Performance evaluation of the detector part for development of a Compton Camera

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Yamanaka Taku lab.

Sugiura Seiya　　Iwata Kazushi

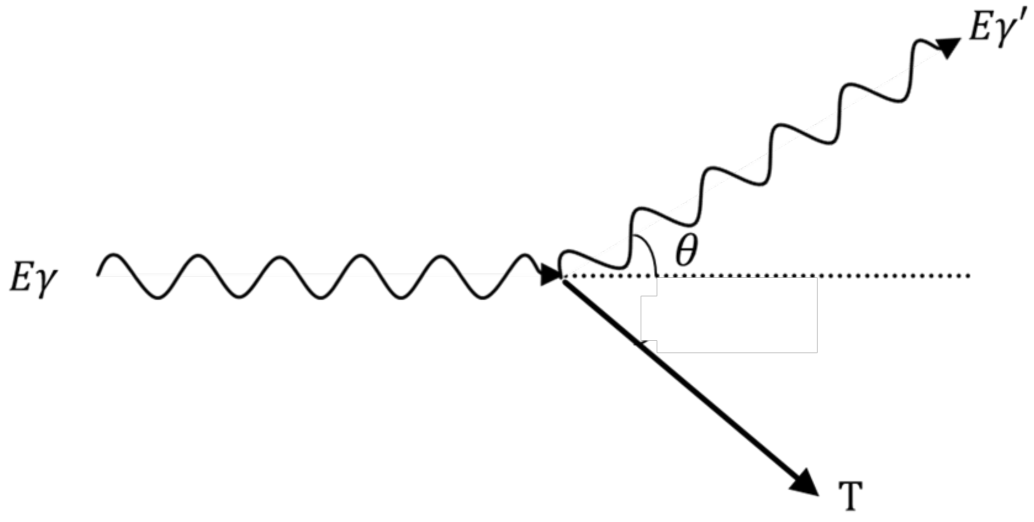
Principle first scintillator

- Compton scattering

$$E\gamma' = \frac{E\gamma}{1 + E\gamma/m_e(1 - cos\theta)} \qquad T = E_\gamma - E_\gamma' = E_\gamma \frac{E_\gamma/m_e(1 - cos\theta)}{1 + E_\gamma/m_e(1 - cos\theta)}$$

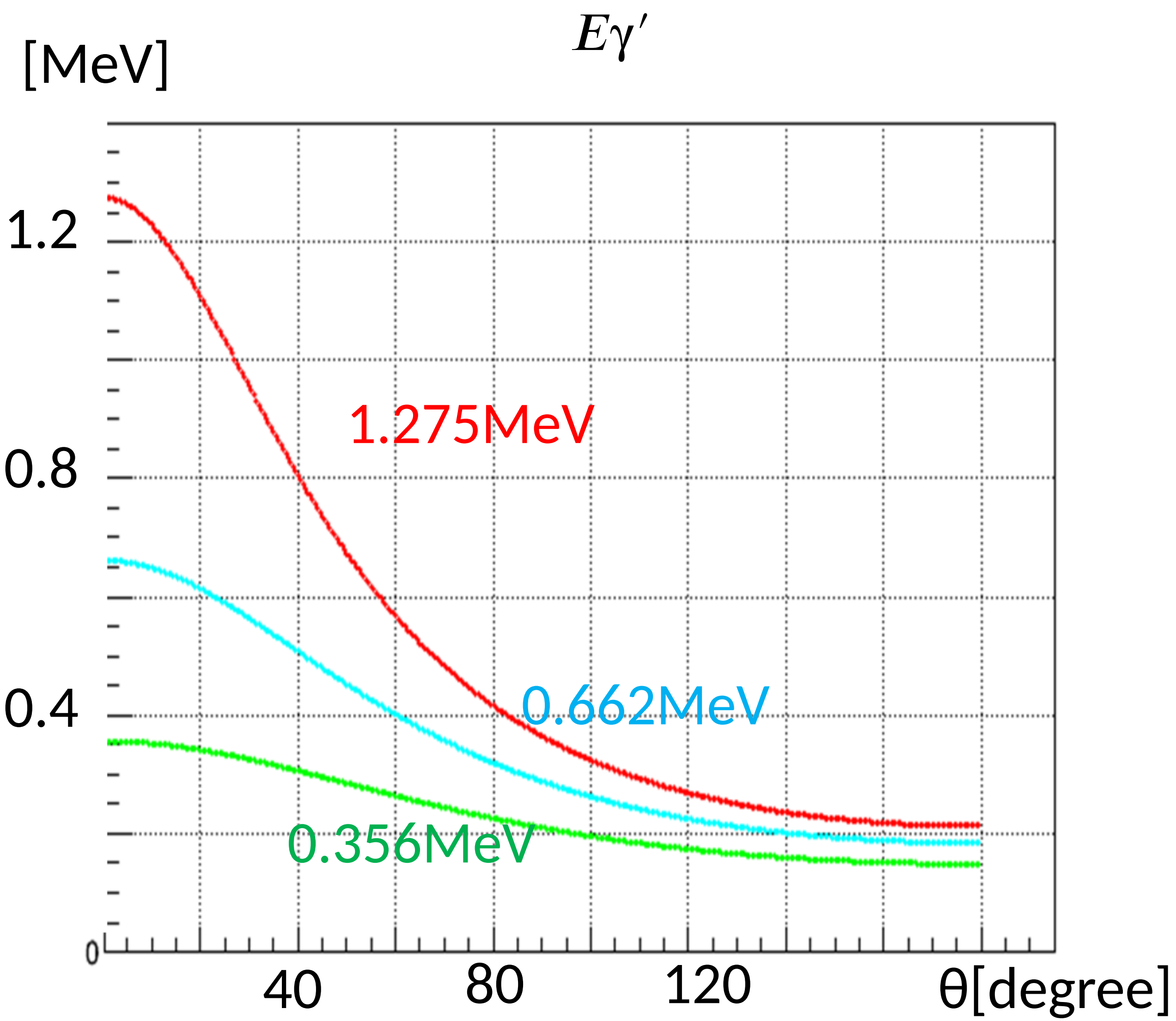
($E\gamma$, $E\gamma'$: energys of entering or scattered γ-ray T: energy of electron

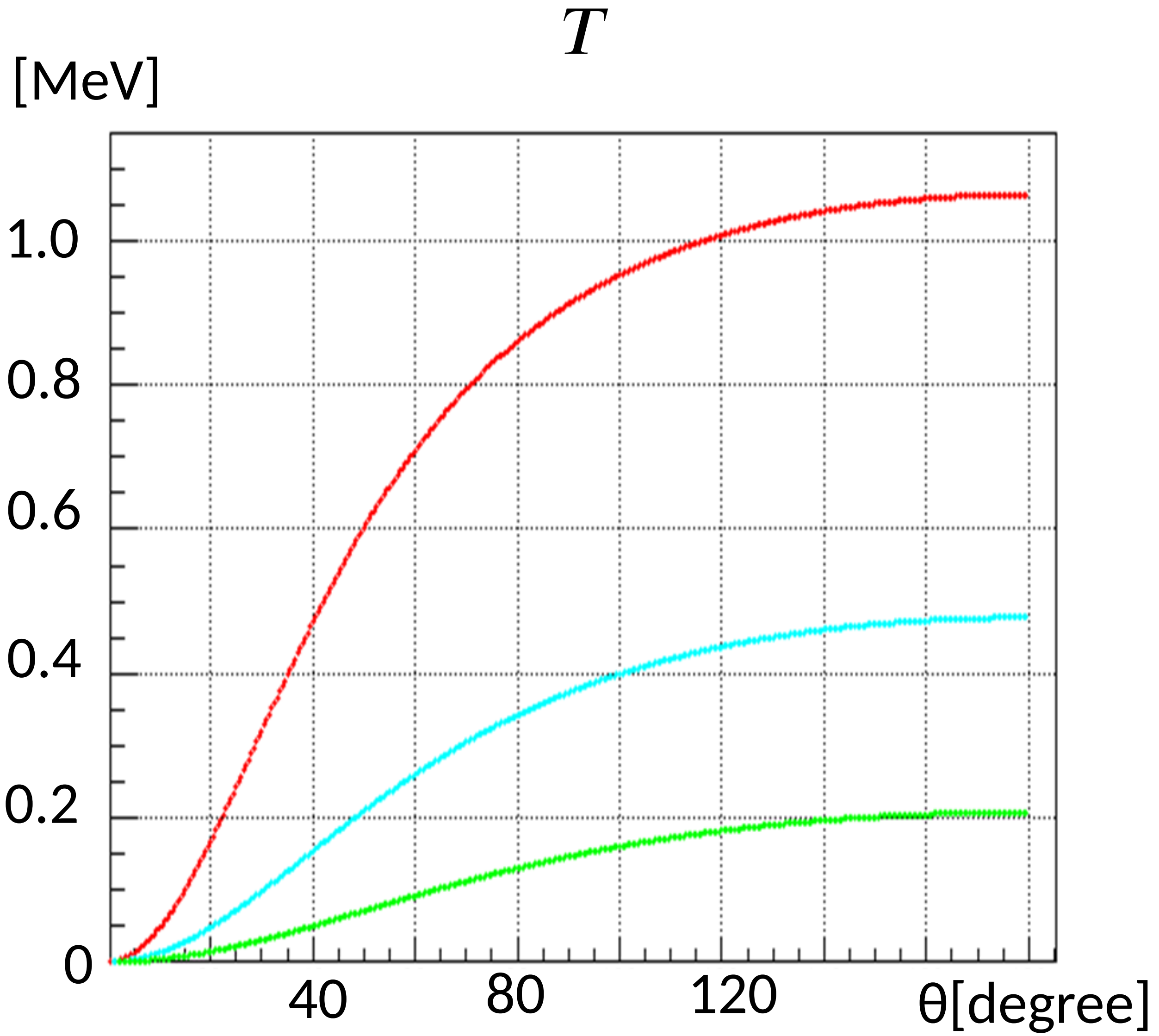
θ: scattered angle of γ-ray m_e: mass of electron 511keV)



