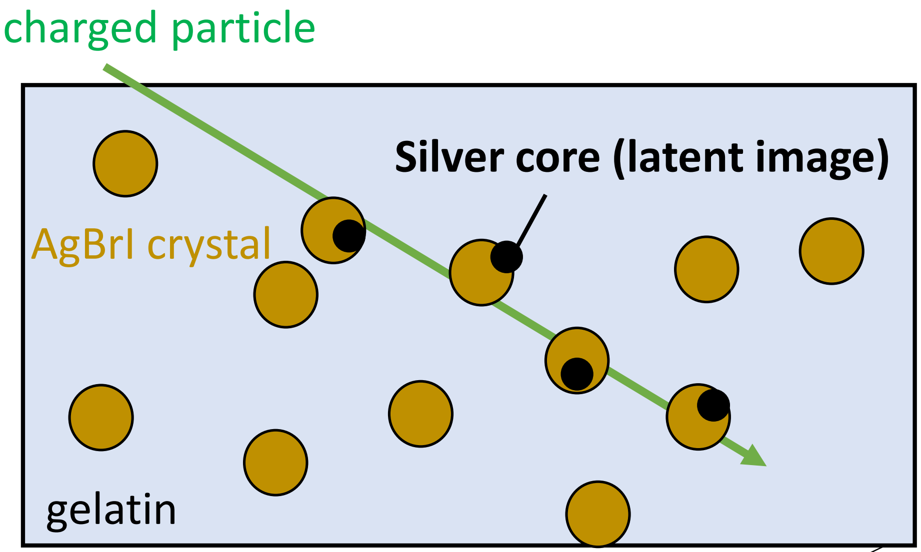
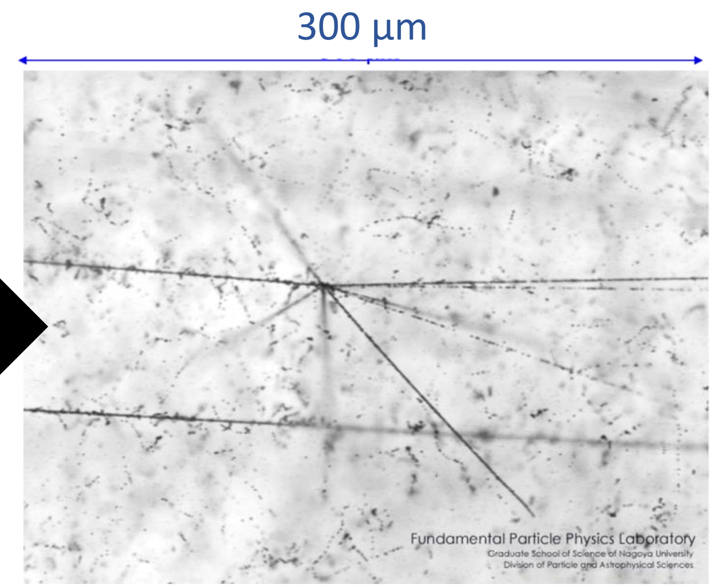
Study for photon emission response to charged particles of NIT

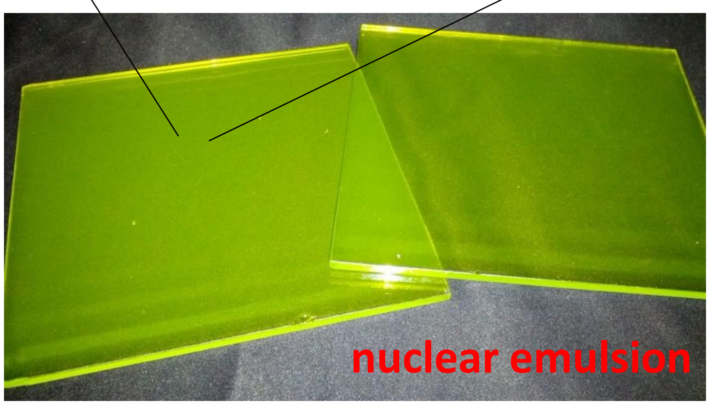
Hiromasa Ichiki

Nuclear Emulsion

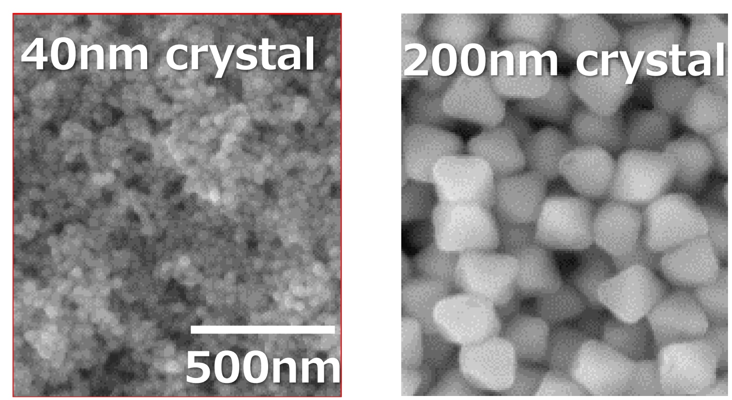


Develo -pment





density : 3.2-3.4 g/cm^3



SEM image

submicron spacial resolution

“photosensitive mechanism” by light or charged particles

The sensitization mechanism is the same ?

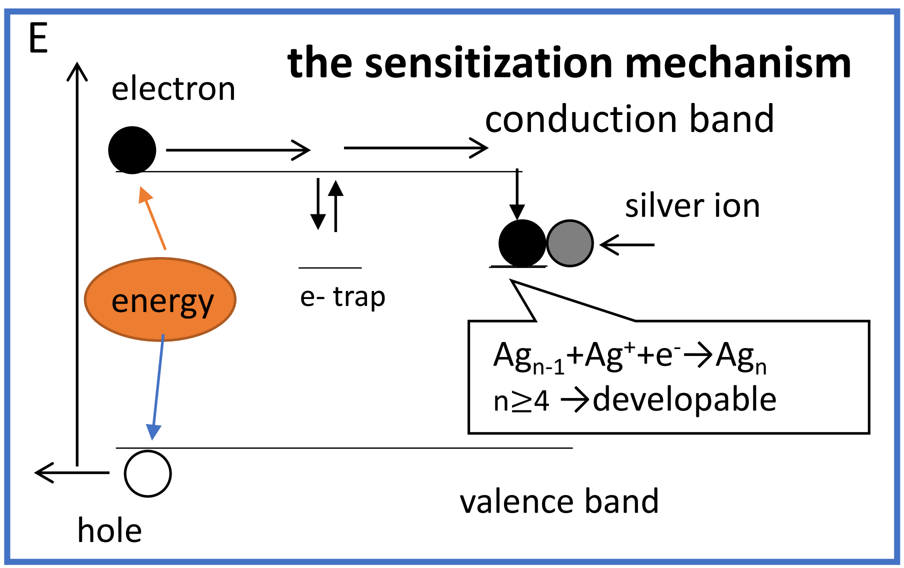
	dE/dx in AgBrI	*e-h pairs generated in the 40 nm crystal	*e-h pairs generated in the 200 nm crystal
α ray	300 [keV/μm]	~2000 [/fs]	~10000 [/fs]
**laser		~0.001 [/fs]	~0.01 [/fs]

**1 kW、ϕ 1mm

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

Charged particle penetrate the crystal

→ a huge number of e-h pair in a very short time



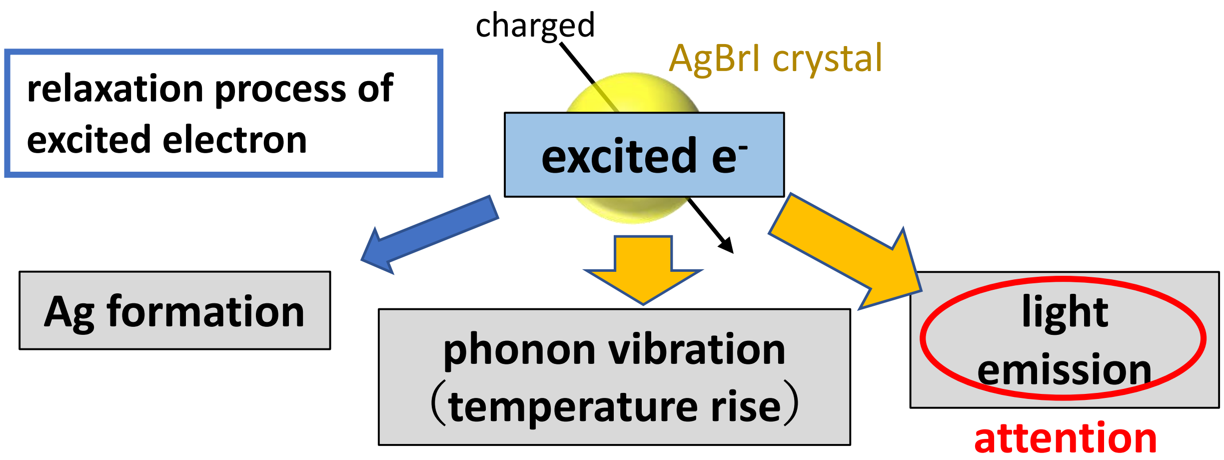
presence of enormous e-h pairs

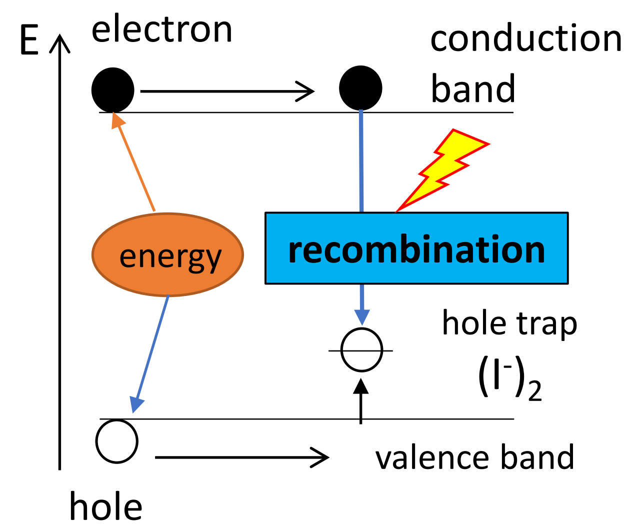
recombination may be intense

→Ag formation is inefficient.

Is the e-h pair used in other processes？

Focus on the light emission process





Research on the light emission of silver halide has been reported.

- light excitation (mainly)
- various crystal shapes (ex. square, octahedron) and dopes

AgBrI crystal（used in our study）

—wavelength ~550 nm (luminescence center is iodine)

◎**The light emission response to charged particle has not been studied.**

a lot of information independent of silver particles (tracks) observation.

→understand the phenomenology when charged particle pass trough the crystal

Motivation

- Understanding of physical properties of crystals
  - wavelength, amount of luminescence, relaxation time

    ⇔ depth of the electron trap（⇔Ag particle formation）

    - change the added chemical
    - change the crystal size

  ⇒**Luminescence become a new evaluation indicator.**

- Application to elementary particle experiment
  - Trigger event location by light emission.

    →no need to analyze the all emulsion.

  - particle ID (difference in the number of e-h pairs generated in a crystal)

    -wavelength/amount of luminescence/relaxation time

    →identify α ray、β ray、nuclear recoil

contents

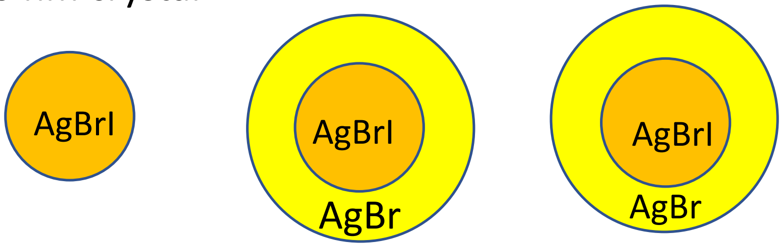
- Observation of luminescence with human eyes
    - light excitation
    - charged particle excitation

- Quantitative evaluation with cryostat
    - MPPC (Multi Pixel Photo Counter)
    - irradiation of α ray
    - irradiation of γ ray

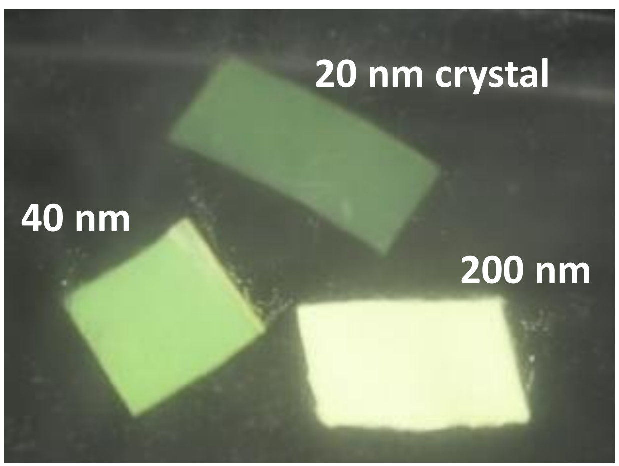
demonstration of luminescence by light excitation

- to reduce thermal deactivation, observed at liquid nitrogen (Lq. N_2) temperature

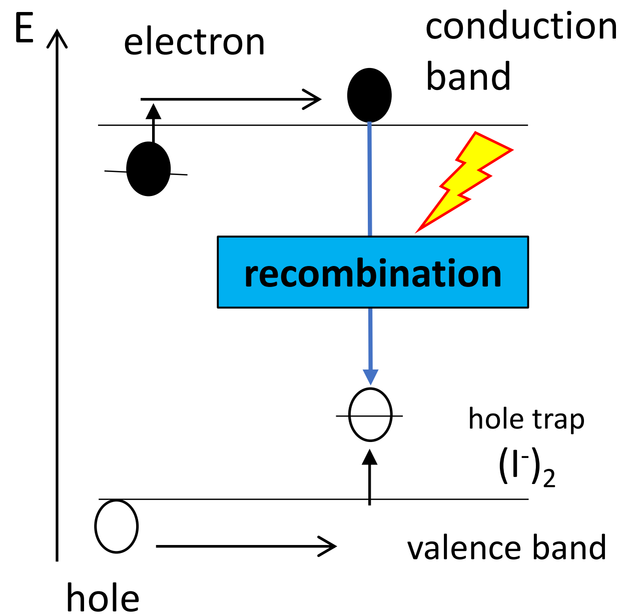
20 nm crystal 40 nm 200 nm



core shell type core shell type

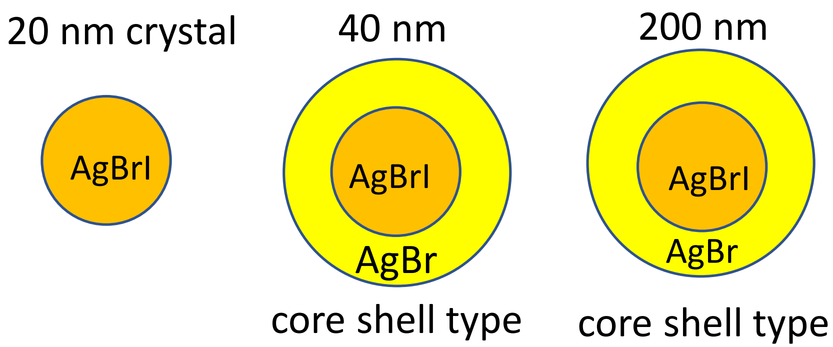


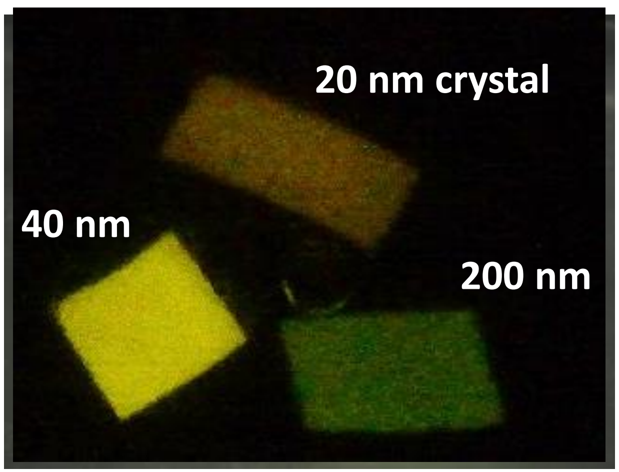
expose fluorescent lamp



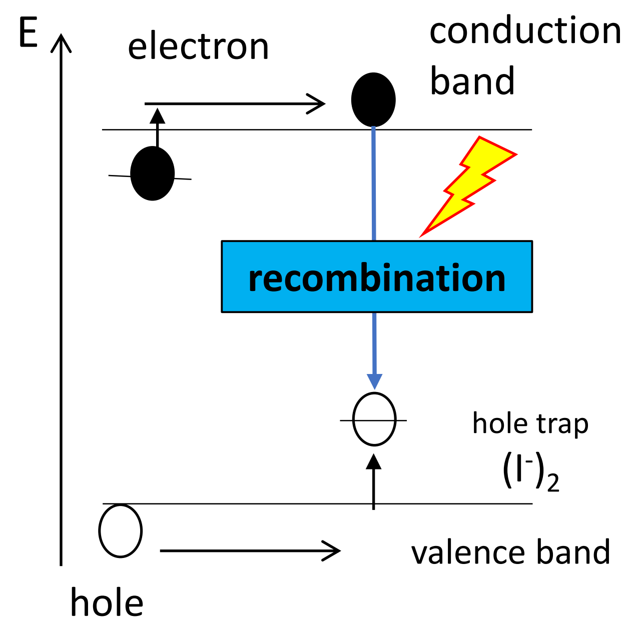
demonstration of luminescence by light excitation

- to reduce thermal deactivation, observed at liquid nitrogen (Lq. N_2) temperature





