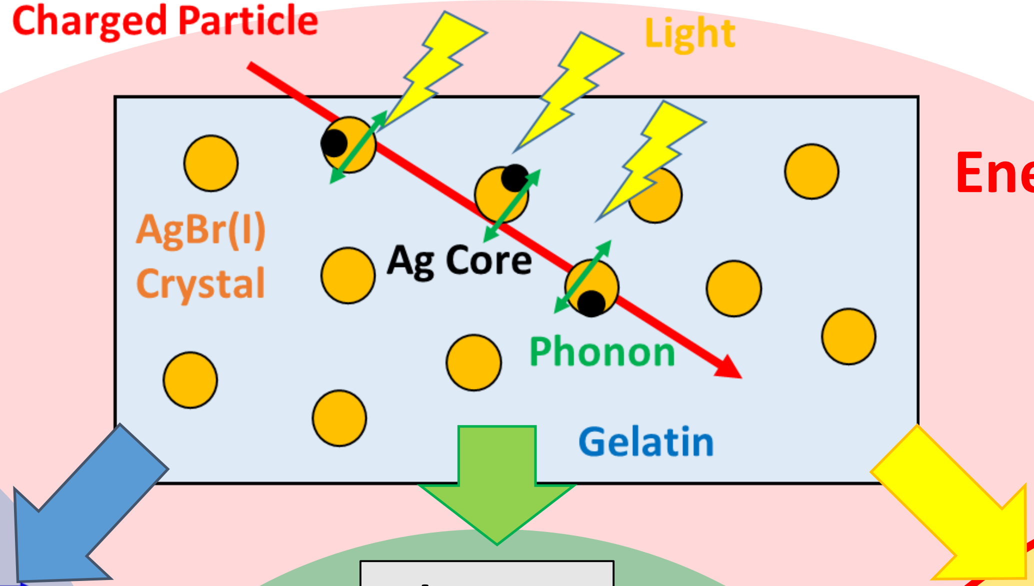
Study for luminescence of fine-grained emulsion by charged particles

2018/05/30

T. Shiraishi @ NEWSdm meeting (Anacapri)

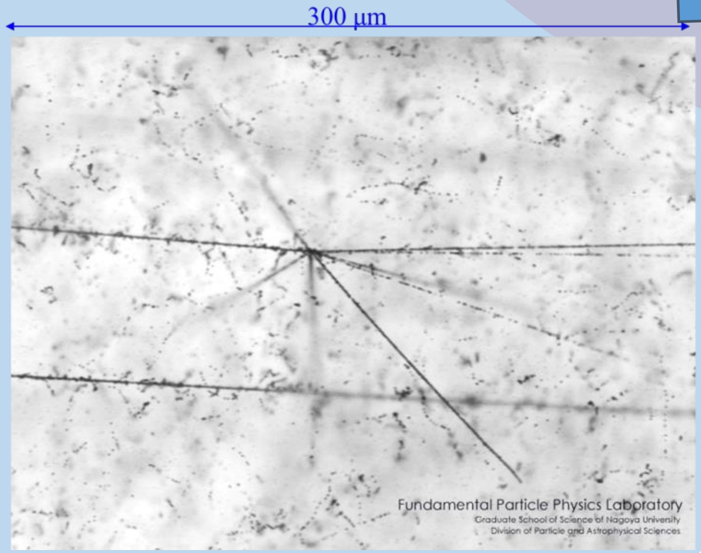
Energy deposition in nuclear emulsion



Energy Deposit

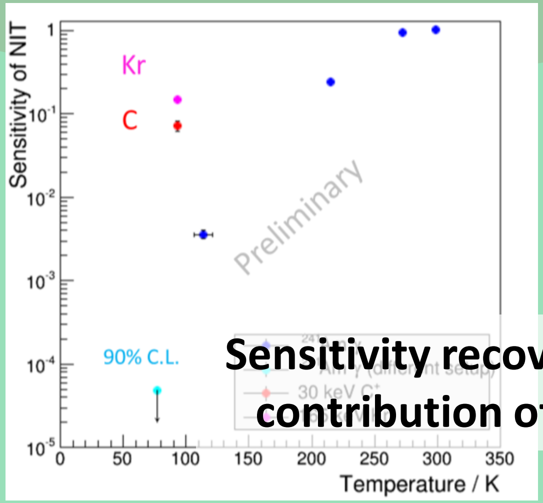
Talk about this!

Ag core Development



Developed Ag can be seen as a track by microscope

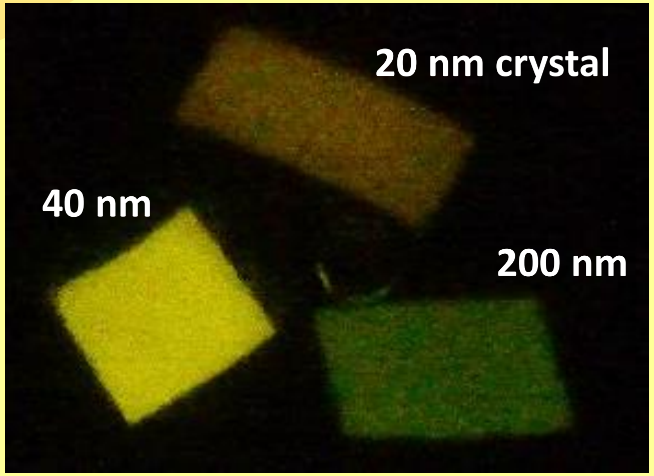
Phonons



Sensitivity recovered by contribution of NSP?

M. Kimura *et al., NIMA (VCI2016) 2016*

Light

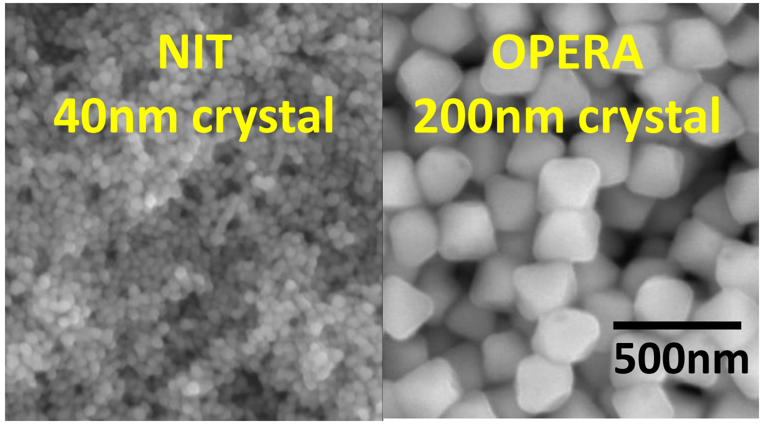


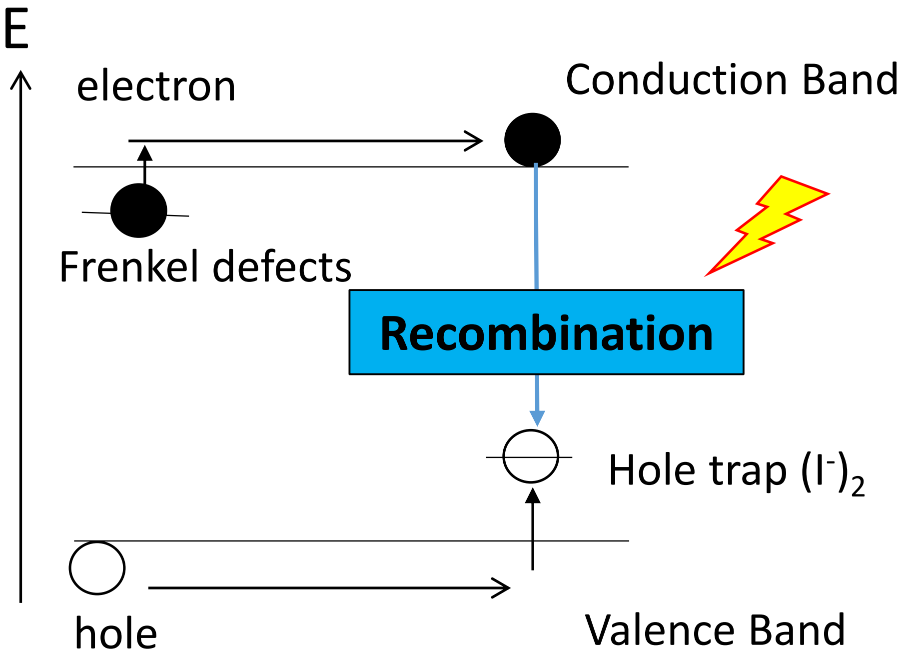
Luminescence after exposure with the fluorescent lamp

Luminescence of AgBr Crystal

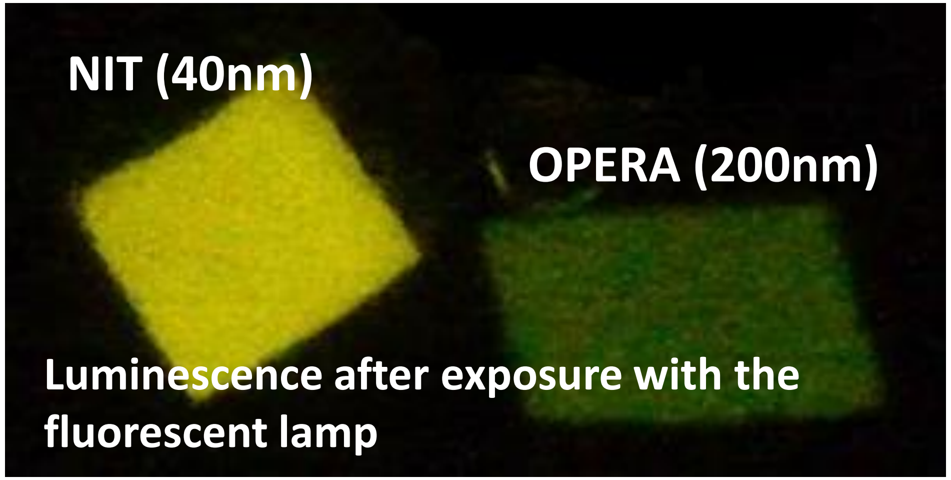
* Reported only photoexcitation

AgBr crystal SEM image



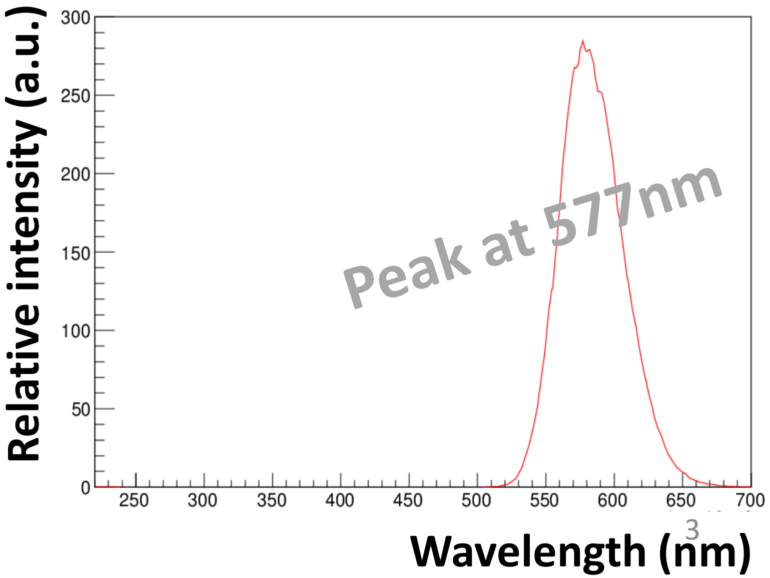


- **Verification of emulsion luminescence excited by light**

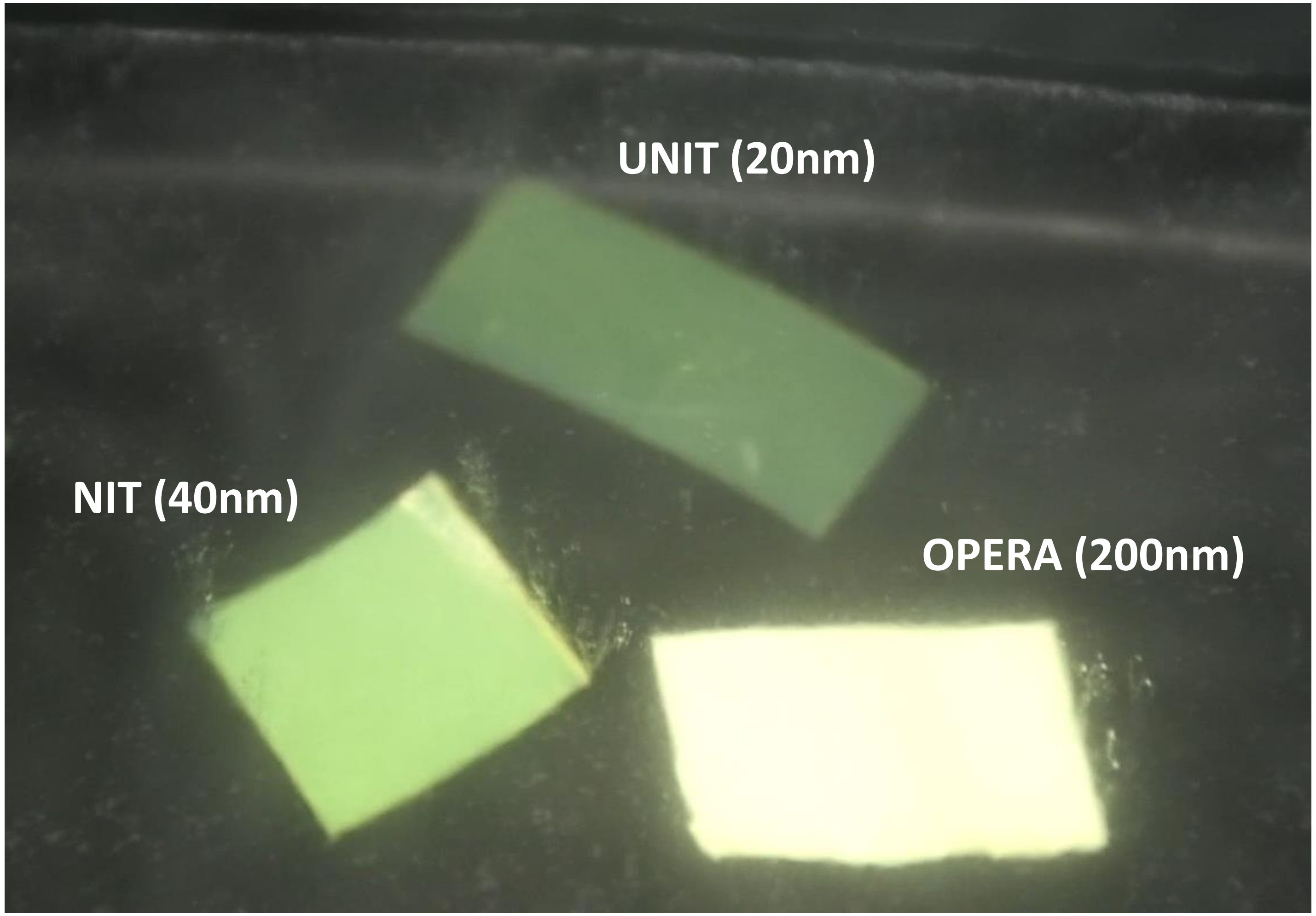


* Observed at Lq. N_2 temperature to decrease heat inactivation

- **NIT (40nm crystal) luminescence spectrum**



Luminescence of emulsions



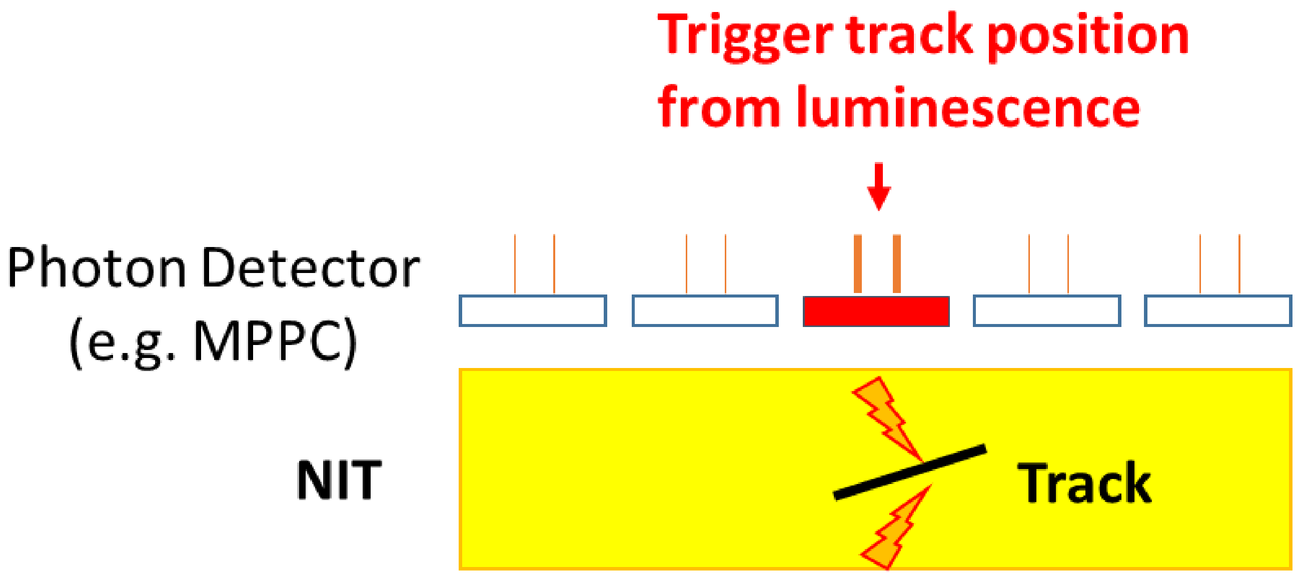
1. Exposed white light
2. Light off
3. Luminescence

Observable luminescence time with the naked eye

- OPERA : ~1s
- NIT : ~7s

* In liquid N_2
** Camera sensitivity is automatically adjusted

Motivation 1
Combined analysis with track detection



- Locate the recorded track position in emulsion with mm accuracy
- Dust and fog don't luminescent
- Identify particle property from luminescence information (intensity, life time, spectrum, …)

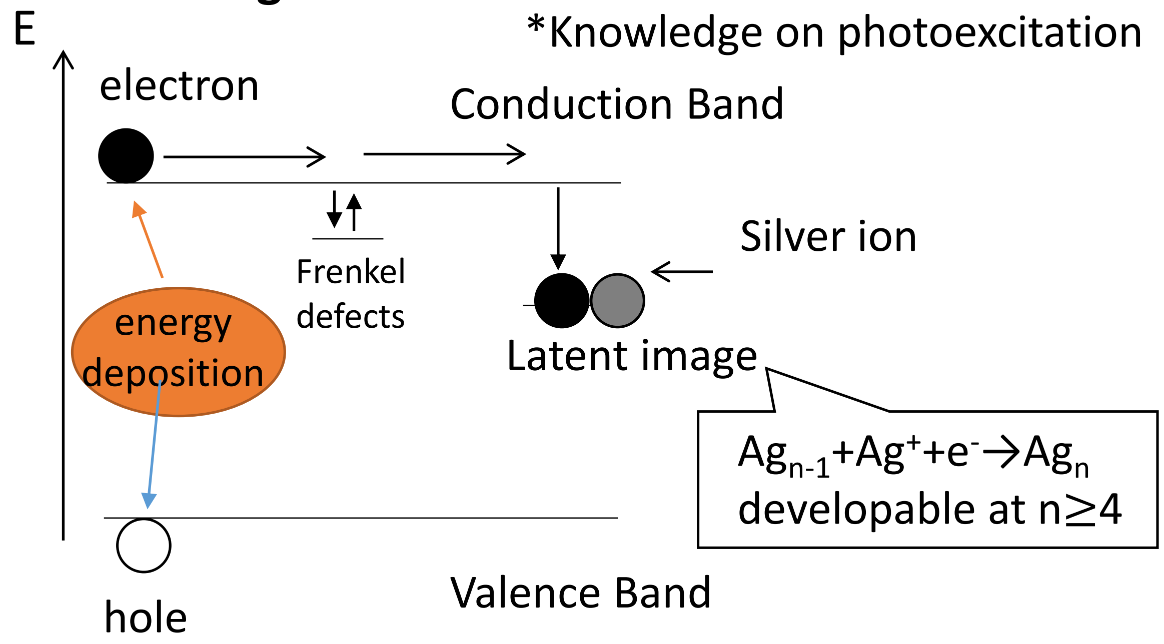
Motivation 2
Elucidation of detection mechanism for charged particles

	dE/dx in AgBr crystal	Number of e-h pairs created in 40nm AgBr*
5.48 MeV α-ray	300 (keV/μm)	2000 (/fs)
60 keV γ-ray	15 (keV/μm)	100 (/fs)
1kW pulse laser		0.001 (/fs)

*1 e-h pair/ 5.8 eV (K. A. Yamakawa, Phys. Rev. 82, 4（1951）)

Ag core creation mechanism

*Knowledge on photoexcitation

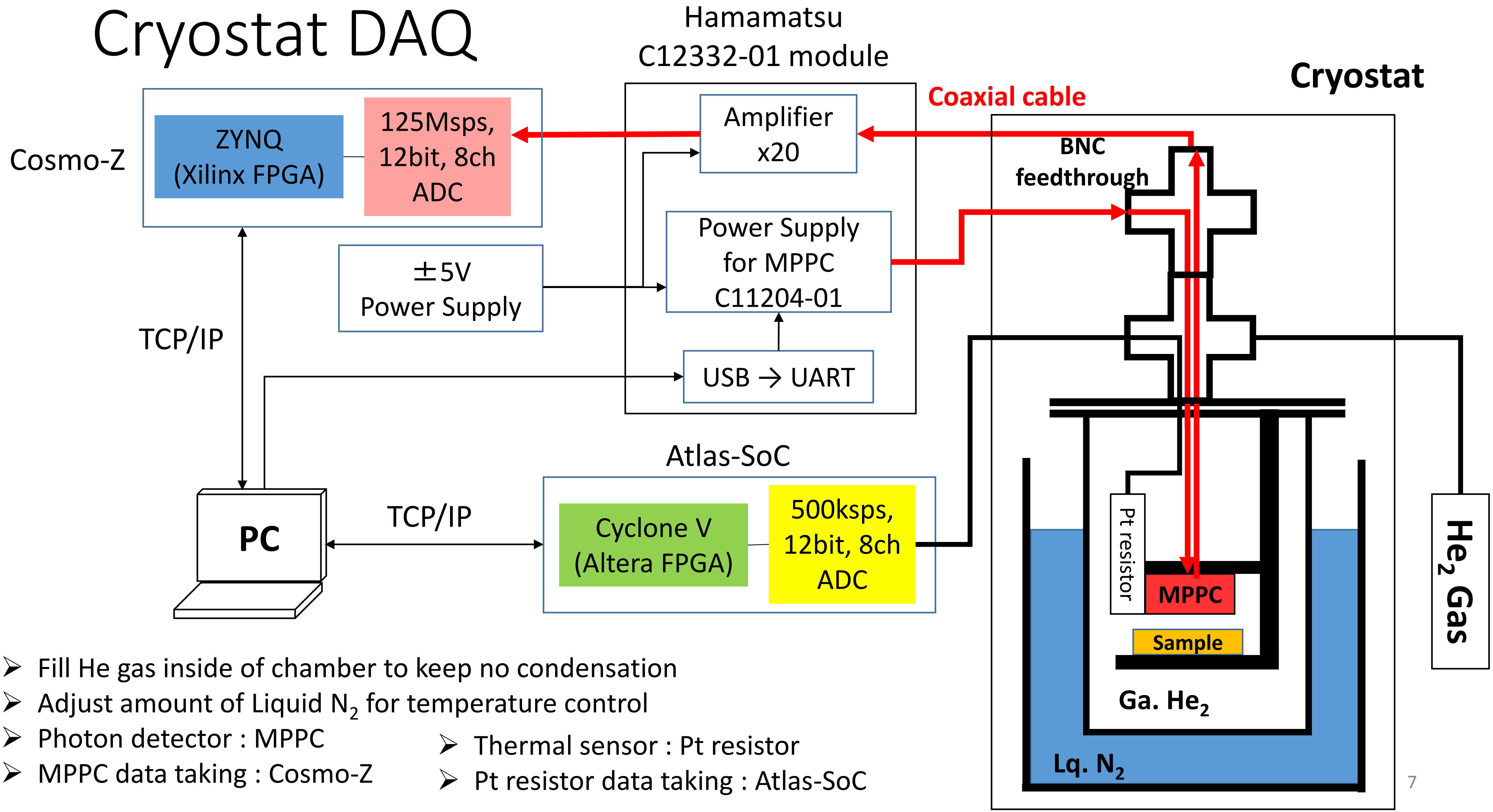


Charged particle create a huge number of e-h pairs locally at the same time **(High illuminance condition)**

Recombination is probably dominant
→ Ag core creation probability decrease

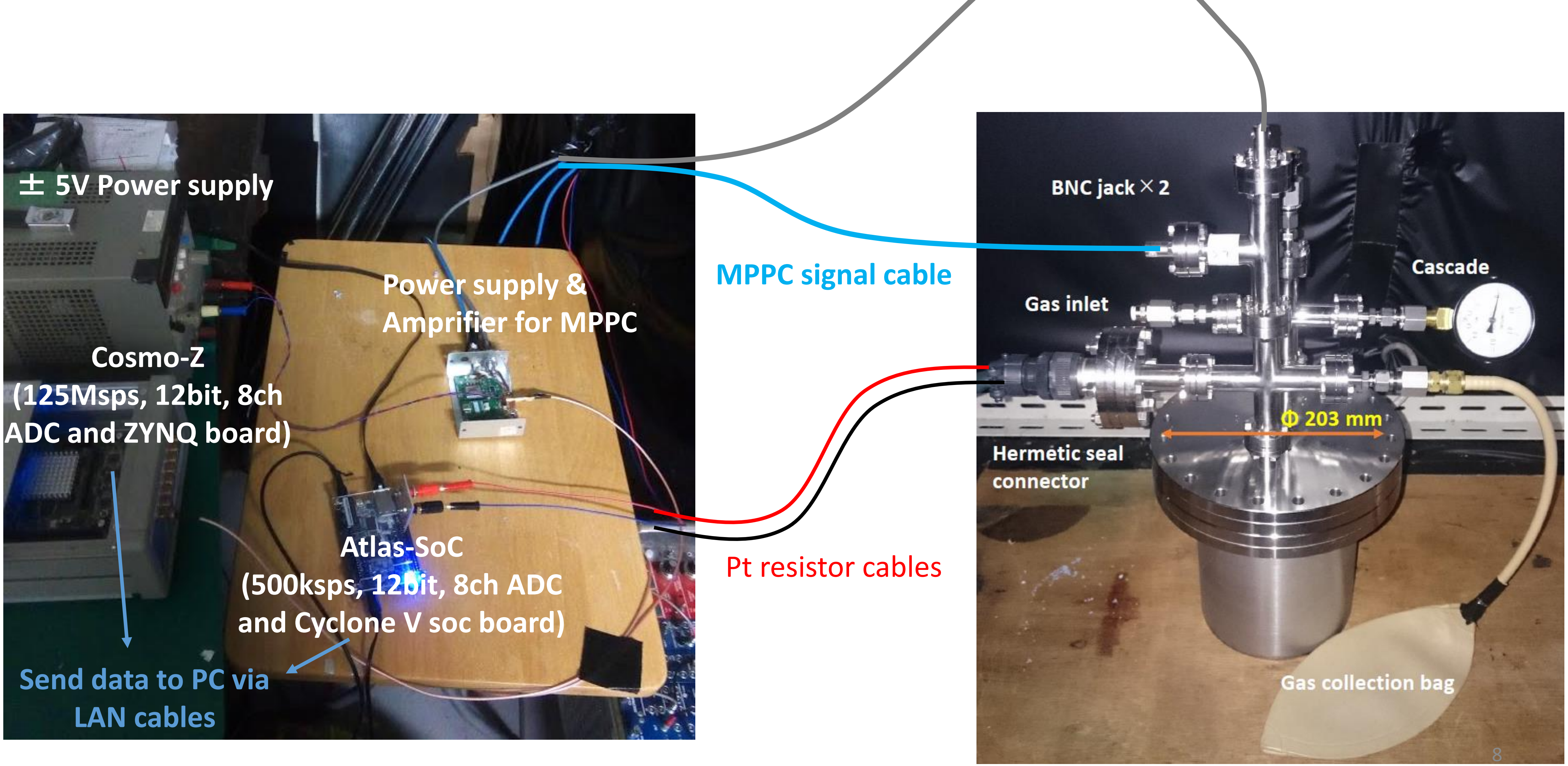
Can we get more information about Ag core creation mechanism from luminescence?