E_γ' and $T \Rightarrow \Rightarrow \theta$

Performance evaluation



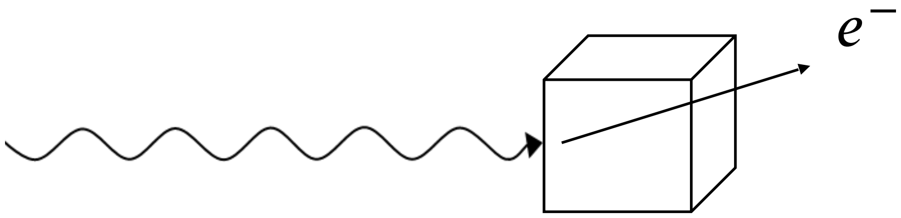


Principle   second scintillator

- Photoelectric effect

$$E = E'_\gamma - \mathrm{B.E.}$$

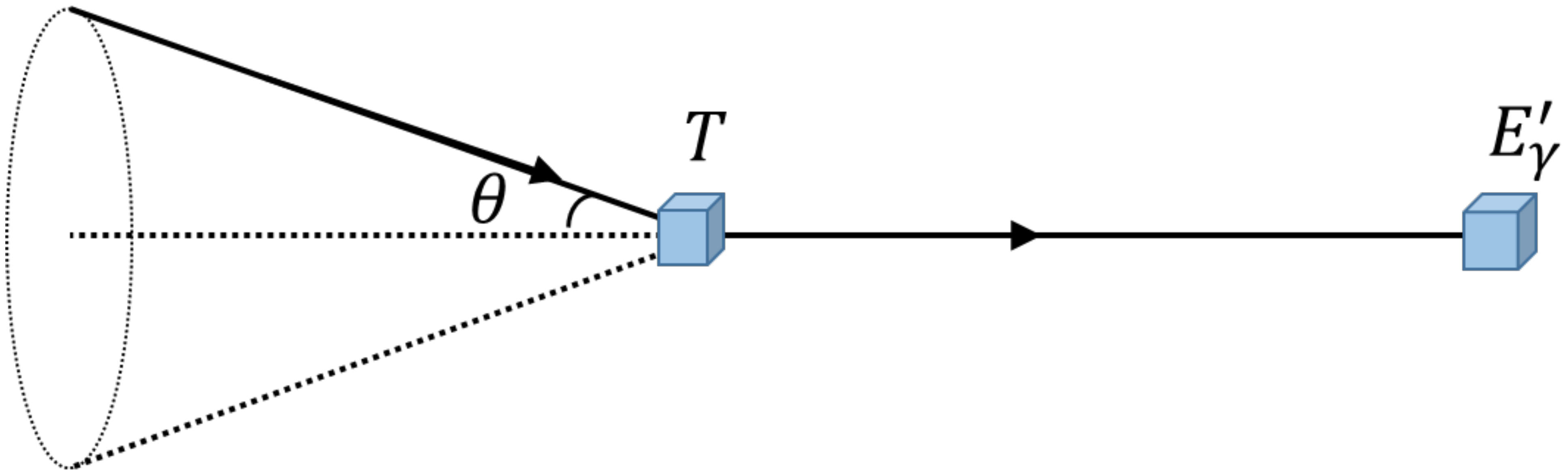
B.E. :binding energy



E and

$$B.E. \Rightarrow \Rightarrow E'_\gamma$$

Principle



Performance evaluation

Using CsI scintillator(10mm×10mm×10mm)