200 nm : ~1 s
20 nm : ~ 4 s
40 nm : ~ 7 s

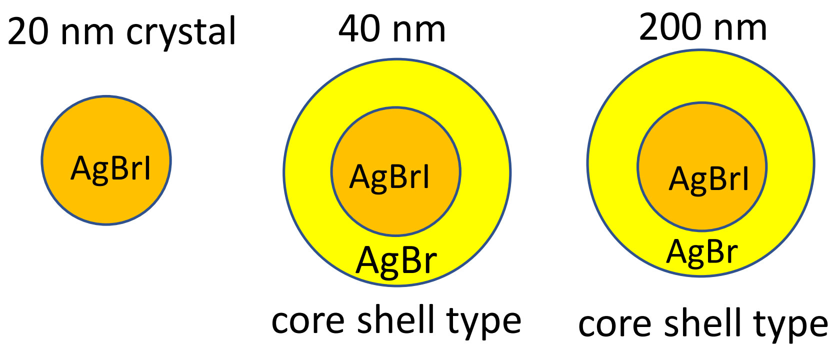


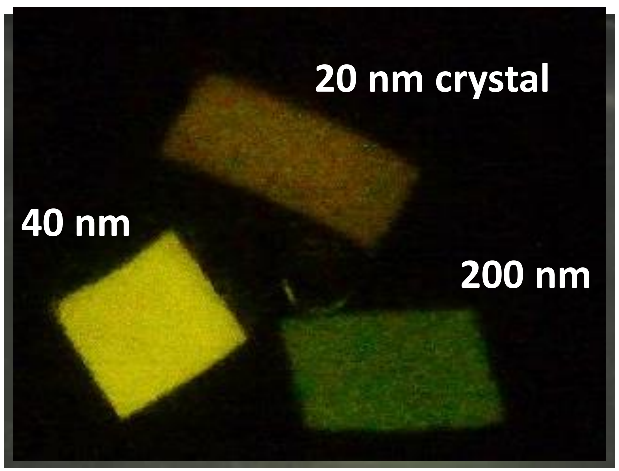
Confirmed the phosphorescence of emulsion by light excitation

evaluate NIT (40 nm crystal emulsion) that showed strongest luminescence

demonstration of luminescence by light excitation

- to reduce thermal deactivation, observed at liquid nitrogen (Lq. N_2) temperature





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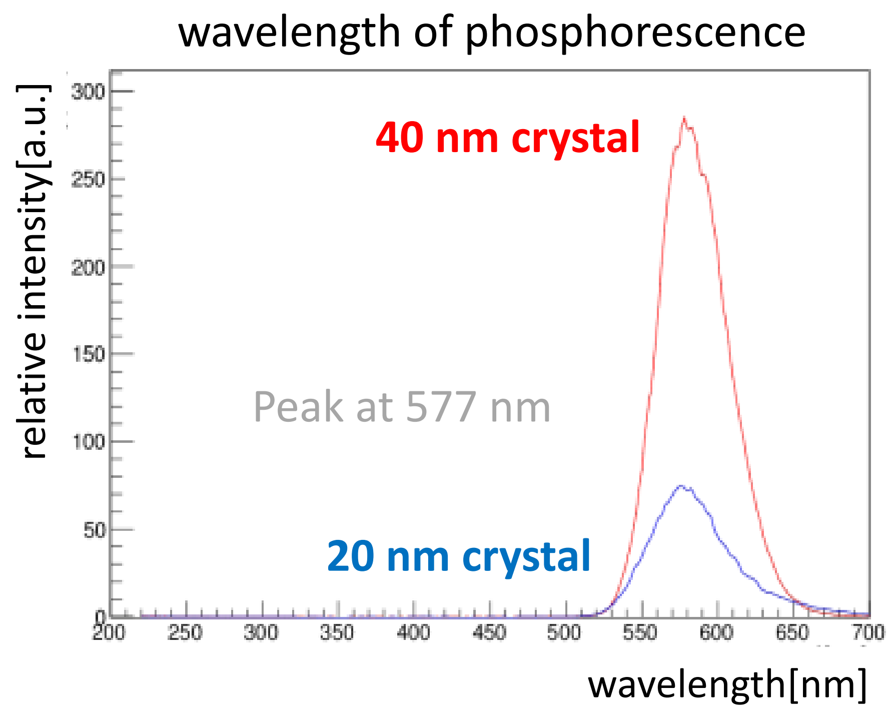


Confirmed the phosphorescence of emulsion by light excitation

evaluate NIT (40 nm crystal emulsion) that showed strongest luminescence

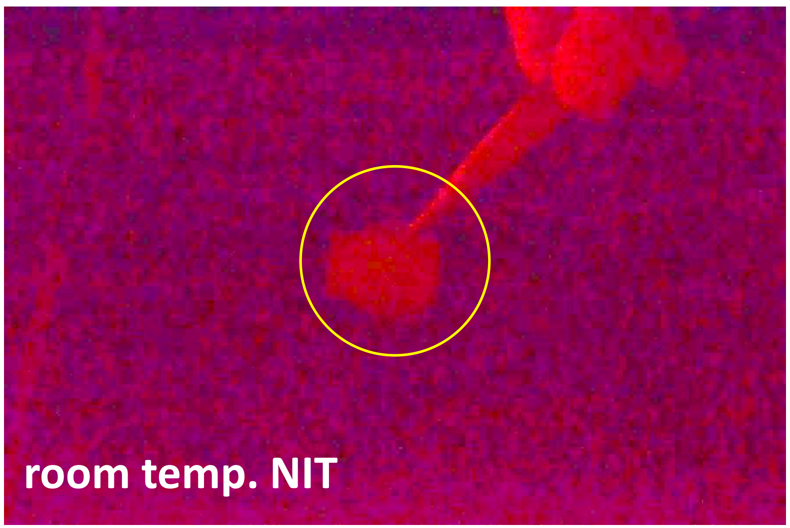
demonstration of luminescence by charged particle excitation

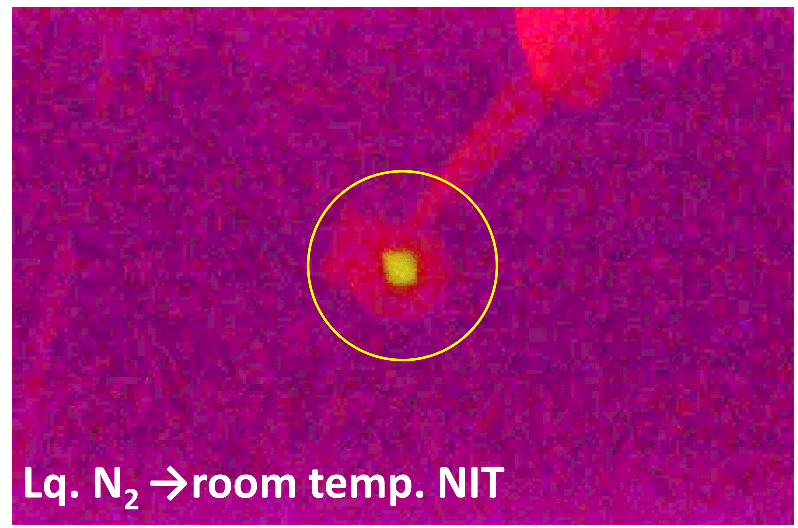
Irradiated α-ray to NIT under stable lq. N_2 temp.
→ Light emission could not be confirmed by human eyes
⇒observed thermally stimulated （temp. rising） NIT

α

^{241}Am

~2 MBq

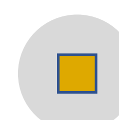




* ISO6400, shutter speed = 4 s (α)

Confirmed the luminescence of emulsion by charged particle excitation！

→then, quantitative evaluation



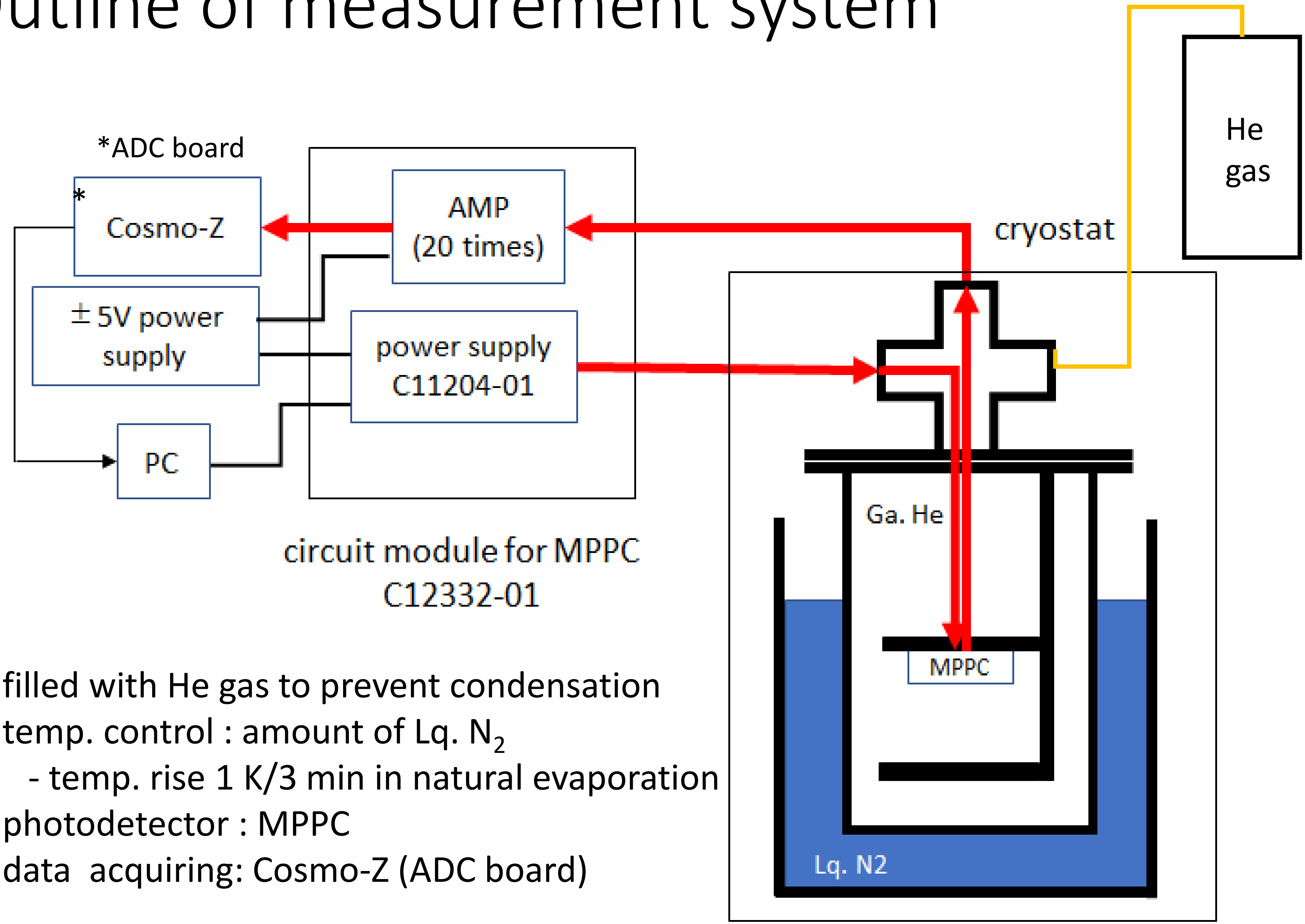
^{241}Am

contents

- Observation of luminescence with human eyes
  - light excitation
  - charged particle excitation

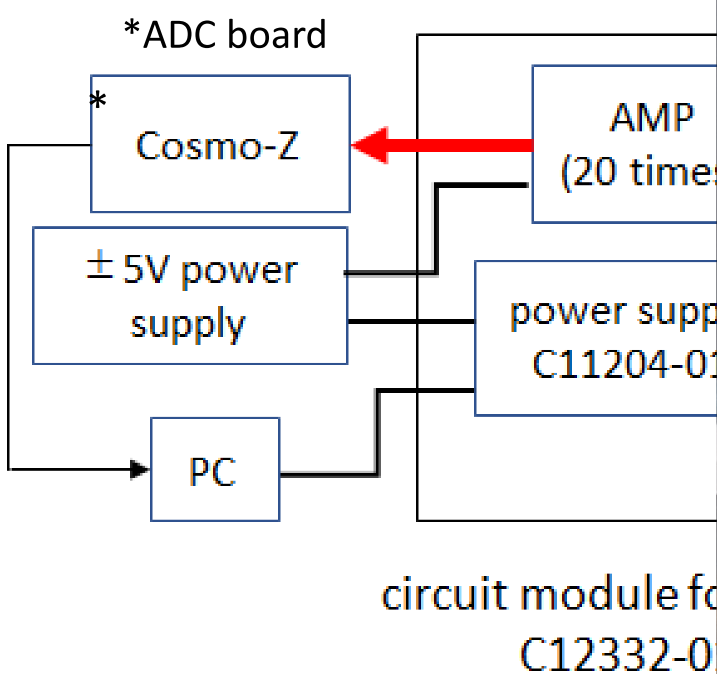
- Quantitative evaluation with cryostat
  - MPPC (Multi Pixel Photo Counter)
  - irradiation of α ray
  - irradiation of γ ray

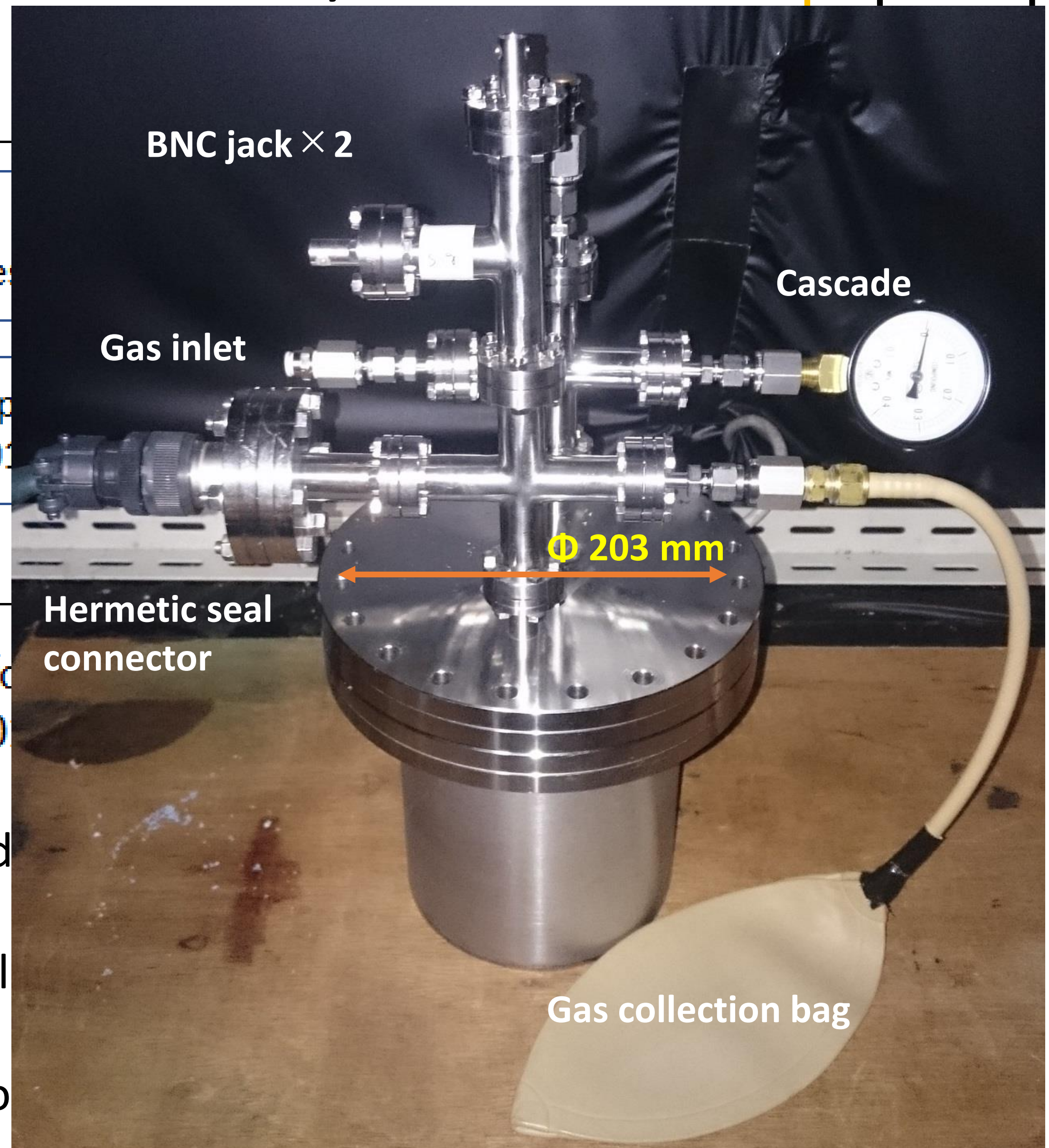
Outline of measurement system



- filled with He gas to prevent condensation
- temp. control : amount of Lq. N_2
  - temp. rise 1 K/3 min in natural evaporation
- photodetector : MPPC
- data acquiring: Cosmo-Z (ADC board)

Outline of measurement system





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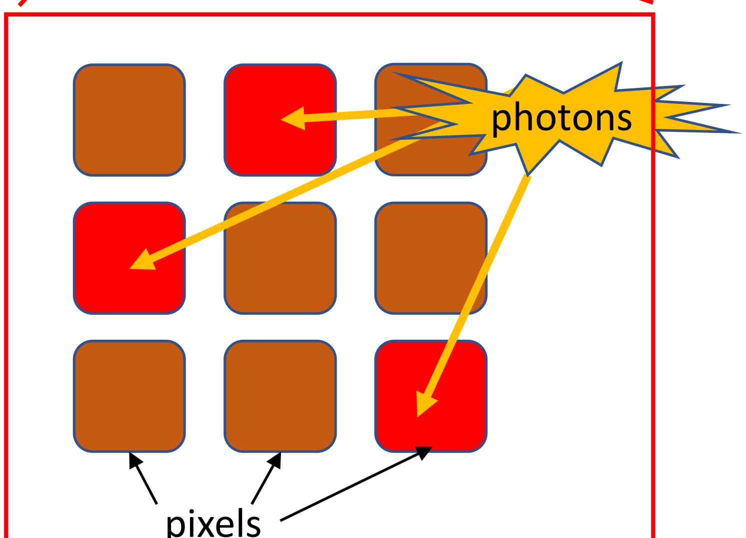
MPPC