Cryostat DAQ

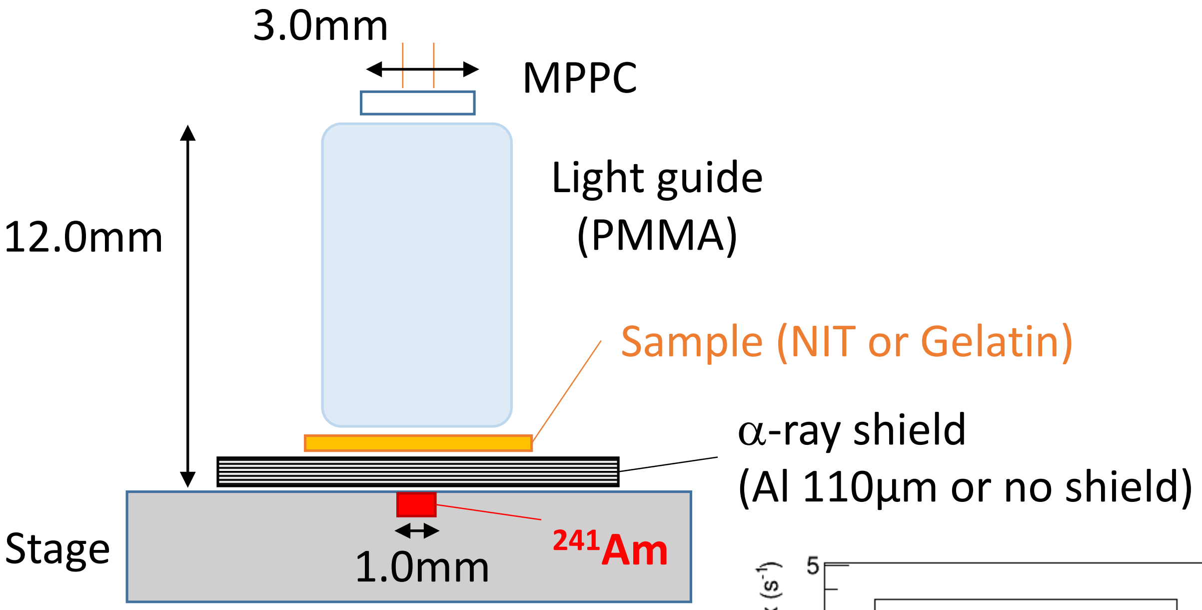


- Fill He gas inside of chamber to keep no condensation
- Adjust amount of Liquid N_2 for temperature control
- Photon detector : MPPC
- MPPC data taking : Cosmo-Z
- Thermal sensor : Pt resistor
- Pt resistor data taking : Atlas-SoC

Cryostat DAQ (Photograph)

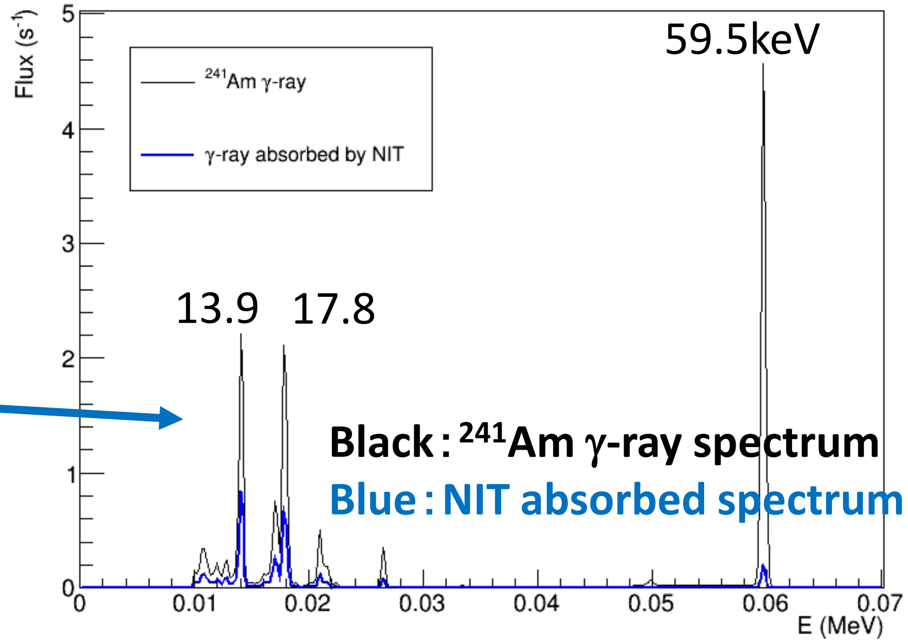


Setup of α-ray and γ-ray exposure

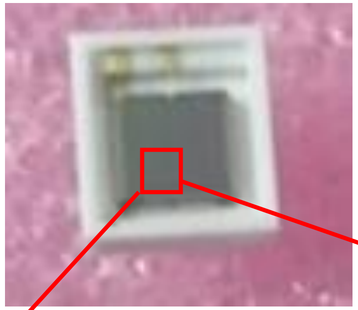


^{241}Am RI

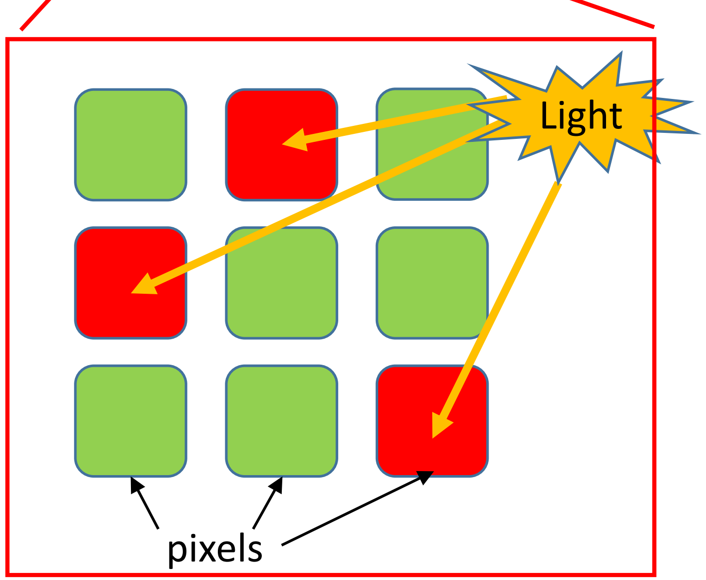
- **α-ray : 5.48MeV**
- **γ-ray : 10〜60keV**
- **Rate to forward : 33 Hz**



Photon detector
VUV-MPPC (S13370-3050CN)

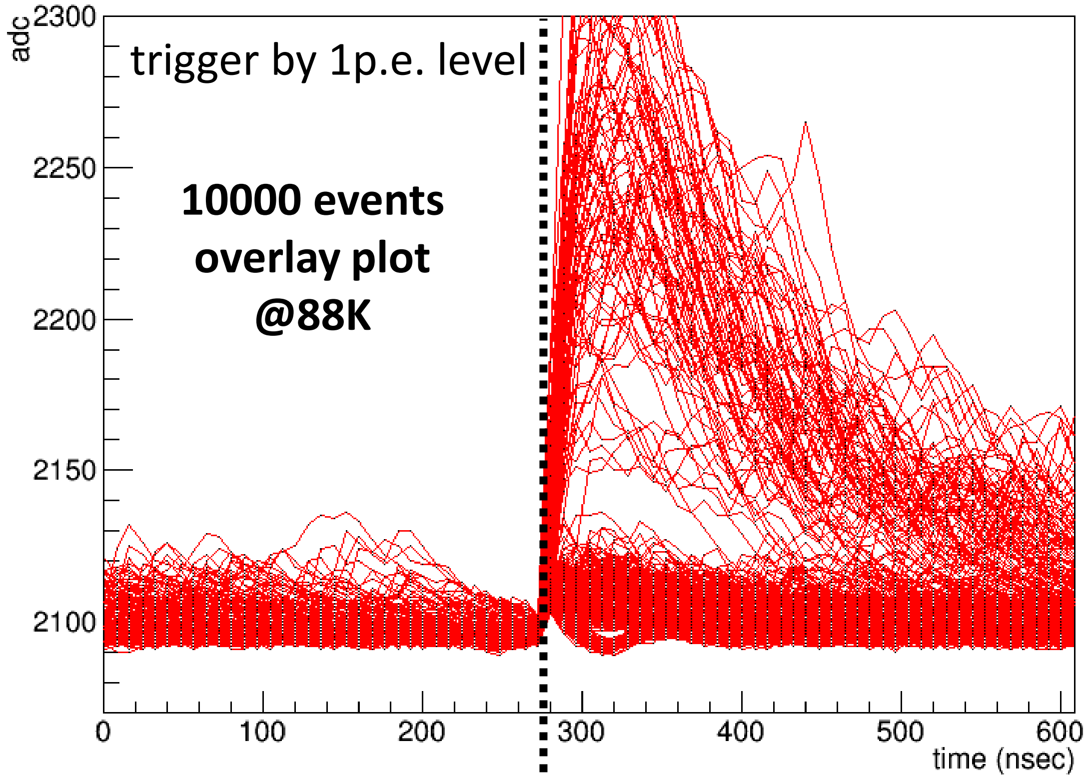


Fiducial Area : 9 mm^2
Number of pixel : 3600
Aperture : 60%
PDE(@577nm) : 32%

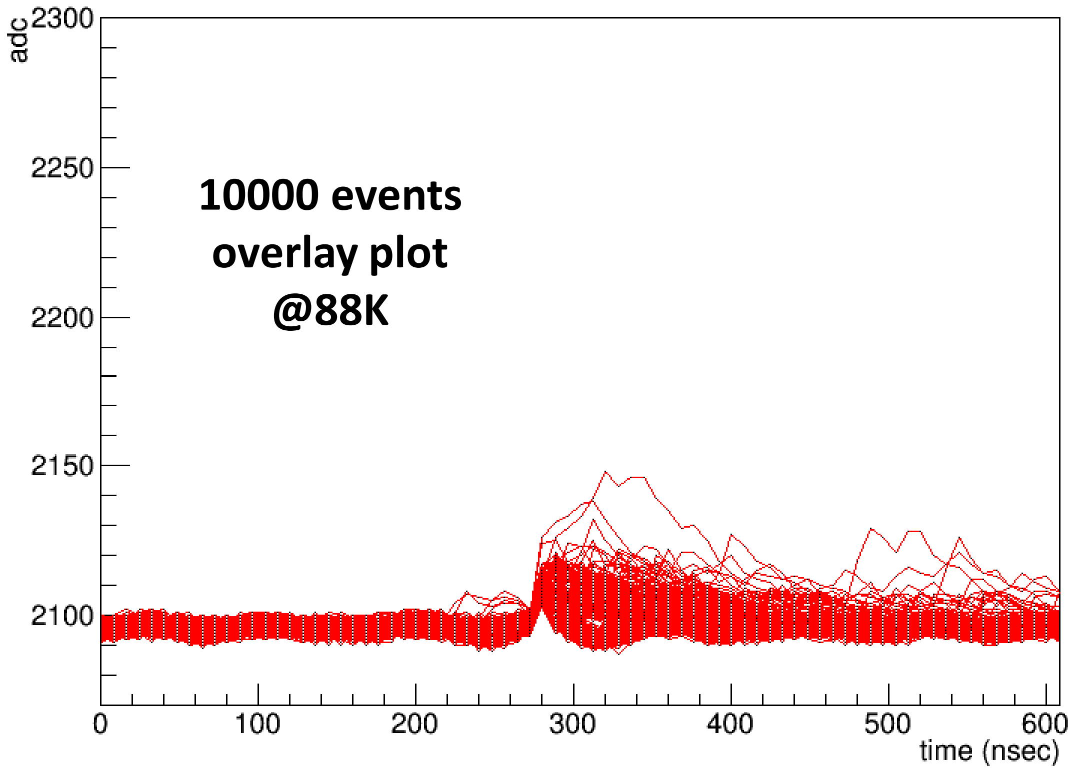


MPPC waveform

α-ray exposure



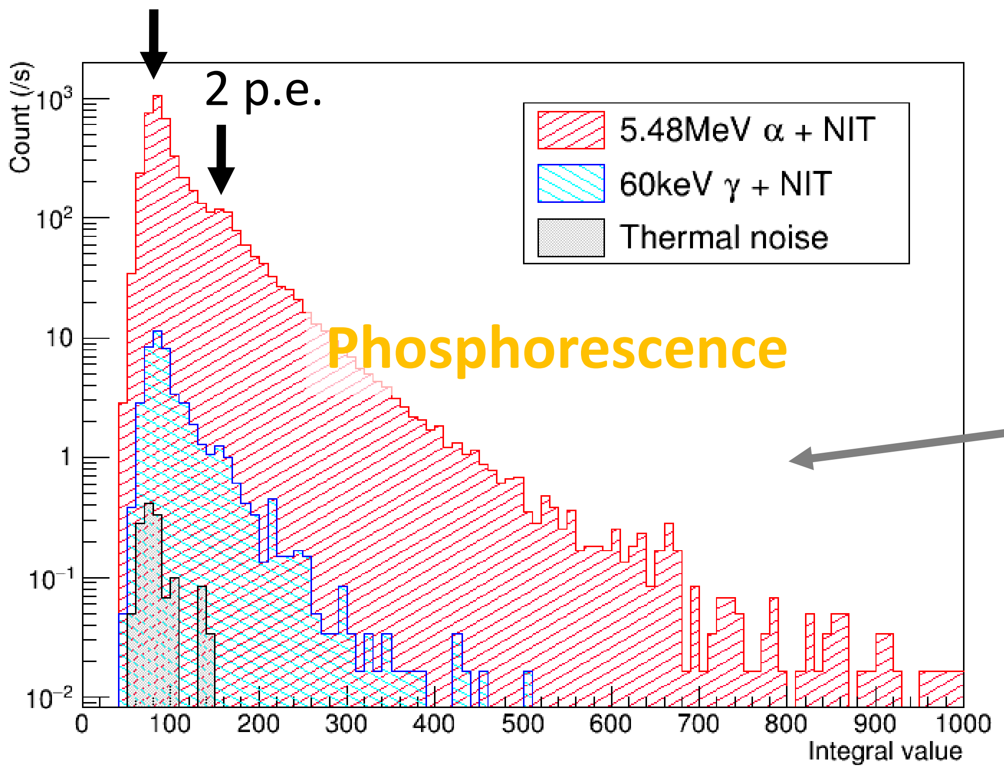
γ-ray exposure

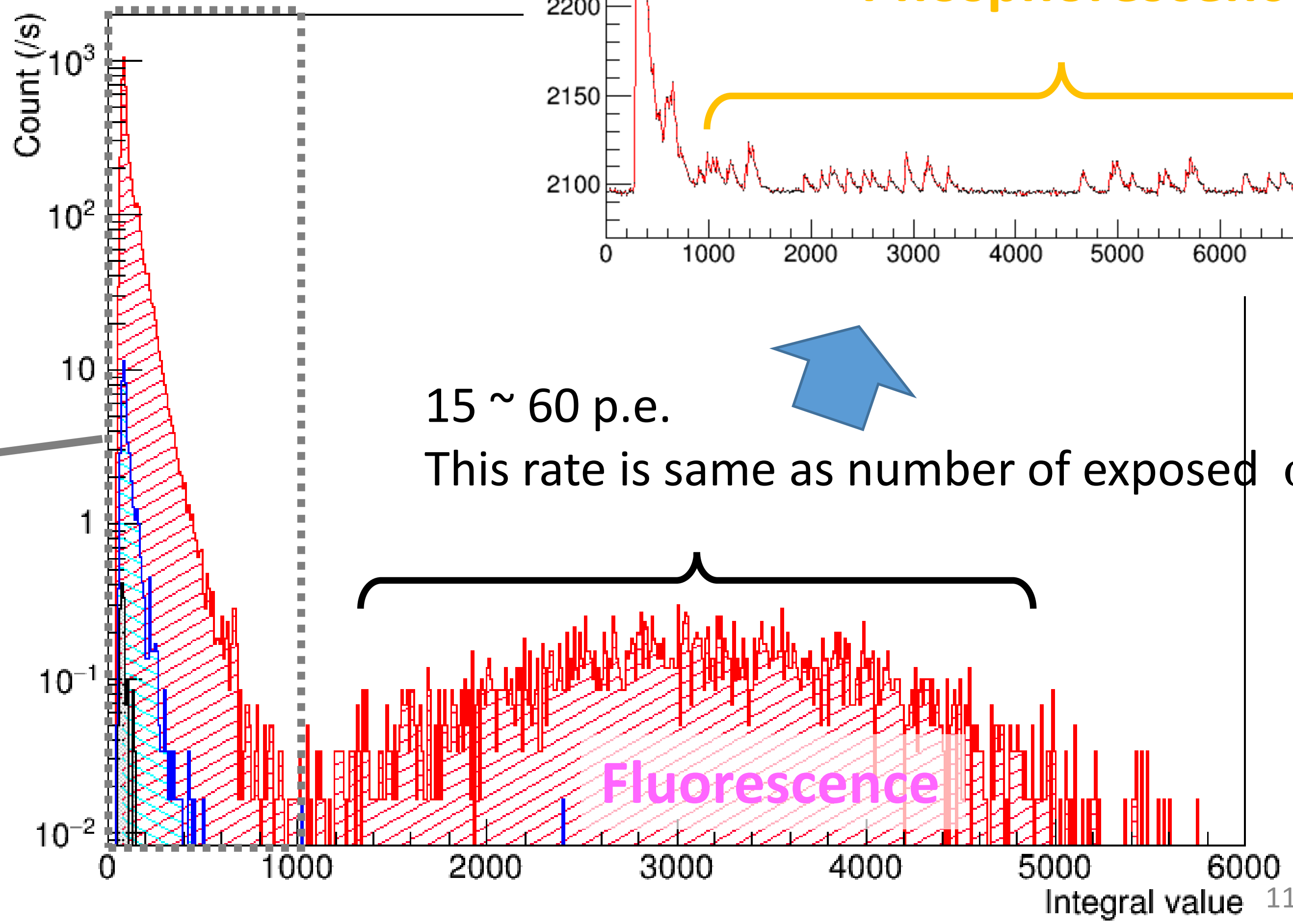


pre-trigger 288ns
(for pedestal correction)

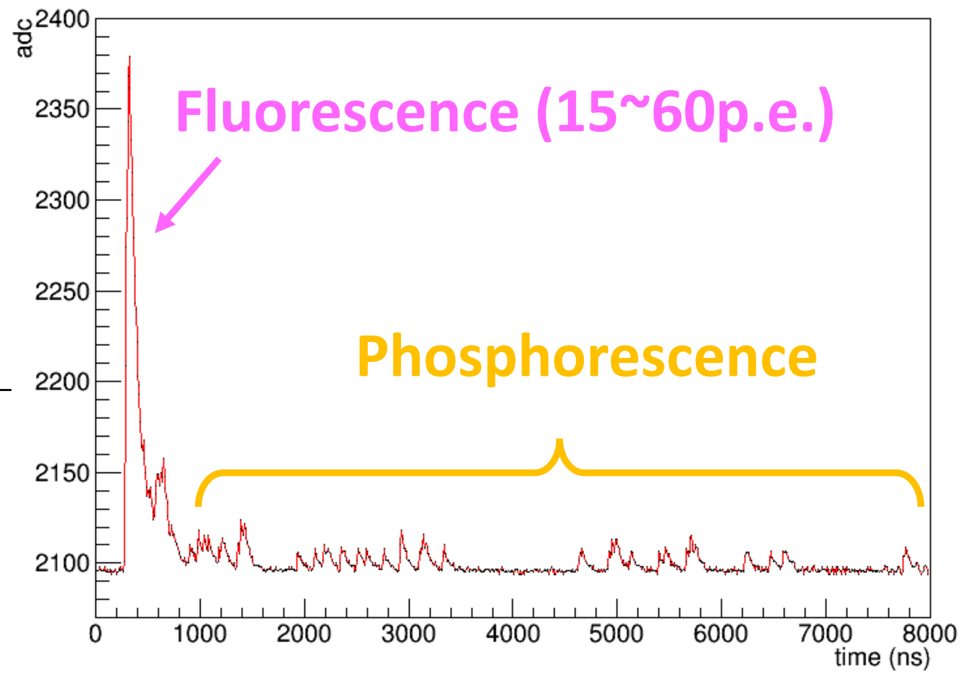
post-trigger 320ns
Integral ADC (Charge) → **Index of number of photon**

Integral ADC (Charge)





Long waveform data (time window 8μs)

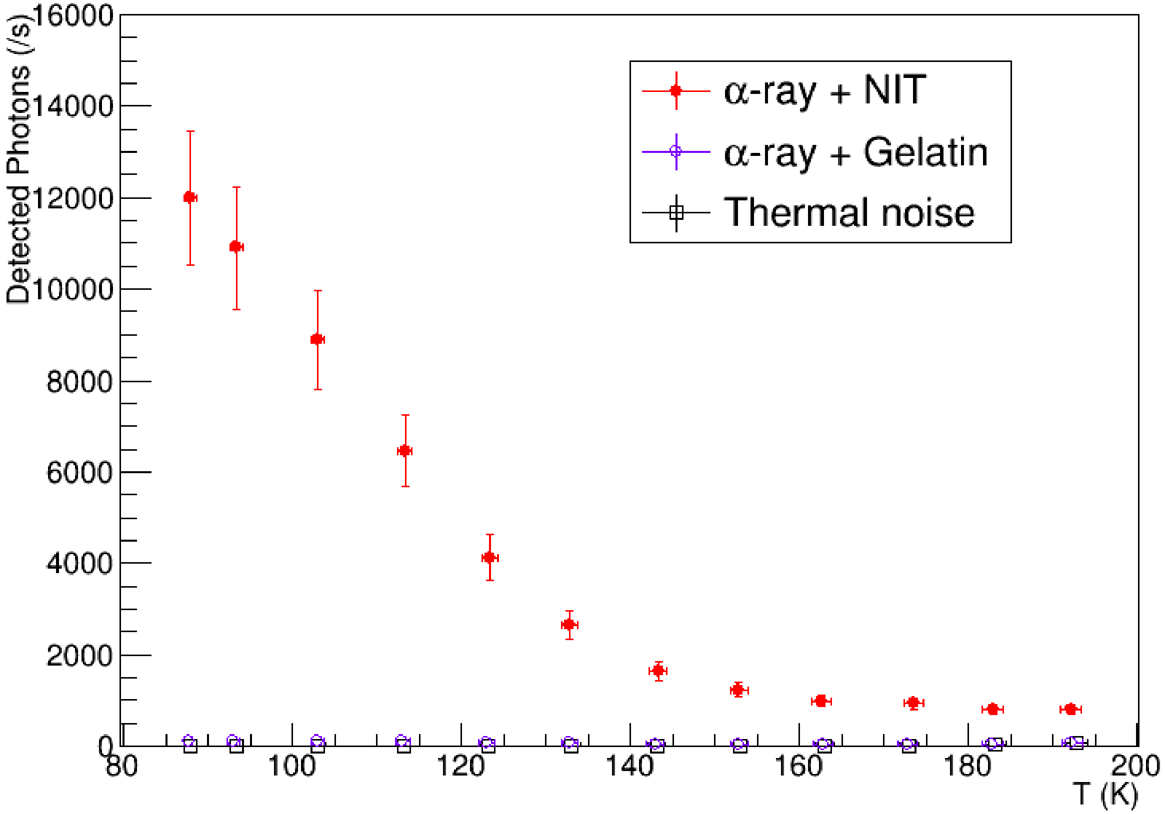


15 ~ 60 p.e.