Evaluation

- Angular resolution
- Systematic error
- Needed event rate

Angler resolution

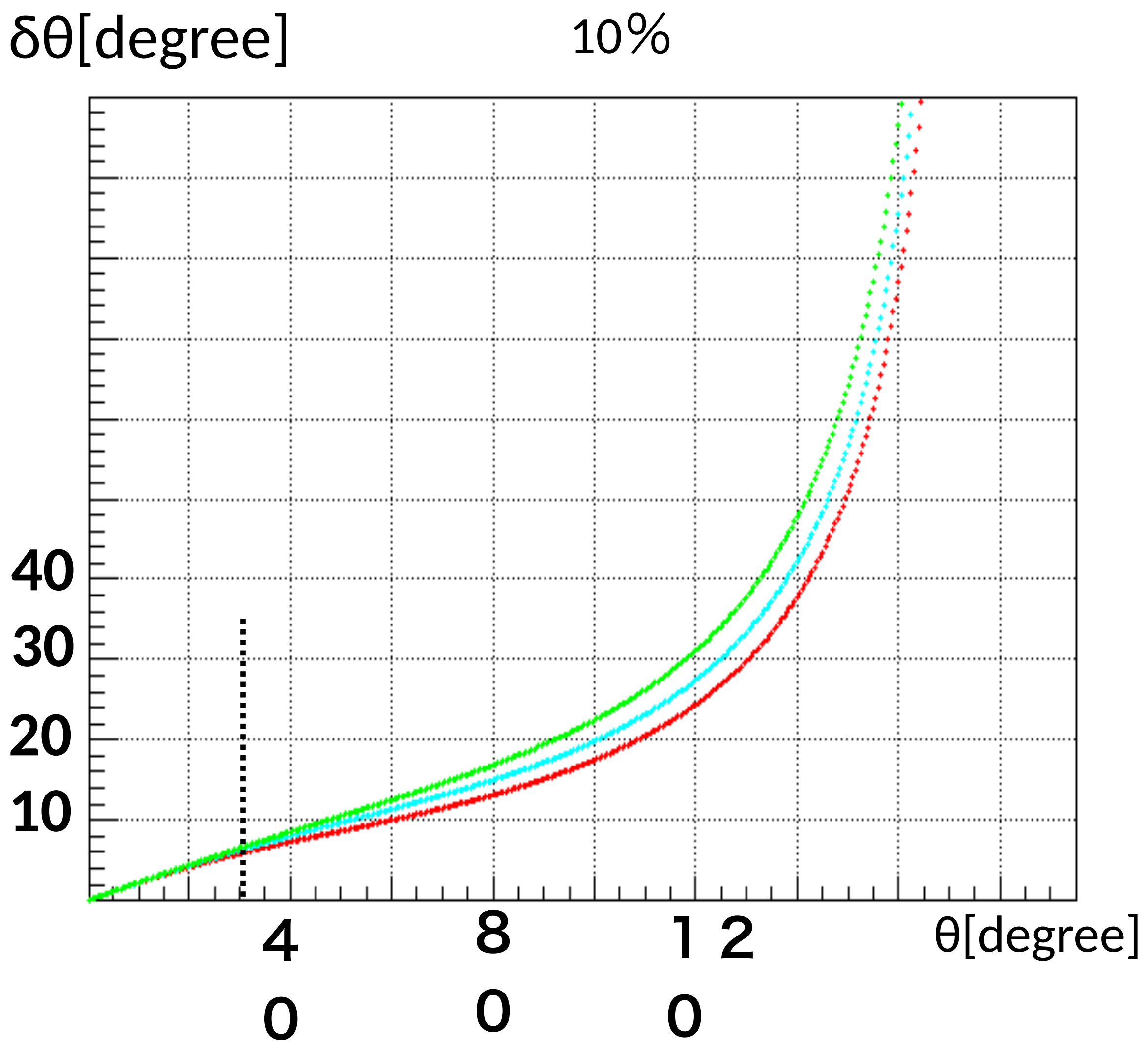
From Compton equation

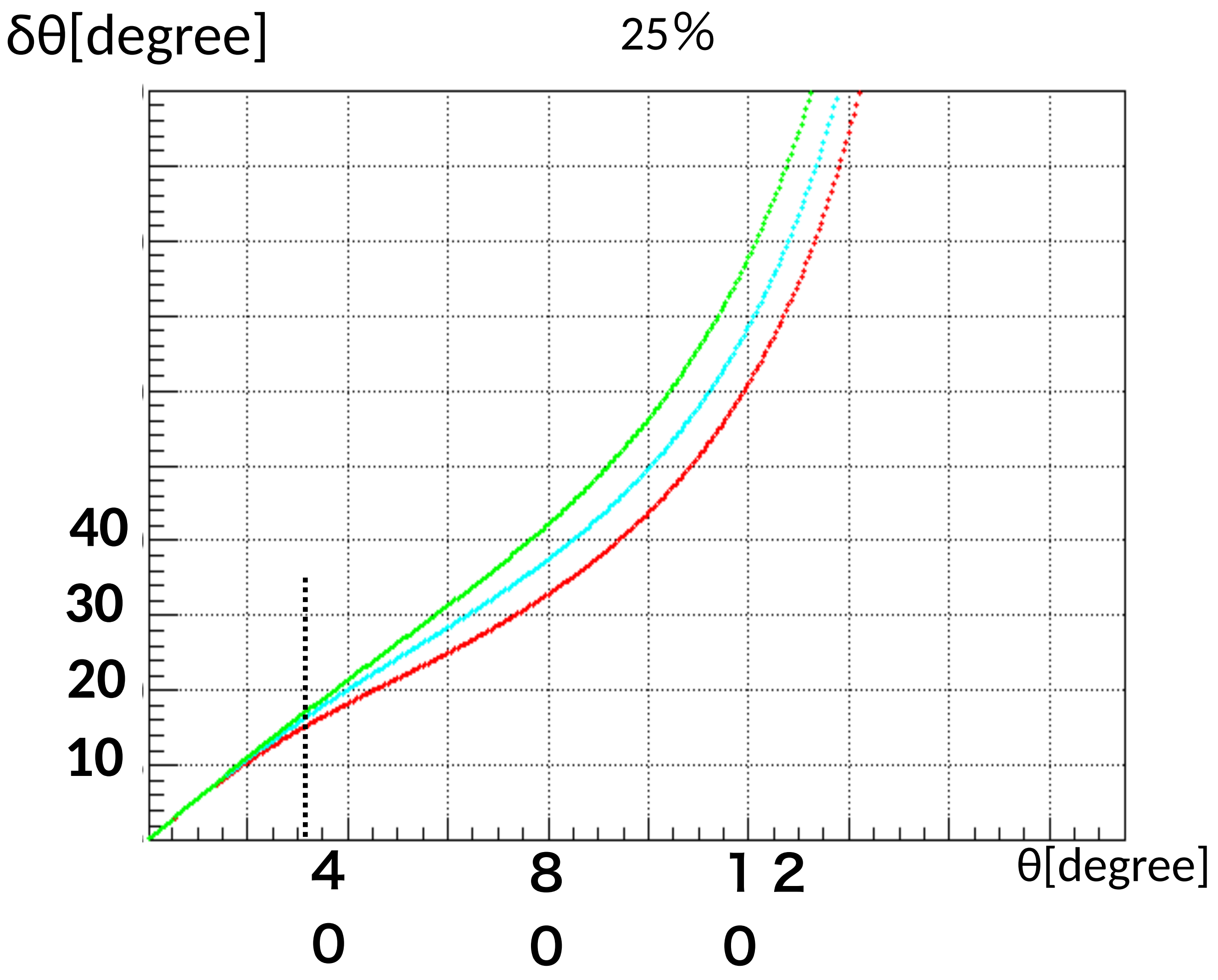
$$\frac{\delta(1-cos\theta)}{1-cos\theta} = \frac{1}{E'_\gamma + T}\sqrt{\left(2E'_\gamma + T\right)^2 \left(\frac{\delta E'_\gamma}{E'_\gamma}\right)^2 + E'^2_\gamma \left(\frac{\delta T}{T}\right)^2}$$

also

$$\delta\theta = \frac{1-cos\theta}{sin\theta} \times \frac{\delta(1-cos\theta)}{1-cos\theta}$$

Angler resolution





Estimate event rates

Factors of event rates are

- Compton Scattering and Photoelectric rates
- Length between radioactive source and first detector, and first detector and second detector

Estimate event rates

The intensity of photon

$$I = I_0 e^{-\mu x}$$

μ :absorption coefficient [1/cm]

$$\mu = N\sigma = N(Z\sigma_{\text{comp}} + \Phi_{\text{photo}} + \tau_{\text{pair}})$$

N: number density of atom or molucule [1/cm^3]

σ_{comp}:Compton scattering[1/cm^2]

Φ_{photo}:photoelectric effect[1/cm^2]

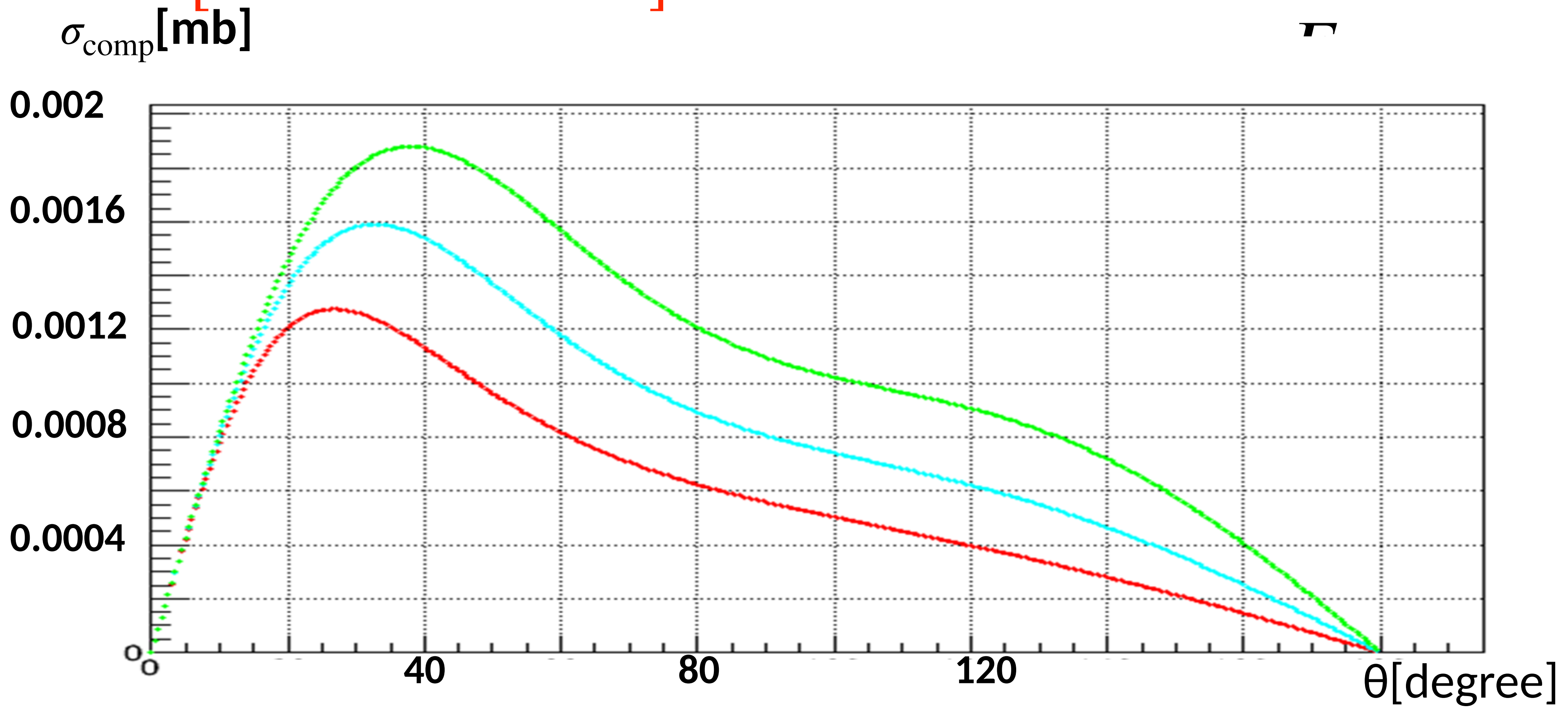
τ_{pair}:pair production[1/cm^2]