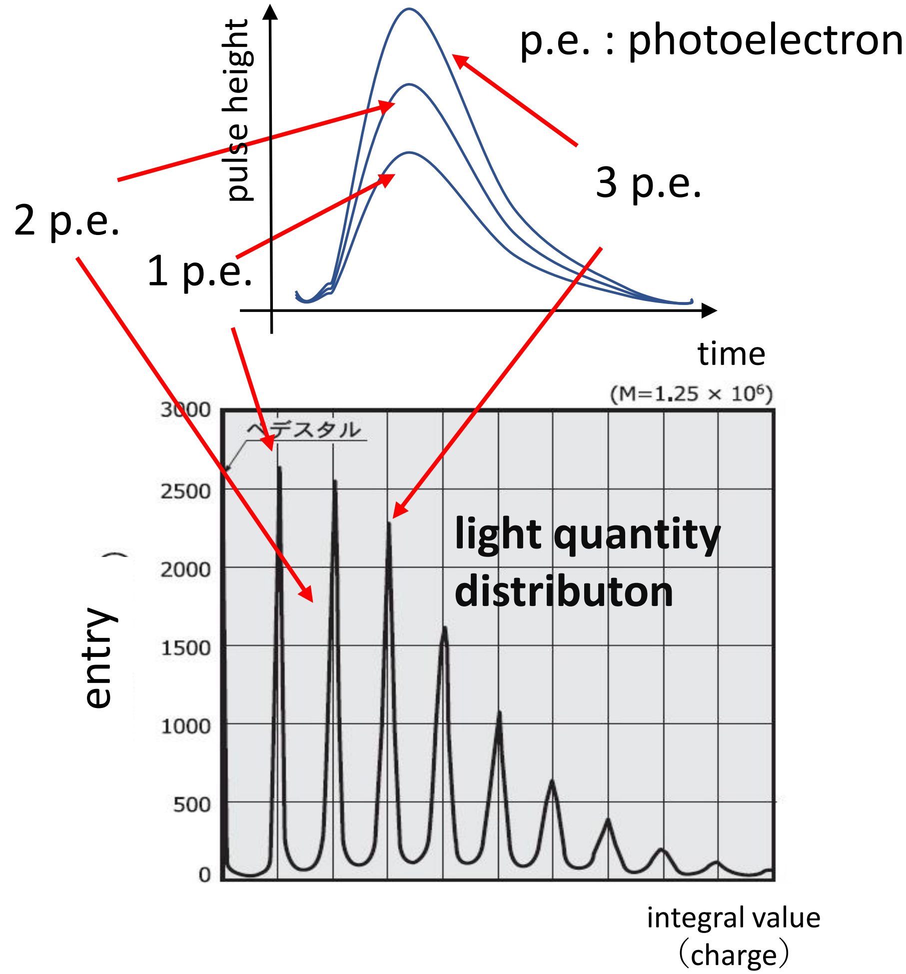
MPPC (Multi Pixel Photo Counter)

- a function to multiply the generated carriers by avalanche multiplication
- output signal is proportional to the # of pixels which detect a photon at the same time

S13370-3050CN
(VUV-MPPC)

effective area : 3 mm*3 mm
number of pixels : 3600
aperture ratio: 60 %





(from Hamamatu Photonics handbook)

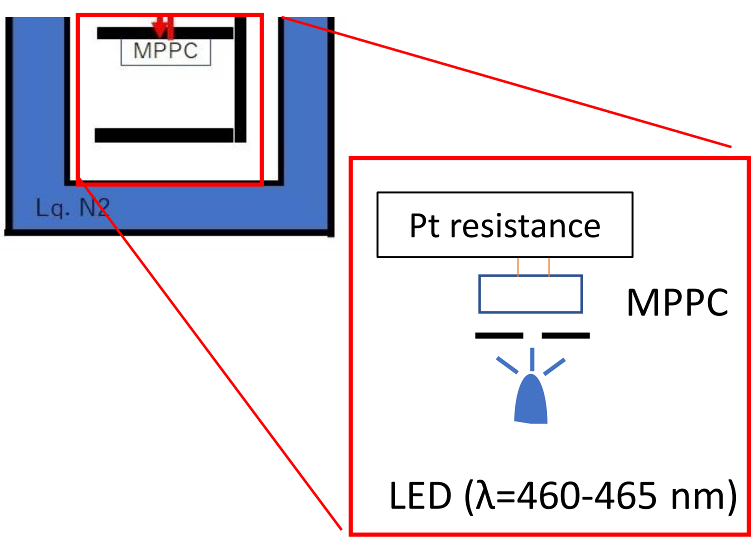
MPPC calibration

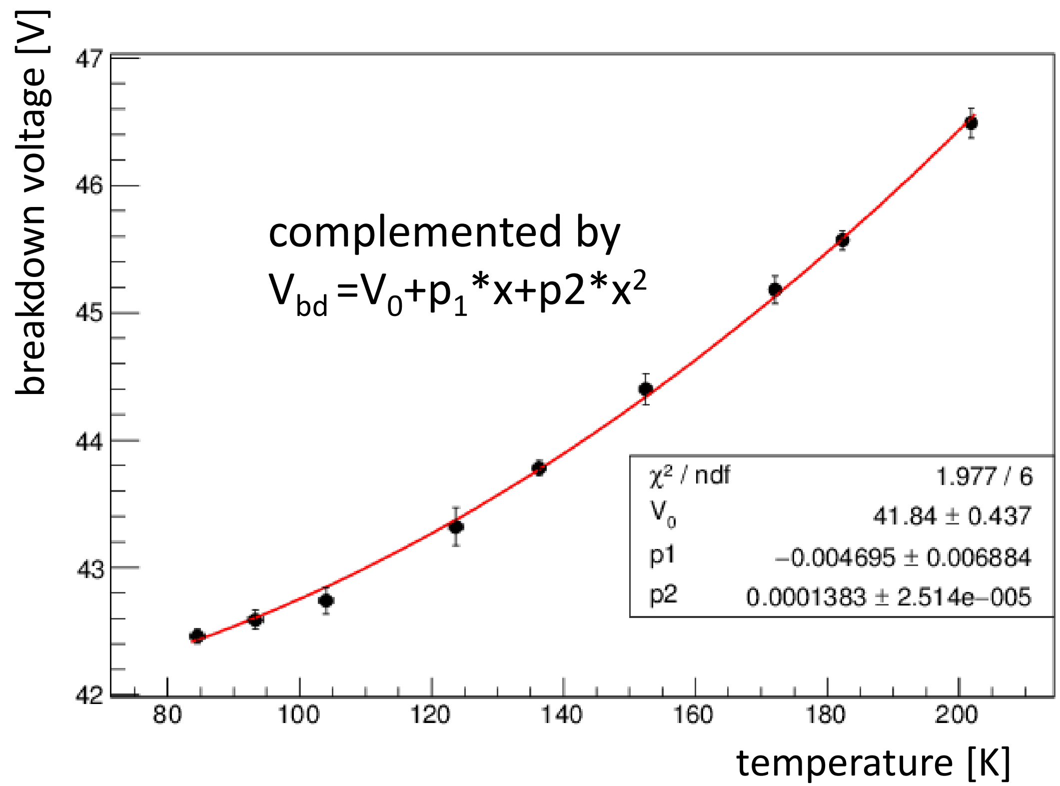
operate MPPC with applied voltage (V_{bias})
$V_{bias} = V_{bd} + V_{over}$

V_{bd} : voltage at which avalanche multiplication starts
(break down voltage)
V_{over} : over voltage

V_{bd} has temp. dependence → calibration is required.
(gain and the ratio of peculiar noise of MPPC change)

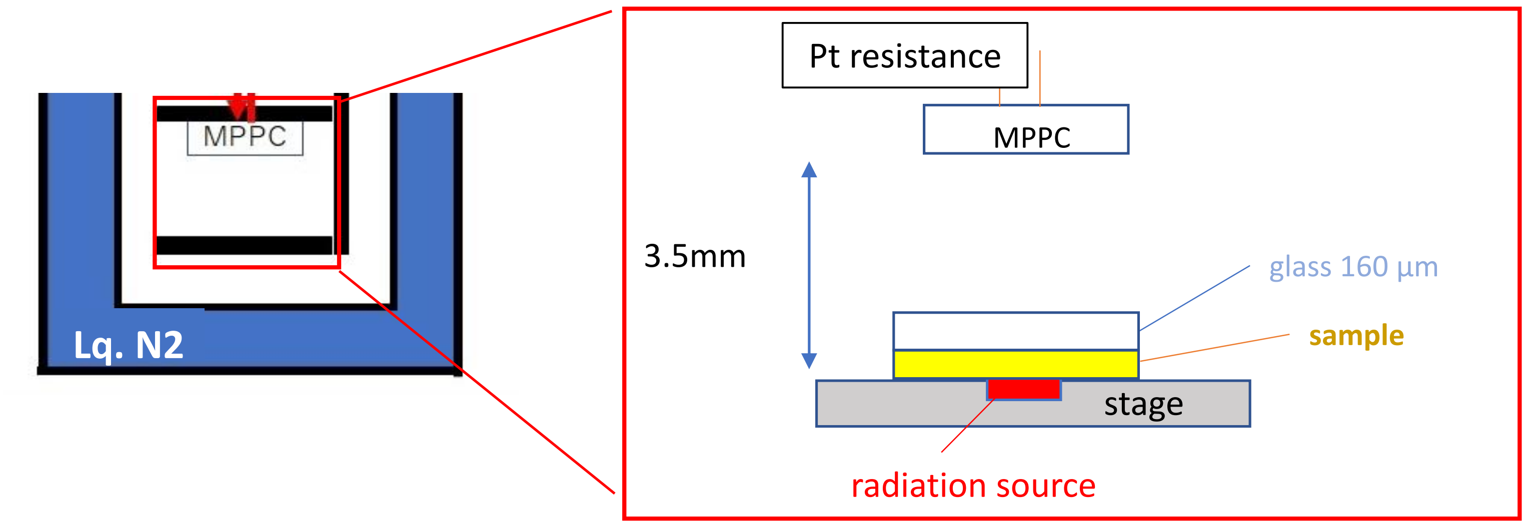
We obtained V_{bd} temp. dependence using LED.



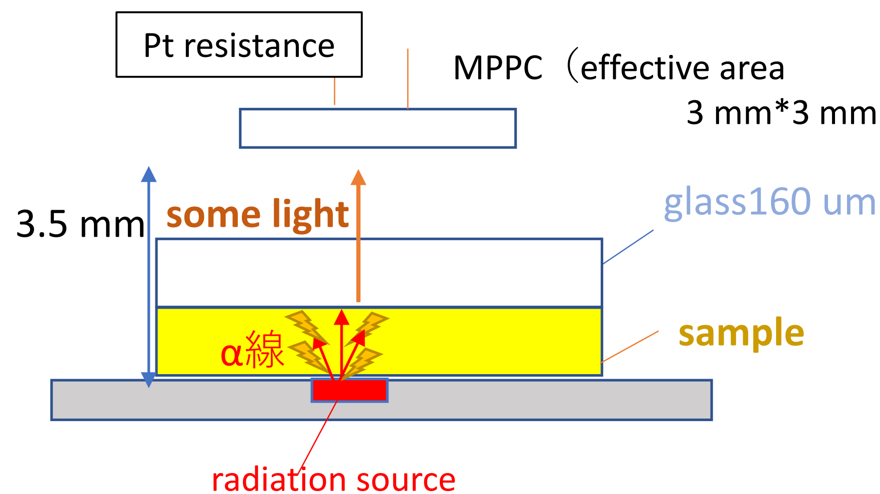


irradiation of α ray

irradiation of α ray



〇Radiation source
^{241}Am （α） 5.48 MeV
33.0 [/s]
1 mm*1 mm



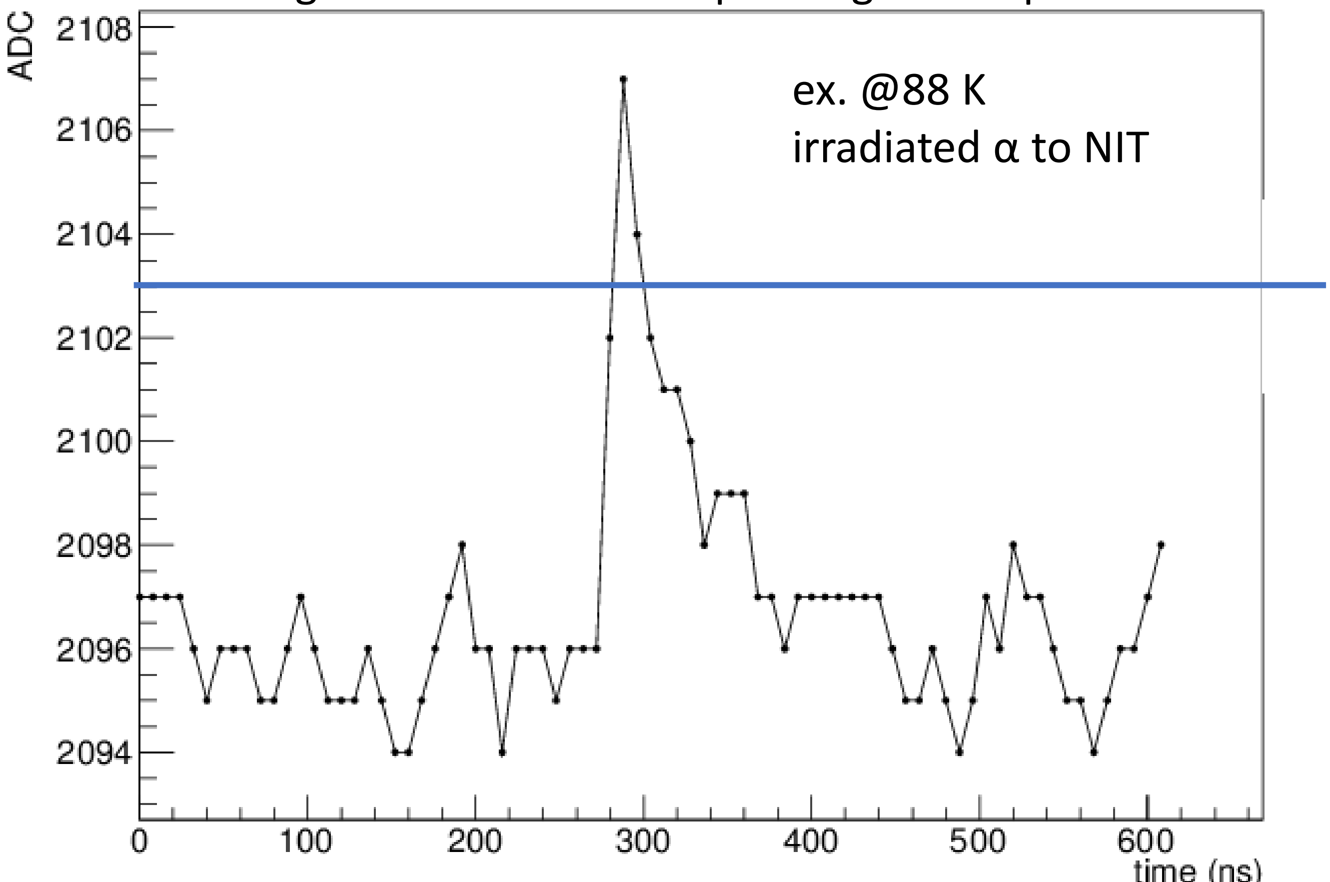
<u>used samples</u>
NIT 38 um*7 mm*3 mm（pellicle : w/o base）
gelatin 40 um*7 mm*3 mm

compared the results between samples

Geometric detection efficiency ~5.8 %

data acquiring・processing

Signal waveform corresponding to one photon



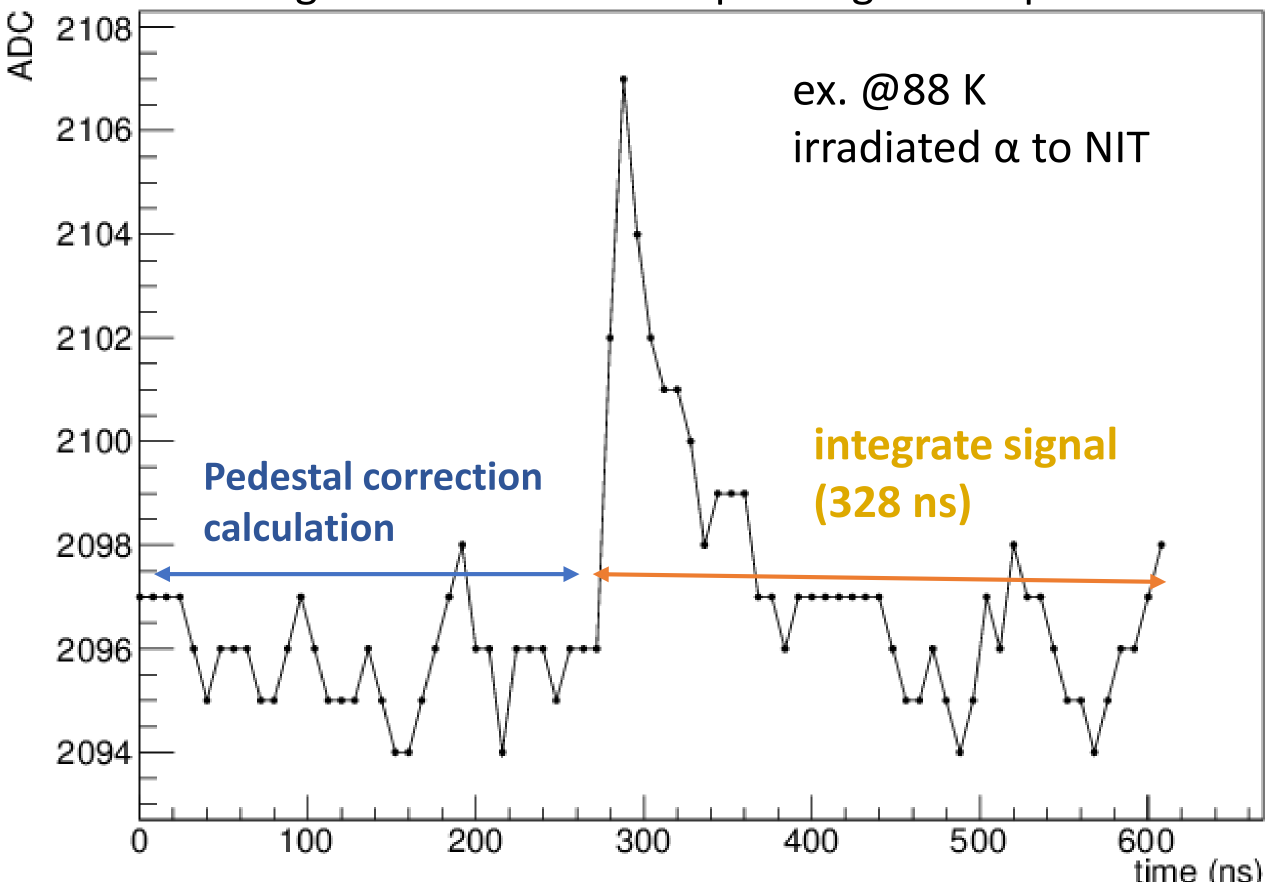
Threshold：ADC 2103
(detect 1 photon signal 99.3%)