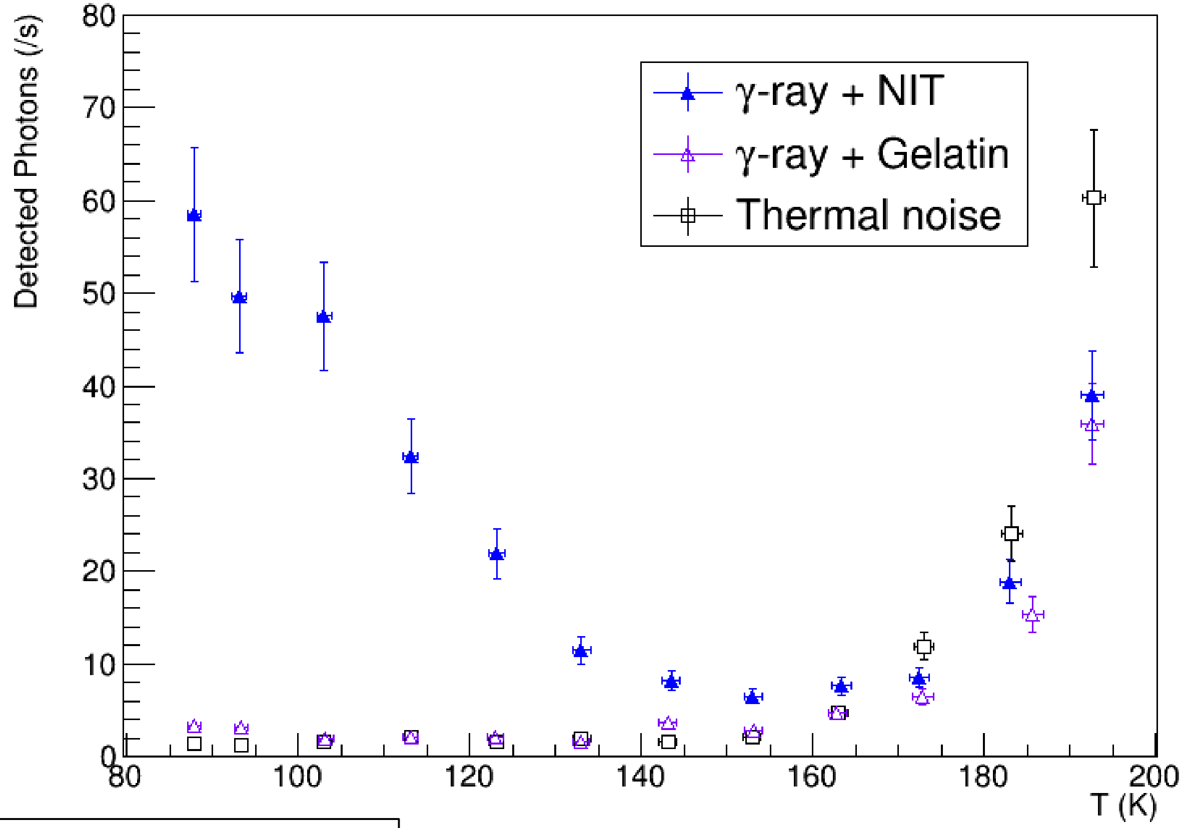
This rate is same as number of exposed α-ray

Detected number of photon

α-ray exposure



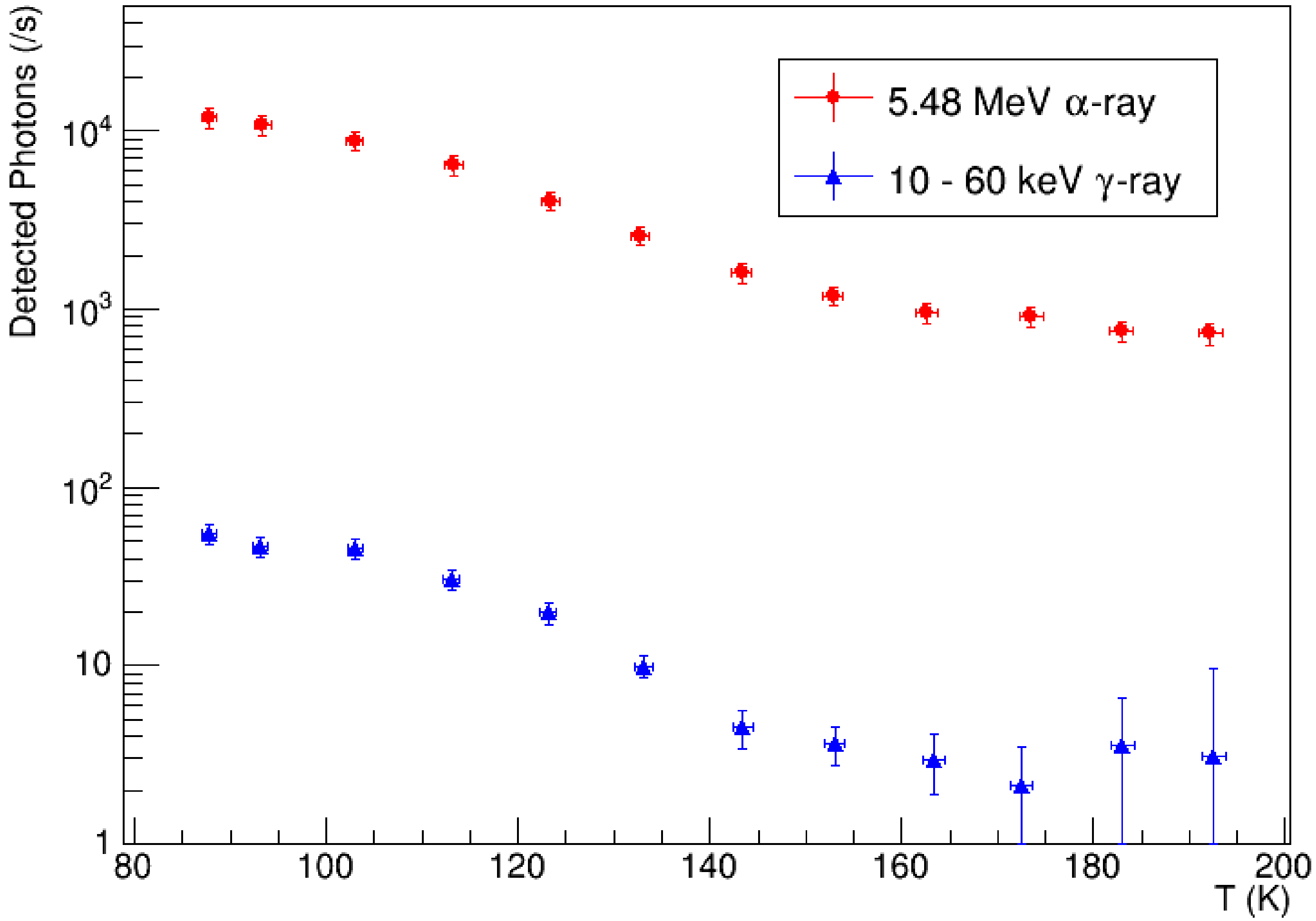
γ-ray exposure



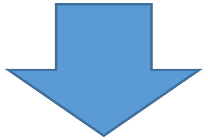
Considered errors

- 1p.e. peak decision accuracy ~ 1%
- Exposed α-ray and γ-ray number ~ 2.2%
- MPPC noise (cross talk and after pulse rate) ~ 10%
- Measurement repeatability ~ 6.8%

Detected number of photon (Background subtracted)

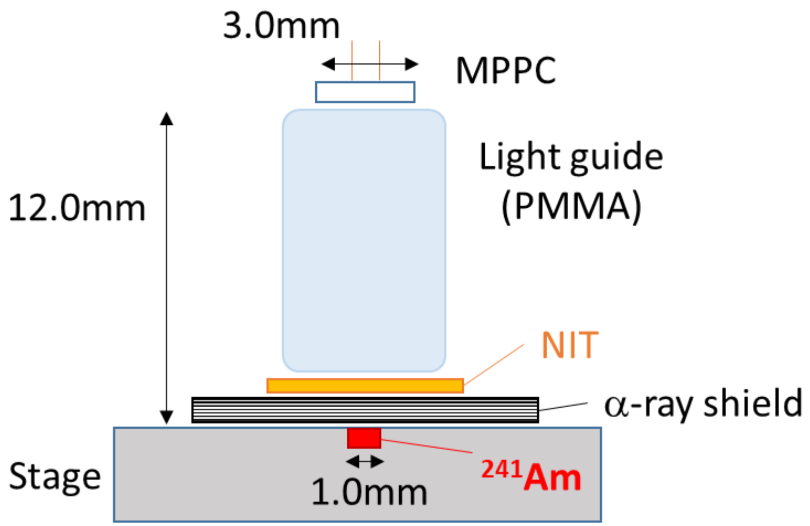


Number of emitted photons by α-ray and γ-ray are measured

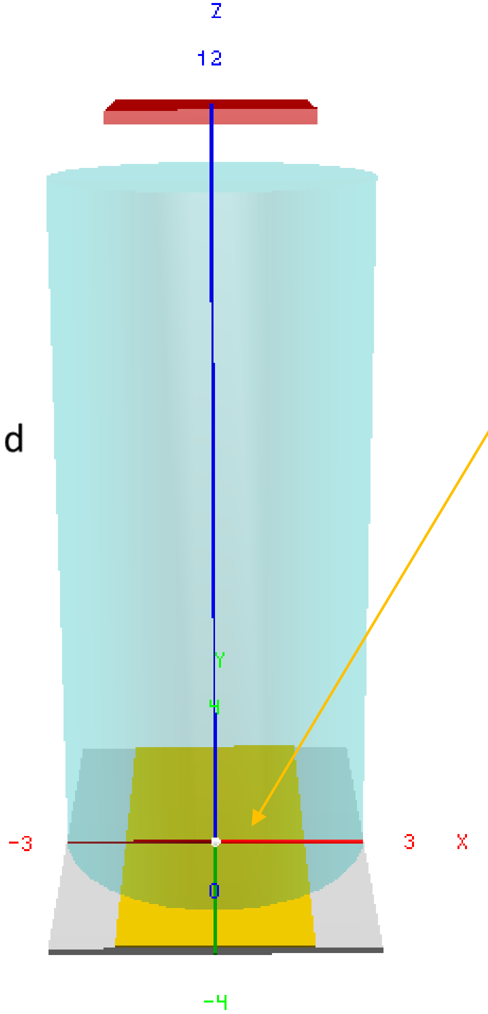


Quenching factor ($\equiv N_{photon}/N_{e\text{-}h\ pairs}$) of AgBr crystal can be calculated

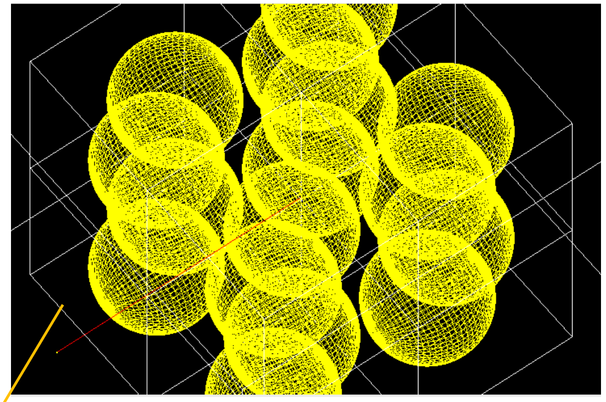
Estimation of energy deposition in AgBr crystal



Geant4 simulation Geometry

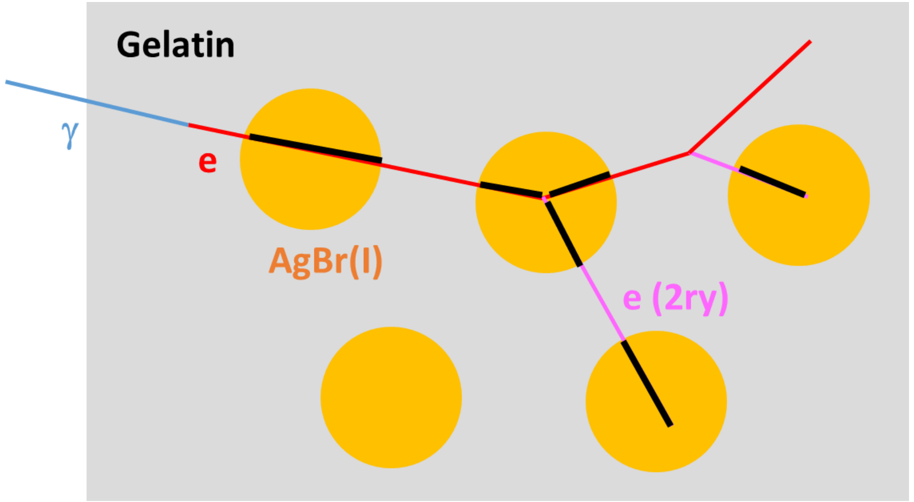


NIT internal structure



- Face centered cubic lattice
- Whole density : 3.44 g/cm^3
- Fill rate of AgBr(I) : 41.5%
- Lattice constant : 75.5nm

e.g. γ-ray simulation



- Integrate energy deposition in crystal by every charged particles
- 2ry generator condition is more than 5nm

Quenching Factor Calculation

Number of detected photons

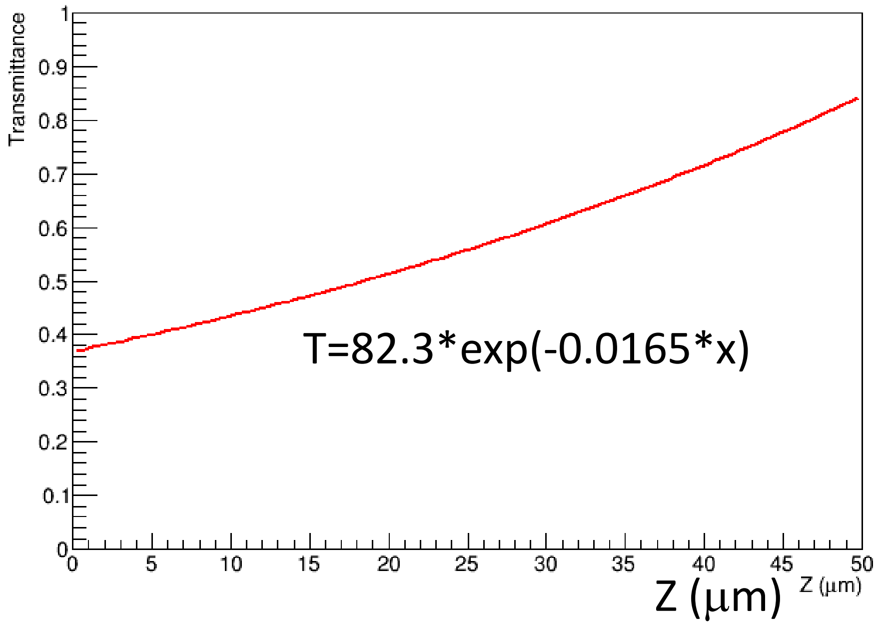
$$\frac{\mathrm{DetectedPhotons}}{\Omega \times \mathrm{PDE}_{MPPC}} = \eta \times \int \frac{\mathrm{Edep}(z)}{\mathrm{Egap}} \times \mathrm{Trans}(z)\, dz$$

Solid angle ～0.14

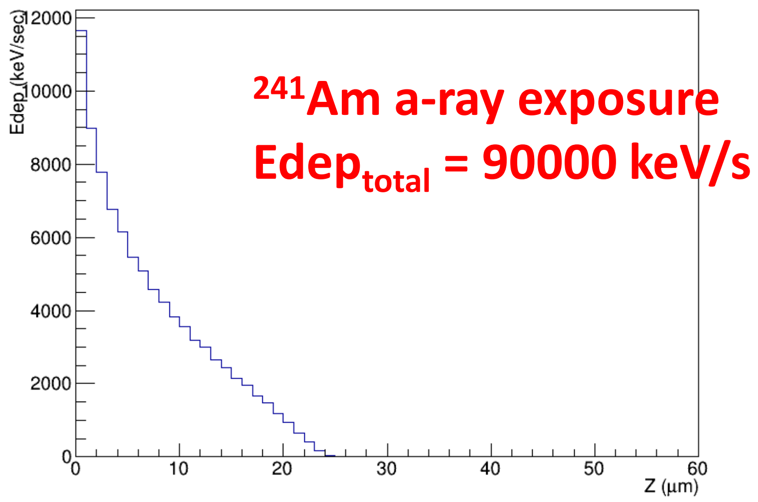
MPPC photon detection efficiency ～0.32

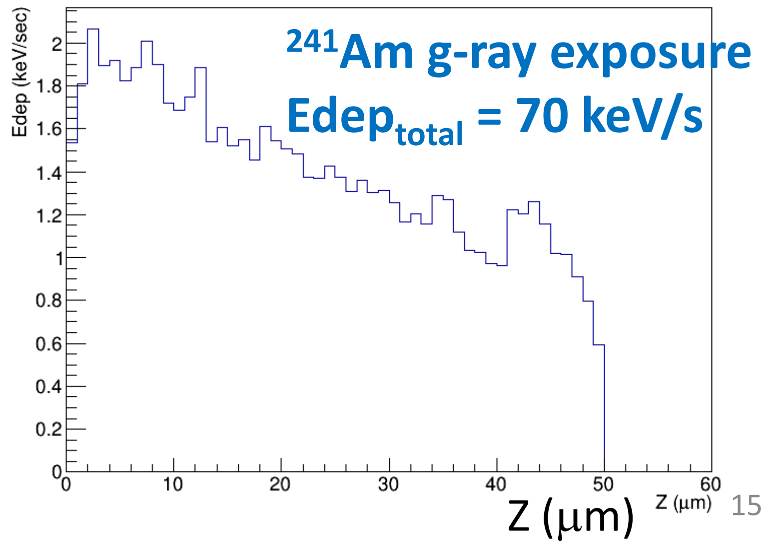
AgBr energy gap ～5.8eV

NIT Transmittance of 577nm light

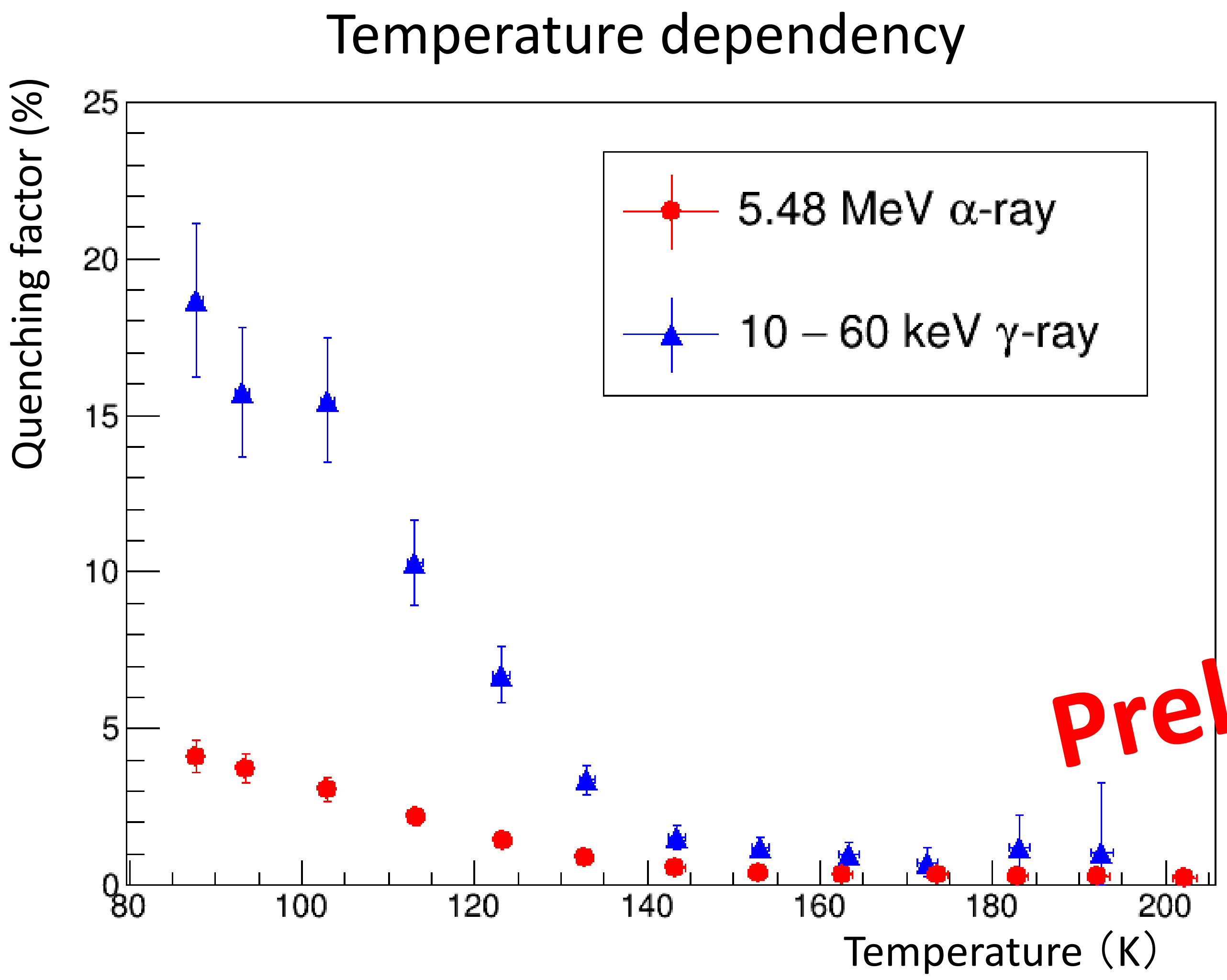


Energy deposition in NIT's AgBr crystal

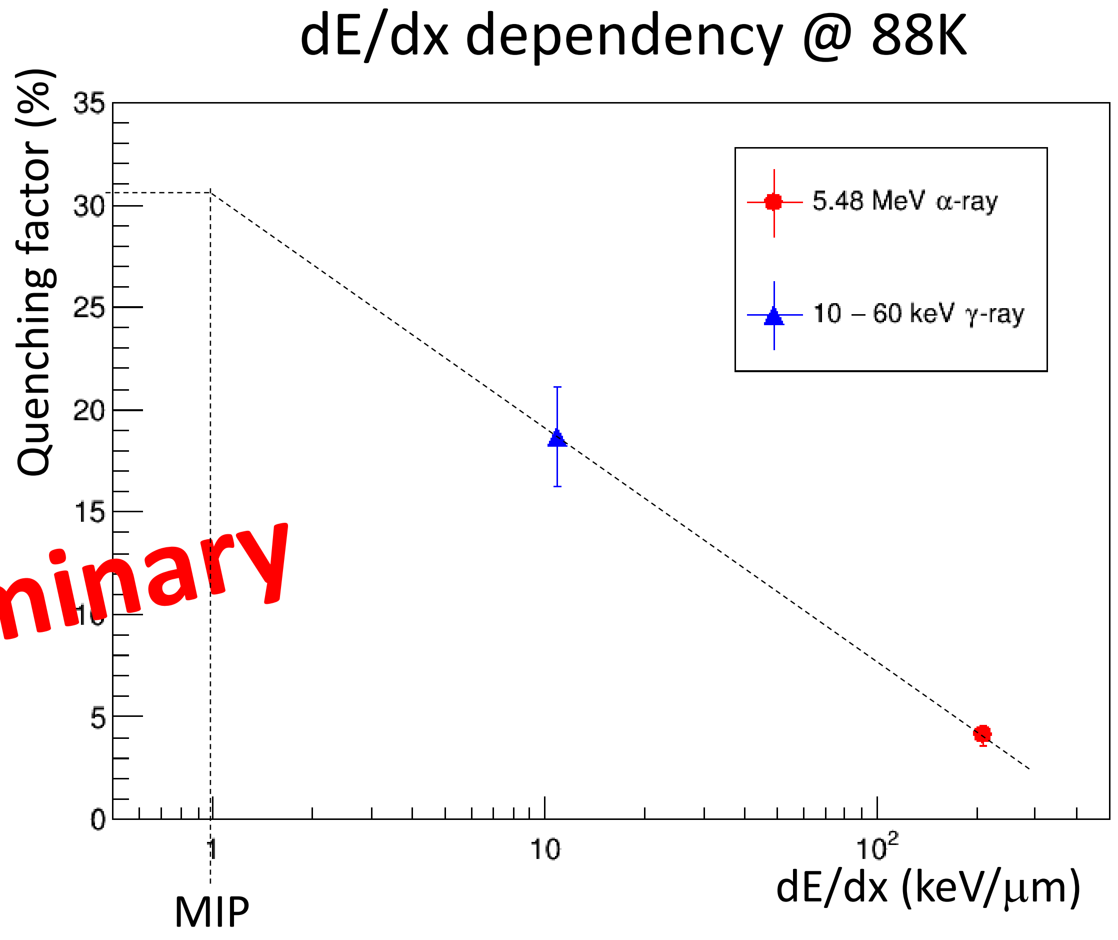




Quenching Factor



Preliminary



Quenching factor is ~30% for MIP???

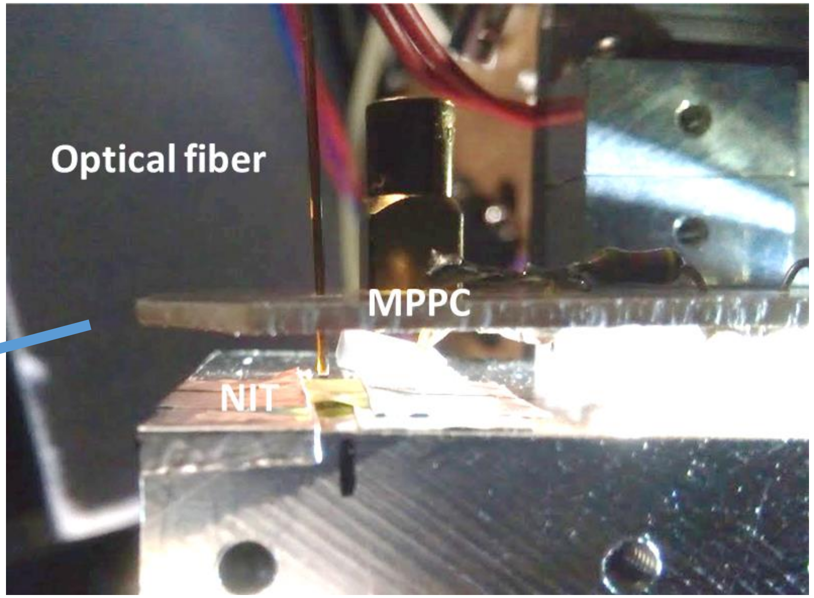
Comparison with typical scintillators

Preliminary

	Ce : GAGG	Tl : NaI	Scintillating Fiber (BCF-60)	NIT @ 88K (*Gelatin contained)
Density (g/cm^3)	6.63	3.67	1.2	3.44
Life time (ns)	88	230	7	~100 + ~10000
Deliquescent	no	yes	no	no
Number of photon (photon/MeV)	60000 (MIP)	40000 (MIP)	7100 (MIP)	**~4000 (α 5.48MeV)** **~18000 (γ 60keV)** ~30000??? (MIP)
Energy resolution (% @ ^{137}Cs-662keV)	6.3	5.6	???	???
Wavelength (nm)	520	415	530	570?