$E\gamma <$ 1.022MeV ➡ $\tau_{\text{pair}} = 0$

Estimate event rates

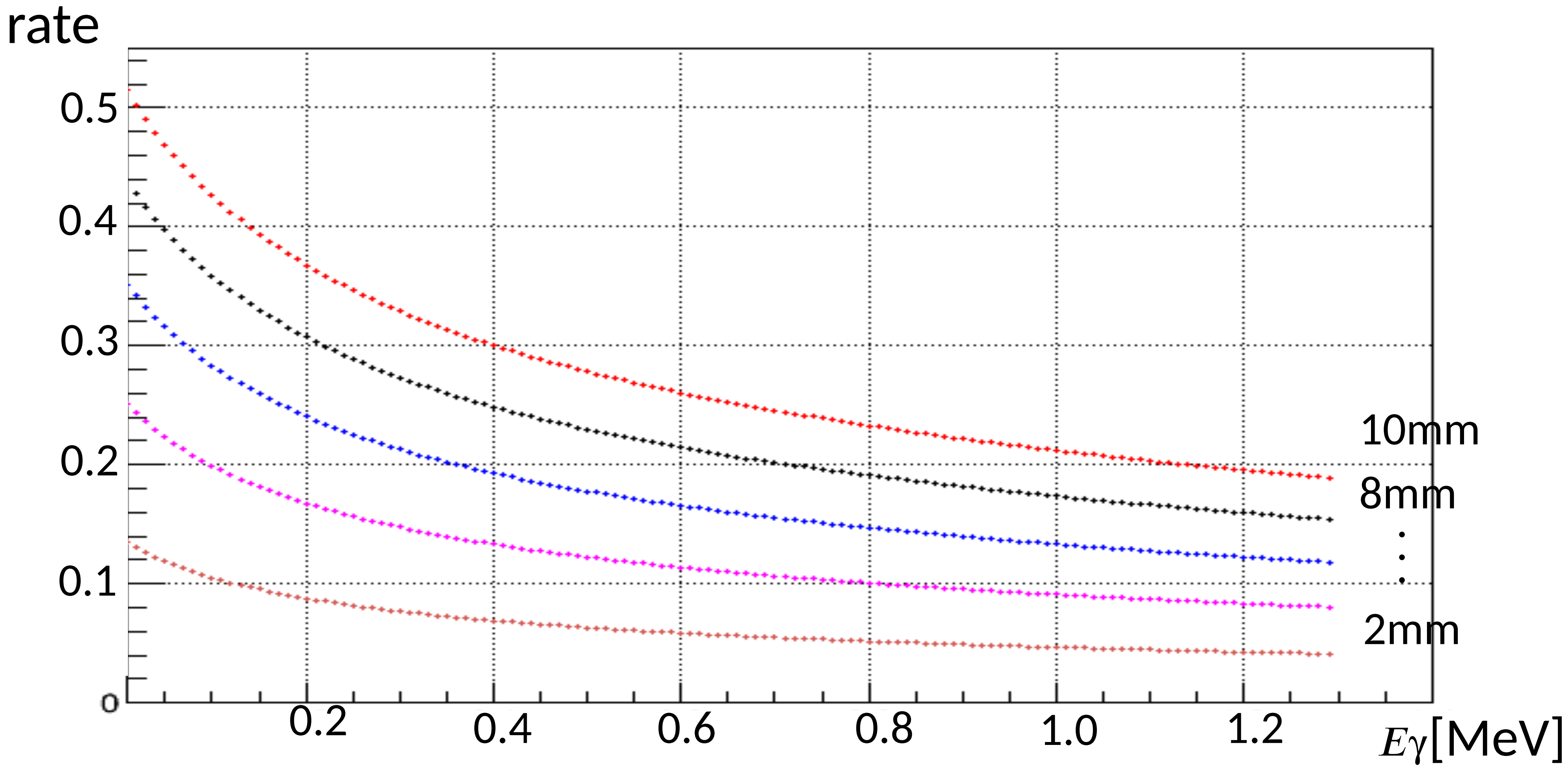
Klein-Nishina formula

$$\frac{d\sigma}{d\Omega} = \frac{r_e{}^2}{2}\frac{1}{[1 + a(1 - cos\theta)]^2}(1 + cos^2\theta + \frac{a^2(1 - cos\theta)^2}{1 + a(1 - cos\theta)})$$