- data acquiring : 88 K, 93 K - 203 K (every 10 K) for 60 s
- applied voltage (V_{bias}) was set to

※104 K, 183 K, 193 K, 203 K
the applied voltage was 0.1 V higher than the calibrated value.
→ Several % of peculiar noises of MPPC might increase.

data acquiring・processing

Signal waveform corresponding to one photon



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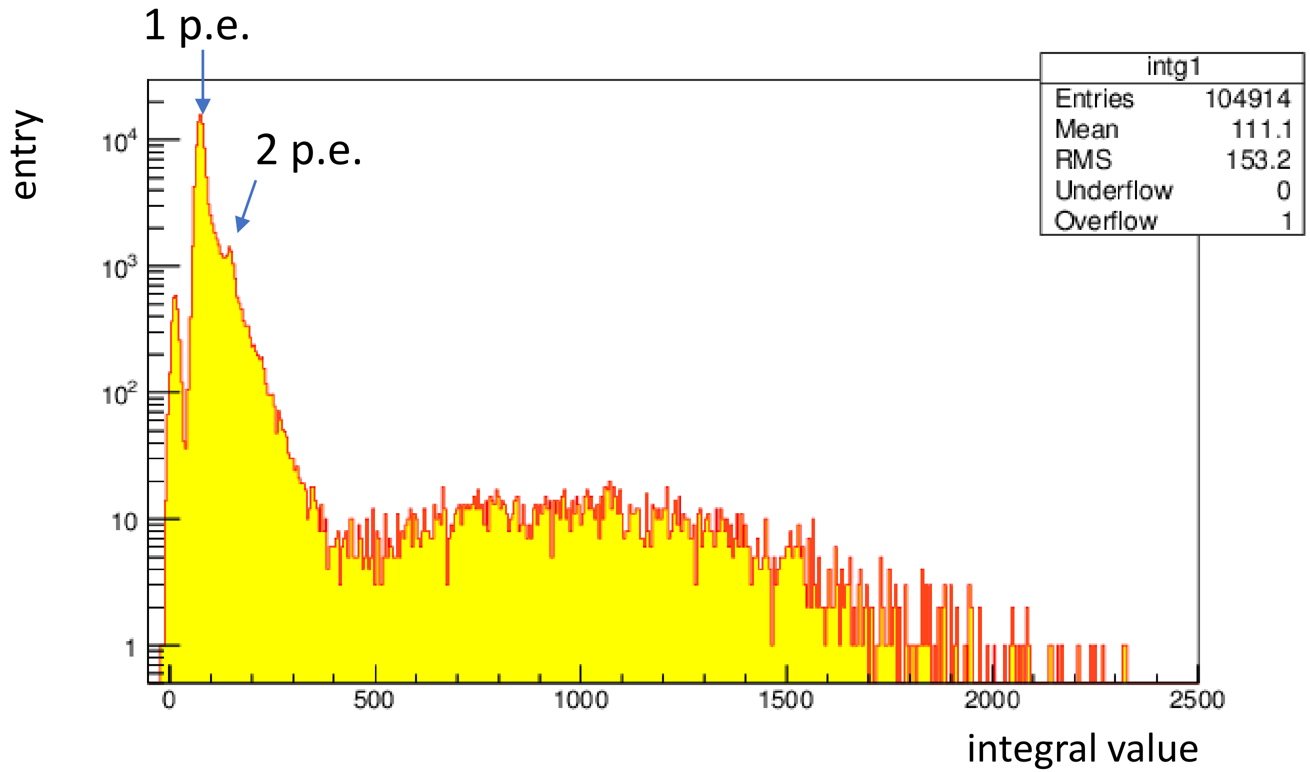
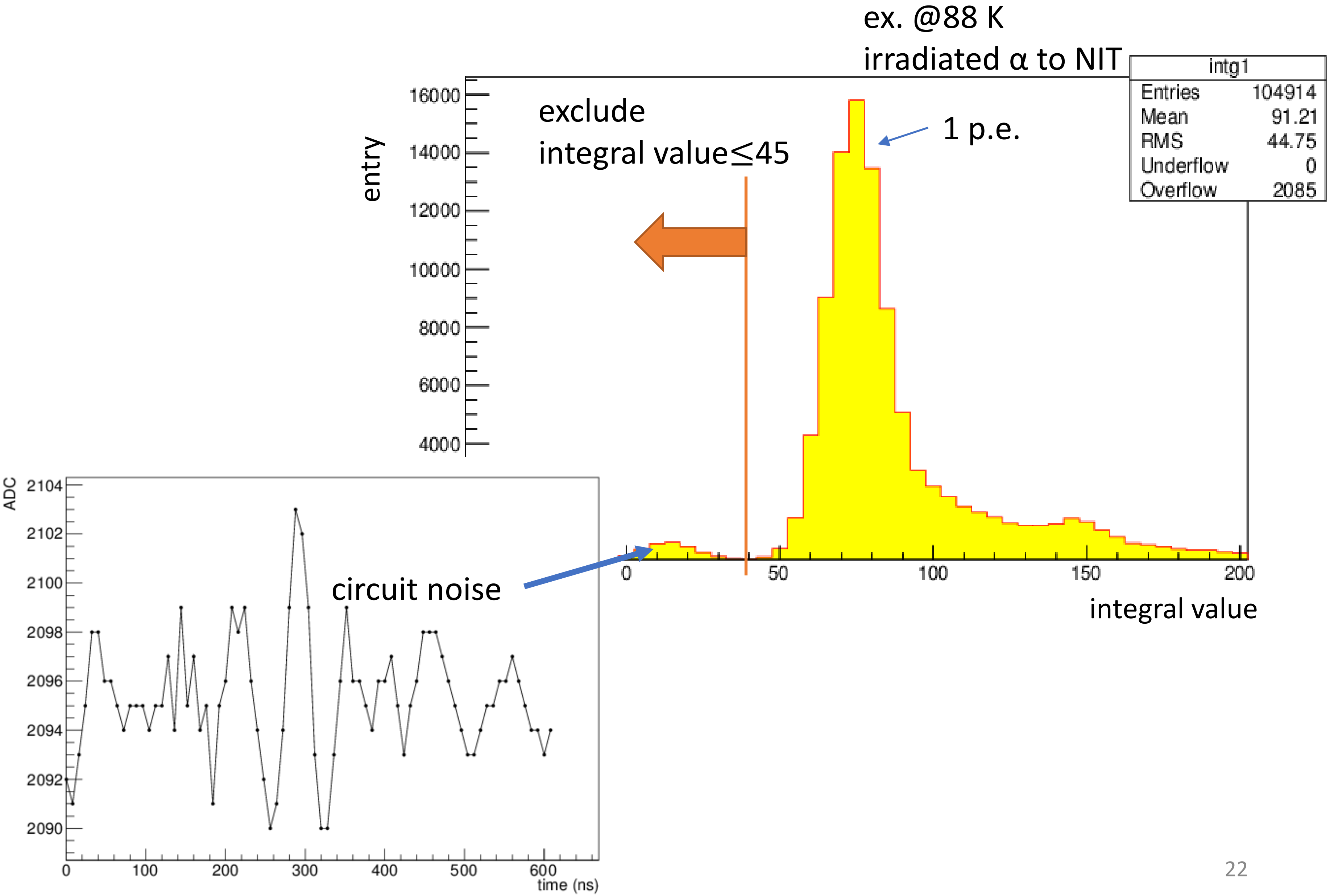
Derivation of the number of the photons

ex. @88 K
irradiated α to NIT

p.e. : photoelectron



Derivation of the number of the photons



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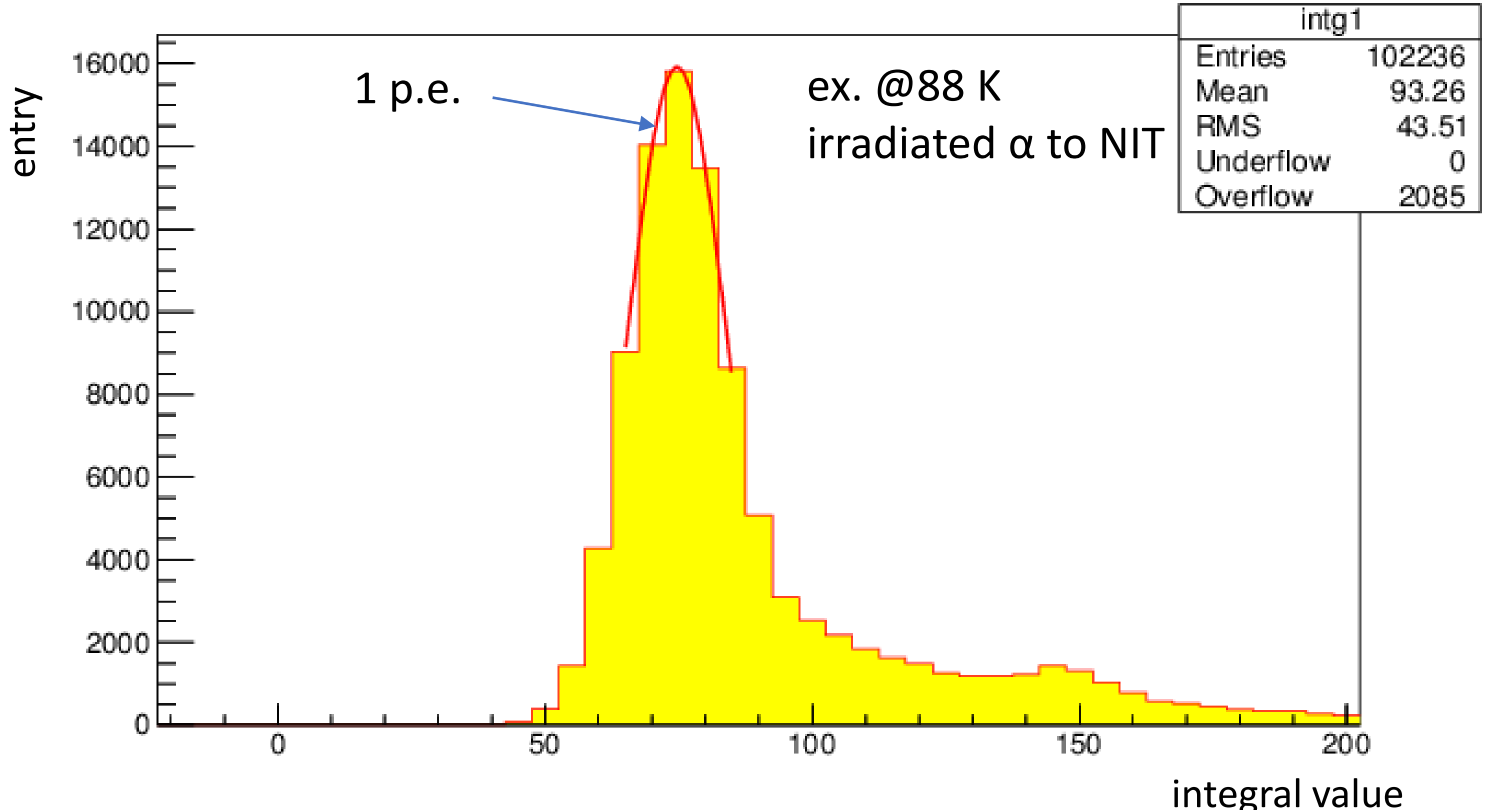


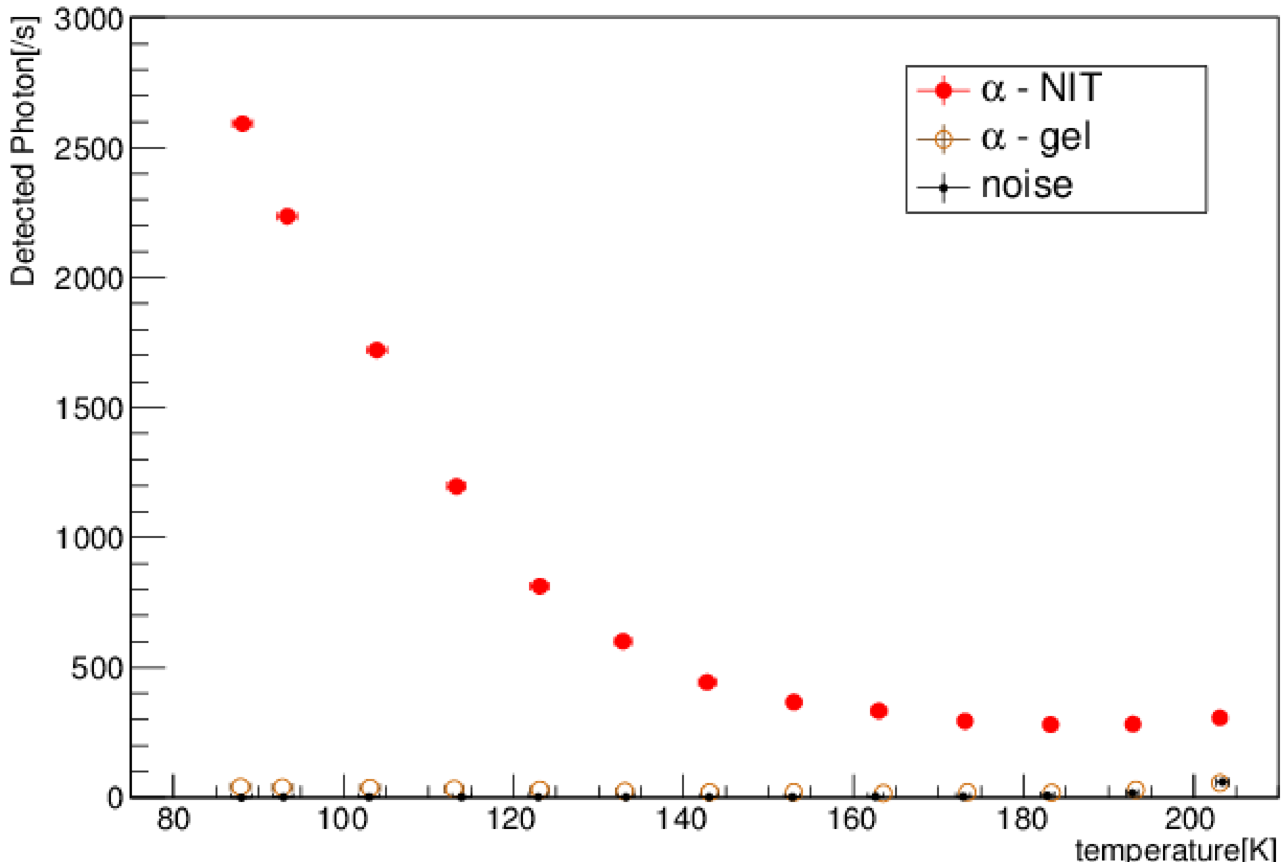
・Obtained 1 p.e. peak with Gaussian fit.

