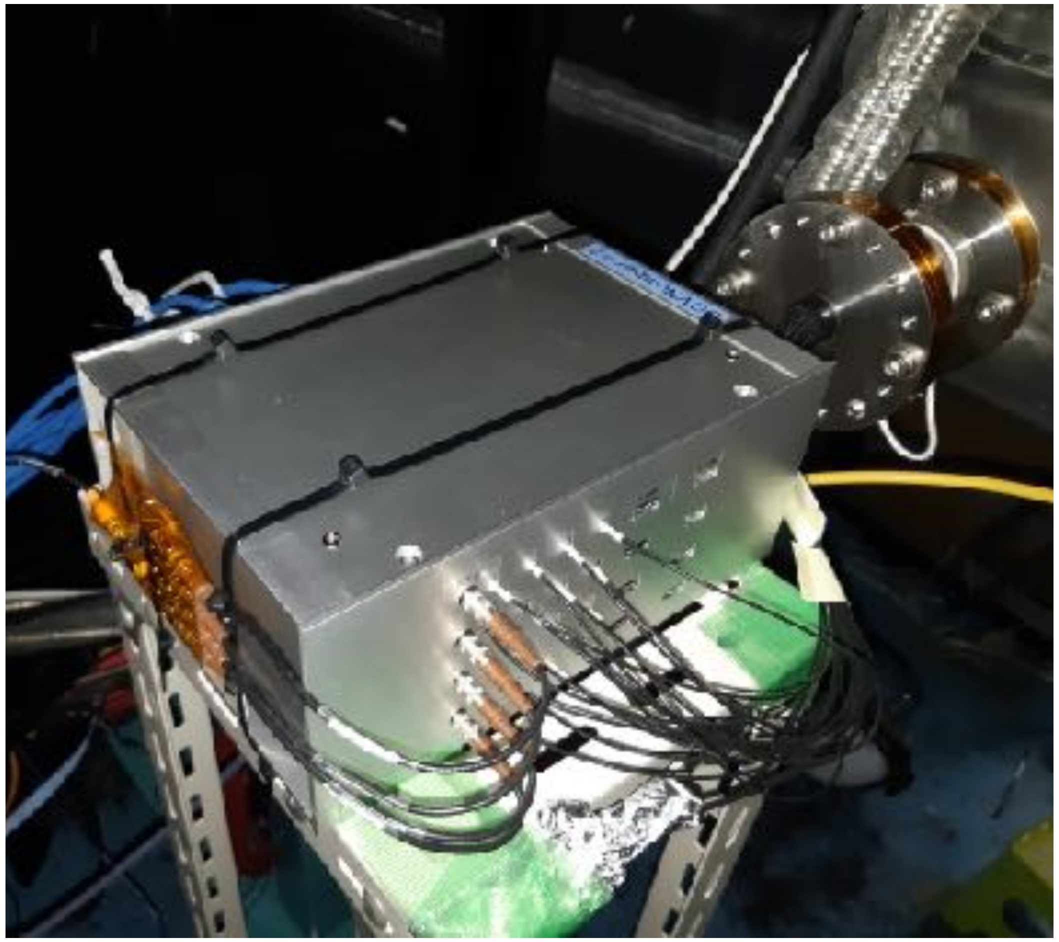
```
float gain[32] = {359.7,402.8,261.2,299.8,
                  328.5,282.1,258.7,206.,
                  327.4,417.2,244.1,294.5,
                  371.1,370.7,227.6,244.1,
                  301.2,340.2,220.4,226.3,
                  263.6,242.2,153.8,155.4,
                  284.2,256.8,173.3,172.1,
                  273.7,263.3,157.2,159.6 };

float norm[32] = {1.291,1.349,1.273,1.325,
                  1.179,1.202,1.185,1.181,
                  1.316,1.324,1.334,1.338,
                  1.178,1.195,1.167,1.182,
                  1.172,1.224,1.211,1.239,
                  1.145,1.132,1.214,1.221,
                  1.296,1.199,1.294,1.249,
                  1.129,1.168,1.161,1.219 };

float norm_module[32] = {2.01,2.083,2.01,2.083,
                         2.049,2.068,2.049,2.068,
                         2.012,2.018,2.012,2.018,
                         2.044,2.05,2.044,2.05,
                         2.01,2.023,2.01,2.023,
                         2.045,2.077,2.045,2.077,
                         2.044,2.007,2.044,2.007,
                         2.05,2.05,2.05,2.05      };
```

```
float lambda_dcv1 = 2469; // Attenuation Length of DCV1
float pos_DCV1 = 7835; // Center position of DCV1
float pos_CC04 = 7540; // Center position of CC04
float att1_f = exp((pos_DCV1 - pos_CC04)/lambda_dcv1);
float att1_r = exp(-(pos_DCV1 - pos_CC04)/lambda_dcv1);

float lambda_dcv2 = 2567; // Attenuation Length of DCV2
float pos_DCV2 = 9346; // Center position of DCV2
float pos_CC05 = 8899; // Center position of CC05
float att2_f = exp((pos_DCV2 - pos_CC05)/lambda_dcv2);
float att2_r = exp(-(pos_DCV2 - pos_CC05)/lambda_dcv2);

float att[32] = {att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att1_f,att1_f,att1_r,att1_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r,
                 att2_f,att2_f,att2_r,att2_r };
```

```
float a1 = 170*3/4;
float x = 5*17/317;
float b1 = (x+120)/2;
float c1 = sqrt((a1*a1)+(b1*b1));
float sin1 = a1/c1;

float a2 = 210*3/4;
float b2 = 210/2;
float c2 = sqrt((a2*a2)+(b2*b2));
float sin2 = a2/c2;

float path_length[32] =
      {sin1,sin1,sin1,sin1,
       1.,1.,1.,1.,
       sin1,sin1,sin1,sin1,
       1.,1.,1.,1.,
       sin2,sin2,sin2,sin2,
       1.,1.,1.,1.,
       sin2,sin2,sin2,sin2,
       1.,1.,1.,1. };
```

```
float calib_factor_wo_path[32];
float calib_factor[32];

for(int i=0;i<32;i++){
  calib_factor_wo_path[i] = att[i]/(gain[i] * norm[i] * norm_module[i]);
  calib_factor[i] = att[i]*path_length[i]/(gain[i] * norm[i] * norm_module[i]);
}
```


NO. 09



Run
Trig'd
Ch1 20.0mVΩ Ch2 20.0mVΩ M 100ns A Ch1 ↘-12.4mV
Ch3 20.0mVΩ Ch4 20.0mVΩ