Estimate event rates

In ScI scintillator



Hardware part

Detector

- CsI crystal

CsI (Tl) (Reading Edge Algorithms)
size:10mm×10mm×10mm

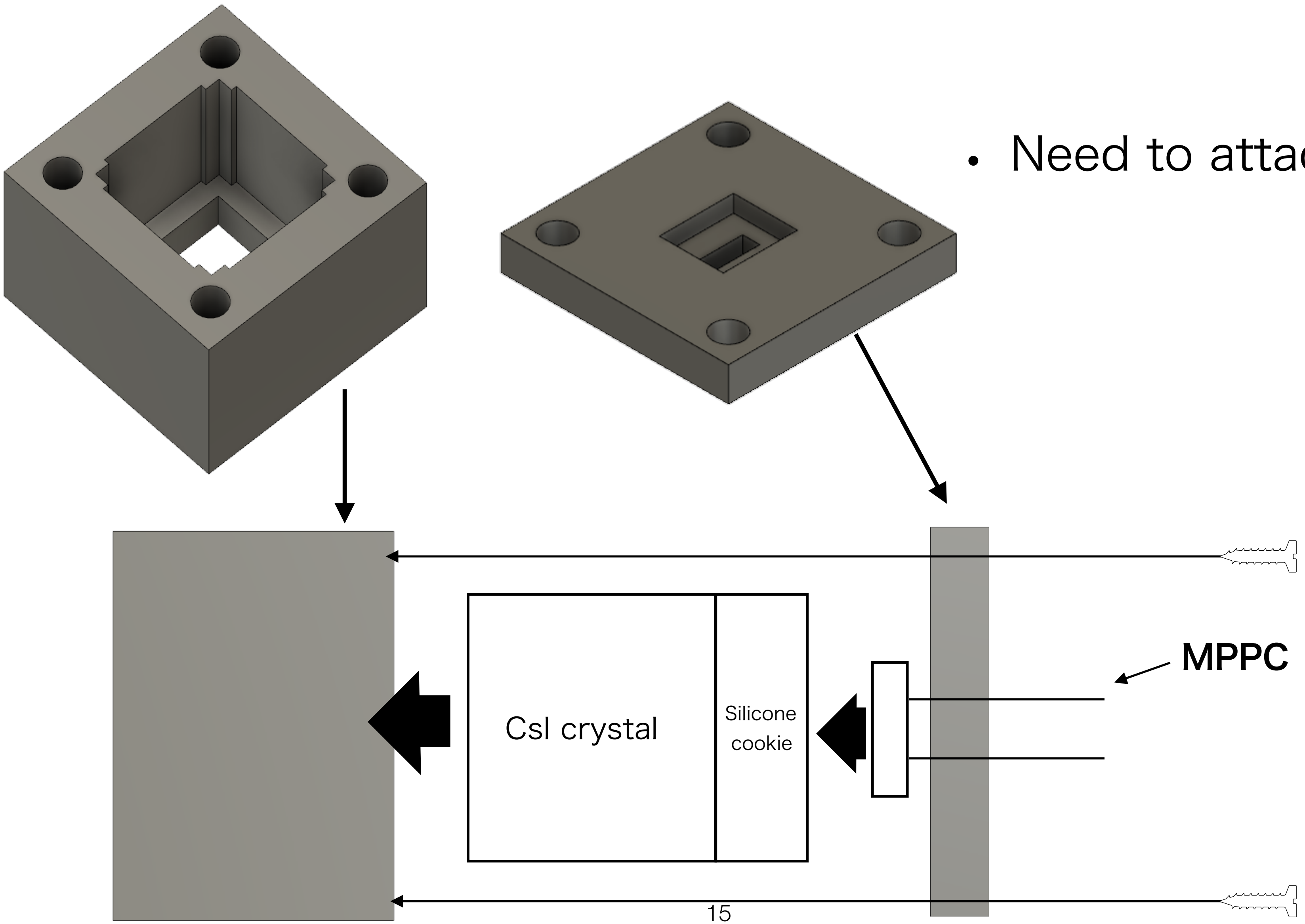
- MPPC

S13360-1325CS (HAMAMATSU)
photosensitive area :1.3mm×1.3mm
pixel pitch : 25um

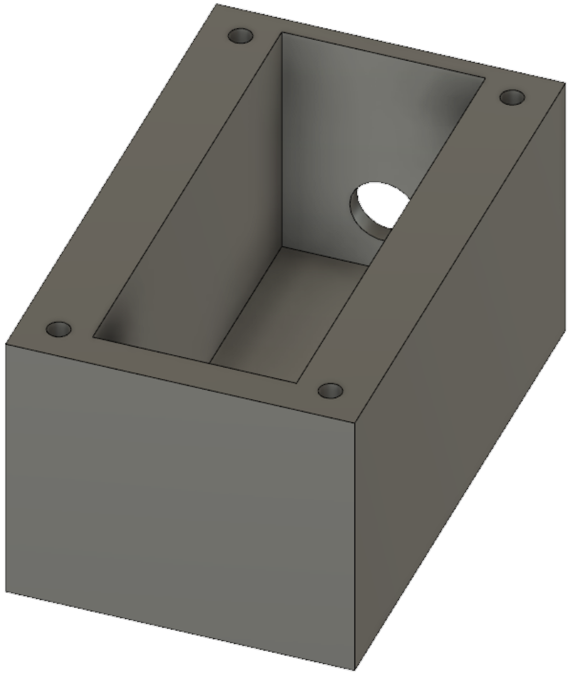
→We need a detector with MPPC and CsI

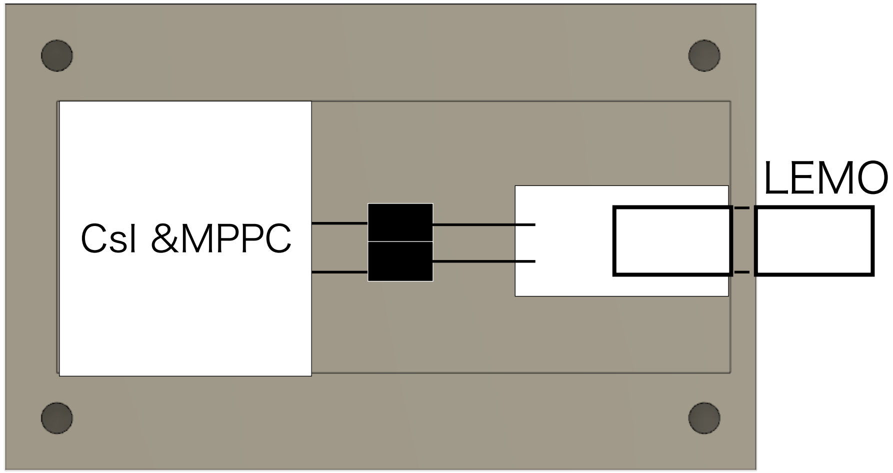
CsI and MPPC

- Need to attach CsI and MPPC



BOX

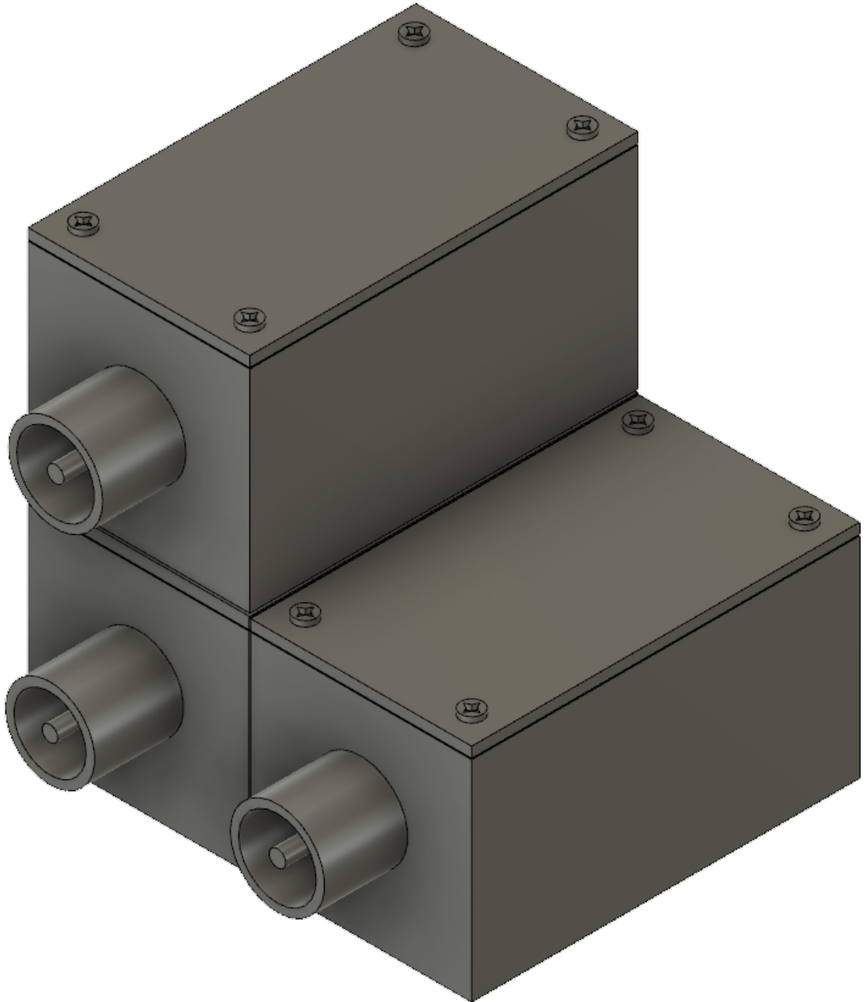




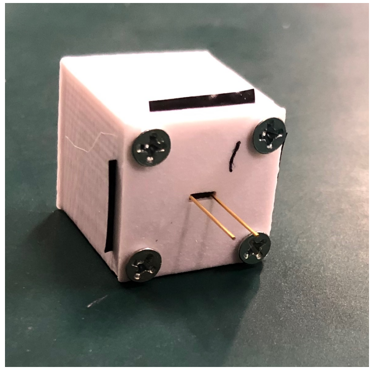
top view

- Box is filled silica gel because CsI is weak to humidity
- Use LEMO connector for easily detachable feature

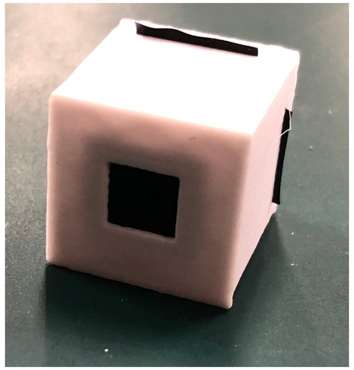
- Stack like this



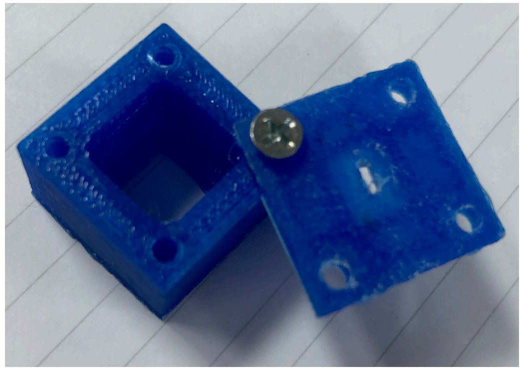
CsI and MPPC and BOX



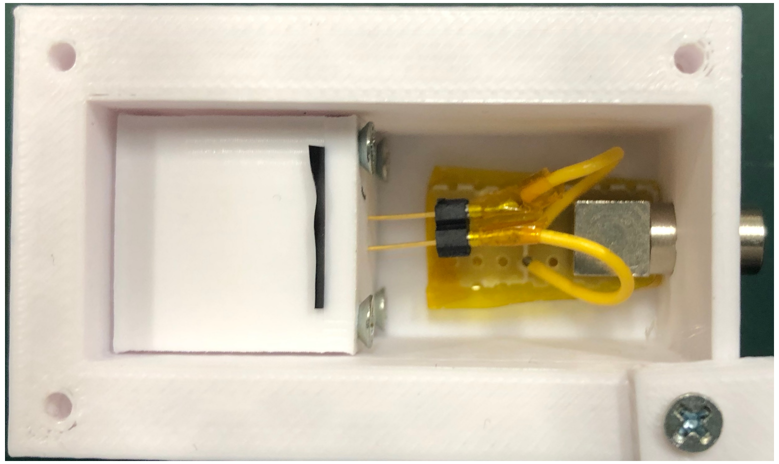
assembly



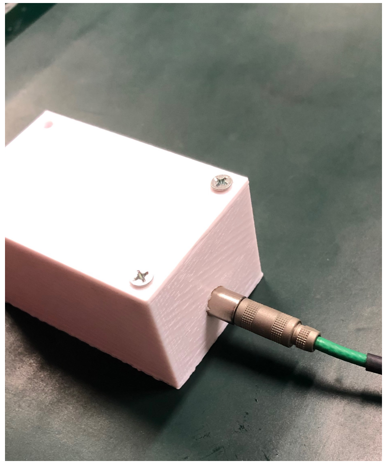
behind



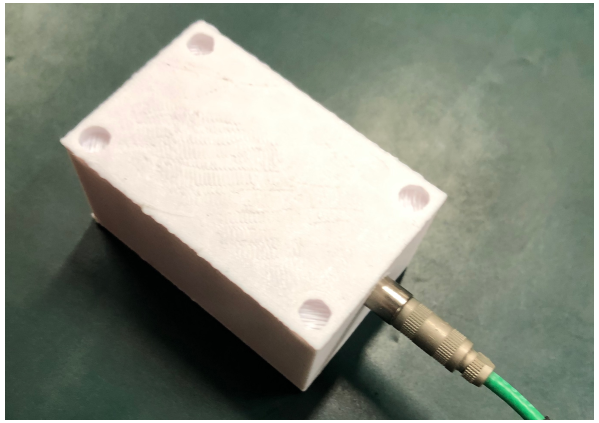
CsI and MPPC



inside the box



appearance



behind

EASIROC MODULE

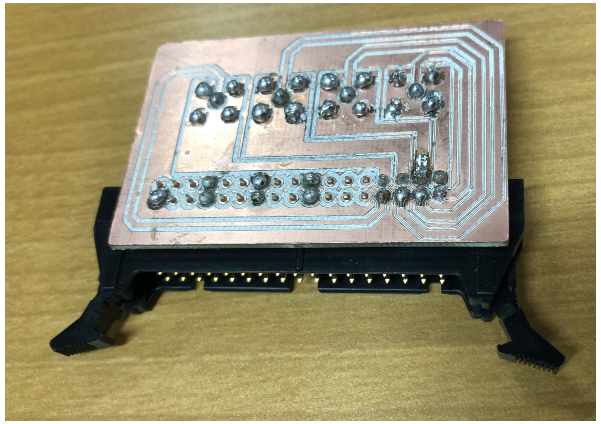
- NIM EASIROC MODULE

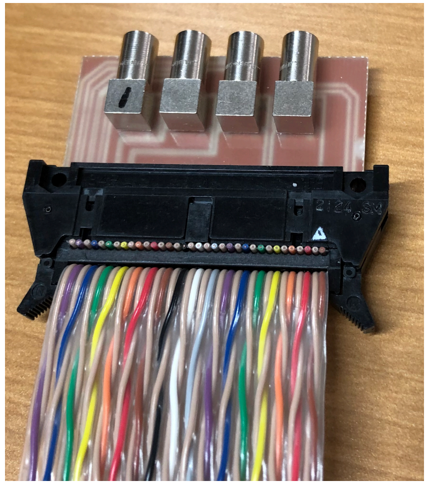
  →64 MPPCs can be operated simultaneously