・Regarded the mean value of fitting result as integral value corresponding to one photon. (We call this value "gain")

・ $\dfrac{\text{the area of the light quantity distribution}}{\text{"gain" (mean value of fitting result)}} = \text{the number of photons}$

results

α ray irradiation result



error for temp. ： Measurement error of thermometer (JIS standard)

errors for detected photon ：

・ determination accuracy of 1 p.e. peak ~1%

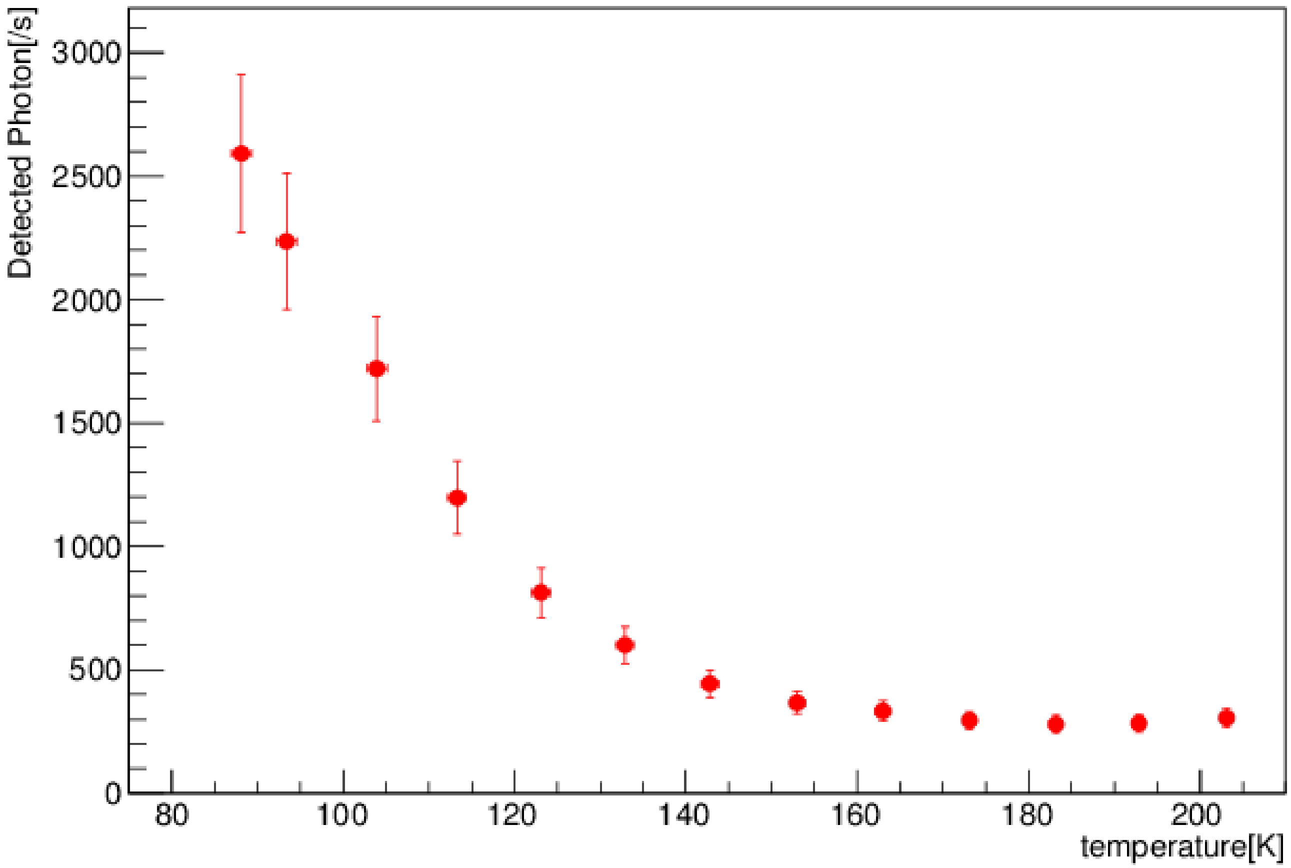
・# of irradiated α ray ~ 2.2%

・ peculiar noises of MPPC (cross talk & after pulse ratio) *~10 %

・ repeatability ~6.8 %

*T. Igarashi, master's thesis, Waseda Univ.

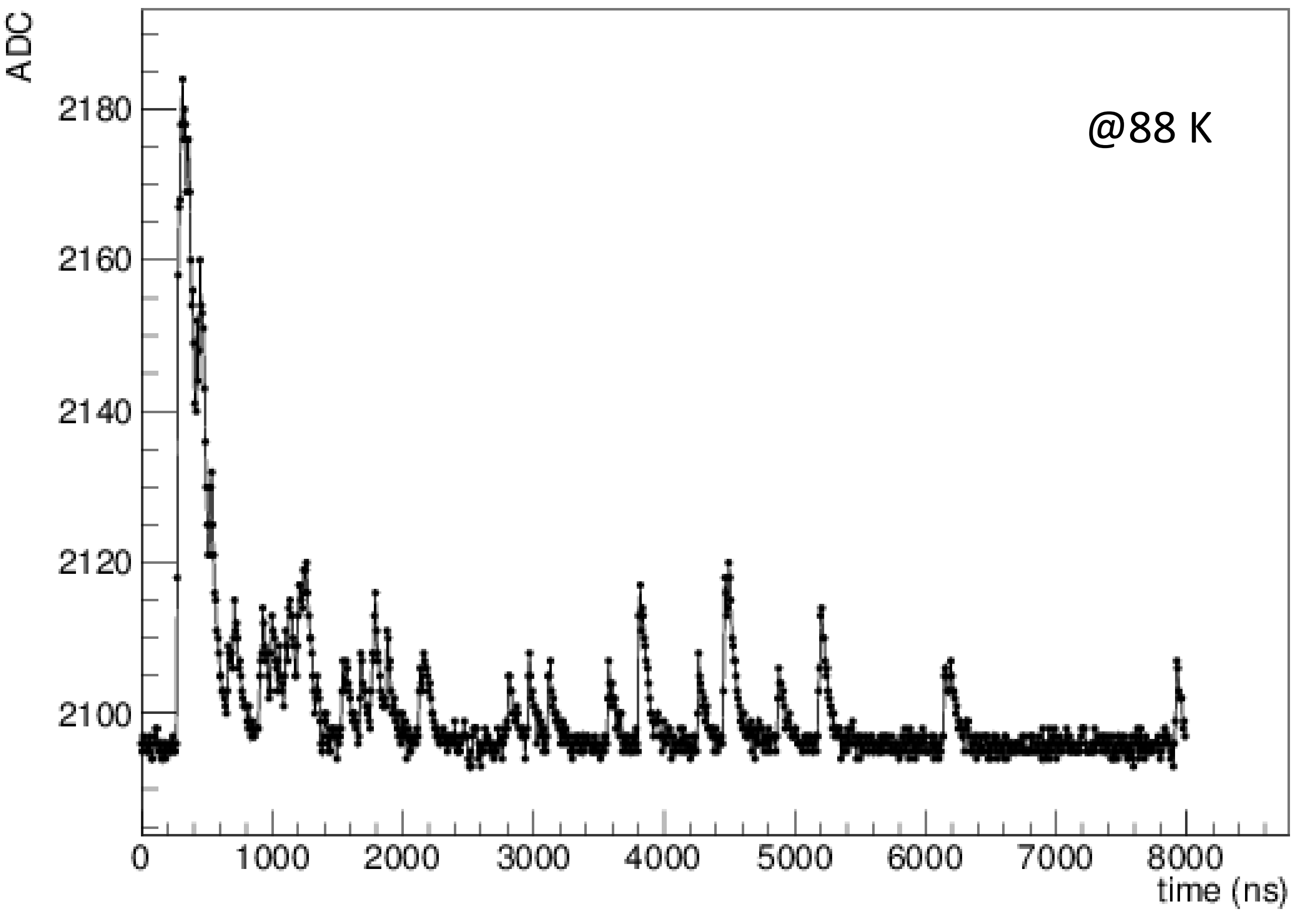
Temperature dependence of luminescence by α ray irradiation



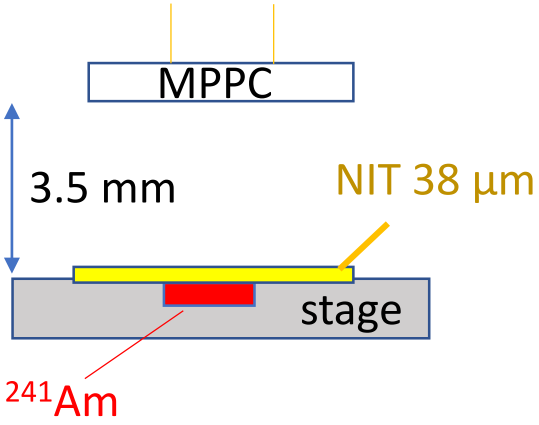
Detected significant excess！

# of photon emission was saturated at high temperature (>140 K)

the emission waveform for one α-ray



Trigger threshold : ADC 2143 (triggered signal ~33 cnt/s)



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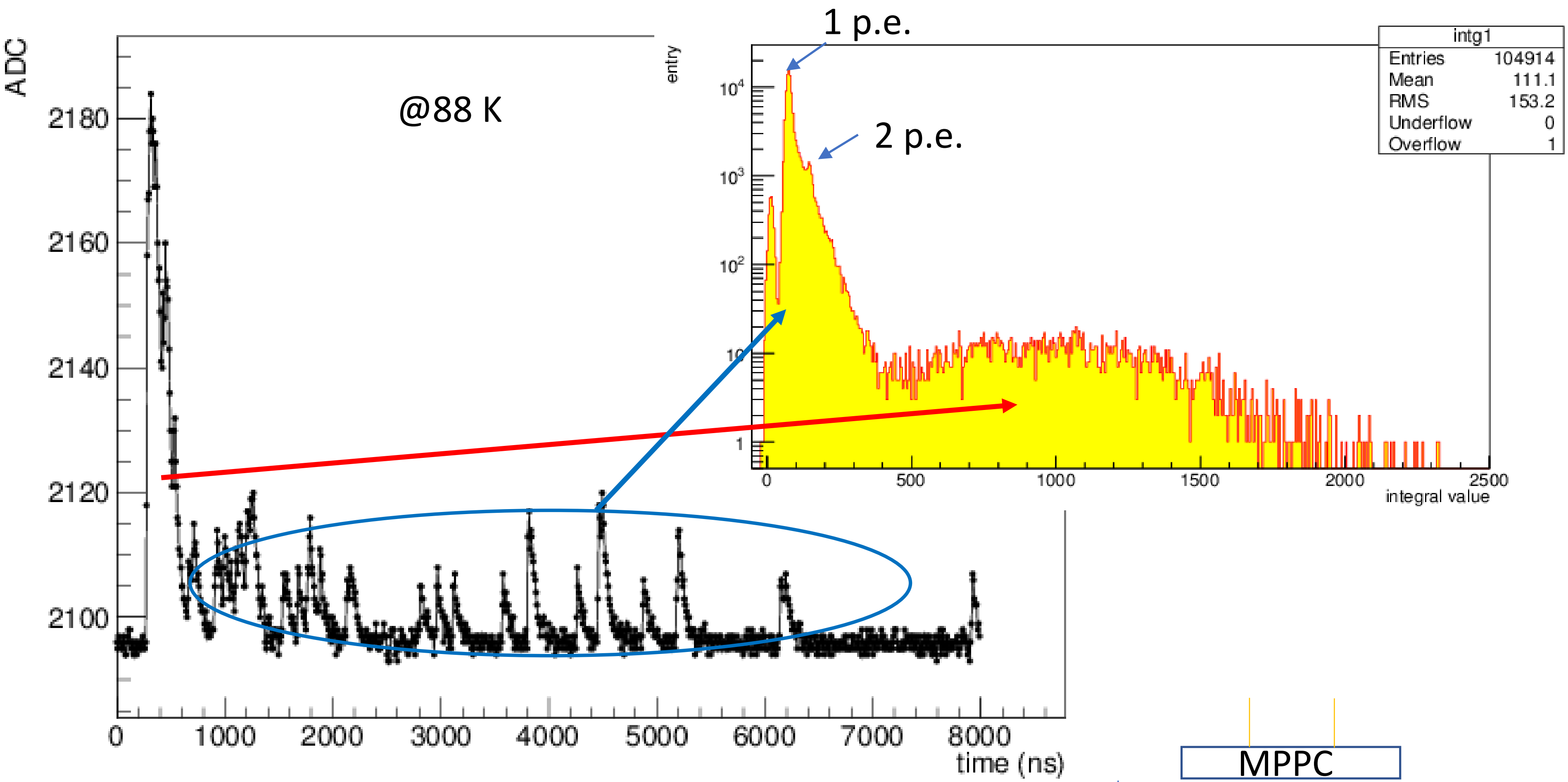
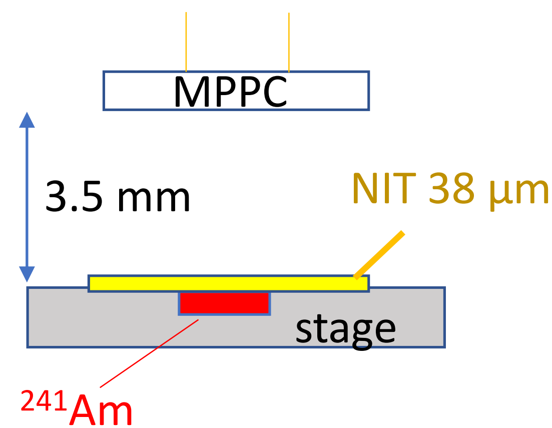
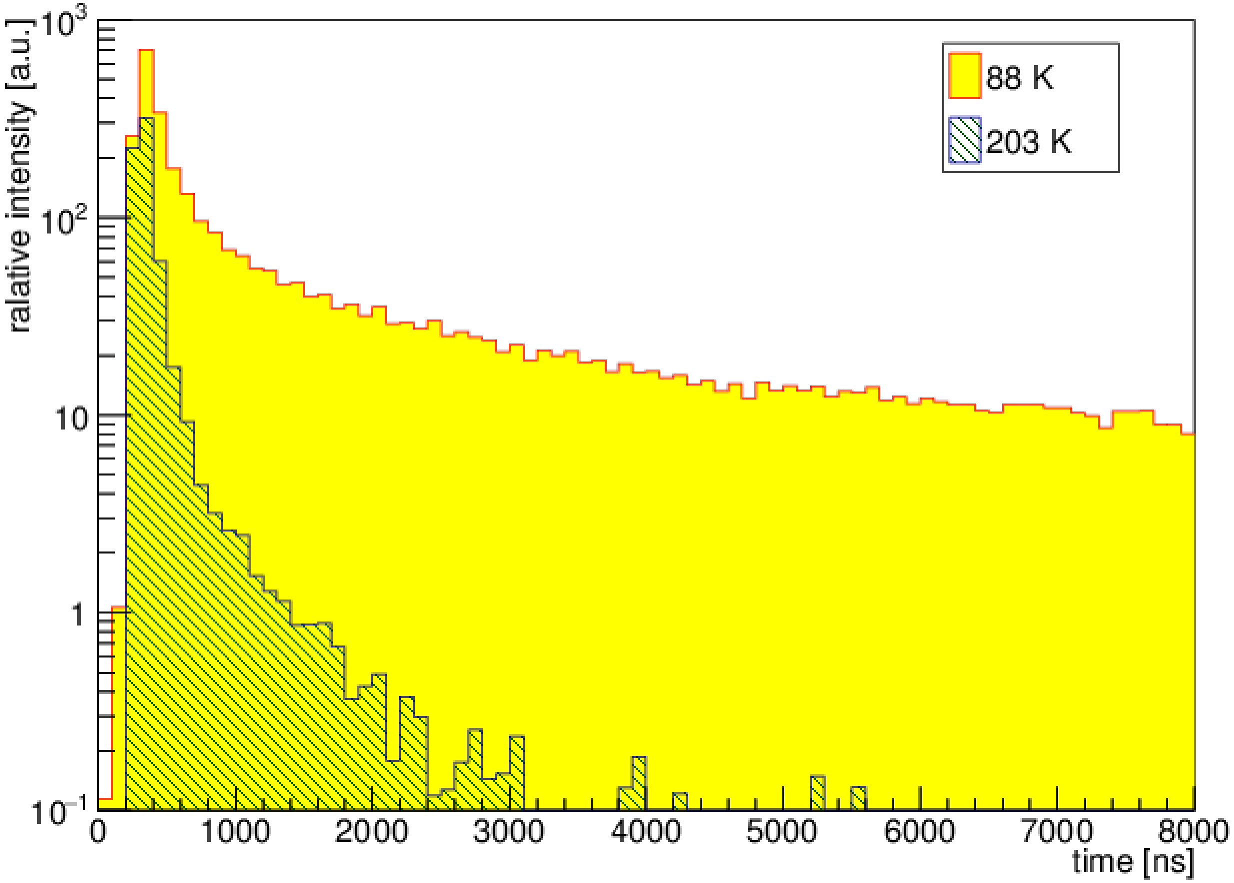




Trigger threshold : ADC 2143 (triggered signal ~33 cnt/s)

Performed data acquiring 88 K & 203 K for30 s
→compared two waveforms

comparison of emission waveform



@ high temp (203 K) : the slow components (phosphorescence) decrease
fast components (fluorescence) become dominant

→ Fluorescence is caused by the formation of enormous e-h pairs
at the moment when α rays pass.

expect : the luminescent properties vary corresponding to dE/dx (or the particles)

Energy conversion efficiency to luminescence

(Energy conversion efficiency to luminescence) = 5.8*(# of detected photons)

/(energy deposit in the AgBrI)/(transmittance)/ (Geometric detection efficiency)

/(photon detective efficiency of MPPC)

Geant4 simulation
6.6 MeV (ave.)

T [%] = 82.3*exp(-0.0165*x)
T : transmittance、 x : thickness

Calculation from setup
~5.8%

reference value 32%
(298 K、 V_{over} = 4)

Assumed wavelength 577 nm
（phosphorescence）

- Dead time of Cosmo-Z (ADC board) ~13 % (corrected)
- Loss due to transmittance of glass ~8 % (corrected)

errors considered:

- Transmittance of NIT ~5 %
- Determination accuracy of 1 p.e. peak ~1%
- # of irradiated α ray ~ 2.2%
- Peculiar noises of MPPC (cross talk & after pulse ratio)
  *~10 %
- Repeatability ~6.8 %

*T. Igarashi, master's thesis, Waseda Univ.