Not yet optimized!
We can change amount of Iodine dope, size of AgBr crystal, …

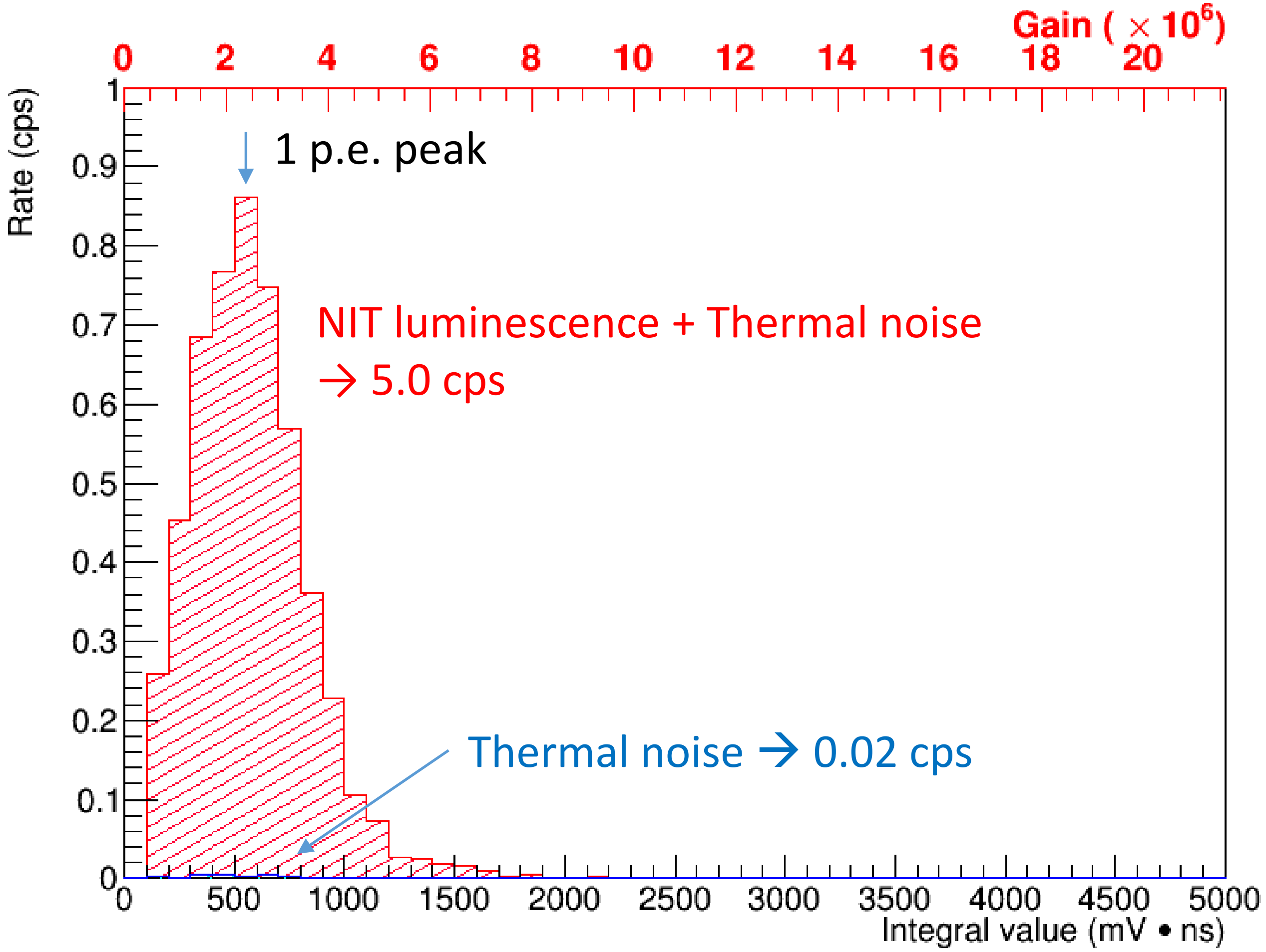
Luminescence spectrum analysis (On going)



1. Trigger luminescence by MPPC inside of chamber
2. Optical fiber guide the luminescence to outside of chamber
3. Monochromator selects the wavelength (~10nm width)
4. PMT detects monochro-photon

Luminescence spectrum analysis (On going)

PMT signal
(No monochromator measurement)



- ✓ It is succeed to guide NIT luminescence to outside of chamber with high S/N

- ☐ 6/12~ monochromator will be available
- ☐ NIT luminescence spectrum by charged particles will be able to be observed

Summary

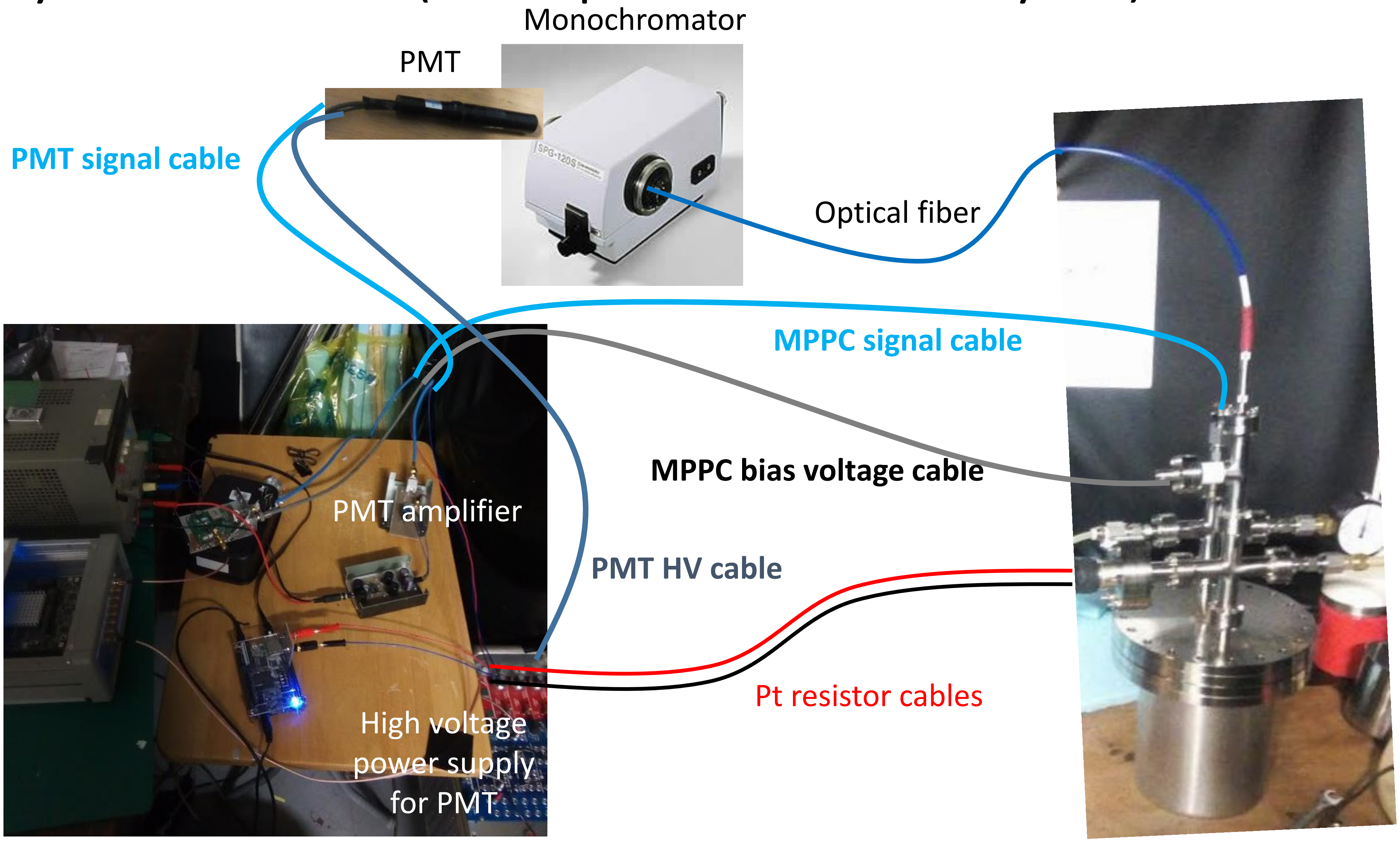
- This is the **first observation of luminescence of emulsion by charged particles**
- Measured the rate of contribution to luminescence of NIT excited by α-ray and γ-ray
  - Luminescence efficiency is very high at low temperature (may be comparable to plastic scintillator)

Plan

- Application for detector
  - Measure for nuclear recoil event and M.I.P.
  - Multi-channel readout
- Elucidation of detection mechanism for charged particles
  - **Spectrum analysis**
  - Change crystal property

Backup

Cryostat DAQ (for spectrum analysis)



To increase detection efficiency

- Use GaAs PMT
  - High quantum efficiency
- Use wide optical fiber (600μm→1mm)
- Increase RI rate
  - Do anyone have high rate RI (> 100Bq) which can be used at low temperature (77K) ?
- Light collection
  - It seems difficult to collect light to optical fiber (600μm, NA=0.22)

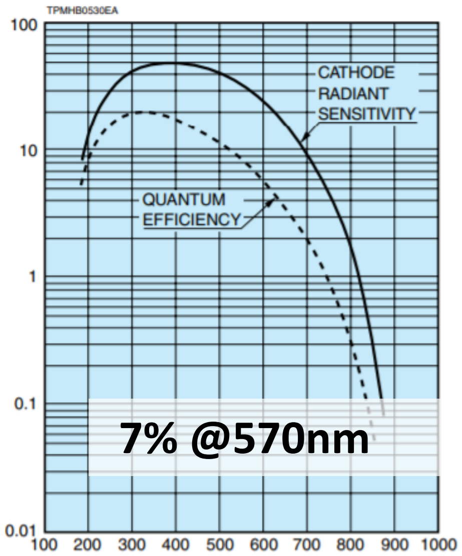
GaAs PMT

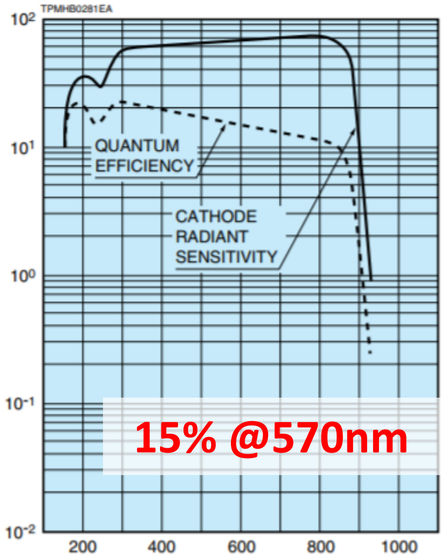
From Hamamatsu data sheet

R1463 (multi-alkali PMT)

R943-02（GaAs PMT）

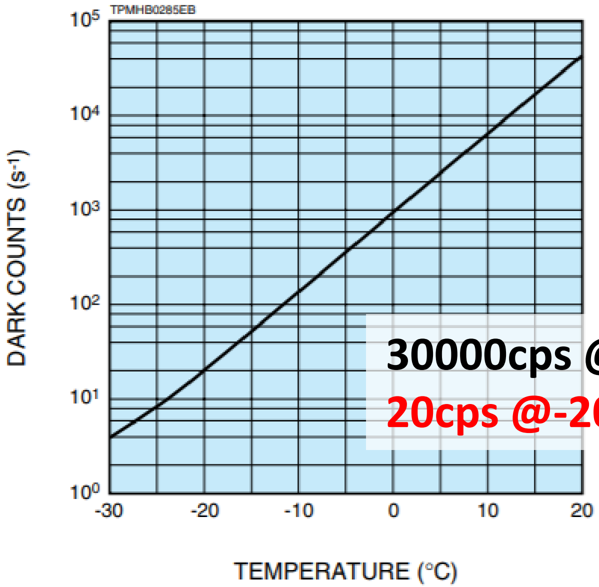
Quantum efficiency



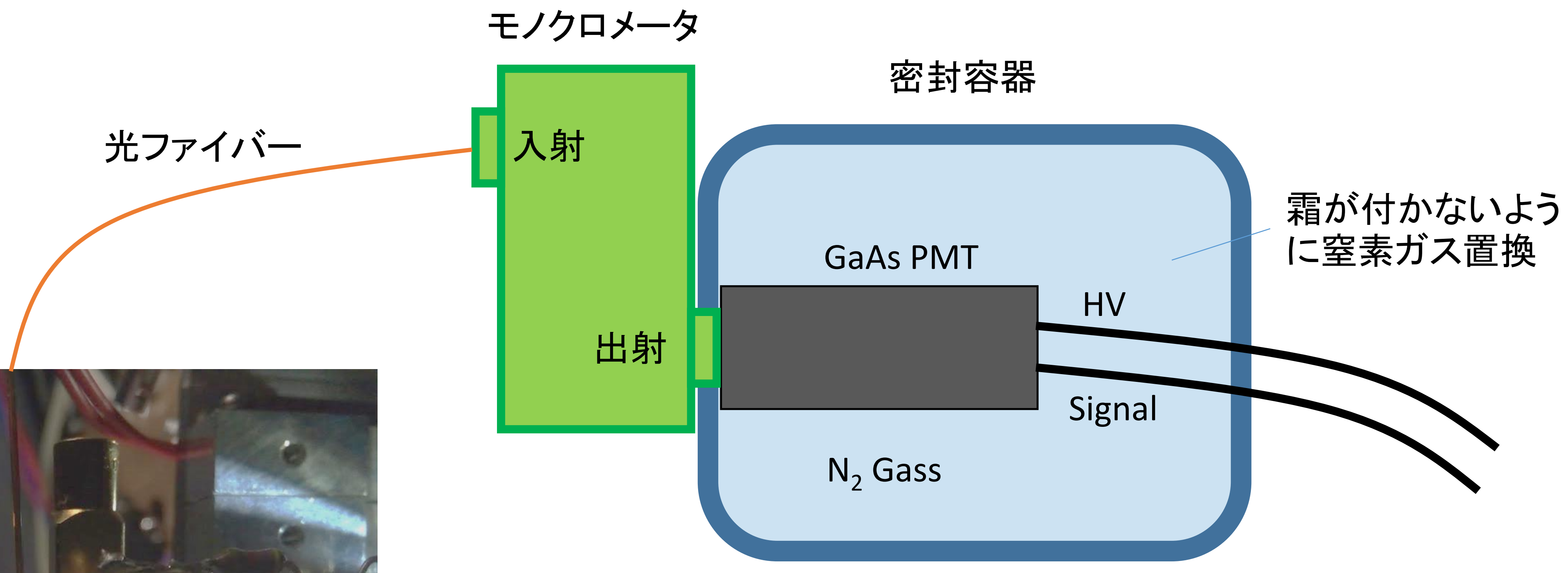


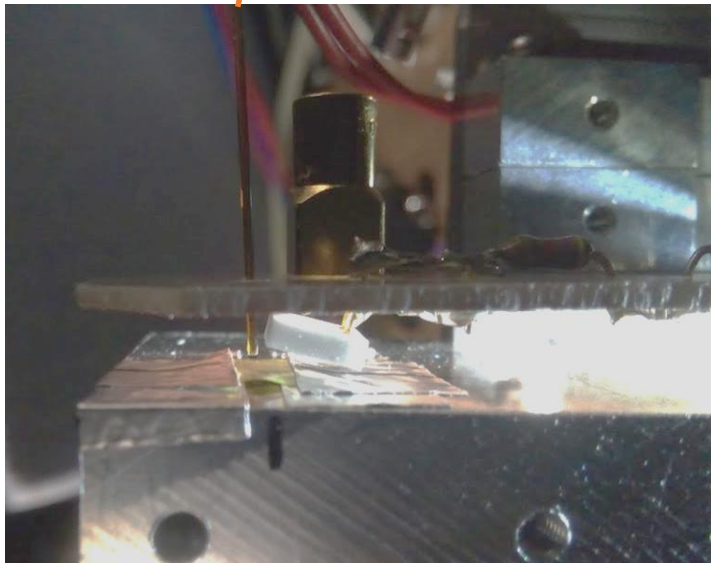
Thermal noise rate

100cps @20℃



GaAs PMT を-20℃ぐらいに冷やしたい

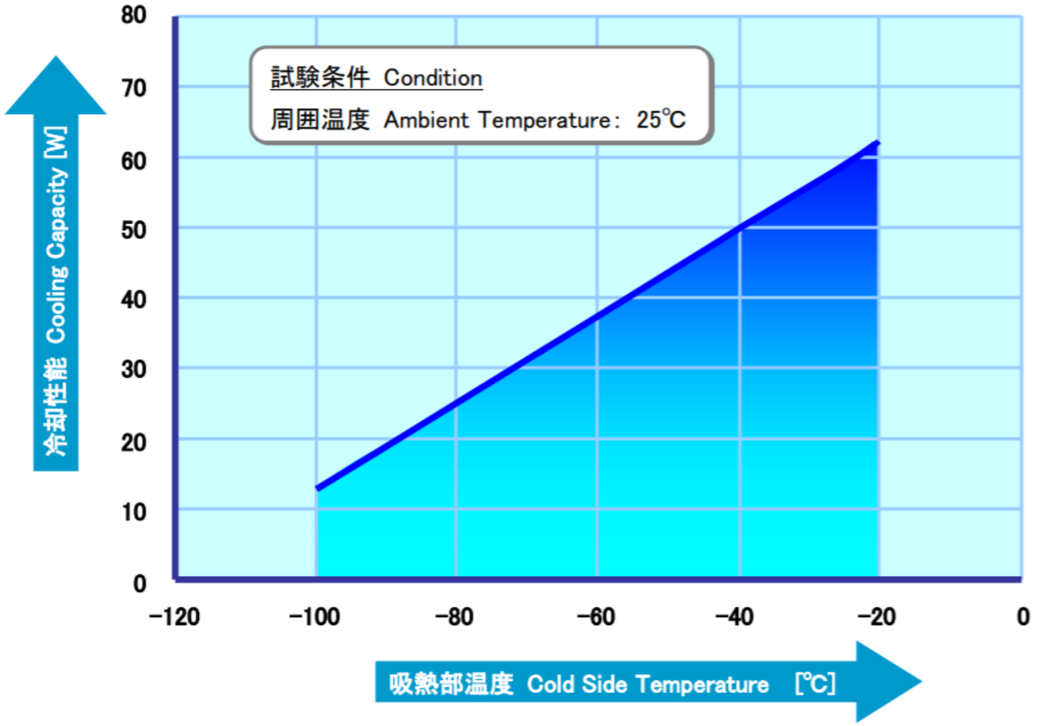




どうやって冷やす？
・氷水系は使いたくない
・保冷剤・ドライアイスだと溶ける、温度コントロールできない

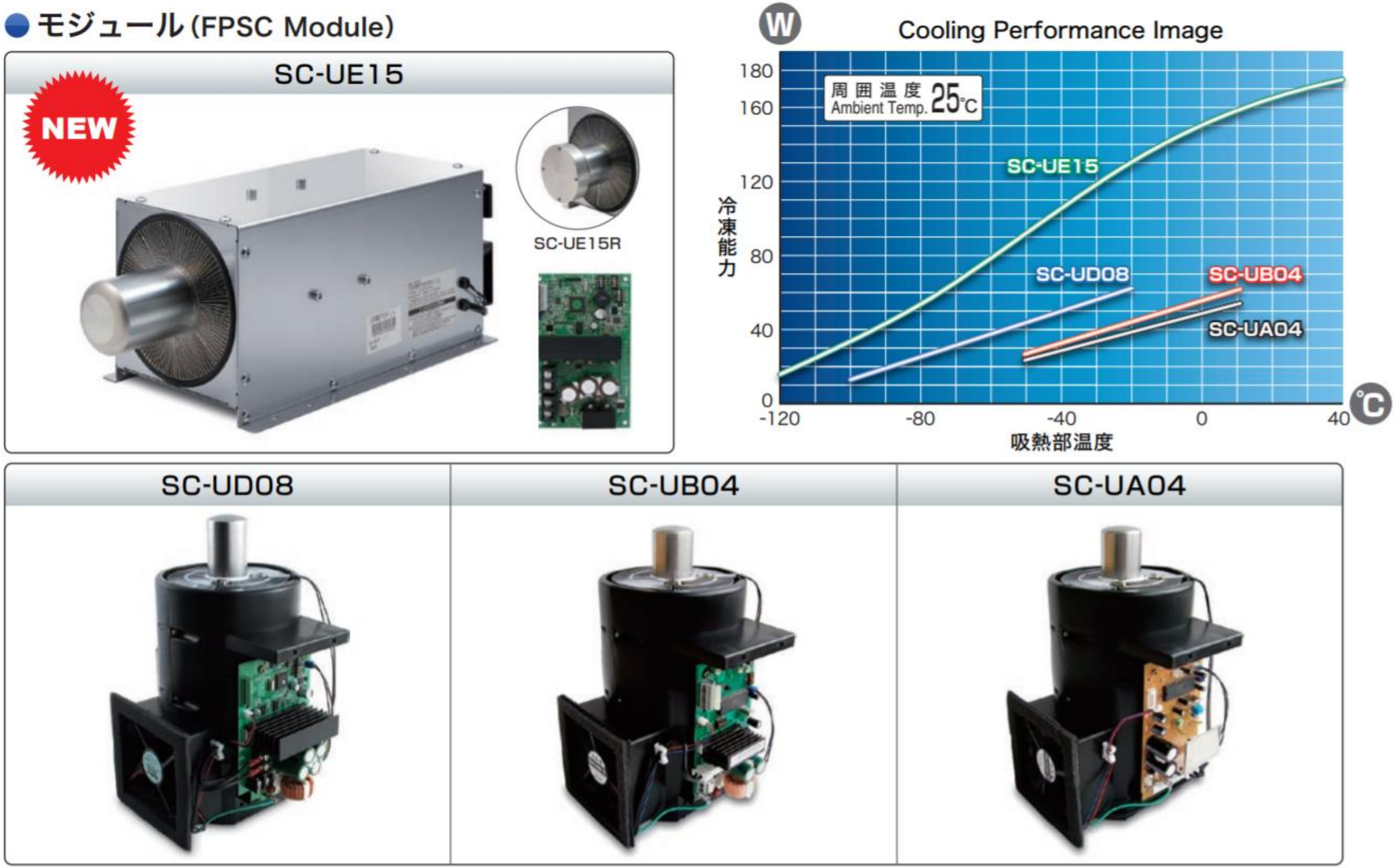
スターリング冷凍機　SC-UD08

冷却性能



・$(10cm)^3$の体積のアルミニウム（2.7kg）の場合
-20℃から1℃下げるのに38s
-40℃から　48s
-60℃から　66s

30万円→



12万円→

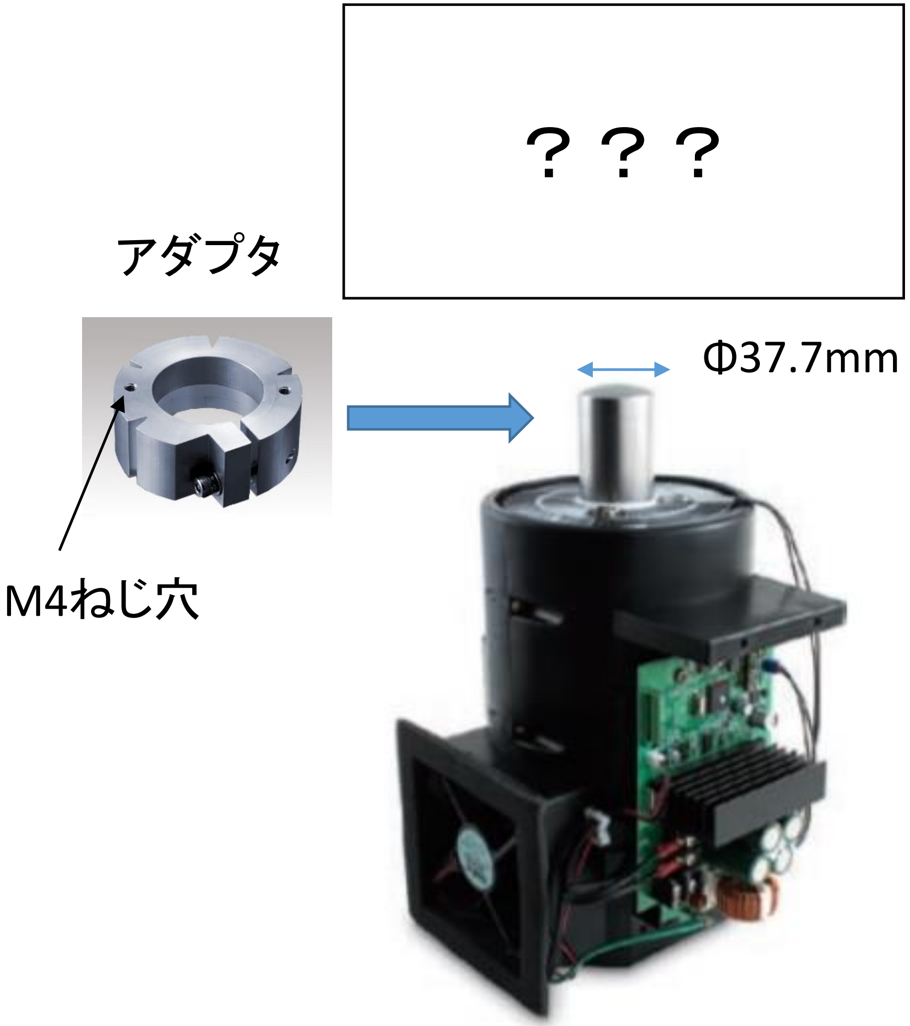
↑10万円

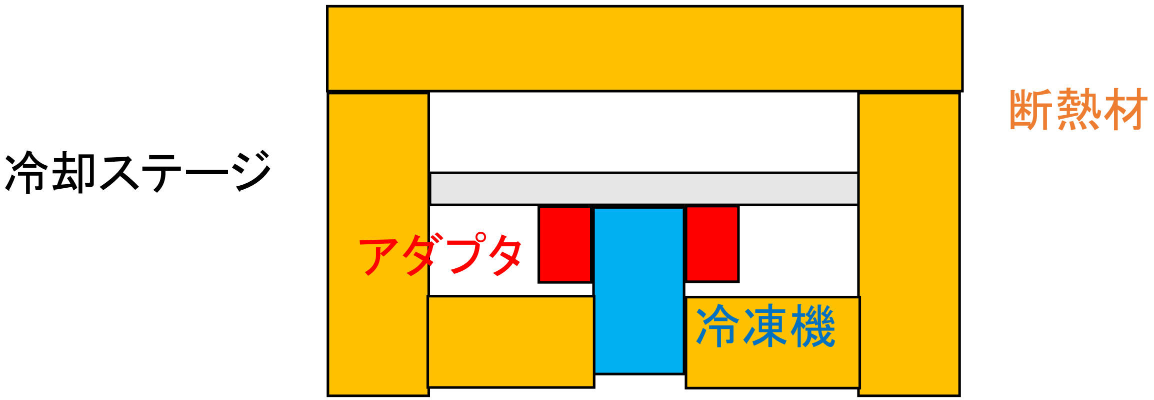
アダプタ

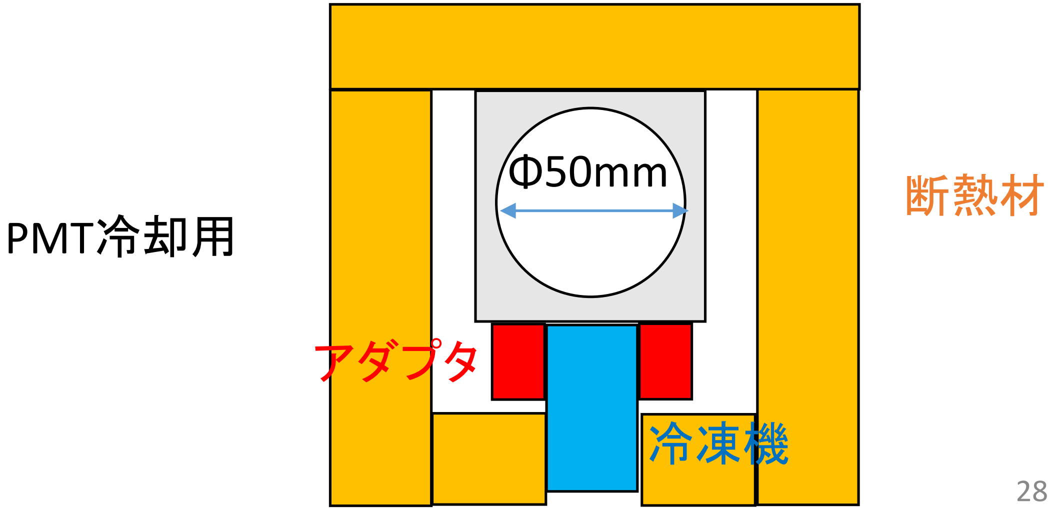
↑5500円

※100W級の24V電源が必要
(Amazonで3000円ぐらい)