This module uses Flat cable

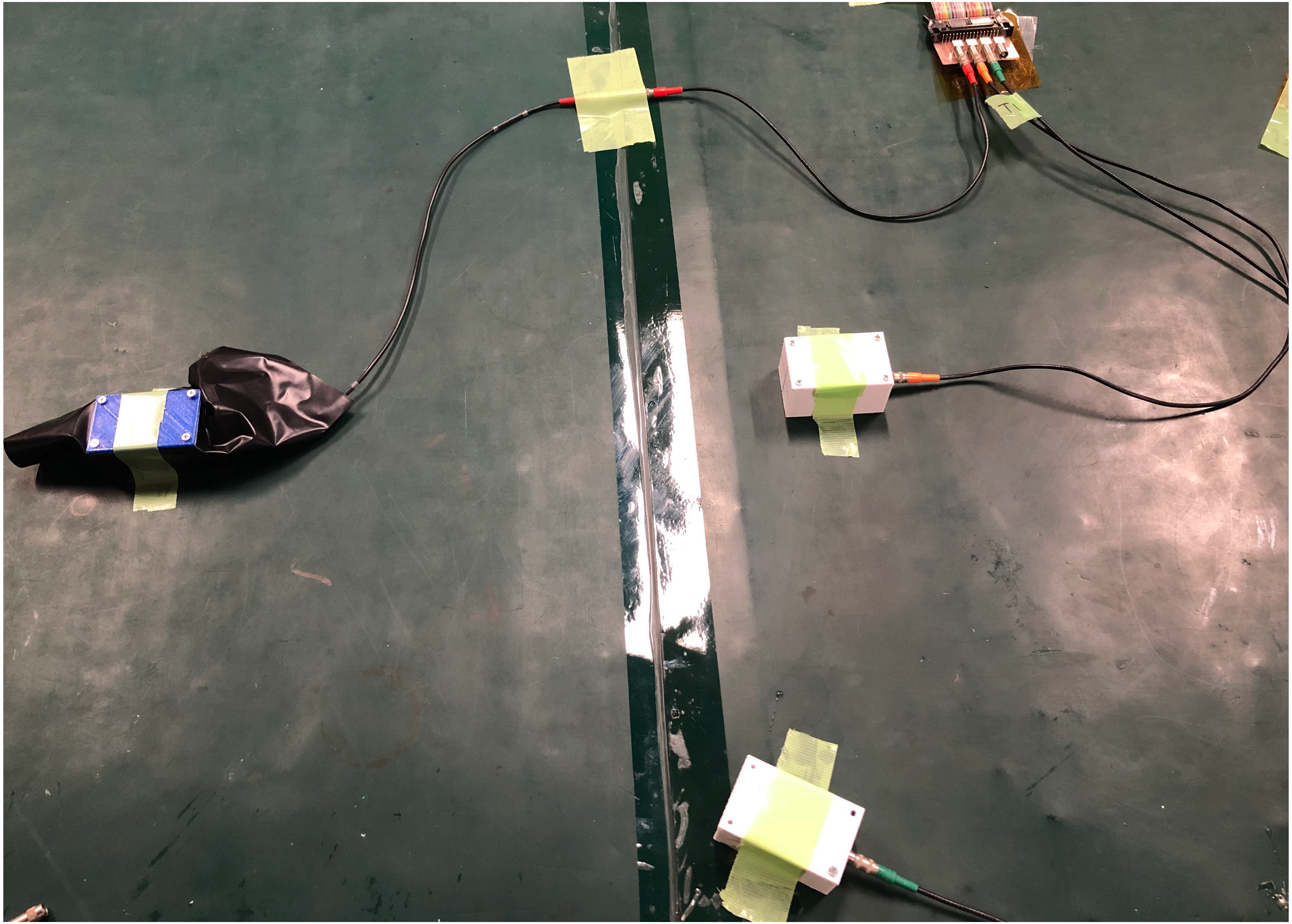
↓

Made a Flat cable to LEMO adapter board



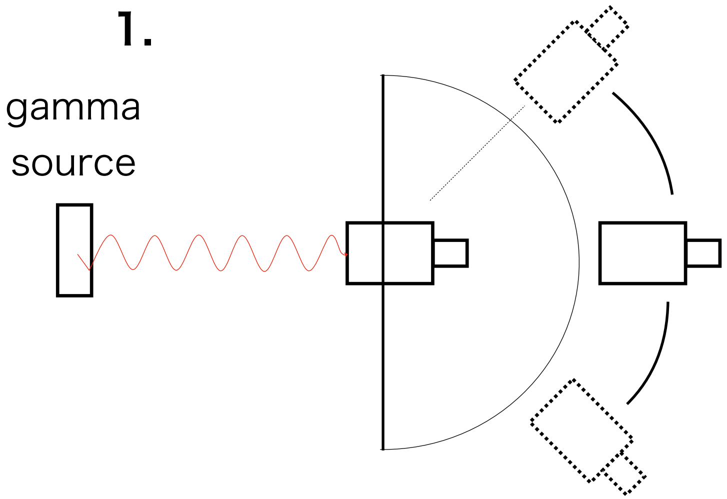


Set up

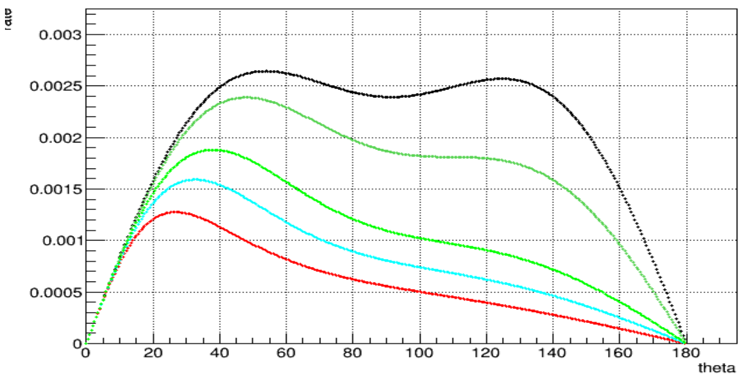


Future prospect

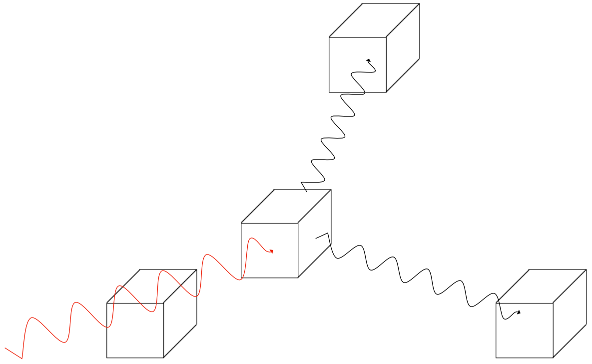
1.



- Measure the angular distribution



2.



- Measure the location of gamma source

conclusion

- Error and the rate were calculated
- we have the necessary equipment

We shall specify the location of source!!

Back Up

Performance evaluation

Prepared sources for test

source	**γ energy**	**Emission prob. Per decay**	**Radioactivity**
Na	1.275 MeV	100 %	496.02 kBq
Cs	0.662 MeV	85%	91.09 kBq
Ba	0.356 MeV	62%	716.69 kBq

Angler resolution

From Compton equation

$$1 - cos\theta = \frac{Tm_e}{(T + E_\gamma{}')E_\gamma{}'}$$

And error propagation

$$\frac{\delta(1 - cos\theta)}{1 - cos\theta} = \frac{1}{E'_\gamma + T}\sqrt{\left(2E'_\gamma + T\right)^2 \left(\frac{\delta E'_\gamma}{E'_\gamma}\right)^2 + E'^2_\gamma \left(\frac{\delta T}{T}\right)^2}$$