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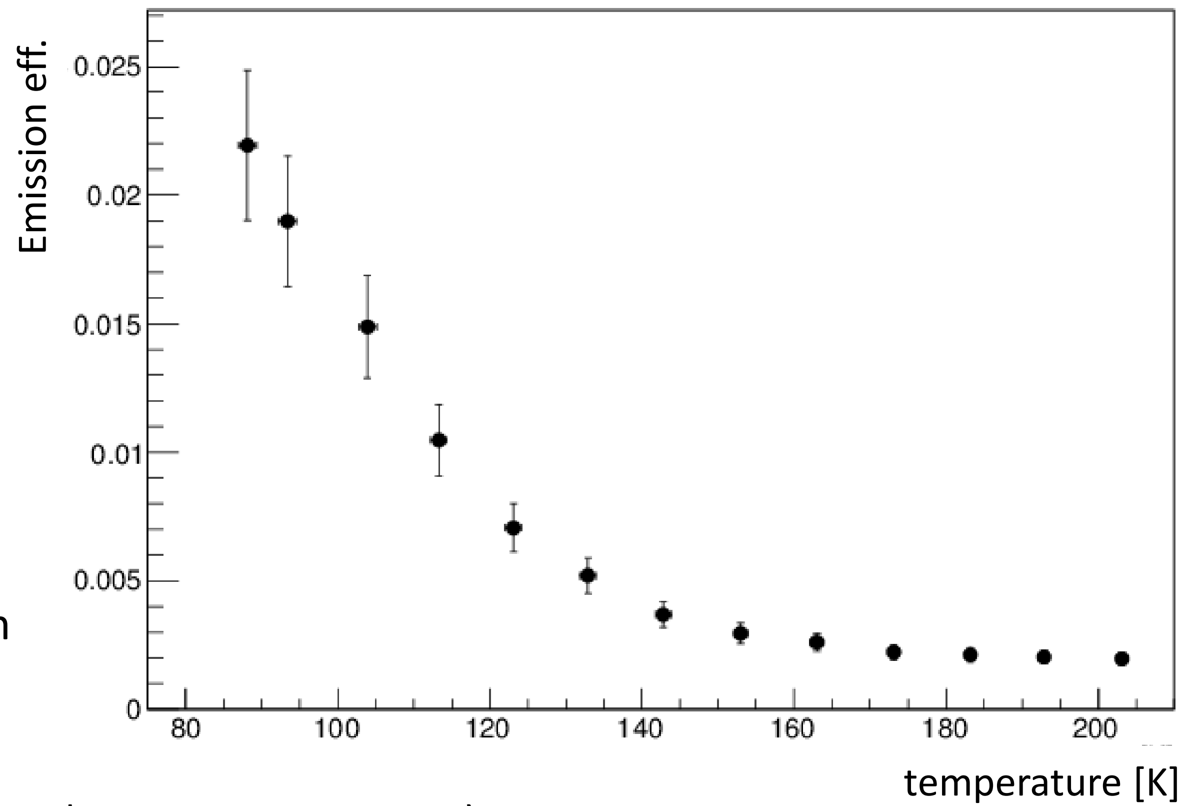


(Luminescence by bound excitons : *496 nm →1.4 times)

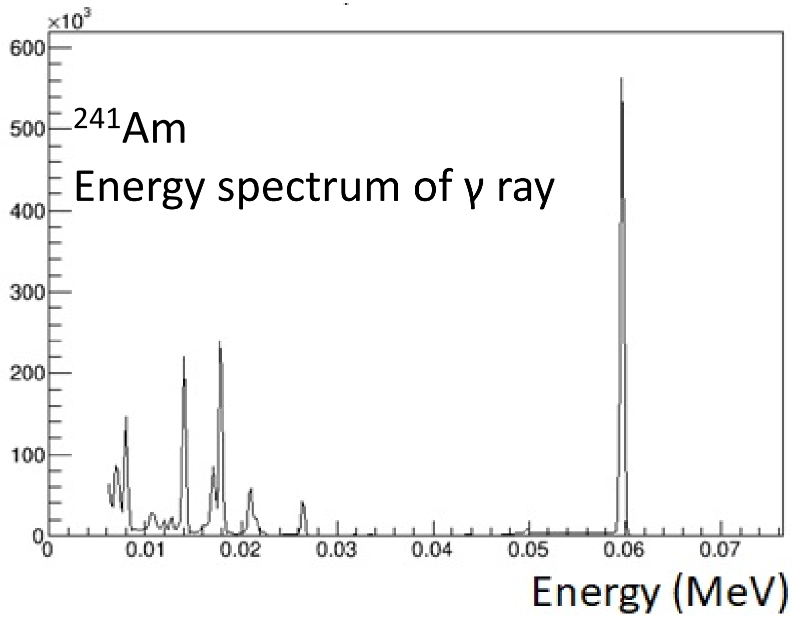
*H. Kanzaki, J. Soc. Photogr. Sci. , 49-5 (1986)

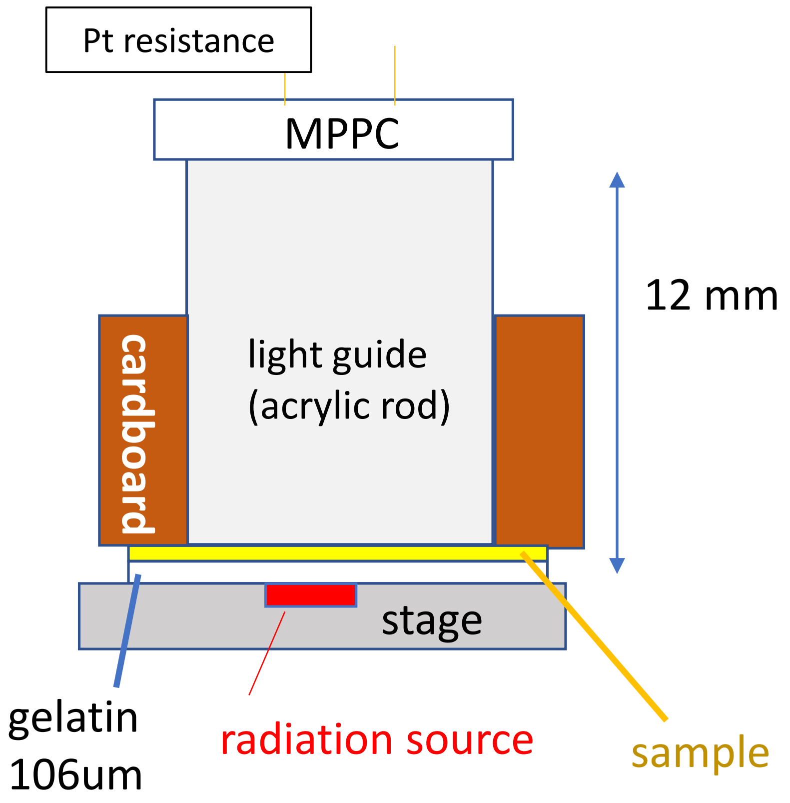
irradiation of γ ray

irradiation of γ ray

energy of γ ray is low

- to reduce γ entering MPPC directly
- not reduce light intensity



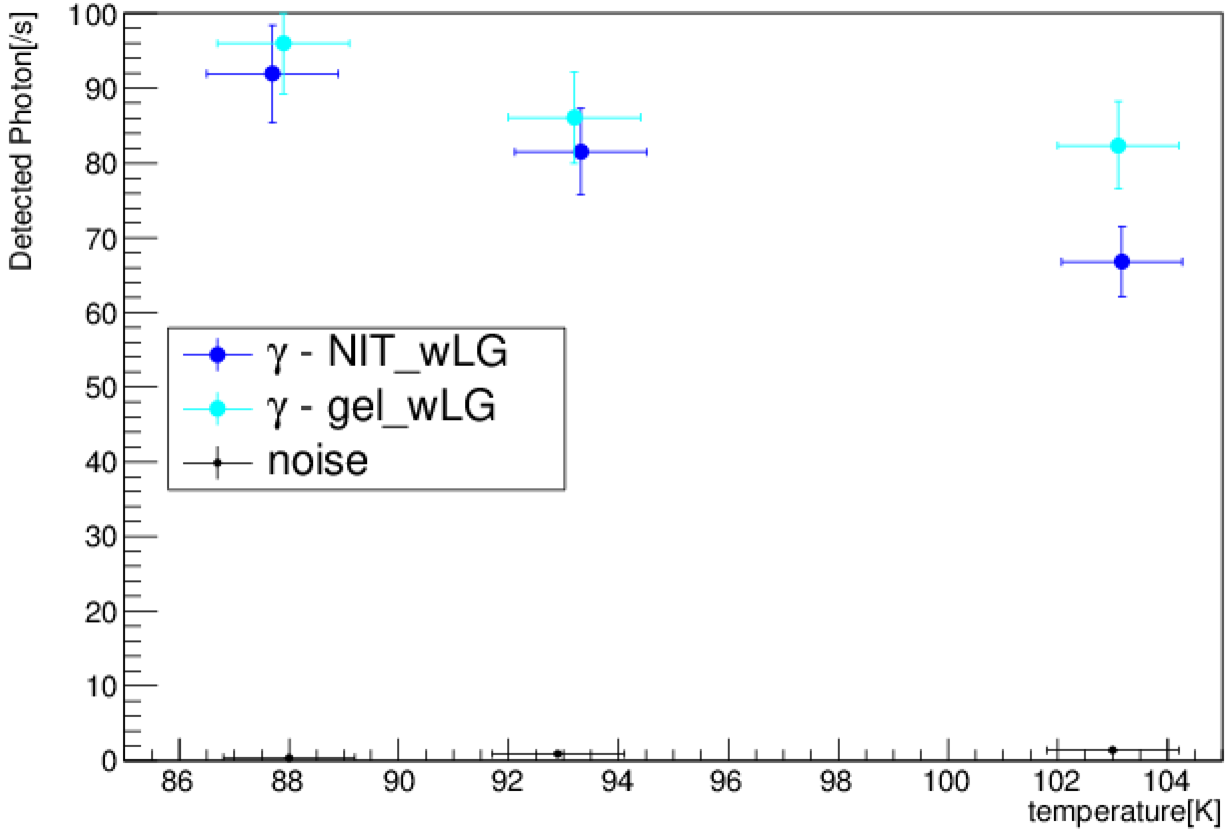


<u>used samples</u>

NIT　37 um*7mm*3 mm （pellicle : w/o base）

gelatin 40 um*3 mm*7 mm

result



We observed something luminescence.
There is no difference between samples (NIT and gelatin).
It is necessary to verify what the detected signal is.

summary

- evaluated emulsion from a new viewpoint of luminescence independent of silver particles (tracks) observation

  □Understanding of physical properties of crystals

  □Application to elementary particle experiment

(1) Observation of luminescence with human eyes

— Confirmed the phosphorescence, wavelength peak was about 577 nm

— Confirmed the luminescence of emulsion by charged particle

(2) Quantitative evaluation for luminescence by charged particle

α ray：

— Observed luminescence from 88 K to 203 K.

— Confirmed the components of fluorescence.

— Ene. conversion efficiency to luminescence @ 88 K was 2.2 %.

→ equivalent to plastic scintillator (Assumed emission wavelength of 577 nm)

γ (β) ray：

— Quantitative evaluation of luminescence has not been achieved.

（luminescence by β ray was confirmed by another test）

→update the measurement system to perform quantitative evaluation

prospects

Understanding of physical properties of crystals

- Measurement of luminescent spectrum

  — Identification of emission wavelength

  →Phenomenology at the moment when charged particles pass through the crystal

- Observe the change in the luminescent properties when changing the crystal size and doping

Application to elementary particle experiment

- Observe the luminescence caused by γ （β） ray and nuclear recoil

  — Comparing difference in luminescence of each particles：

  □Relationship between dE / dx and emission intensity

  □Difference of luminescent properties (time constant, wavelength)

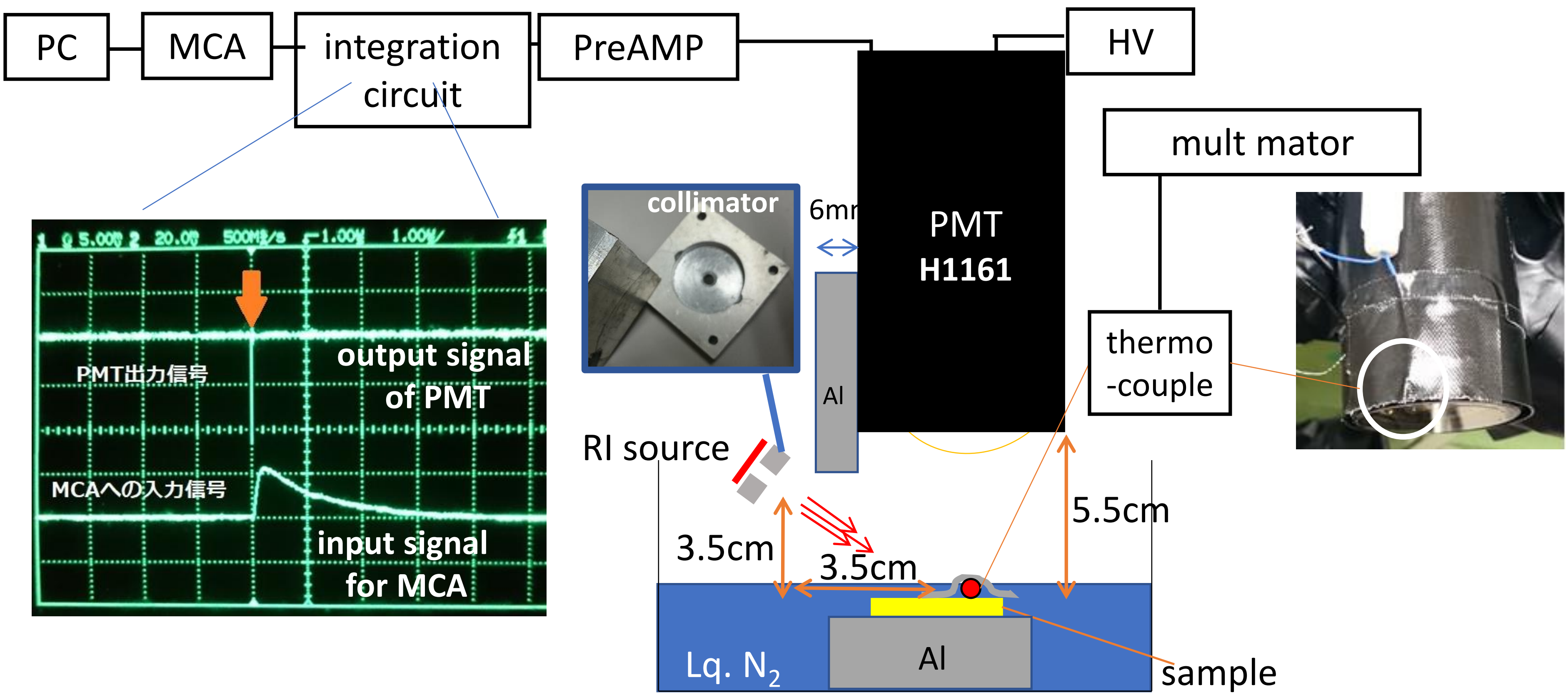
  \- the key is nuclear stopping power

- Narrow down the event location by using luminescence

  (Combined analysis of tracks observation and light emission)

back up

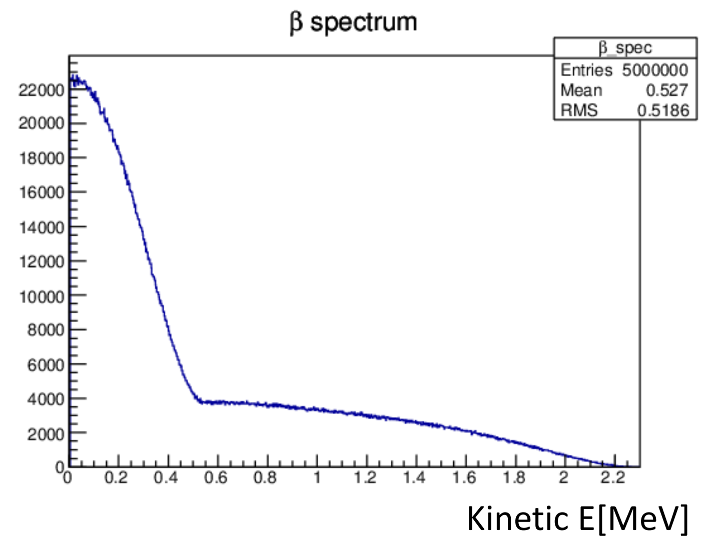
measurement system



RI source: Sr90(βsource)

^{90}Sr —(28.79y, β:100%, 0.546MeV)→ ^{90}Y —(64.00h, β:100%, 2.28MeV)→ ^{90}Zr

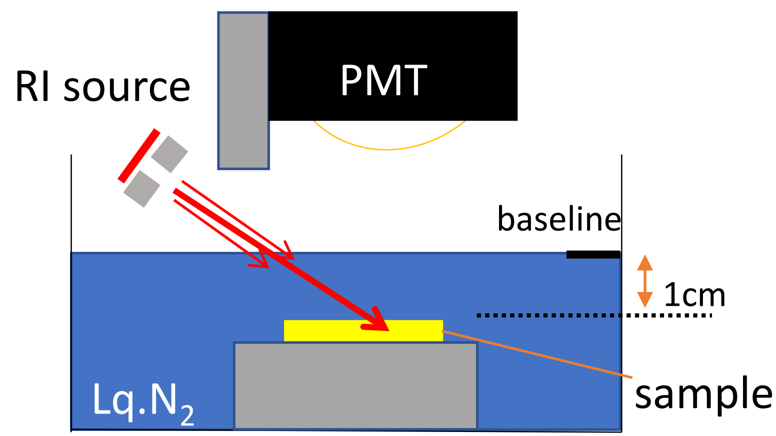
Activity:~594kBq
(D.C.1990→D.C.2016)
rate of β(@NIT)：1160[/s]



<u>used samples</u>
NIT 150 um*10.9cm^2（薄膜）
Gel.: gelatin 80um*10.8 cm^2 (60% of film)

<u>**測定手順**</u>

- LN2を基準線まで注ぐ
- 暗幕をかけ、PMTに電圧をかける
- 2分ごとに20秒間MCAでデータ取得
  (MCSモード：単位時間当たりの信号数カウント)