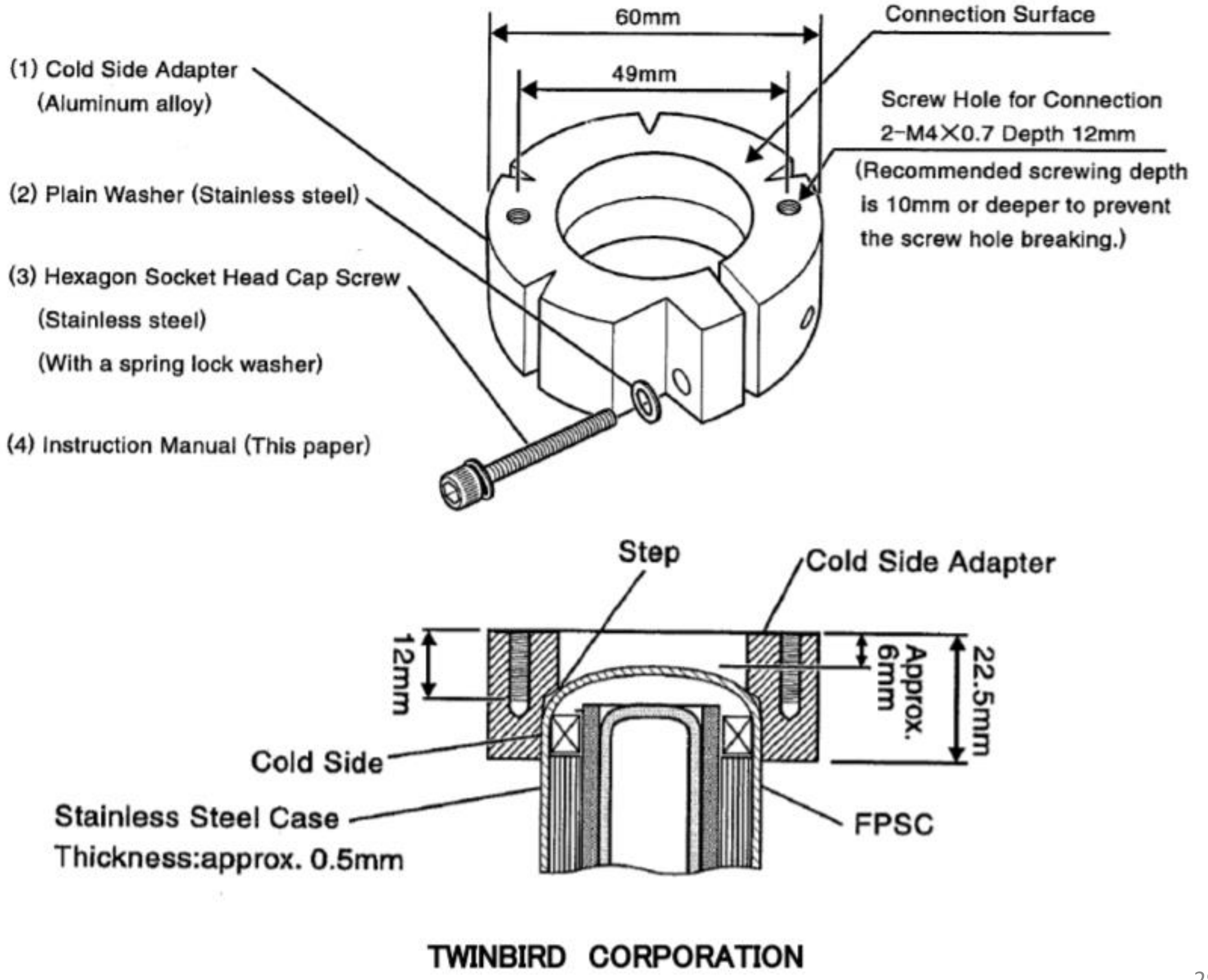
治具は各自で作れば良い





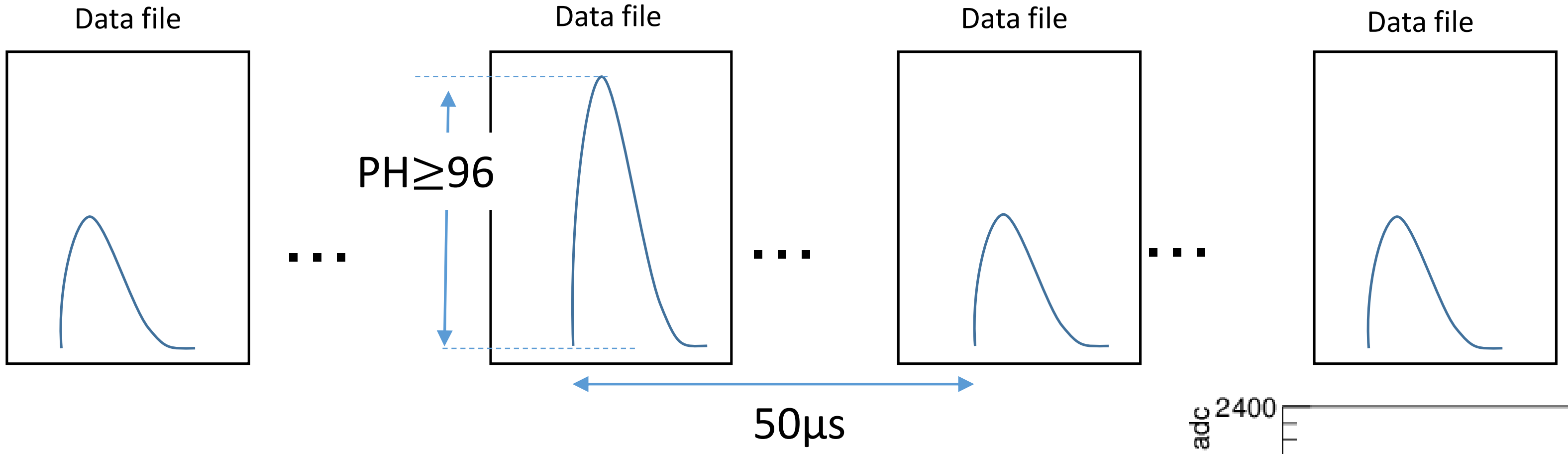


アダプタ

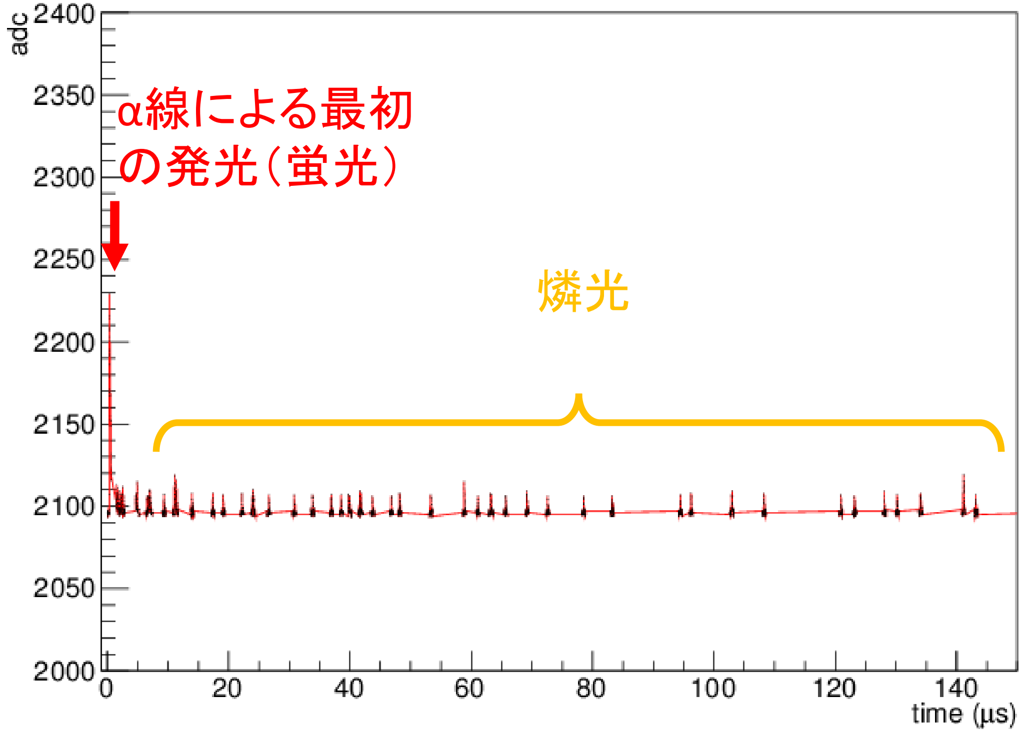


60mm
49mm
Connection Surface
(1) Cold Side Adapter
(Aluminum alloy)
Screw Hole for Connection
2-M4×0.7 Depth 12mm
(Recommended screwing depth
is 10mm or deeper to prevent
the screw hole breaking.)
(2) Plain Washer (Stainless steel)
(3) Hexagon Socket Head Cap Screw
(Stainless steel)
(With a spring lock washer)
(4) Instruction Manual (This paper)
Step
Cold Side Adapter
12mm
Approx. 6mm
22.5mm
Cold Side
Stainless Steel Case
Thickness:approx. 0.5mm
FPSC
TWINBIRD CORPORATION

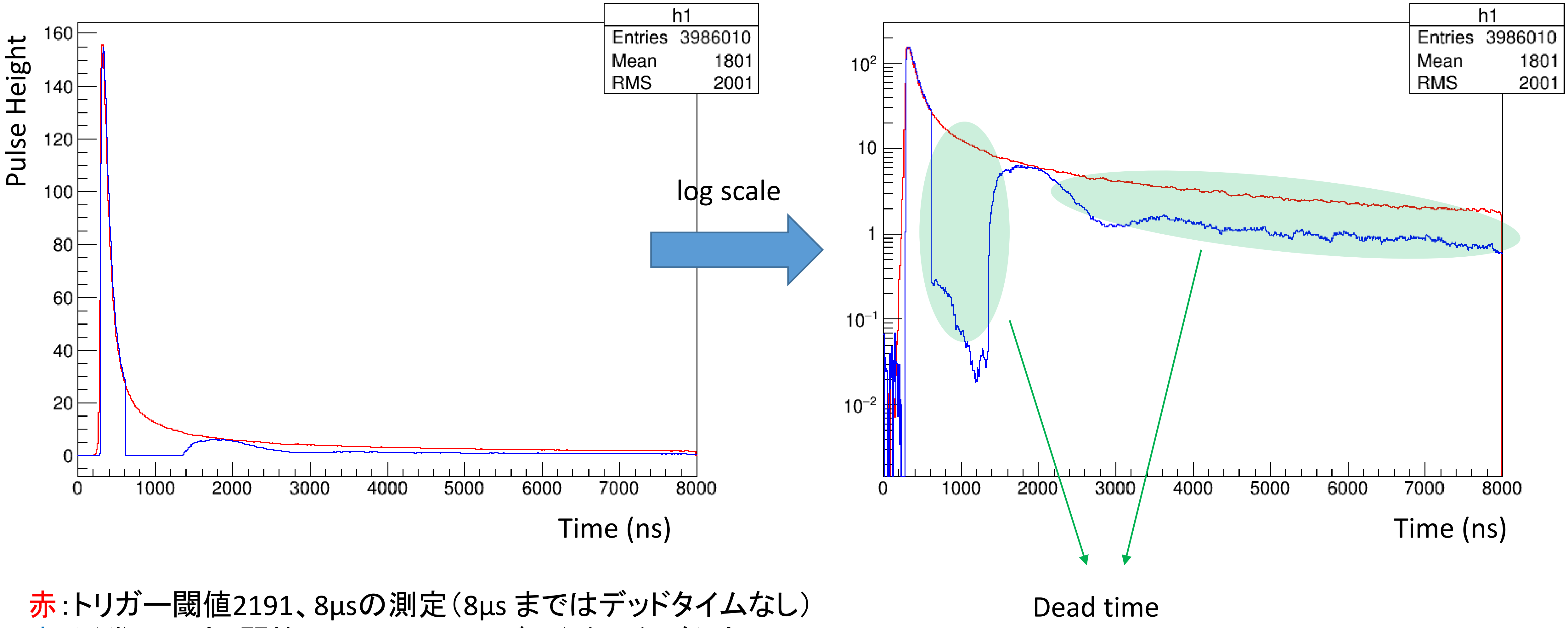
Data connection



通常の測定
・トリガー閾値：2103
・タイムウィンドウ：600ns
（デッドタイム～800ns）

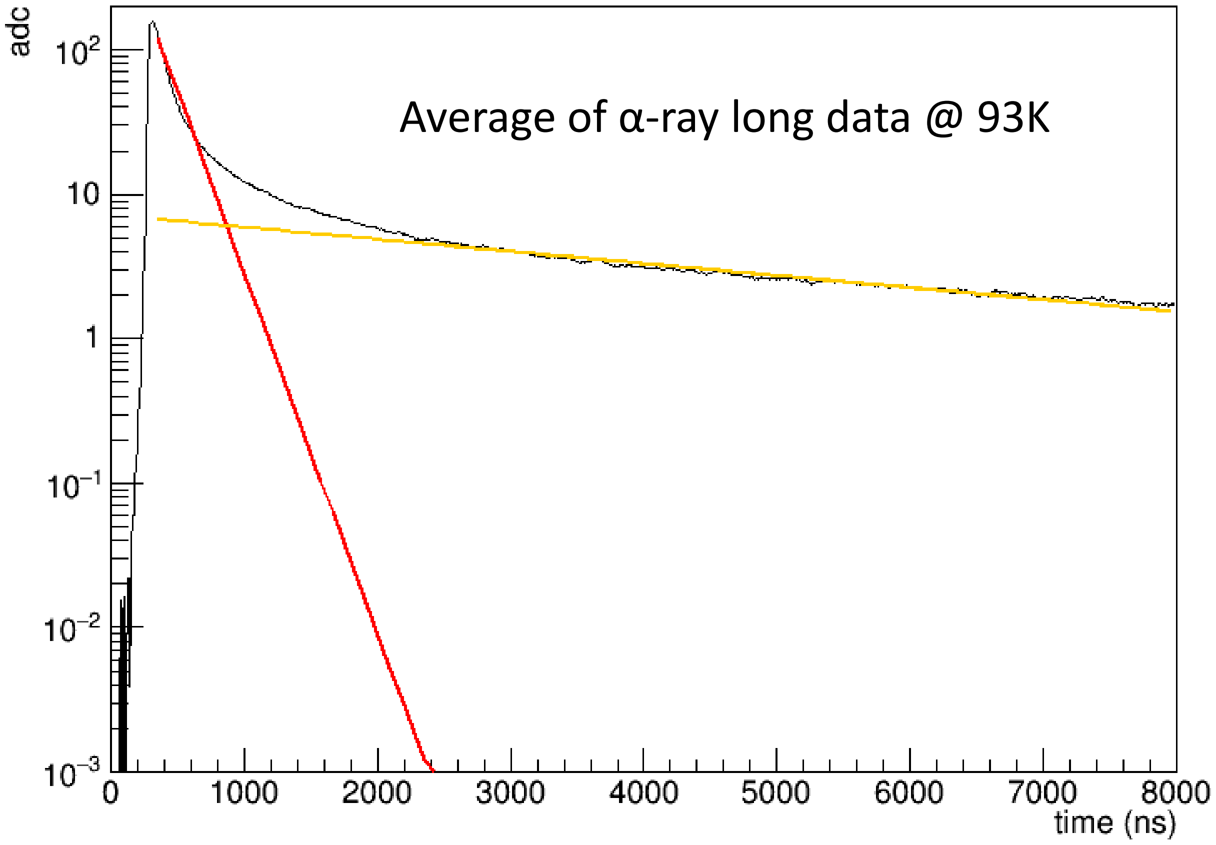


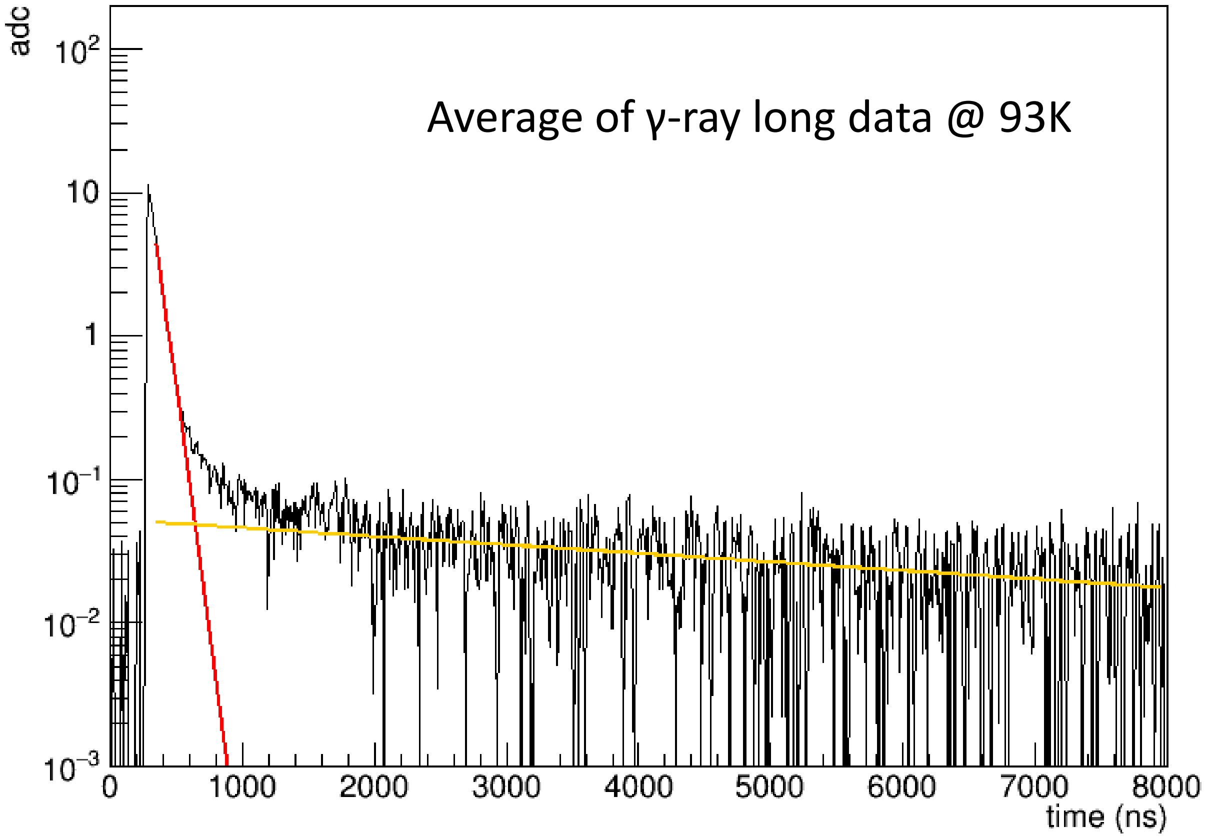
Averaged waveform

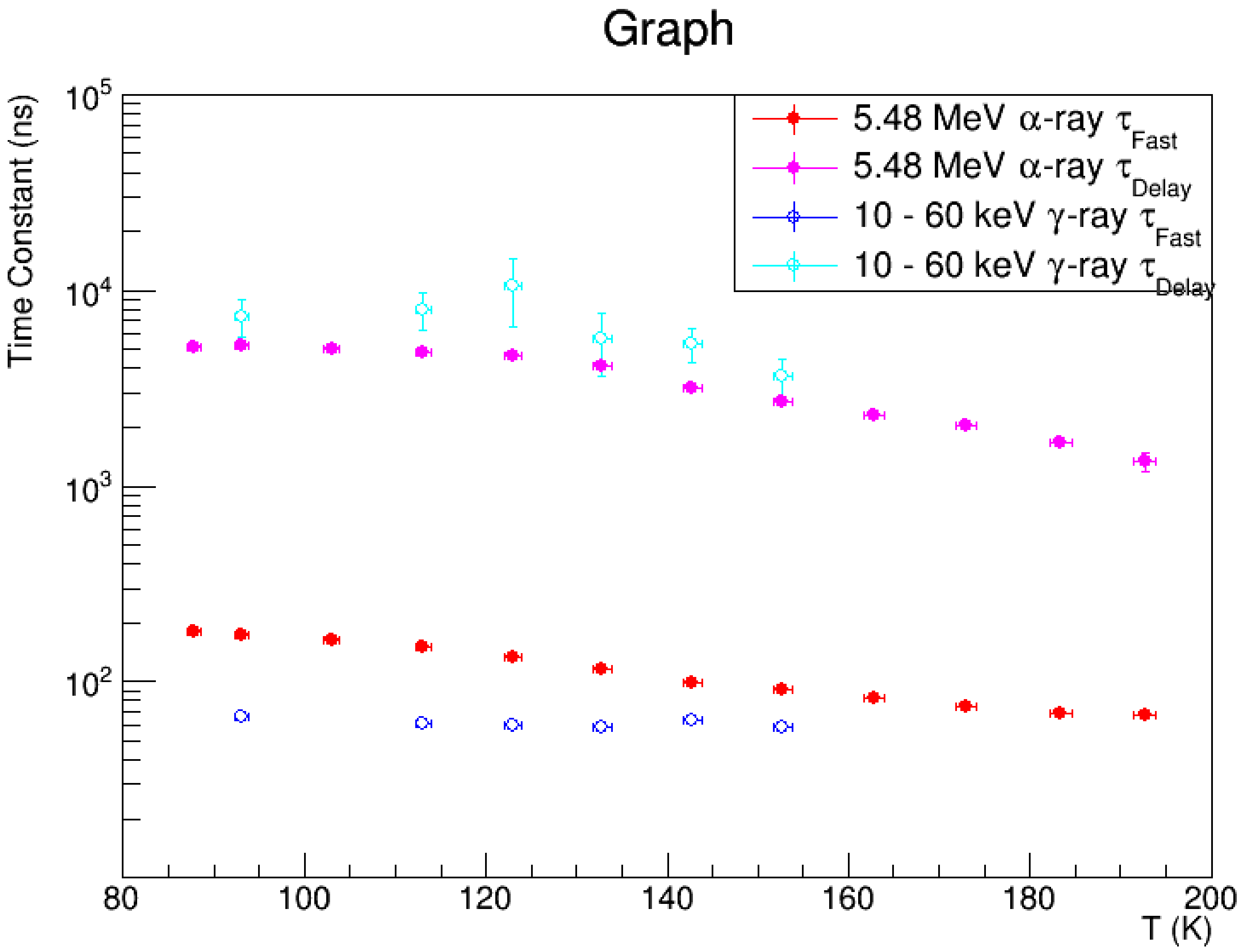


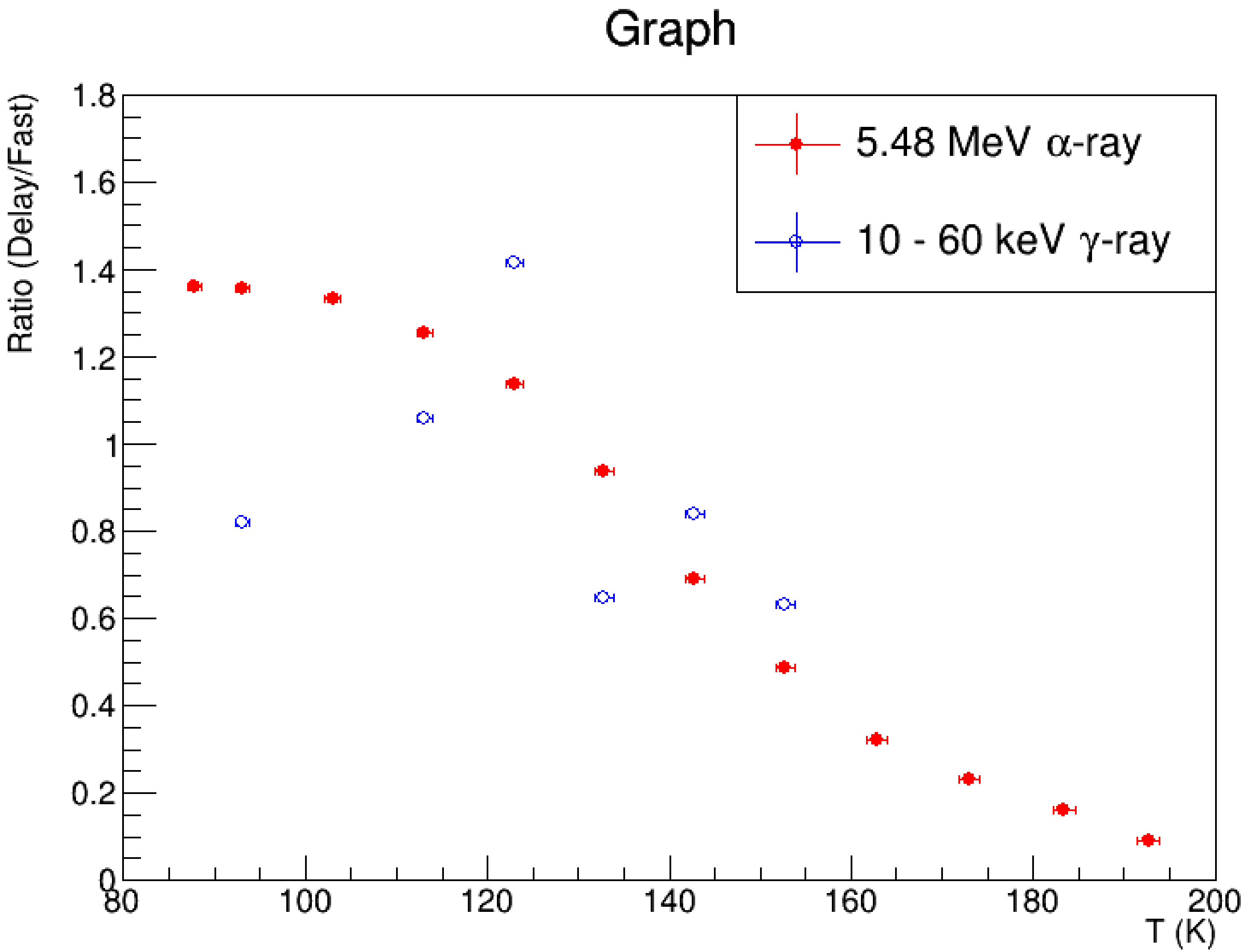
赤：トリガー閾値2191、8μsの測定（8μs まではデッドタイムなし）
青：通常の測定（閾値2103、600ns）でデータをつなげたもの