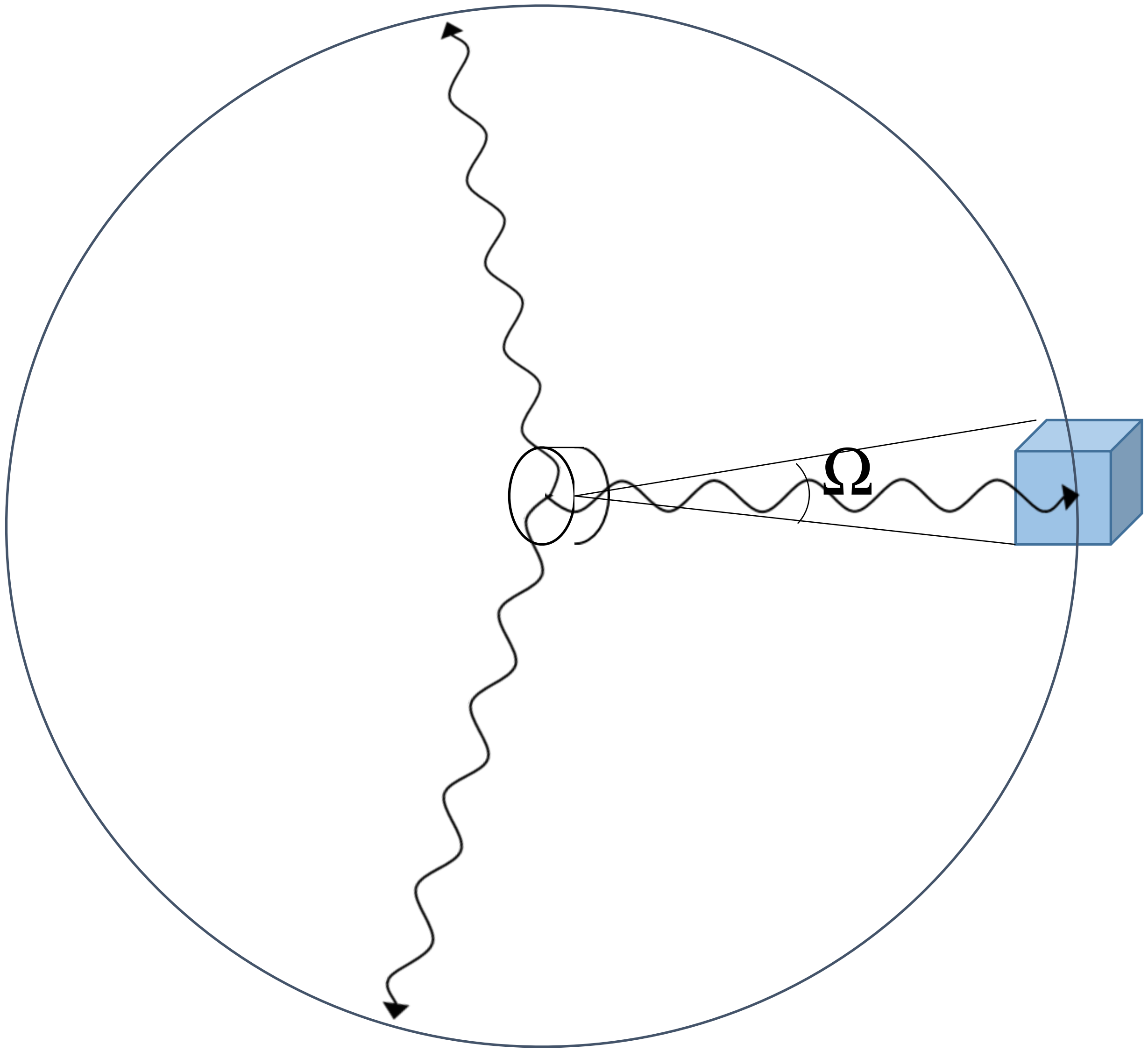
Also

$$\delta(1 - cos\theta) = sin\theta\delta\theta$$

From the above

$$\delta\theta = \frac{1 - cos\theta}{sin\theta} \times \frac{\delta(1 - cos\theta)}{1 - cos\theta}$$

Estimate event rates



$$\left(Radioactivity\right) \times \frac{r^2\Omega}{4\pi r^2}$$

Estimate event rates

Klein-Nishina formula

$$\frac{d\sigma}{d\Omega} = \frac{{r_e}^2}{2}\frac{1}{\left[1 + a(1 - cos\theta)\right]^2}(1 + cos^2\theta + \frac{a^2(1 - cos\theta)^2}{1 + a(1 - cos\theta)})$$

$r_e = 2.81 \times 10^{-15}$[m] classical electron radius,

$$a = \frac{E_\gamma}{m_e}$$

and total cross section is

$$\sigma_c = 2\pi {r_e}^2 \left\{ \frac{1 + a}{a^2}\left[\frac{2(1 + a)}{1 + 2a} - \frac{1}{a}\ln(1 + 2a)\right] + \frac{1}{2a}\ln(1 + 2a) - \frac{1 + 3a}{(1 + 2a)^2} \right\}$$

Estimate event rates

Two boxes are made with
Polylactide($(C_3H_4O_2)_n$)
Molecular weight 72n [g/mol]