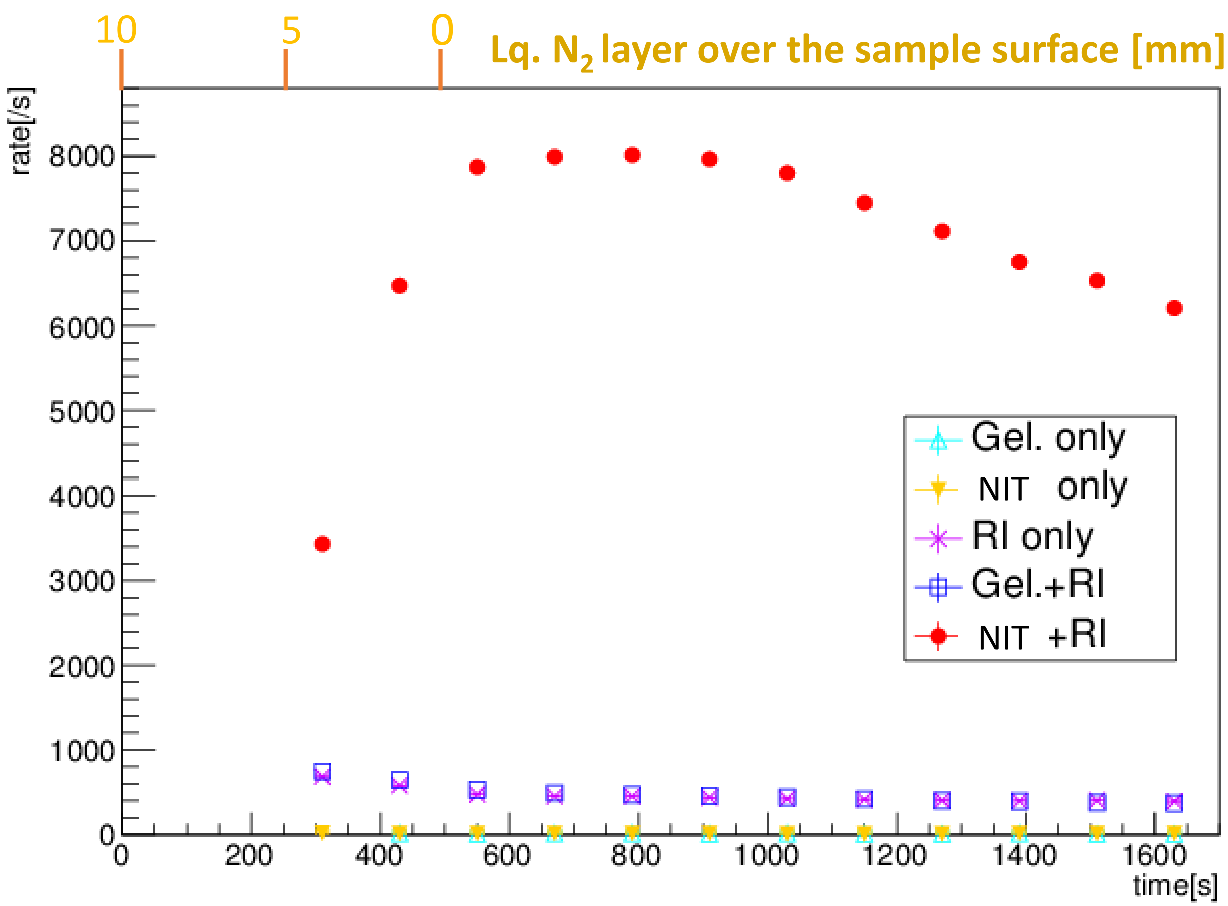


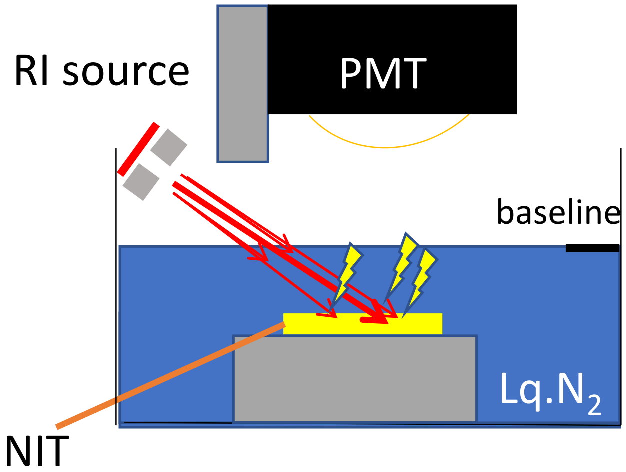
- set only the sample（Film/Gel.)
- set only the radiation source（RI）
- set the sample and radiation

Lq. N_2 evapolation:1mm/50s

measurement was performed in these 5 situation

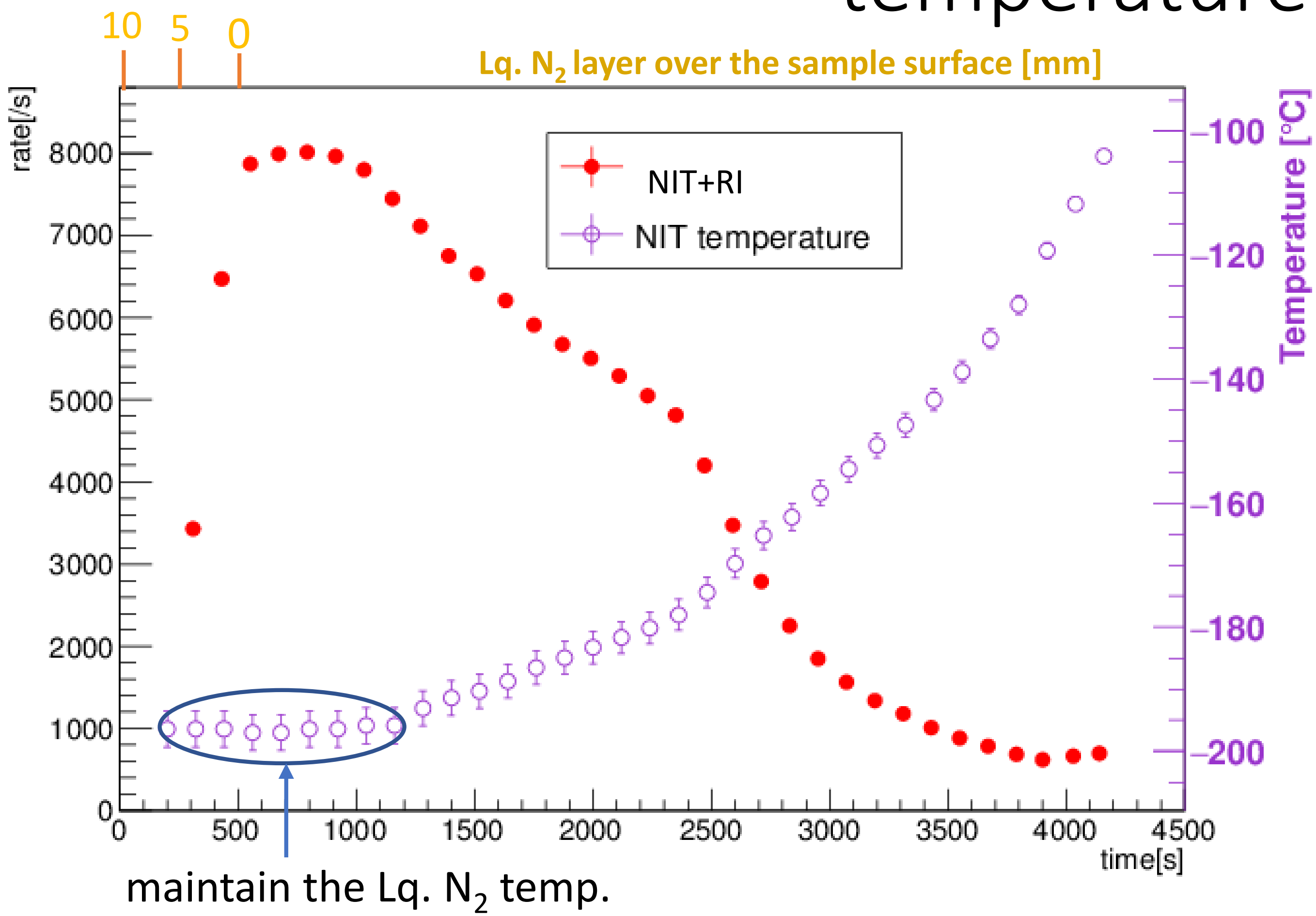
result





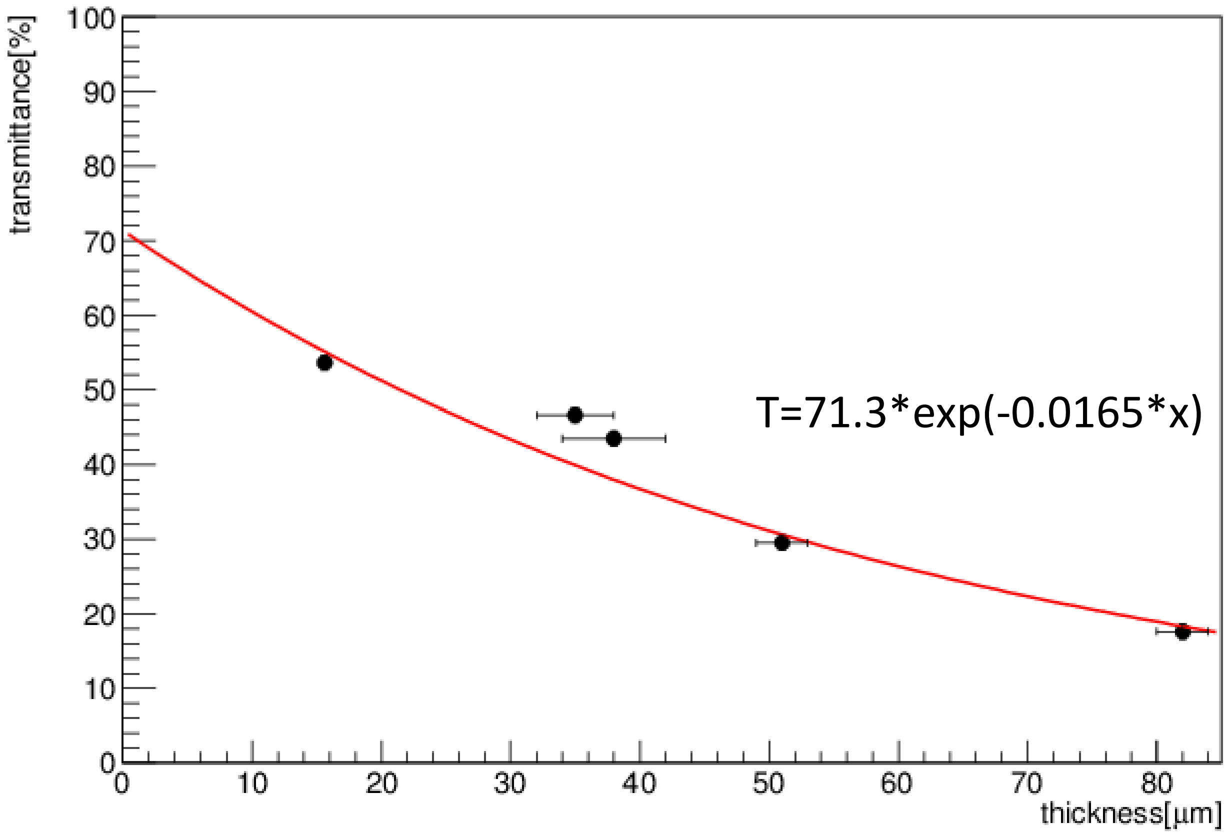
Lq. N_2 evapolation :1mm/50s

Correspondence between NIT temperature and rate

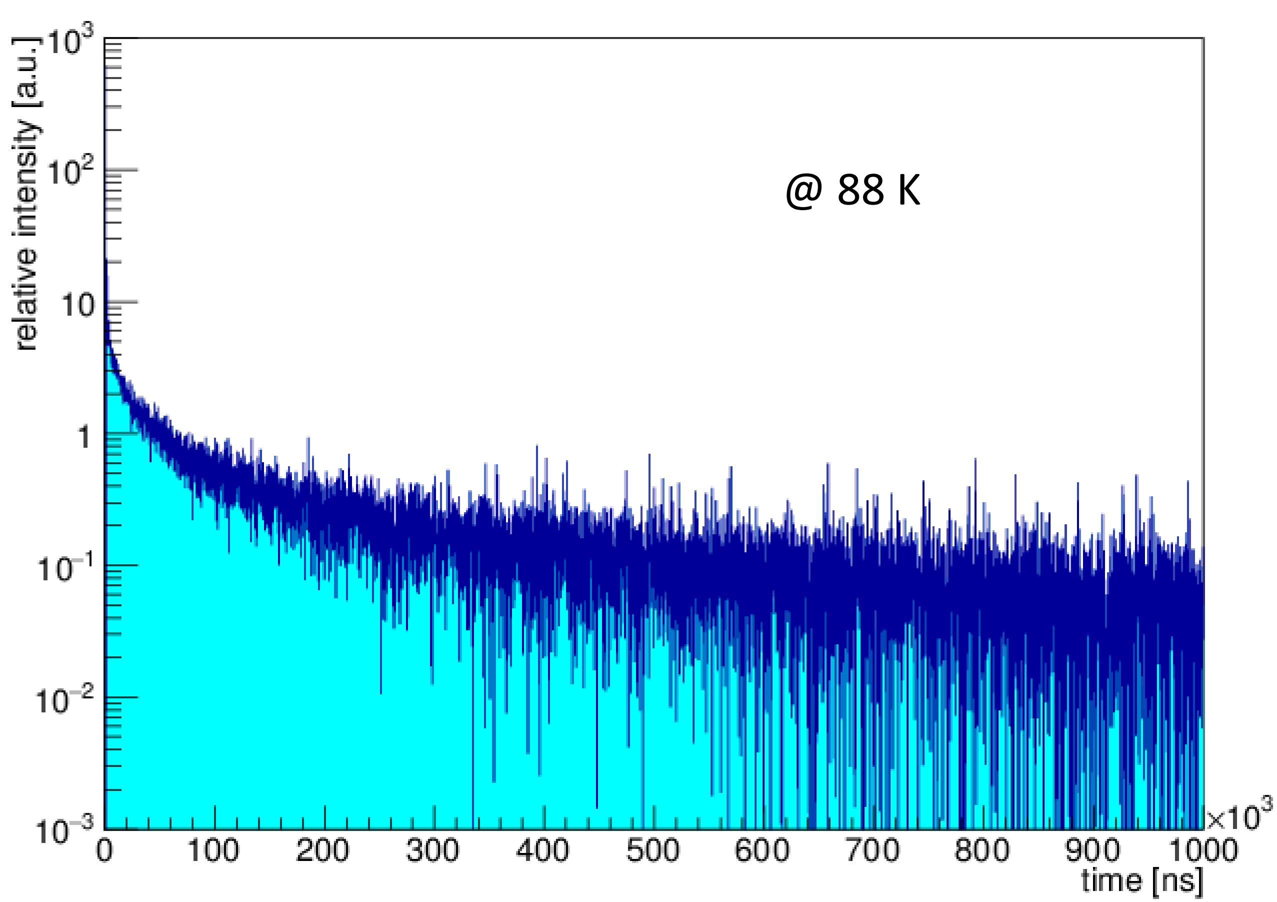


Temperature control did not achieve.

thickness of NIT VS transmittance

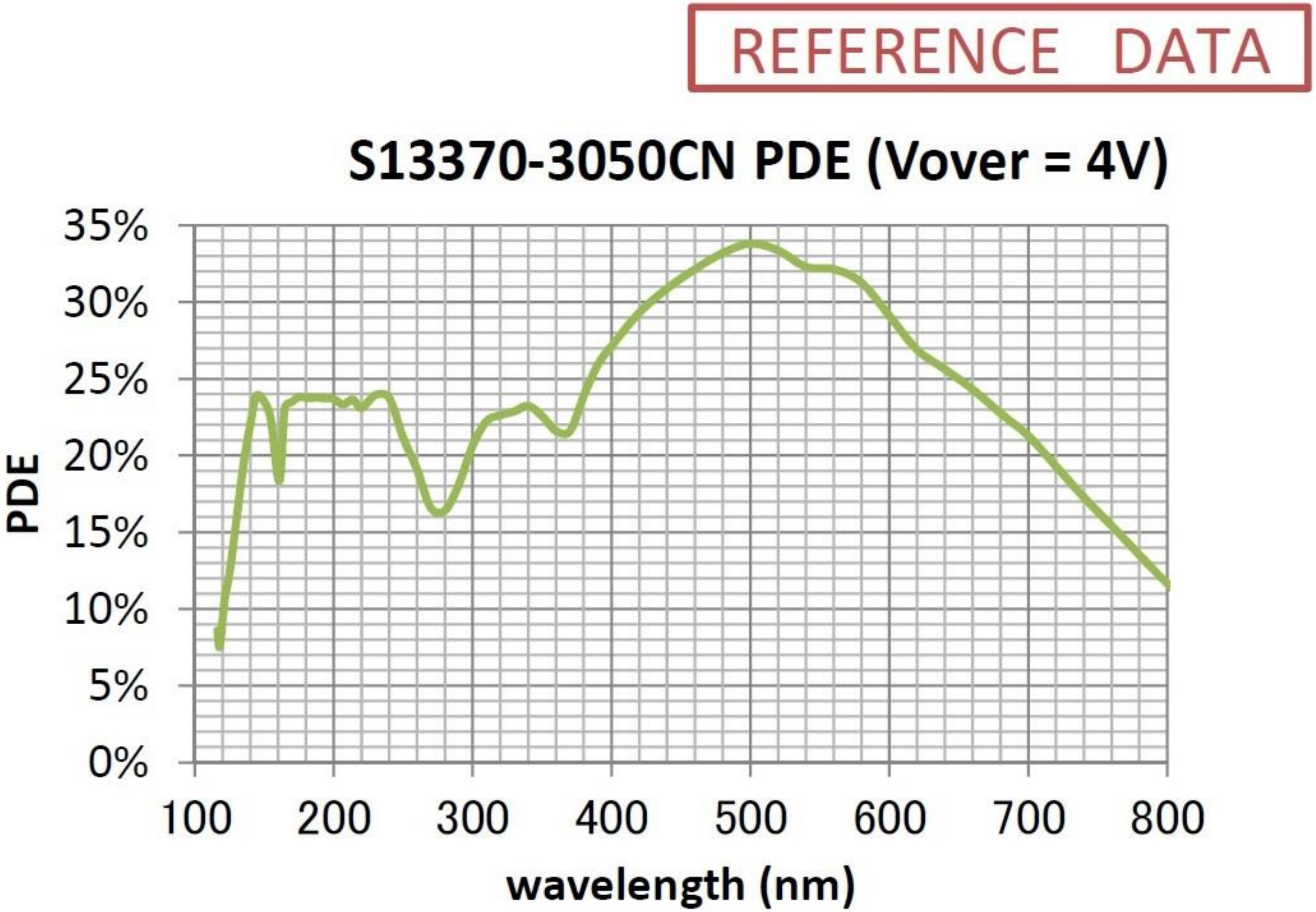


透過率と厚み (経路長) の関係 : T=A*exp(-ax)
A : 界面での反射による損失、T : 透過率、a : 吸収計数、x : 厚み (経路長)
実際の測定では光はNIT中で発生し、表面での反射の影響は一度。一度の反射での損失は反射率をRとすると$(1-R)^2=0.713$を解けばよく、R=0.155が得られる。
T=82.3*exp(-0.0165*x)

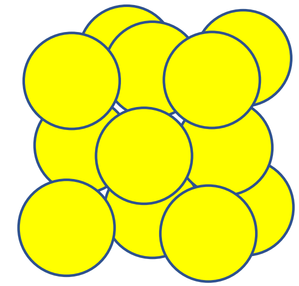


Phosphorescence lasts tens of μs.