Long data (time window 8μs)



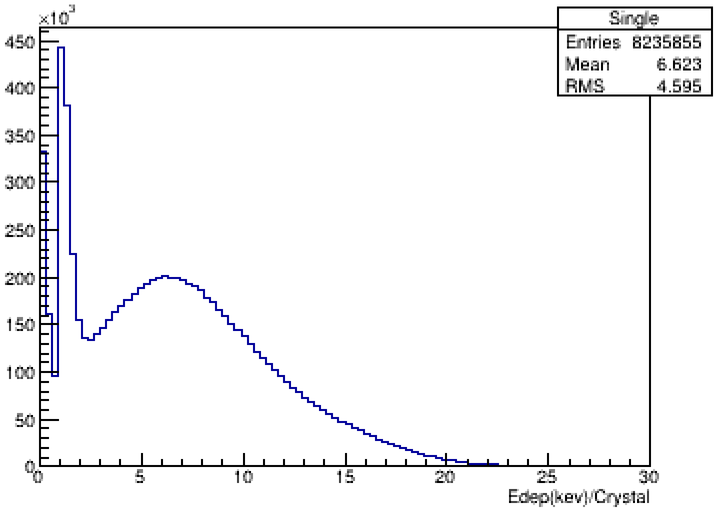


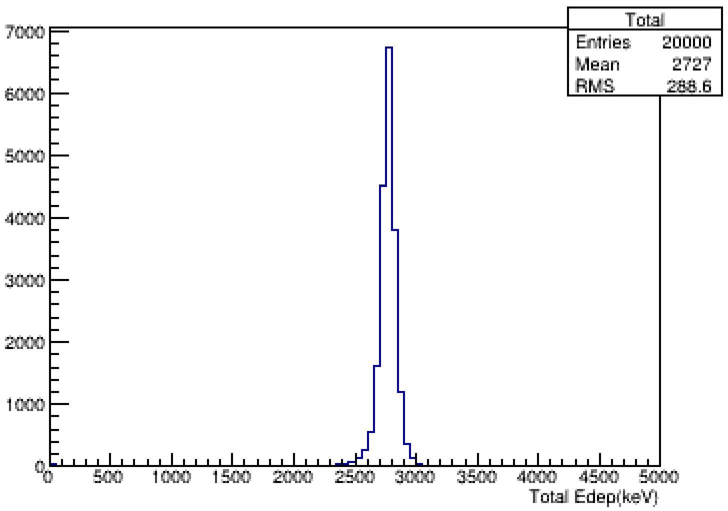

Graph
Time Constant (ns)
10^5
10^4
10^3
10^2
80
100
120
140
160
180
200
T (K)
5.48 MeV α-ray τ_{Fast}
5.48 MeV α-ray τ_{Delay}
10 - 60 keV γ-ray τ_{Fast}
10 - 60 keV γ-ray τ_{Delay}

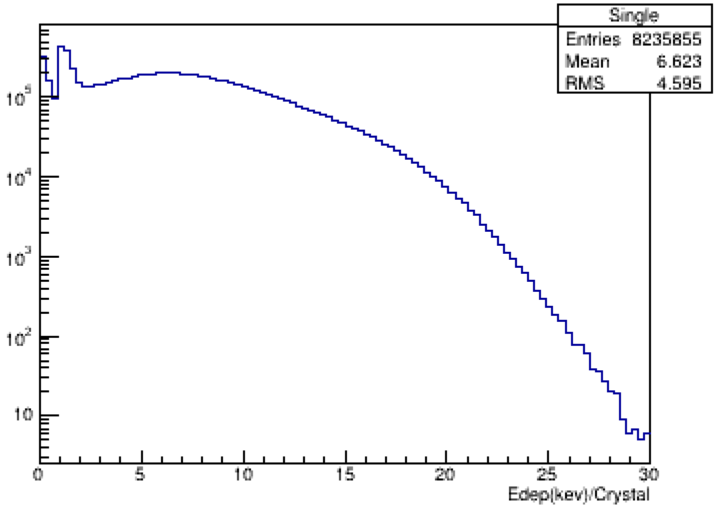


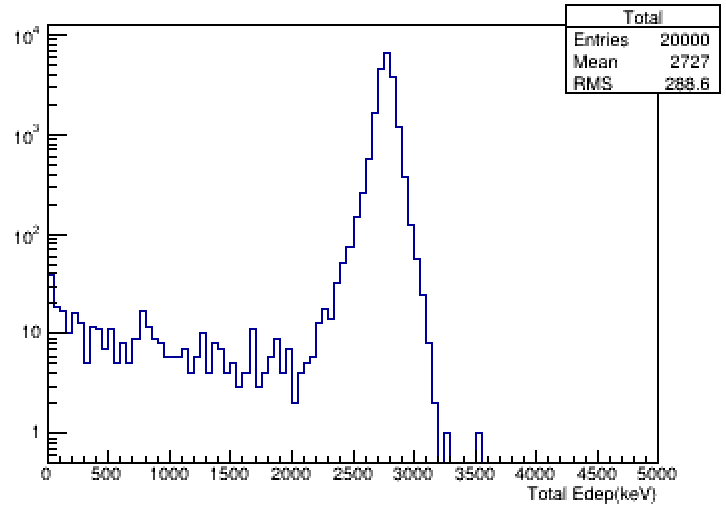
Graph
Ratio (Delay/Fast)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
80
100
120
140
160
180
200
T (K)
5.48 MeV α-ray
10 - 60 keV γ-ray