thickness 0.2cm ×2

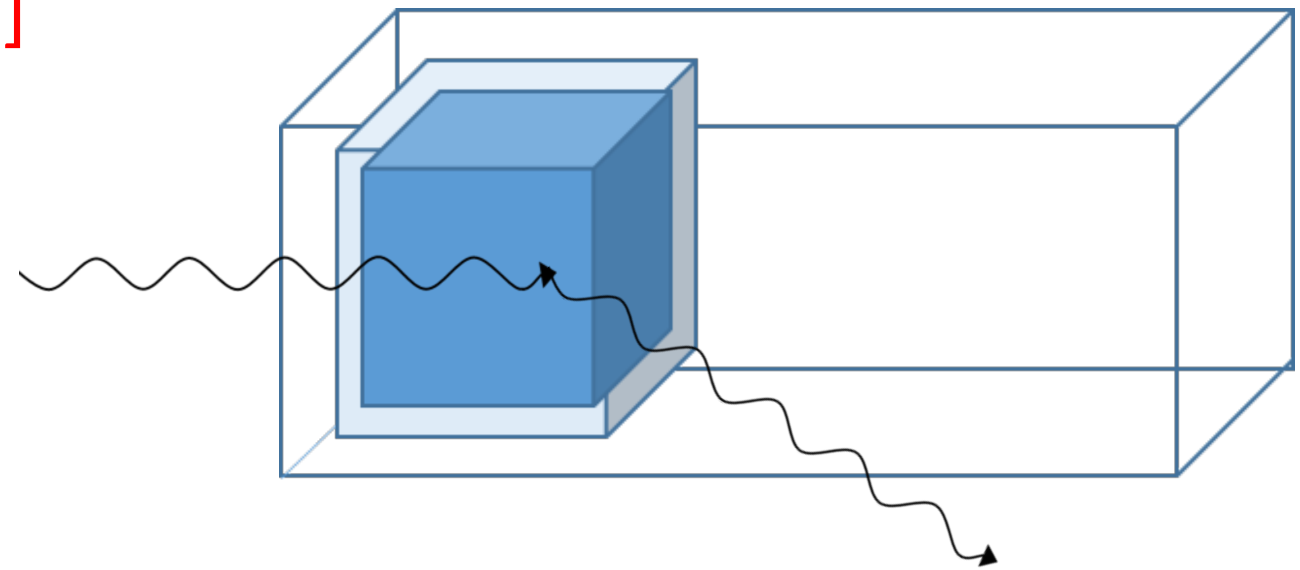
density 1.25g/cm^3

➡Number density of electron

$$n = NZ = \frac{1.25}{72} \times (6.02 \times 10^{23}) \times 38$$

$$= 3.97 \times 10^{23}\ [1/\mathrm{cm}^3]$$

Each of the scintillators is in two boxes



Transmittance

$$e^{-0.4n\sigma_c}$$

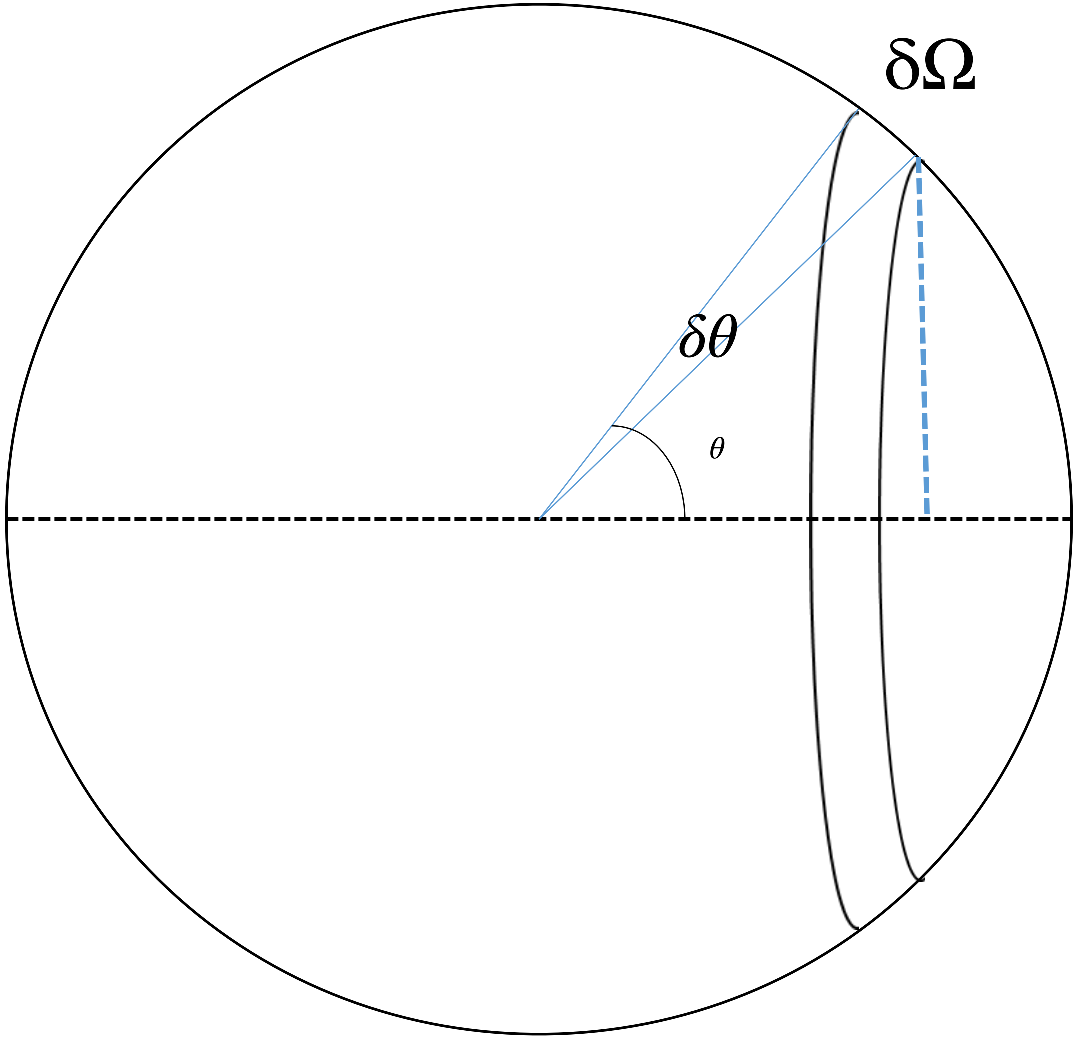
Estimate event rates

Solid Angle

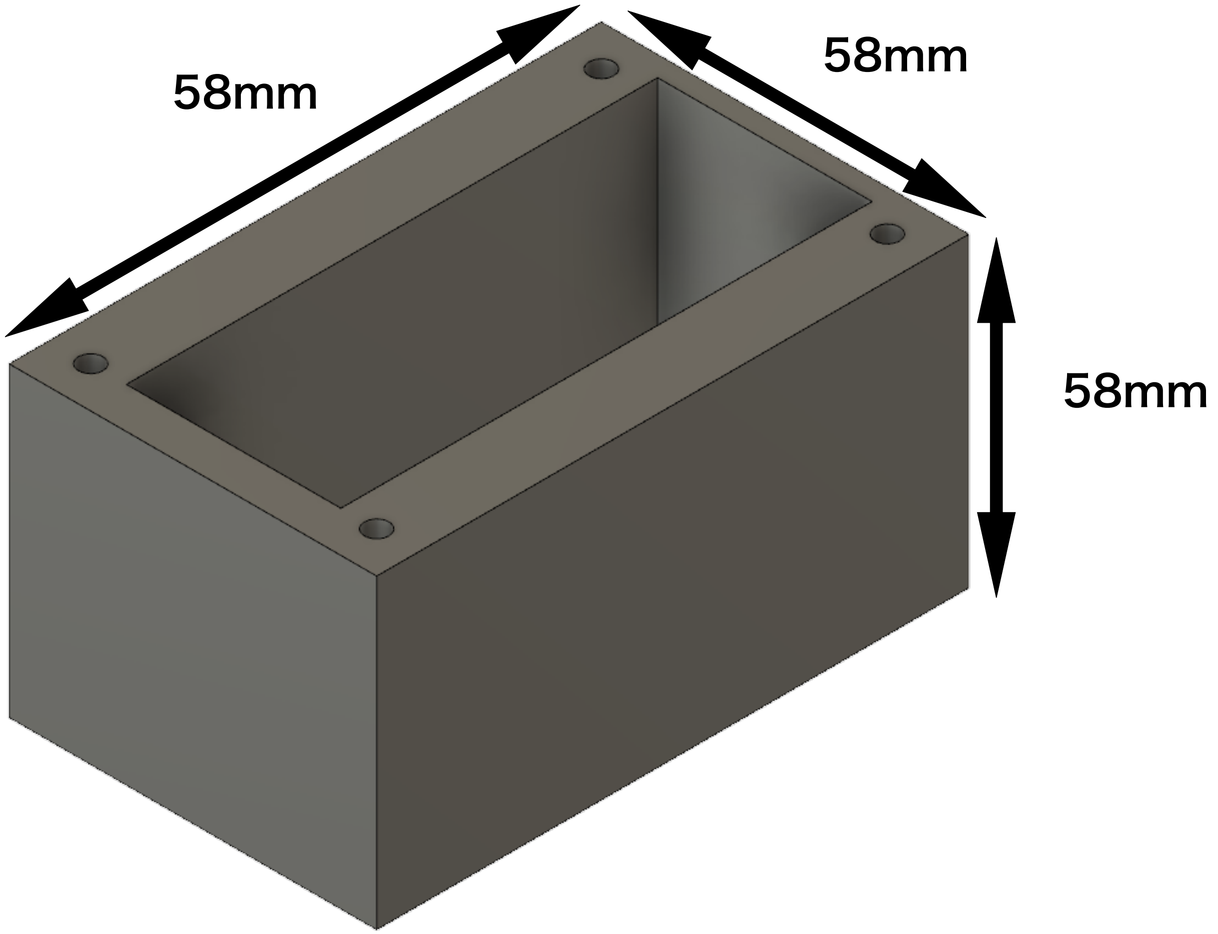
$$\delta\Omega = \int_{\theta-\delta\theta/2}^{\theta+\delta\theta/2} d\Omega \, 2\pi sin\theta$$

$$= 4\pi sin\theta sin\delta\theta$$

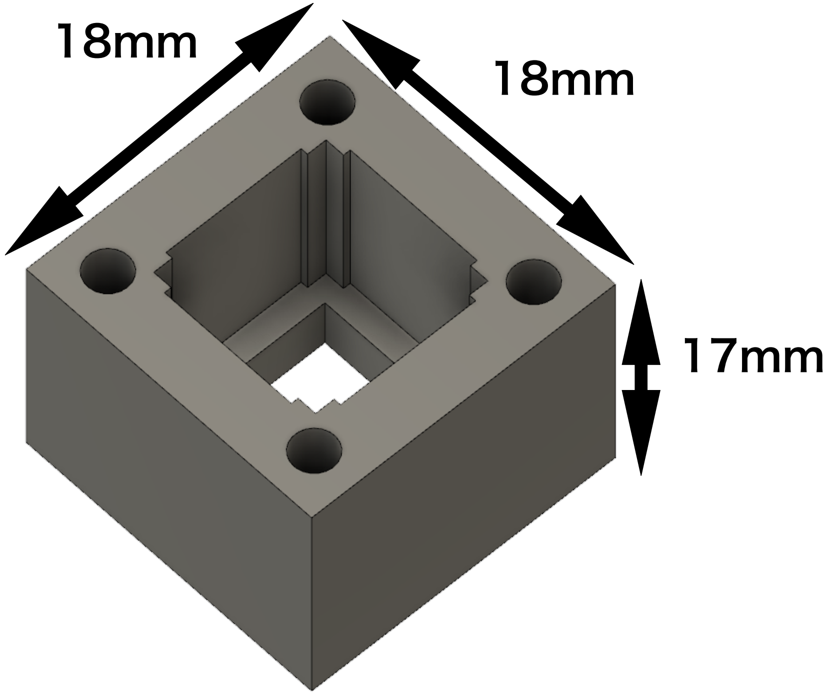
$$\sigma_{\mathrm{comp}} = \frac{d\sigma}{d\Omega}\delta\Omega$$

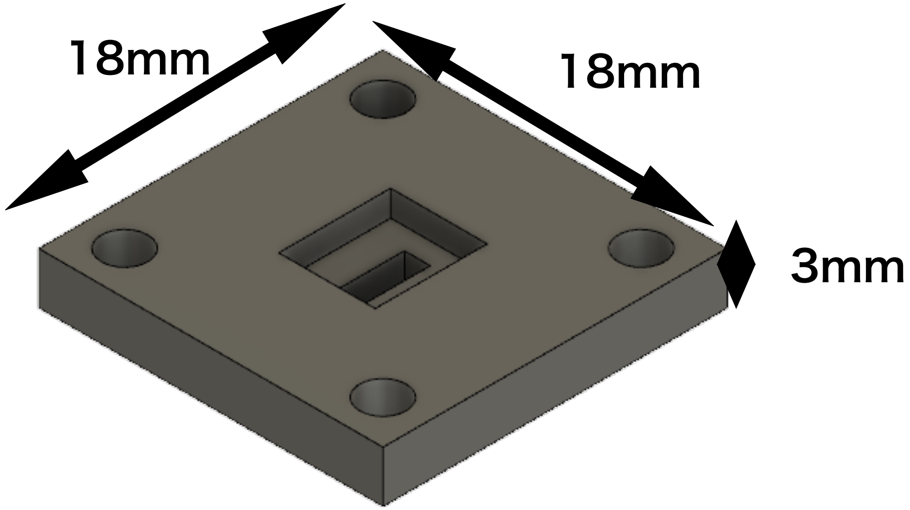


Box size



CsI and MPPC size





Detector

Desired detector conditions

- Detector needs drying system because CsI has deliquescence.
- Cable length can be adjusted freely.
- Requires CsI and MPPC fixation and alignment

→I made it using 3D printer.

EASIROC

- NIM EASIROC MODULE

  →MPPC readout ASIC

- The main function

  -64 MPPCs can be operated simultaneously

  -The voltage of each channel can be adjusted (0~4.5V)

  -Module control and DAQ can be performed by a PC

  via Ethernet

Software

- Controller for EASIROC module

Use this to control EASIROC interactively

By rewriting the numerical values in RegisterValue.yml or InputDAC.yml , we can adjust the applied voltage and select the output information

```
High Gain Channel 1: -1
High Gain Channel 2: 32
Probe Channel 1: -1
Probe Channel 2: -1
```

←(32) mean CH32

←(-1) mean don’t use

RegisterValue.yml

CsI

密度	4.53 [g/cm^3]
融点	621[℃]
硬度	2 [Mohs]
屈折率	1.78
潮解性	僅かにあり
発光量	56000 [Photons/MeV]
減衰時間	1050[ns]
ピーク波長	550 [nm]

Reference

- (software of EASIROC)
- (NIM EASIROC)
- (MPPC)