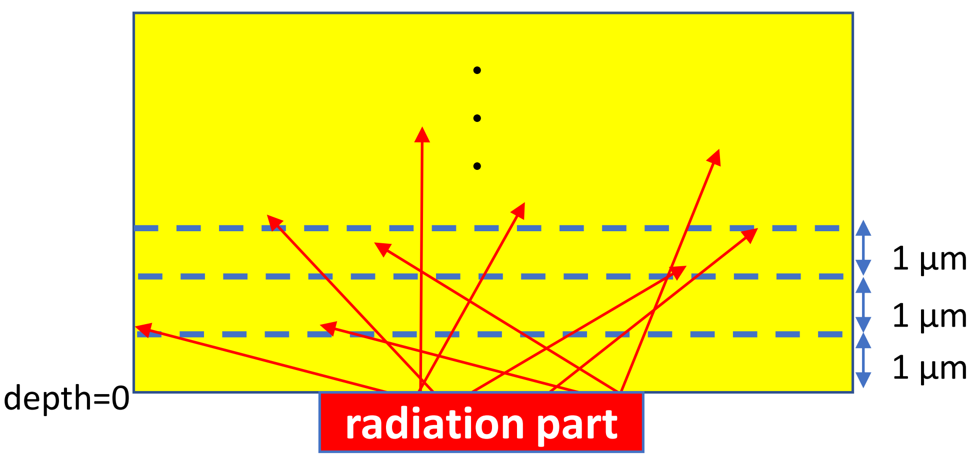
PDE of MPPC

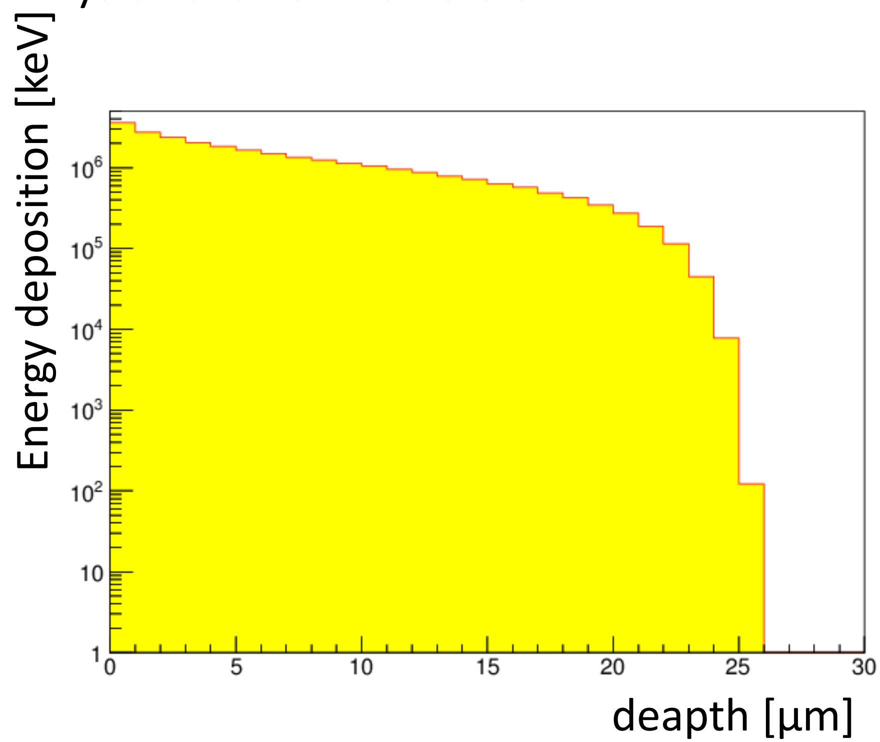

REFERENCE DATA
S13370-3050CN PDE (Vover = 4V)
35%
30%
25%
20%
15%
10%
5%
0%
PDE
100
200
300
400
500
600
700
800
wavelength (nm)

Geaant4 simulation



- Construct the same geometry as measurement
- The AgBrI crystals are arranged in face-centered cubic lattice in NIT.
- Set composition and density with reference to Asada san's paper*
- Irradiate 10000 alpha rays (5.48 MeV), calculate energy deposition in the crystal every 1 µm layer.
- exclude the event which energy deposition in the crystal is lower than 5.8 eV

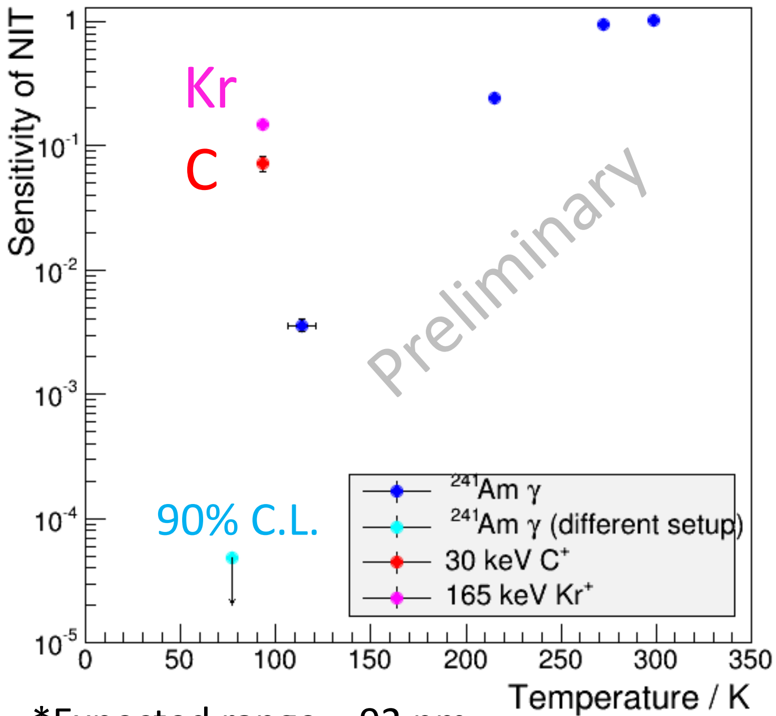




*T. Asada et al. Prog. Theor. Exp. Phys. 2017, 063H01 (2017)

NITの低温でのふるまい(銀核生成)

日本物理学会
2016春季大会で報告



*Expected range = 92 nm

sensitivity≡(目で測定された現像銀数)
/(期待される現像銀数)

低温において：

電子はうつらない

CやKrのイオンはうつる

・核的阻止能(NSP)の寄与

→結晶の温度上昇

⇒**銀核生成率の回復**

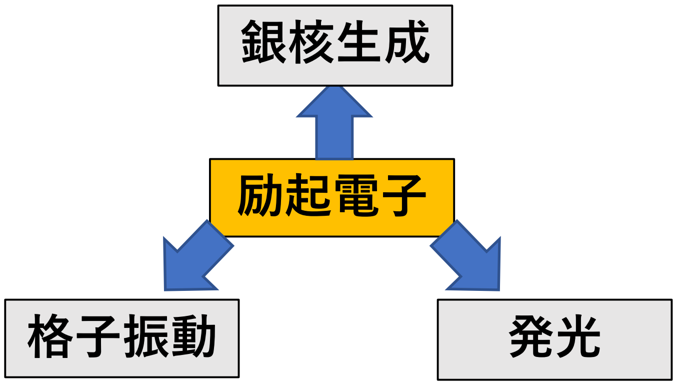
M. Kimura, et al., Nuclear Instruments & Methods in Physics Research A (2016)

上記の結果は新しい知見

発光からのアプローチ

✓ 低温での現象論の理解

✓ 発光にも荷電粒子の違い



MPPCの温度毎のV_{bd}較正

1ピクセルの出力電荷Q

$Q=C*(V_{bias} - V_{bd})$

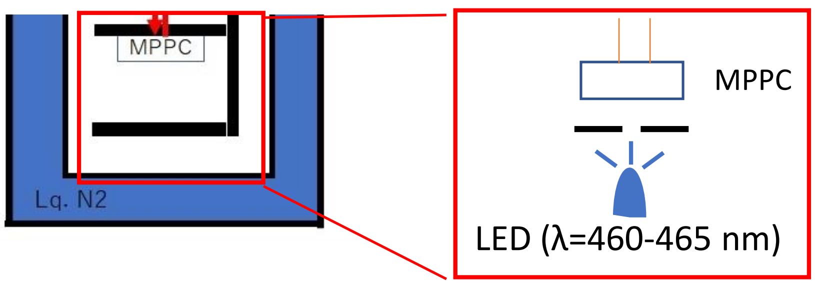
降伏電圧V_{bd}は温度によって変わる

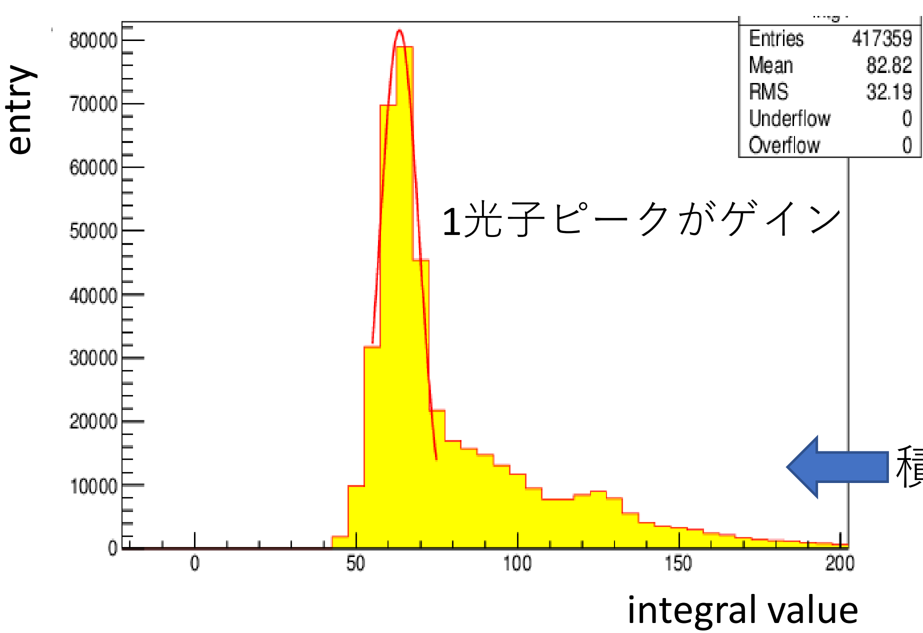
MPPCのゲインは

$$M = \frac{C(V_{bias}-V_{bd})}{e} \left(=\frac{CV_{over}}{e}\right)$$

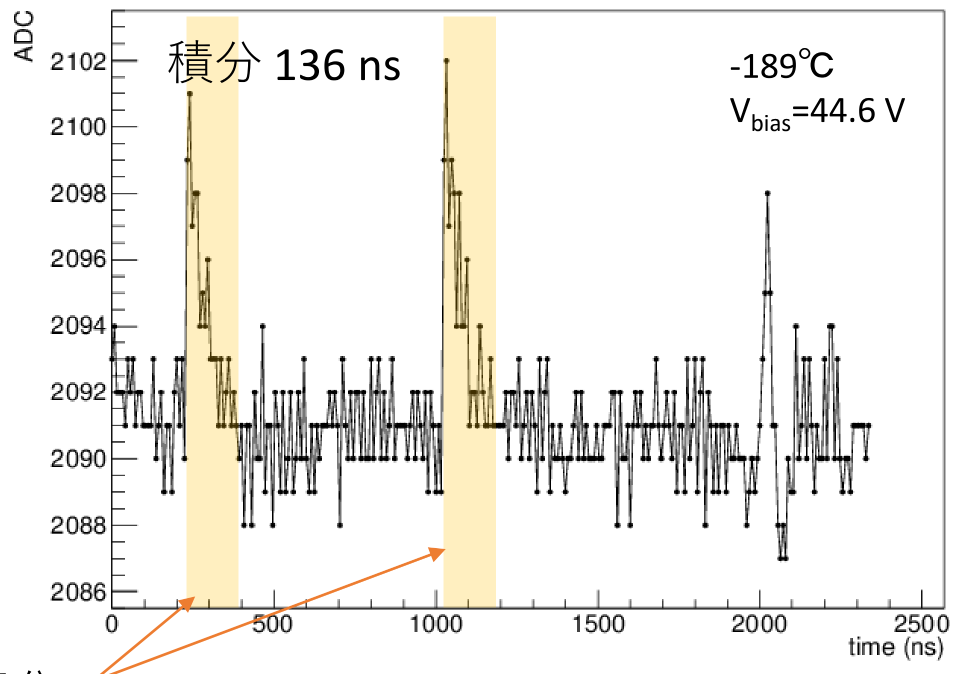
C : 1pix.の静電容量、e : 素電荷

温度を安定させ、V_{bias}を変えた測定を行うとMとV_{bias}の関係からV_{bd}が求まる。



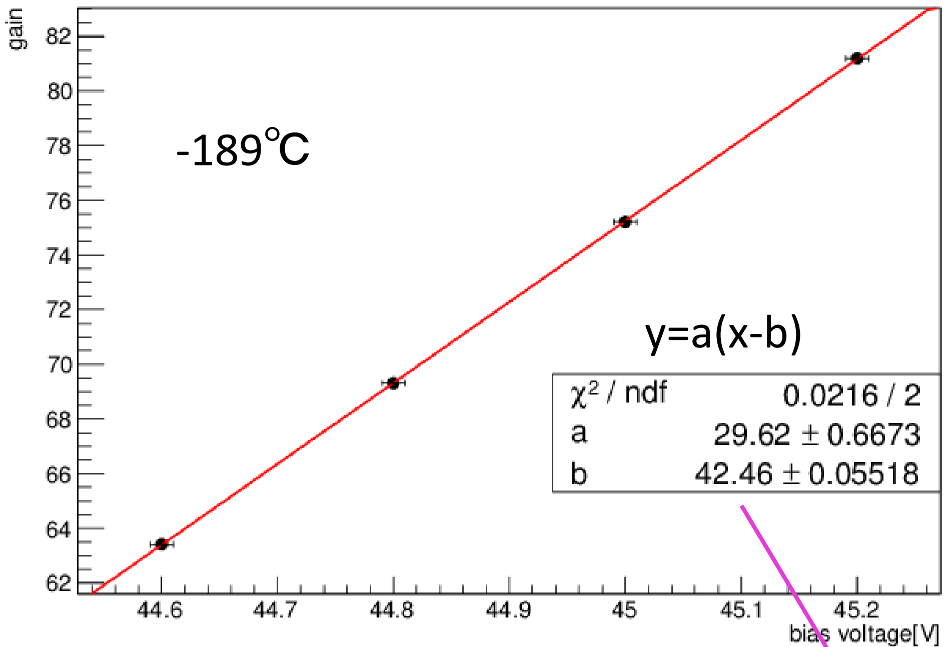


積分



積分範囲外の(time<1888 ns)
でペデスタルを補正

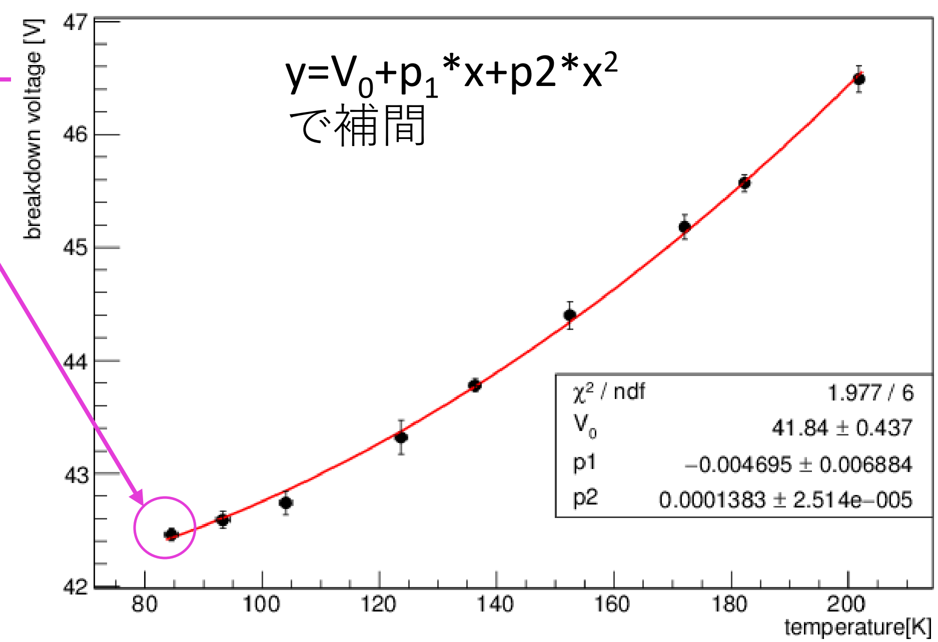
温度毎のV_{bd}較正



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

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