α-ray simulation

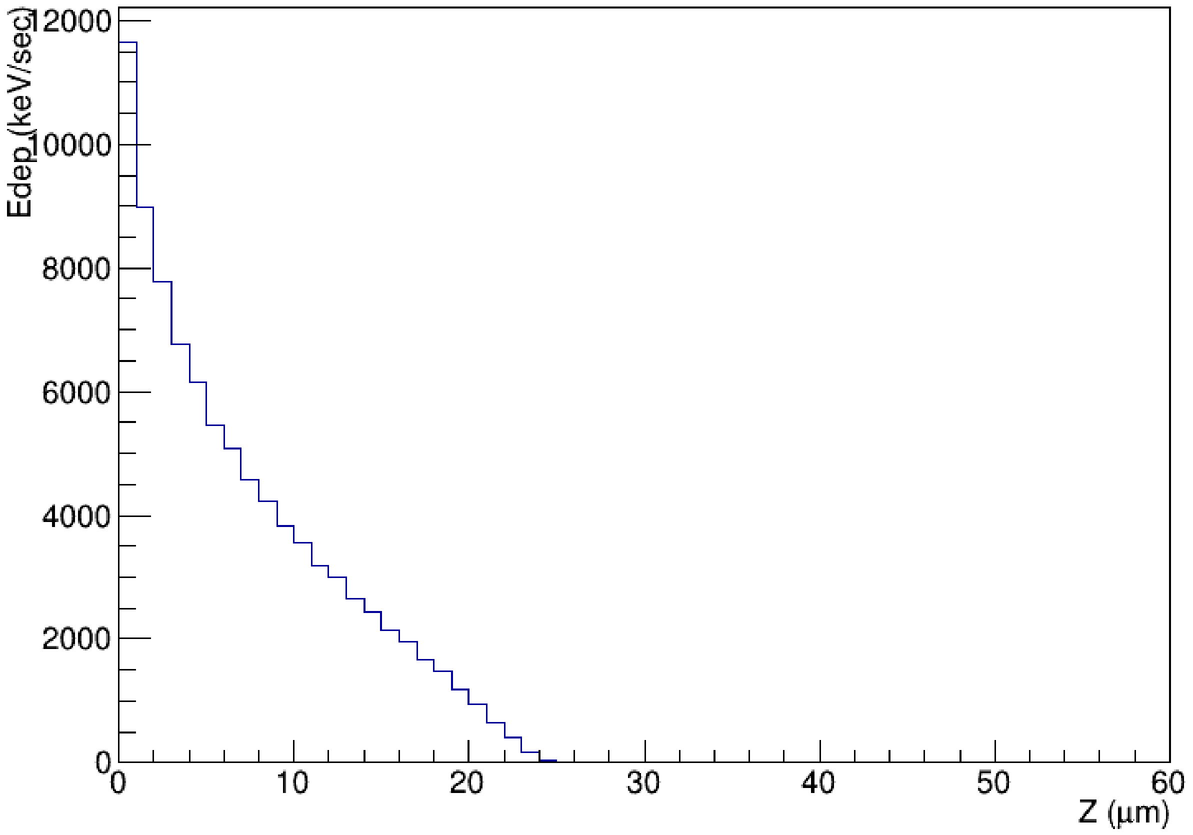


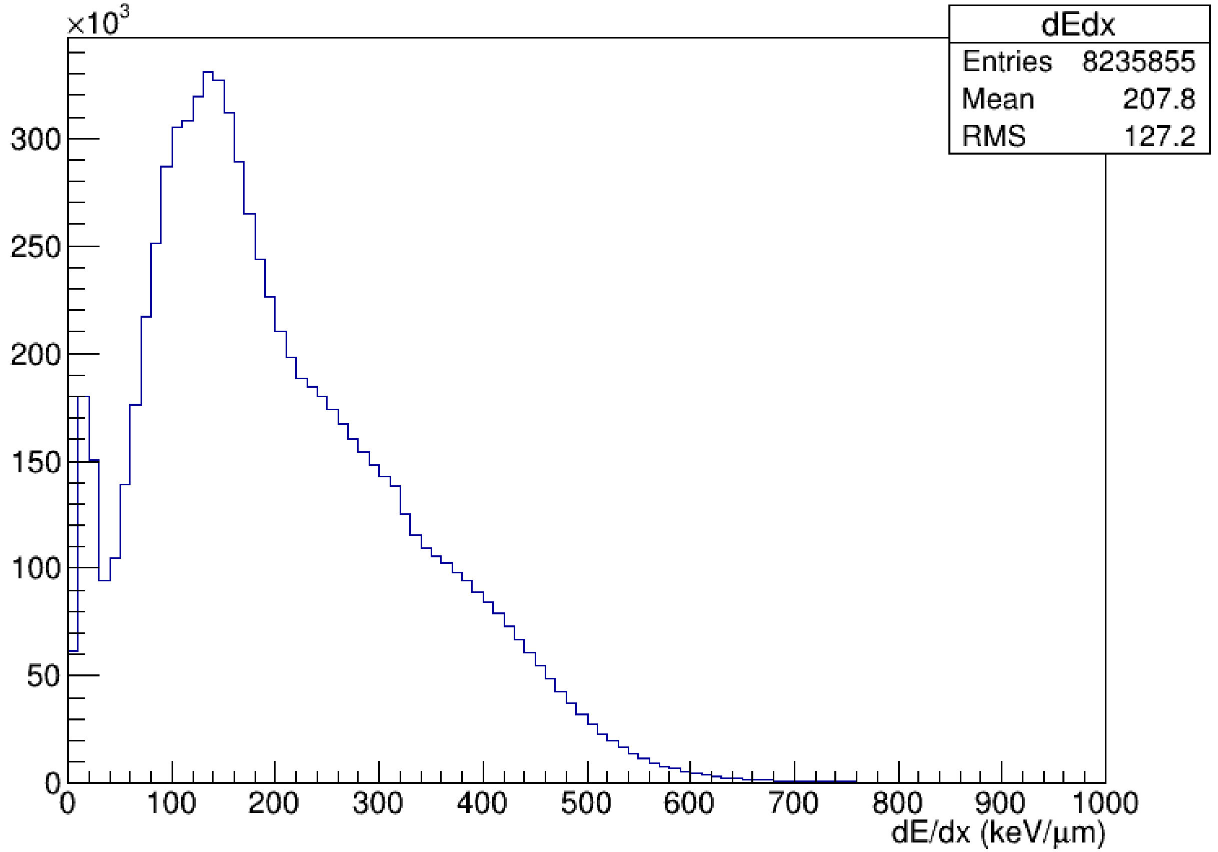




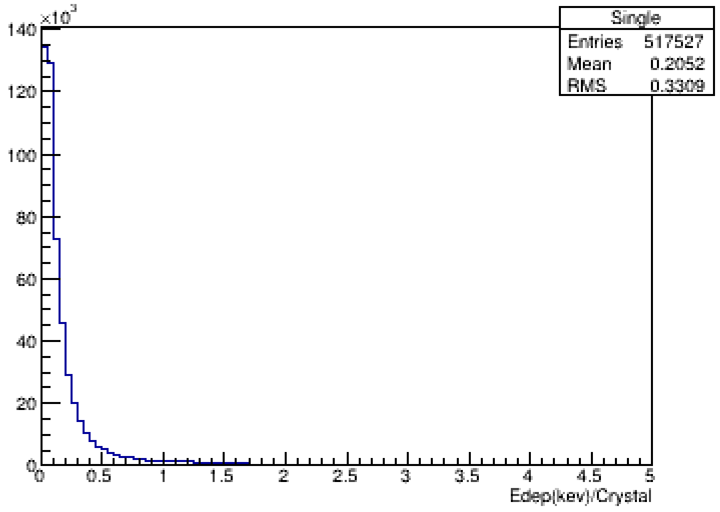


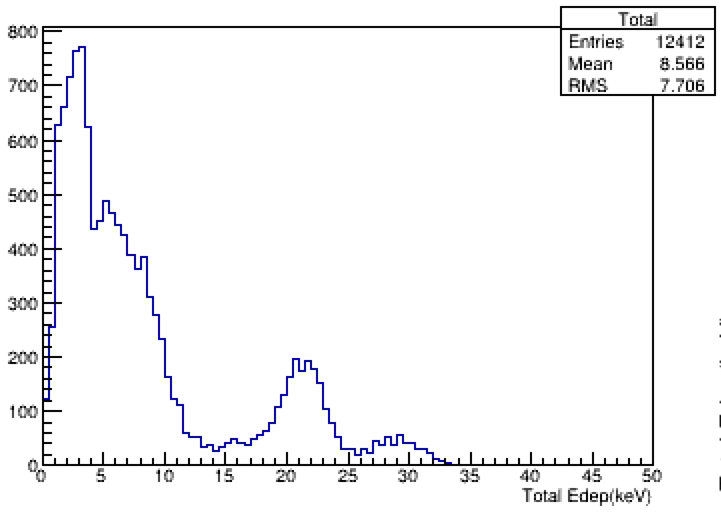
α-ray simulation

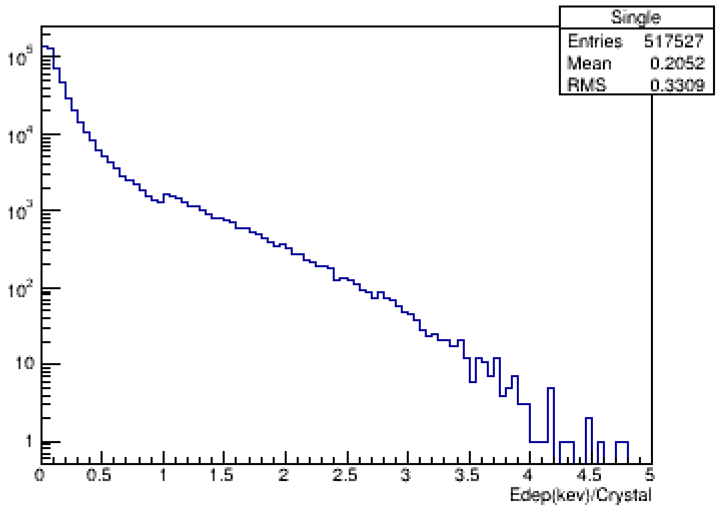


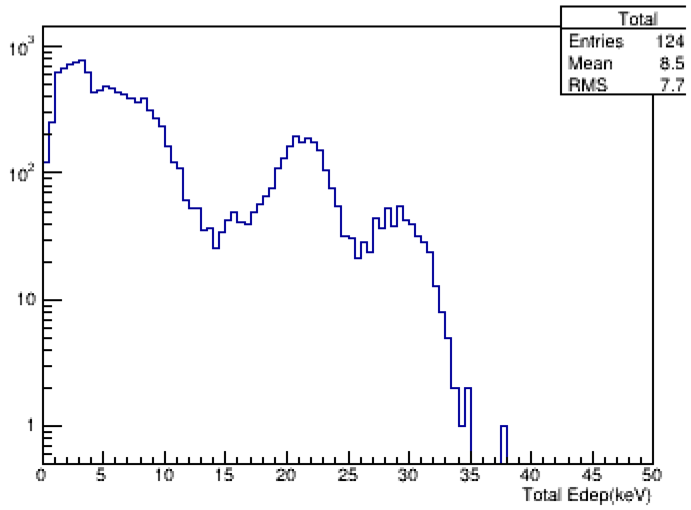


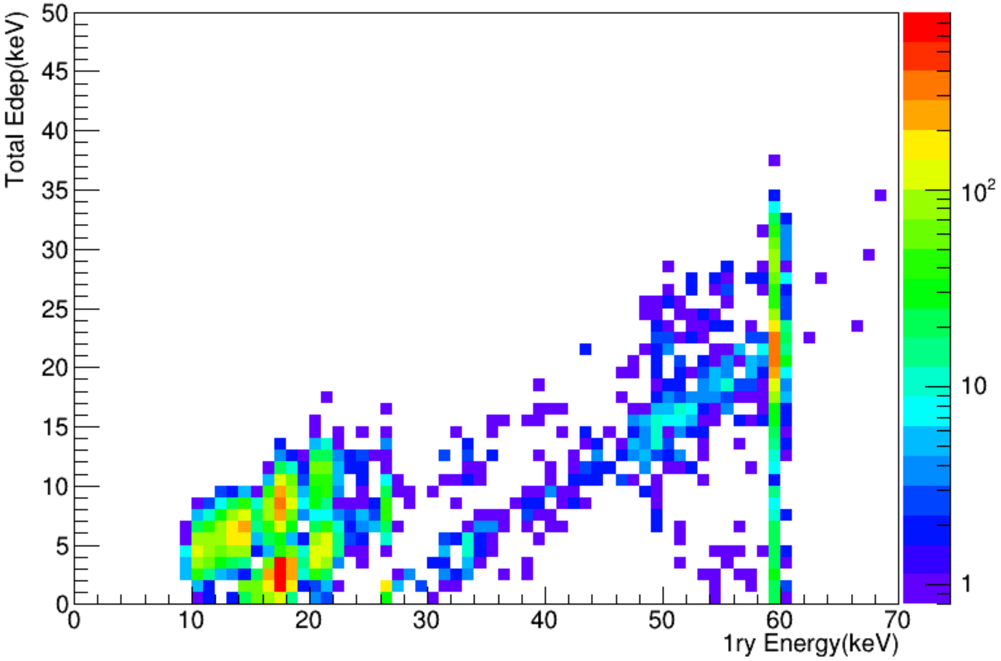
γ-ray simulation



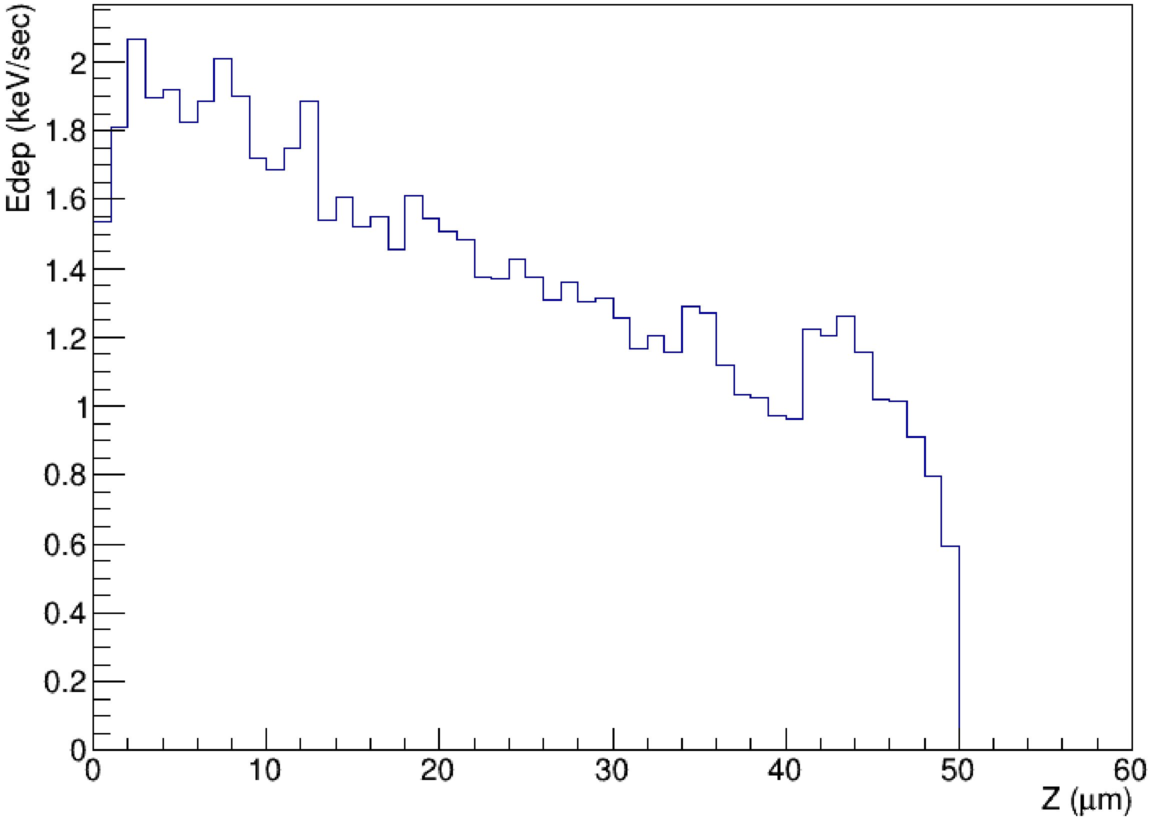


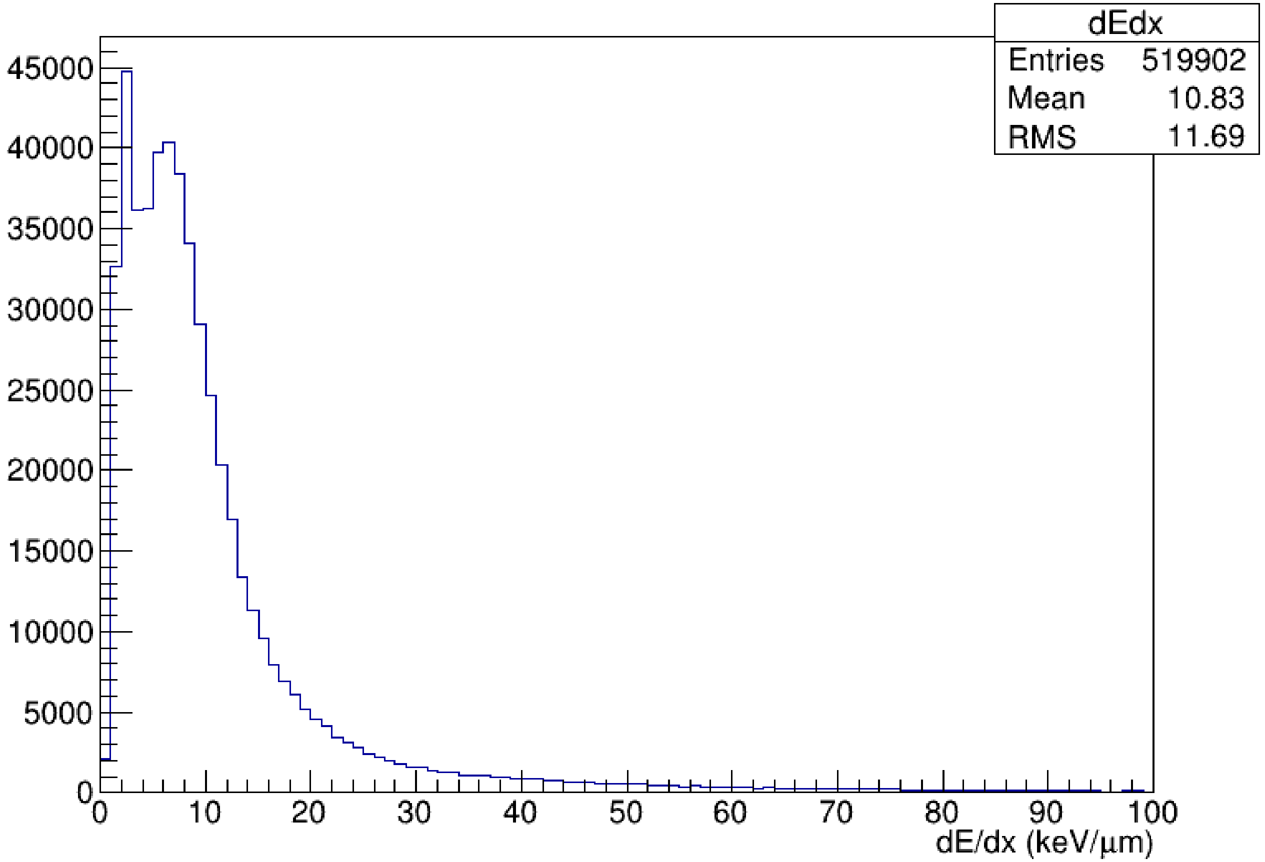






γ-ray simulation

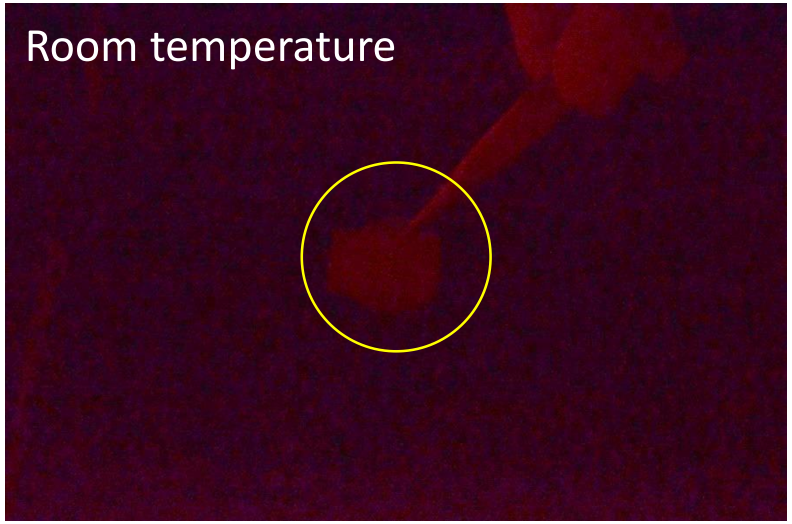


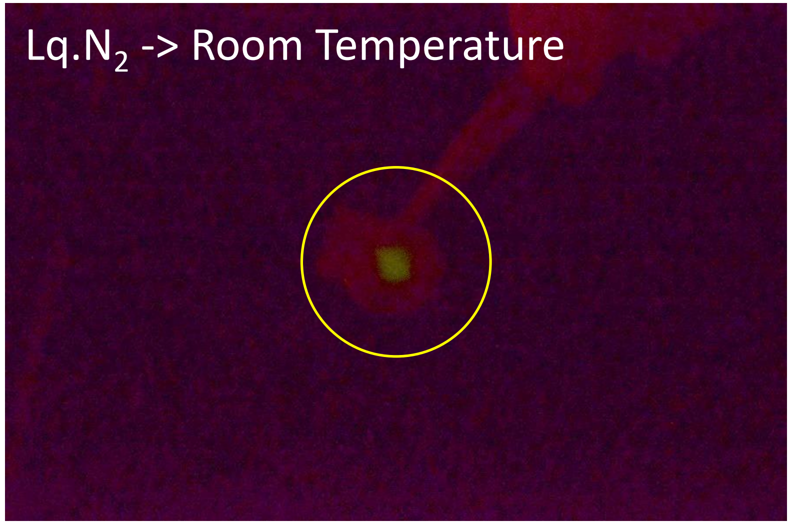


Thermoluminescence of NIT by charged particles

α

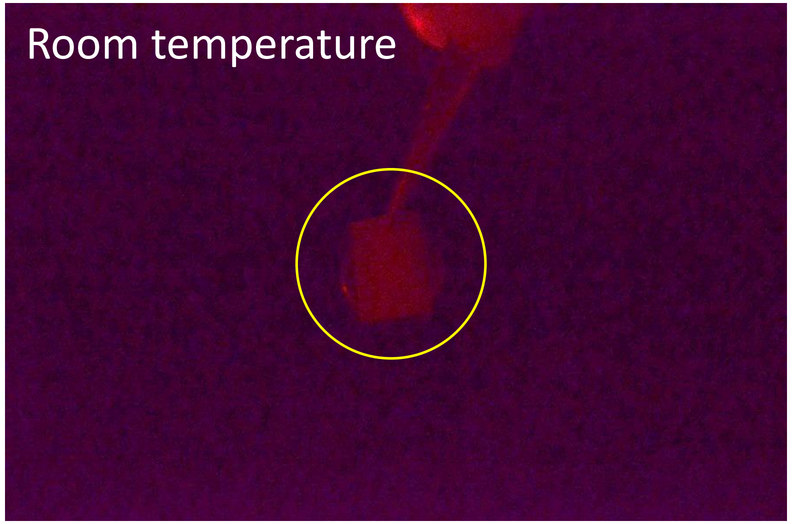
^{241}Am

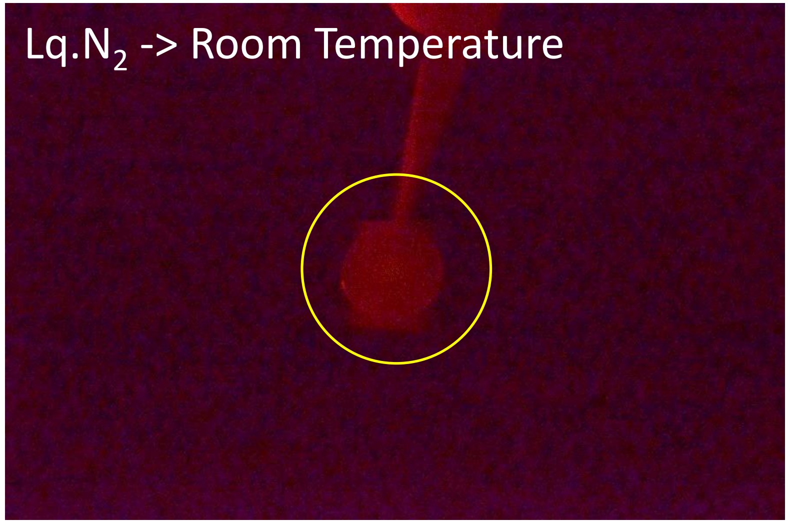




β

^{90}Sr





* ISO6400, shutter speed = 4 s (α), shutter speed = 8 s (β)

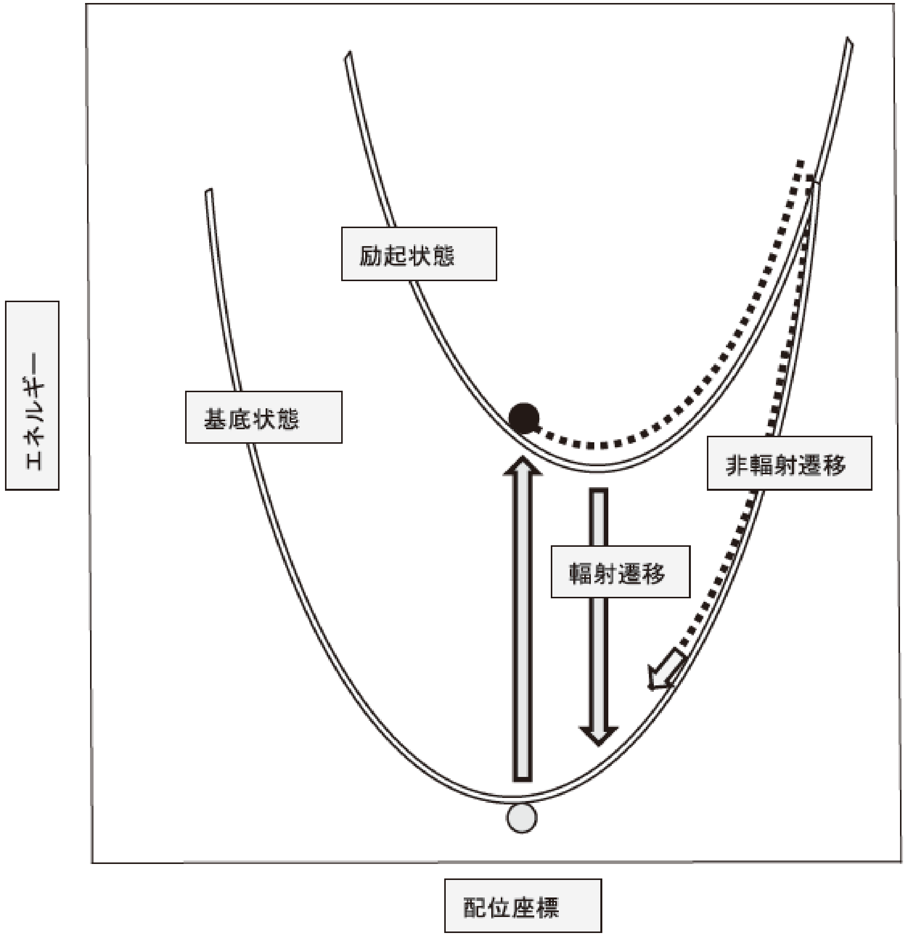


Fig. 3　配位座標による励起状態からの輻射・非輻射遷移の説明図

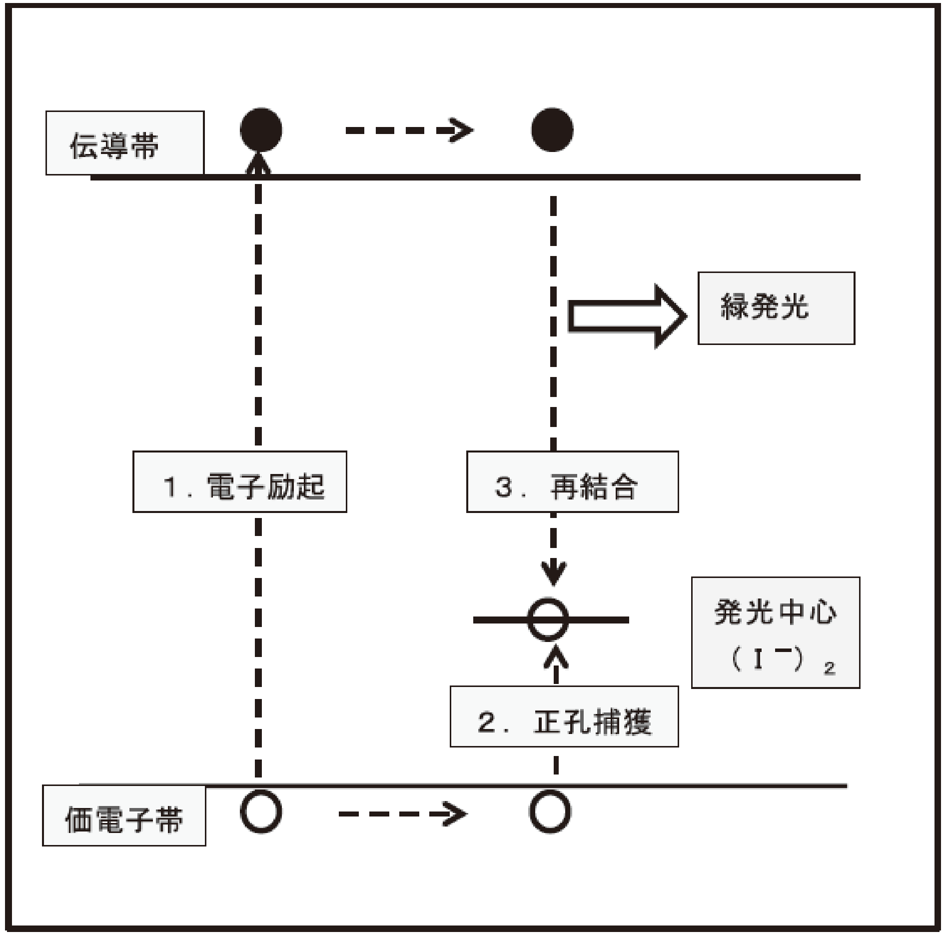


Fig. 4　液体窒素温度での AgBrI 粒子の再結合発光の機構図

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Triboluminescence

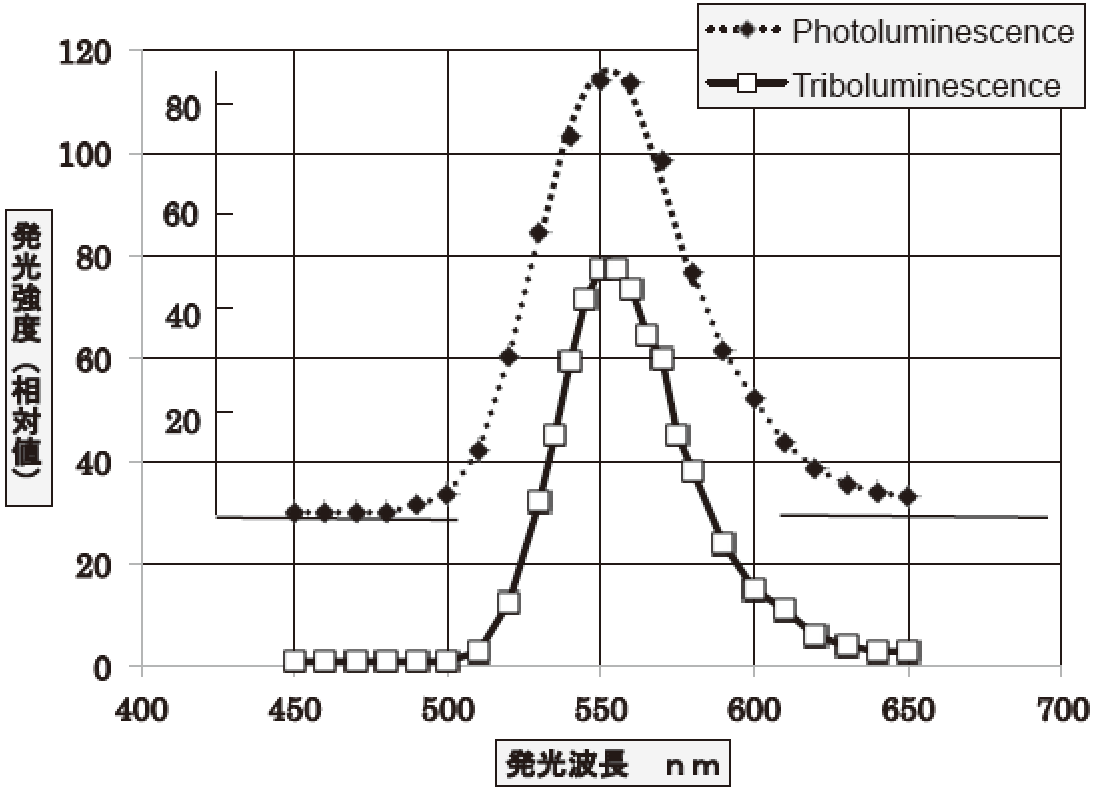


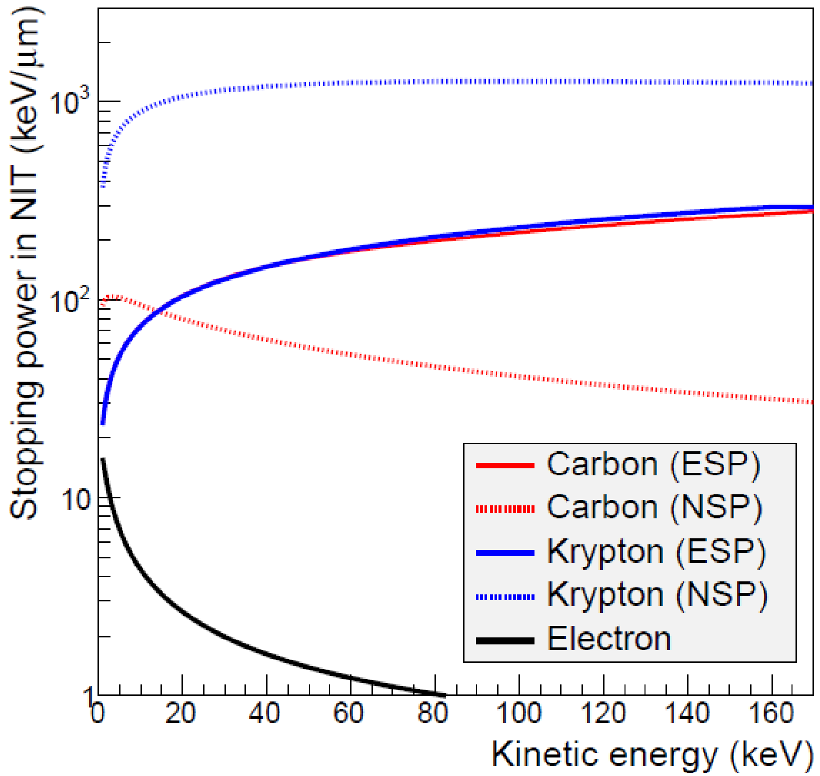
Fig. 5　液体窒素温度での AgBrI 粒子の発光スペクトル[7)]
フォトルミネッセンス，　トリボルミネッセンス

日本写真学会誌2016 年79 巻3 号：2–6　高田俊二、久下謙一

Presented at JPS meeting Autumn 2015

Temperature rise due to phonon effect

Sensitivity recovery from Ag and Br tracks are promising.



Stopping powers in NIT (SRIM simulation)

*ESP: Electron stopping power
NSP: Nuclear stopping power

	Total phonon energy in 40 nm [eV]	δT for 40 nm AgBr [K]	δT for 20 nm AgBr [K]
Ag (150 keV)	18600	58	234
Br (150 KeV)	13800	43	173
C (50 keV)	734	2.3	9.2
He (1000 keV)	15.9	0.050	0.20
H (1000 keV)	0.54	0.0017	0.067

$$\delta T = \frac{\delta E}{C_V}$$

Cv ~ 3.5 x 10^{20} eV/mol/K @ 93 K (51.8 J/mol/K)

* K. Kamran *et al.*, J. Phys. D : Appl. Phys. 40(2007)869-873

Temperature rise due to phonon effect

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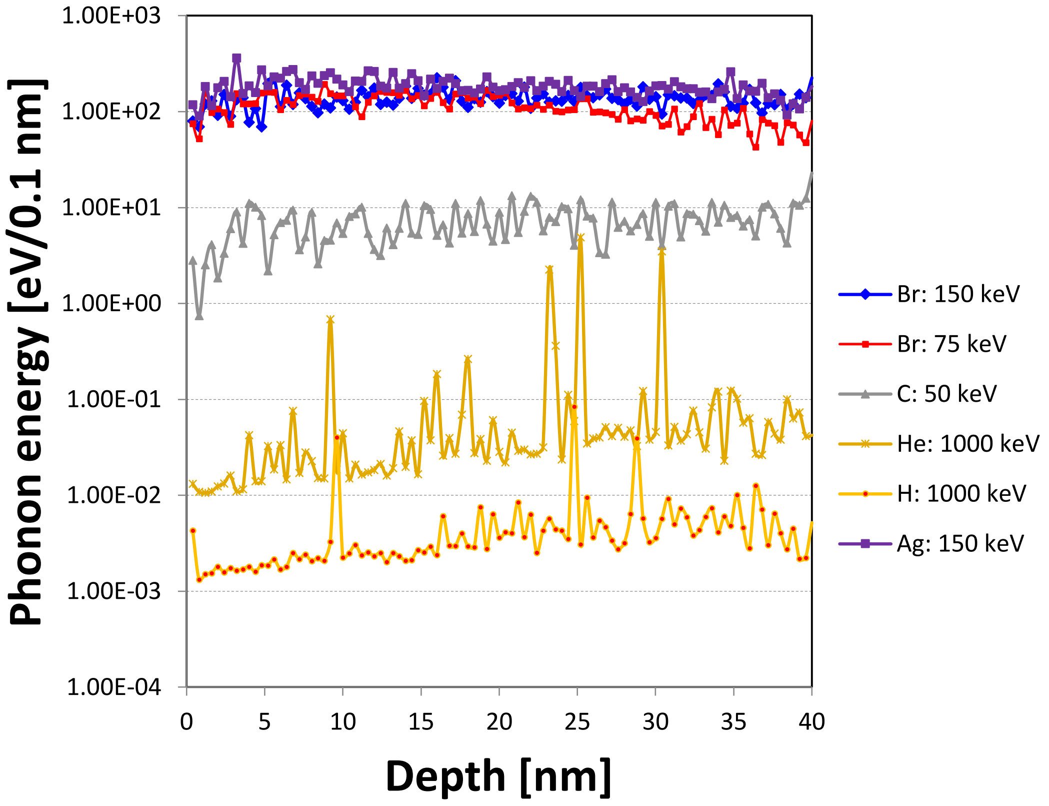

Average phonon energy in 40 nm AgBr layer by various particles (simulated by SRIM)

	Total phonon energy in 40 nm [eV]	δT for 40 nm AgBr [K]
Ag (150 keV)	18600	58
Br (150 KeV)	13800	43
C (50 keV)	734	2.3
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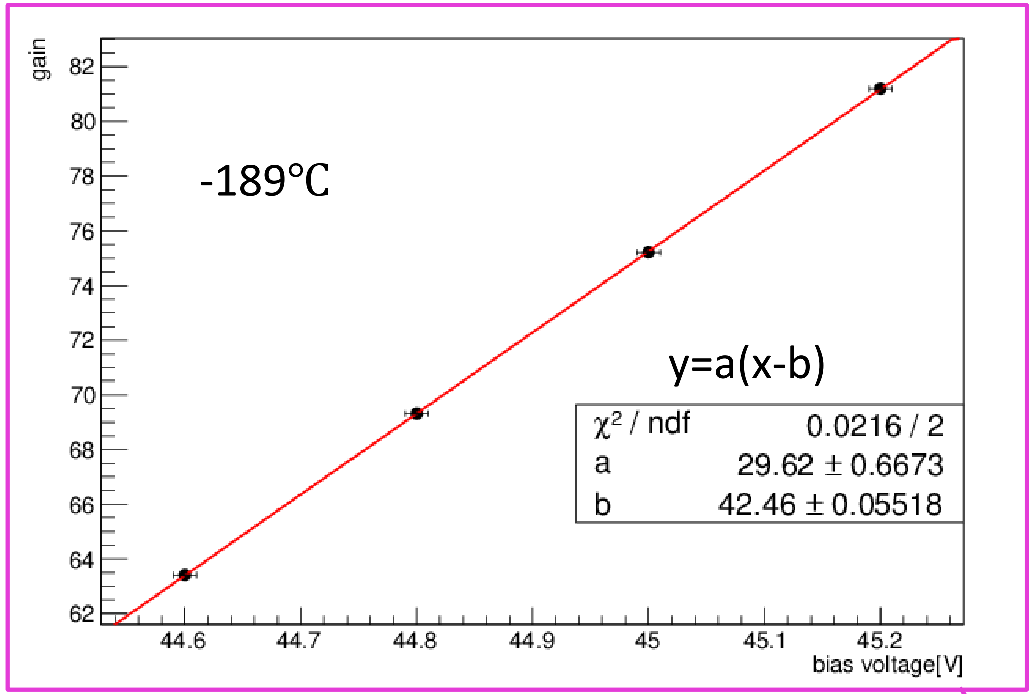
Calibration of MPPC break down voltage



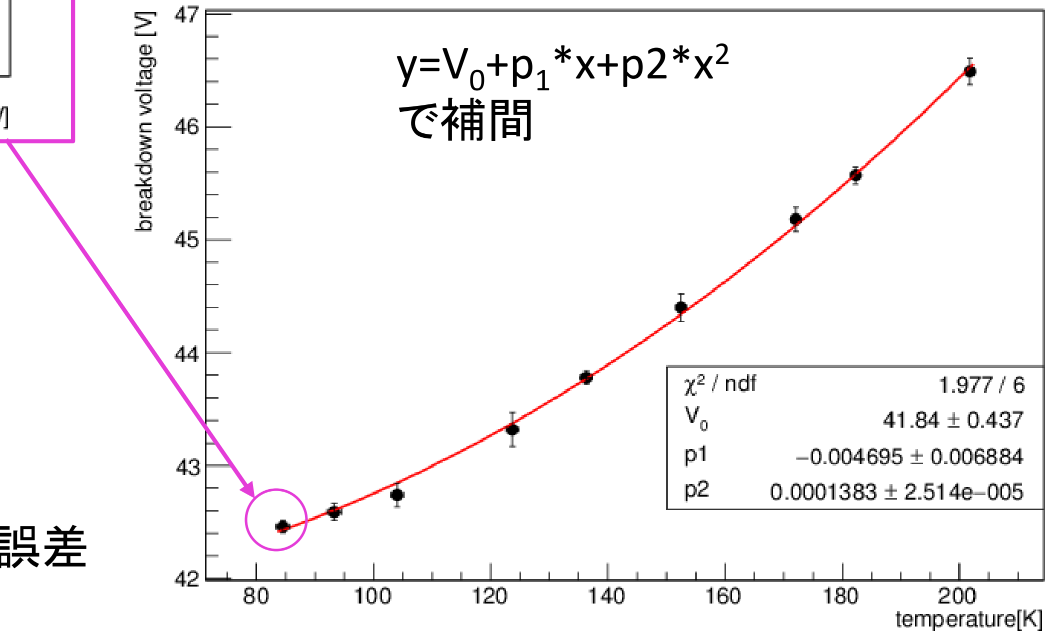
$$M = \frac{A*C(V_{bias} - V_{bd})}{e}$$

縦軸の誤差:

- 4点測定する間の温度上昇
- 1光子ピークの決定精度

横軸の誤差:

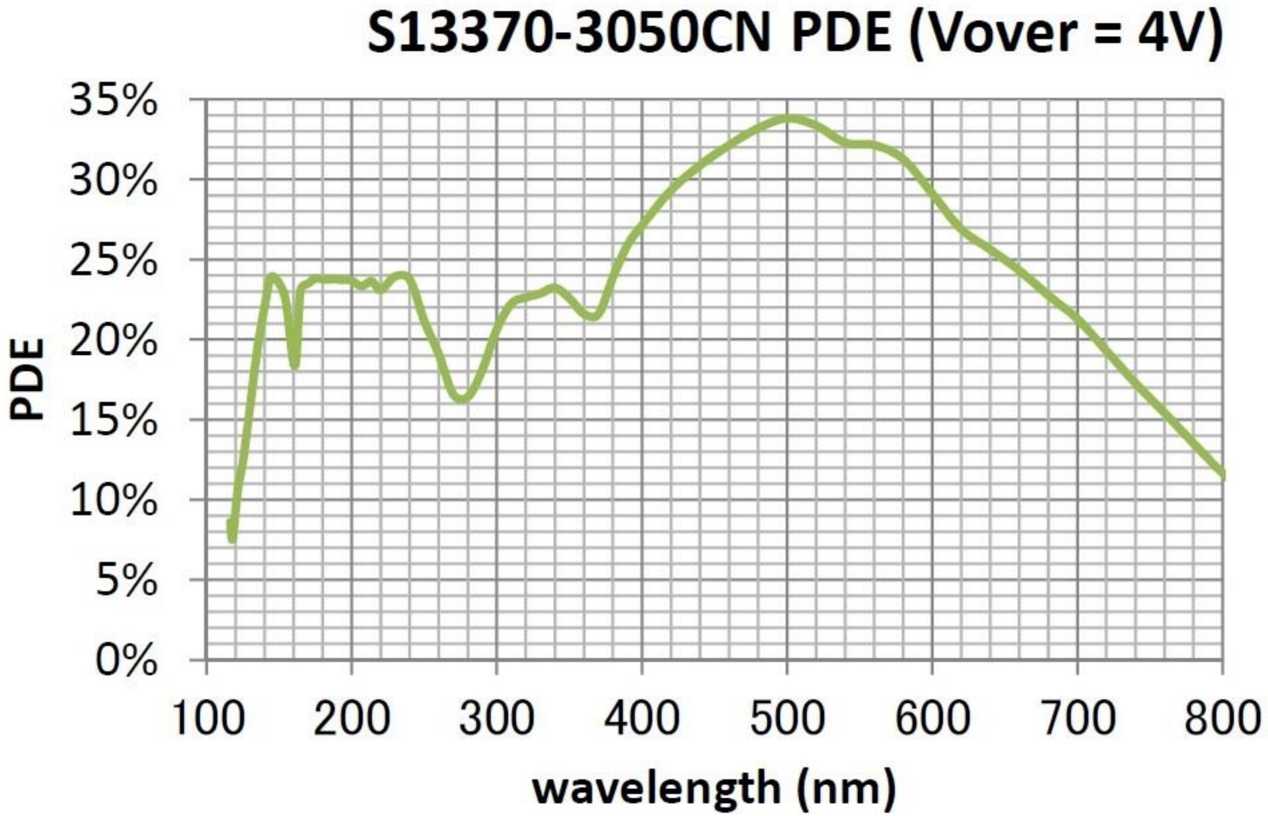
- 設定できる最小単位



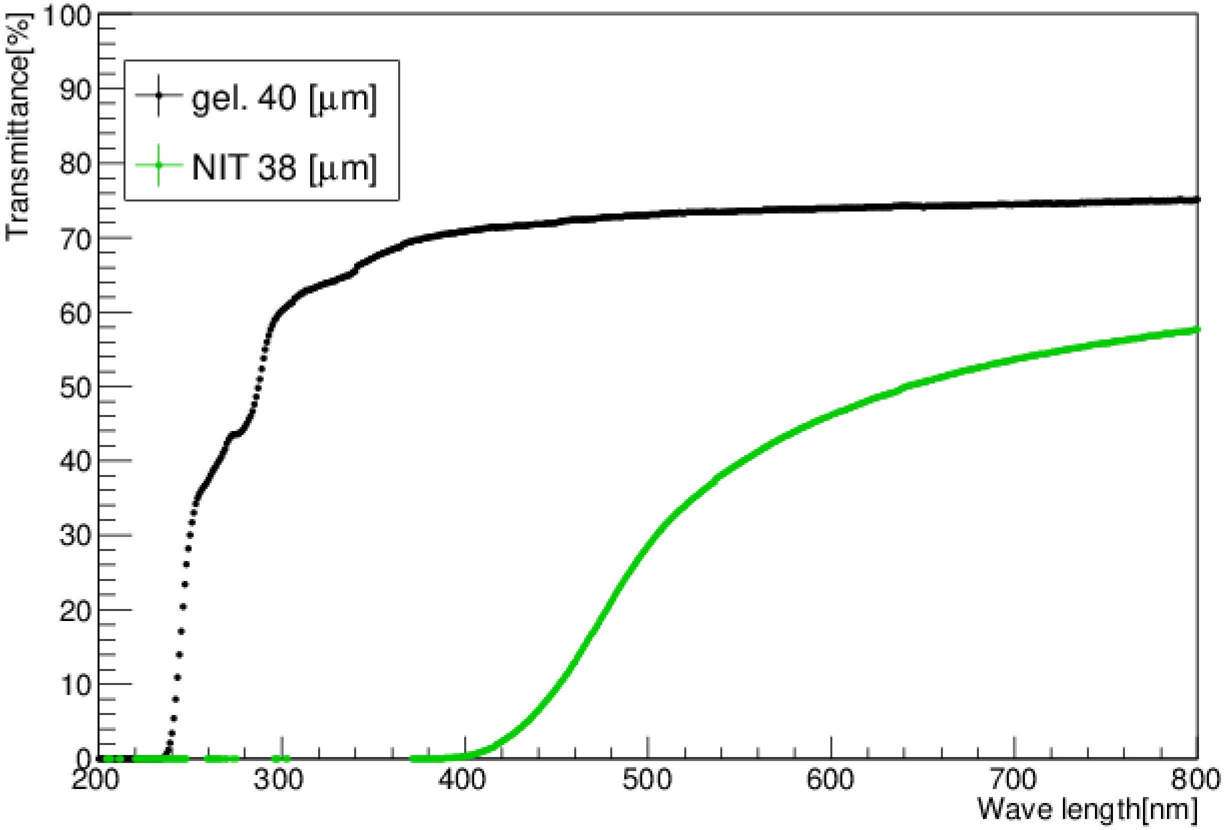
横軸の誤差:

- 温度計の測定誤差

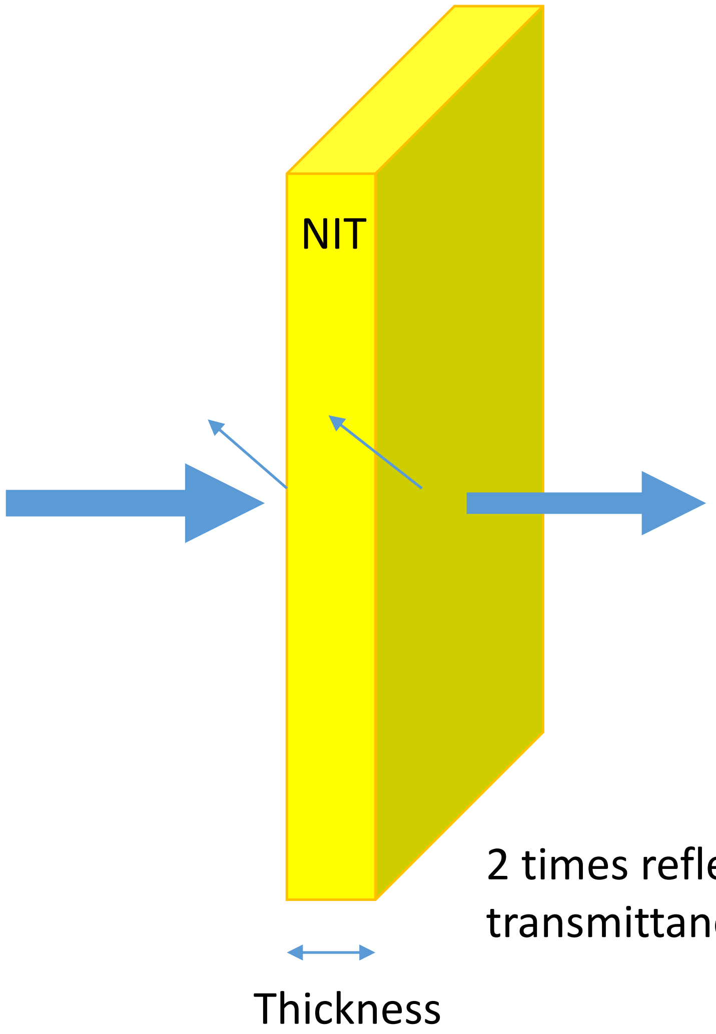
REFERENCE DATA



Transmittance in NIT

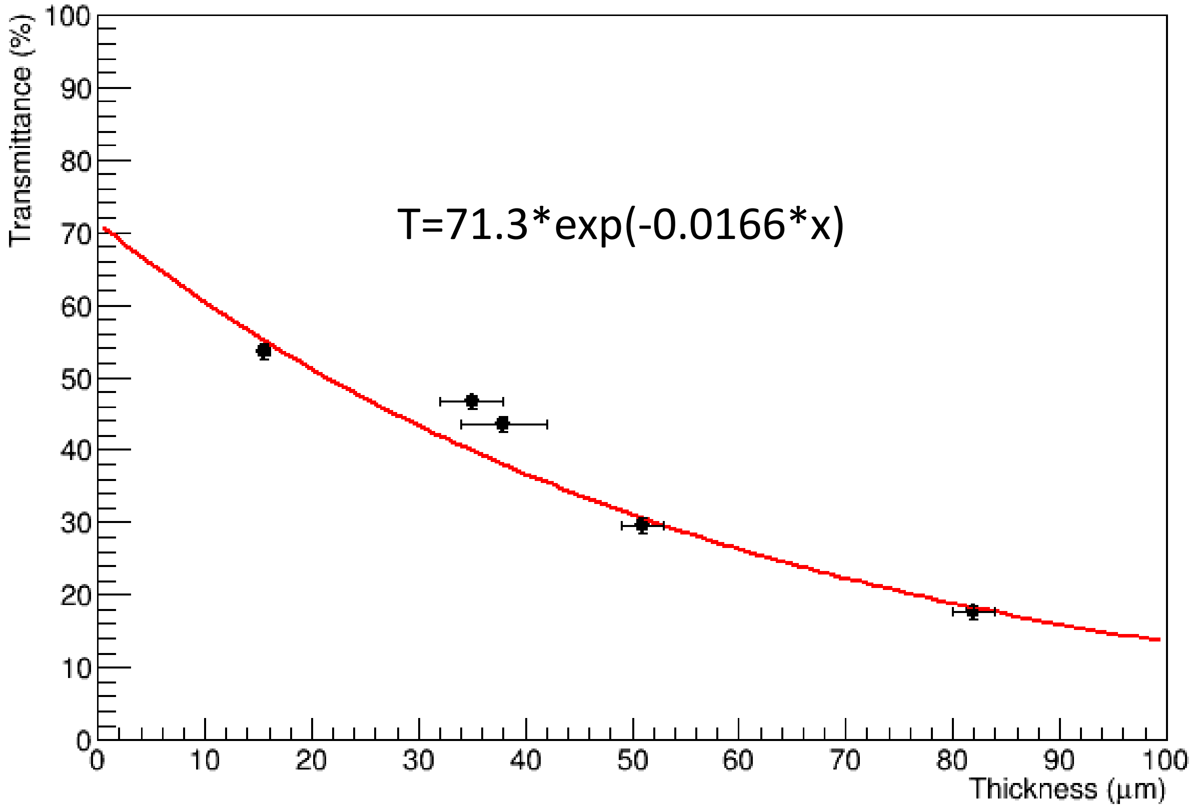


Transmittance in NIT



2 times reflection in transmittance measurement

577nm light transmittance in NIT



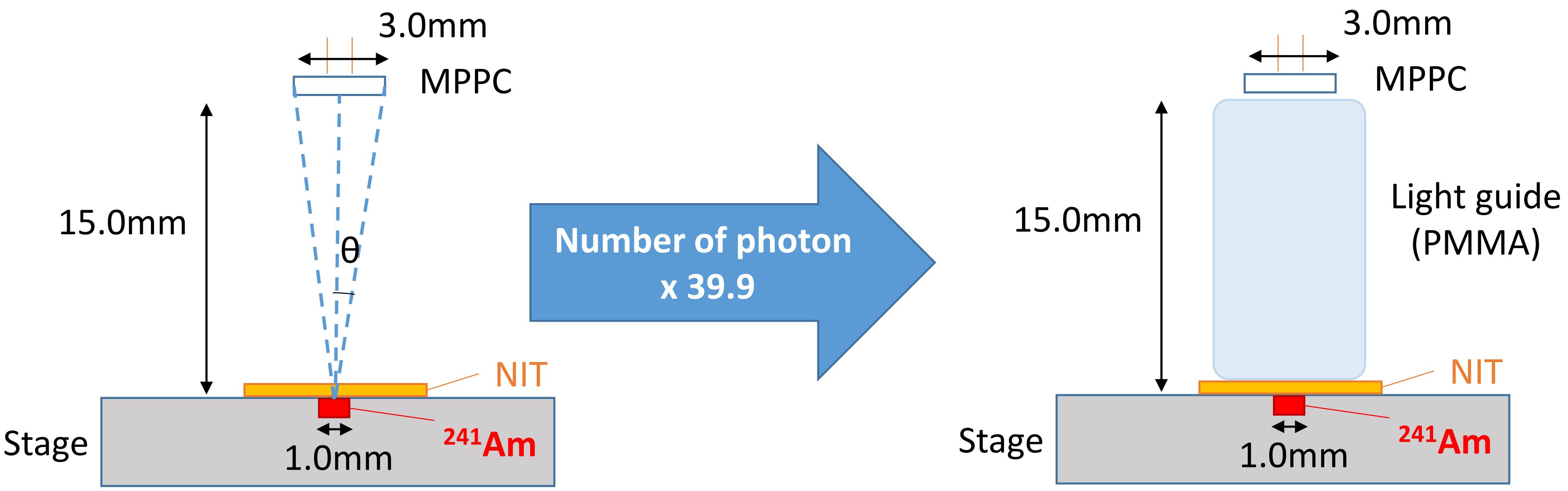
2 times reflection → 71.3%

$(1-R)^2=0.713 \Rightarrow R=0.155$

NIT transmittance is

$T=84.5*\exp(-0.0166*x)$

Solid angle evaluation

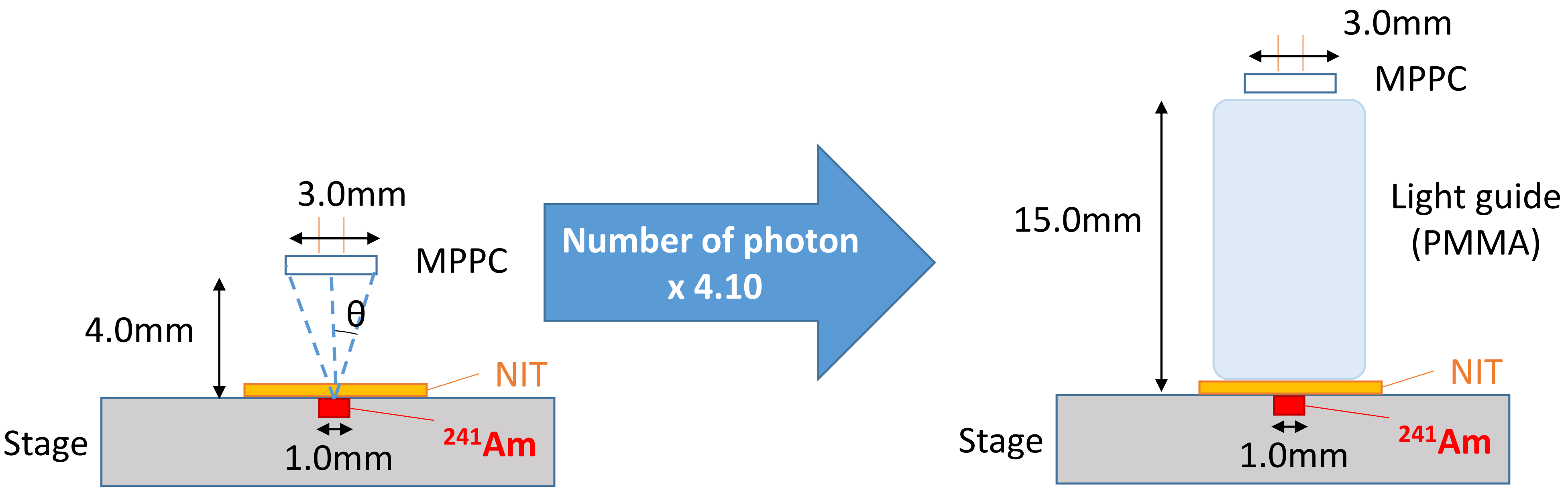


MPPC fiducial area : 3mm*3mm

$$\frac{\Omega}{4\pi} = \frac{4\sin^{-1}(\sin^2\theta)}{4\pi} = 0.00315$$

$$\frac{\Omega}{4\pi} = 0.00315 \times 39.9 = 0.126$$

Solid angle evaluation



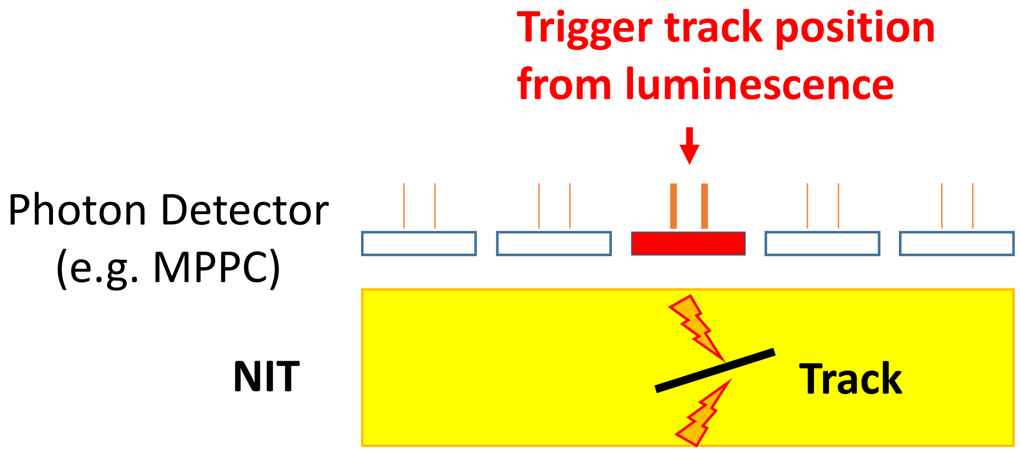
MPPC fiducial area：3mm*3mm

$$\frac{\Omega}{4\pi} = \frac{4\sin^{-1}(\sin^2\theta)}{4\pi} = 0.0393$$

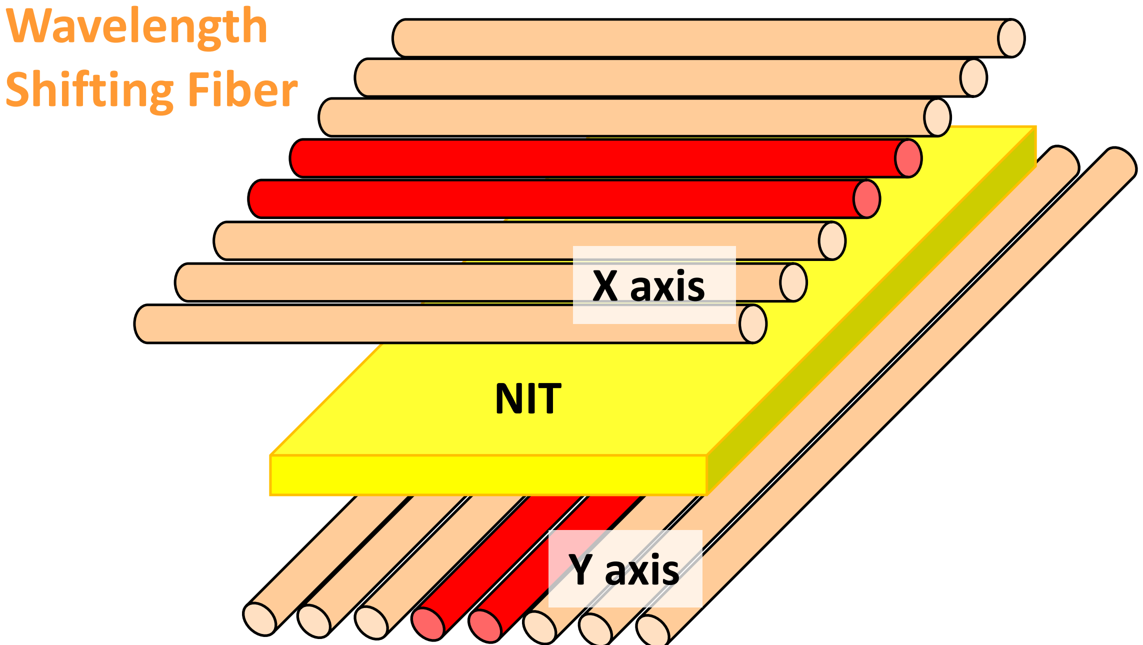
$$\frac{\Omega}{4\pi} = 0.0393 \times 4.10 = 0.161$$

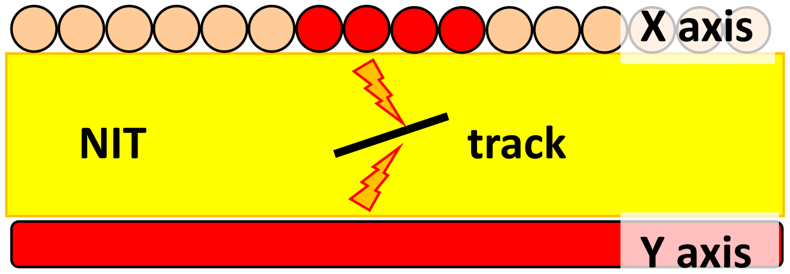
Combined analysis with track detection

1. Direct detection by Photon detector



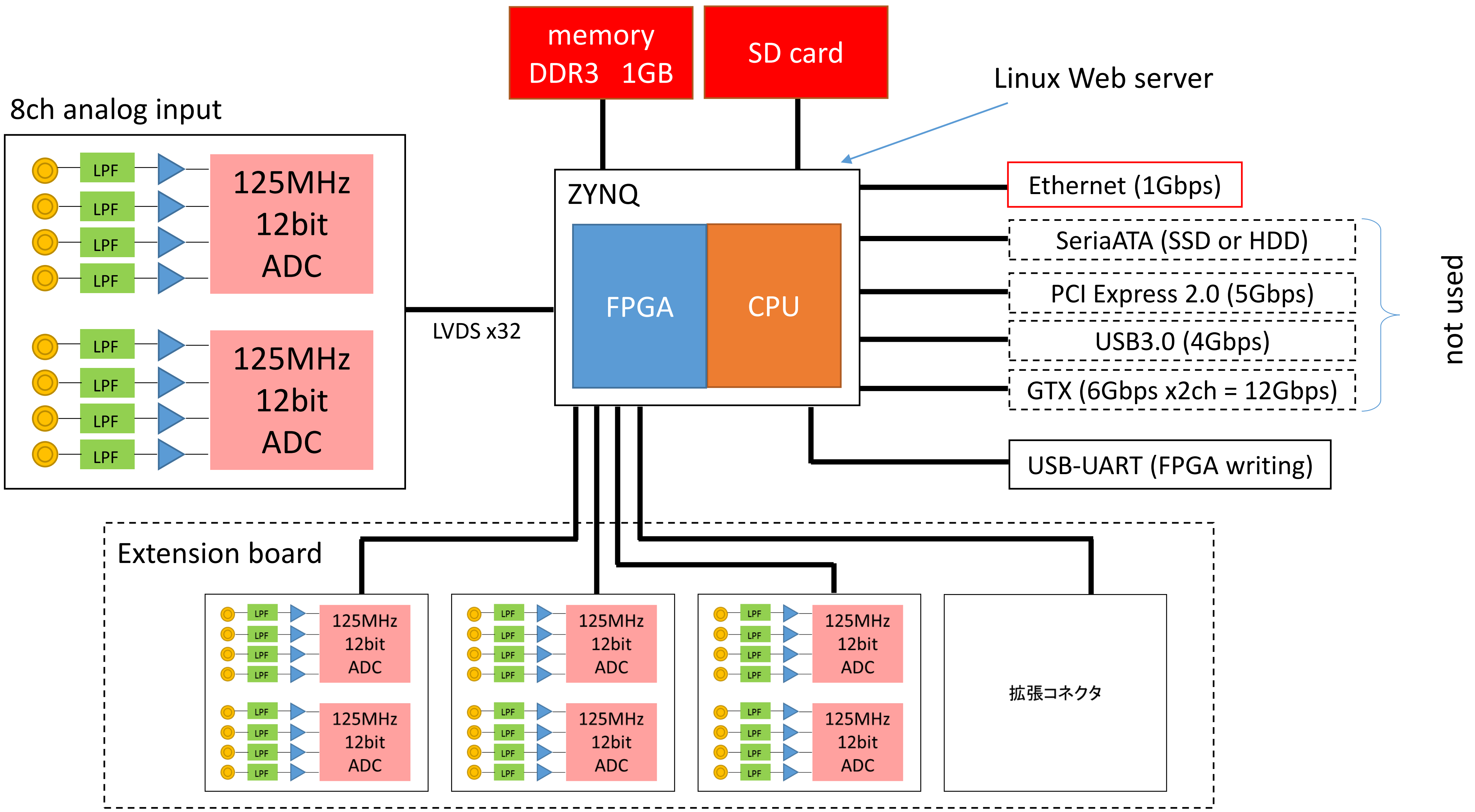
2. Use WLSF (Wavelength Shifting Fiber) to reduce readout channels





Cosmo-Z (ADC and ZYNQ board)

- ADC : 125MHz, 12bit, 8ch
- FPGA : ZYNQ (Xilinx FPGA)


8ch analog input
LPF
125MHz
12bit
ADC
LVDS x32
memory
DDR3 1GB
SD card
Linux Web server
ZYNQ
FPGA
CPU
Ethernet (1Gbps)
SeriaATA (SSD or HDD)
PCI Express 2.0 (5Gbps)
USB3.0 (4Gbps)
GTX (6Gbps x2ch = 12Gbps)
not used
USB-UART (FPGA writing)
Extension board
拡張コネクタ

Thermal conductivity

	density (g/cm^3)	Specific heat (J/kg·K)	Thermal conductivity (W/m·K)
Air @ 0℃	0.001251	1005	0.0241
Air @ -100℃	0.001984	1009	0.0157
He gas @ 0℃	0.000179	5192	0.1442
Stainless @ 0℃	~8	~0.5	~0.2
Aluminum @ 0℃	2.70	0.88	1.95