千葉大学博士論文審査公聴会

A study and development of real-time strontium-90 counters based on Cherenkov radiation detection

チェレンコフ検出に基づいたリアルタイムストロンチウム90カウンターの開発研究

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Contents

1. Introduction

1. Introduction

- Fukushima Nuclear Accident, March, in 2011.
- ^{90}Sr ($\tau_{1/2}$=28.8 yr) and ^{137}Cs ($\tau_{1/2}$=30.2 yr) are focused in the recent study.
- Decay chain: $^{90}\mathrm{Sr} \rightarrow {}^{90}\mathrm{Y} \rightarrow {}^{90}\mathrm{Zr}$.
- ^{90}Y radioactivity is close to that of ^{90}Sr by radioactive equilibrium.
- Strontium is an alkali earth metal and tends to accumulated into the bone.
- Measurement of 10–Bq/kg ^{90}Sr is required rapidly.

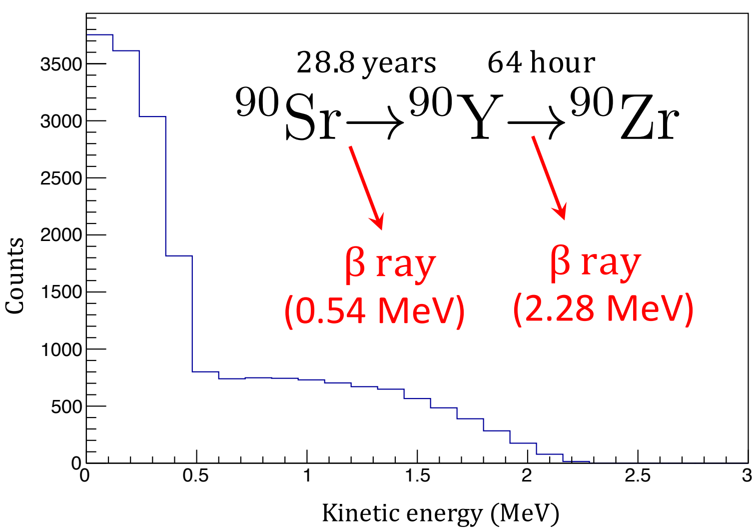


Fig. 1.1: Energy spectrum of β ray from ^{90}Sr and ^{90}Y.

Dose coefficient by ICRP publ.

	^{90}Sr (^{90}Y)	^{137}Cs
Eff. Coeff. (Sv/Bq) (Adult)	2.4×10^{-8}	4.6×10^{-9}
Red Marrow Dose Coeff. (Sv/Bq) (Adult)	1.6×10^{-7}	4.4×10^{-9}
(Infant)	8.6×10^{-7}	6.8×10^{-9}

1. Introduction

1.1. Conventional method of ^{90}Sr radioactivity measurement

- Conventional method based on a Chemical extraction.
  - Sample is burned and become ash, it takes to measure a few week – a month.
  - It is difficult to measure ^{90}Sr concentration of raw-fresh foods rapidly.
- End-point method
  - Magnetic Spectrometer, Calorimeter.
  - It is difficult to determine the end-point because Environmental radiation make be background noise.
- Range method
  - Counting β and γ rays, non-calorimeter, suppressing β rays with low energy.
  - Lower limit: a few Bq/g in 10-min measuring (500-1000 Bq/kg @1-h measuring).
- Cherenkov radiation method
  - Using silica aerogel (n=1.047), Eff.(β(^{137}Cs))/Eff.(β(^{90}Y)) = (2-4)$\times 10^{-2}$.
  - An effective area: $5\times 5\ \mathrm{cm}^2$, detection limit of 0.3 Bq.
  - ^{40}K is most background

1. Introduction
1.2. This study and motivations

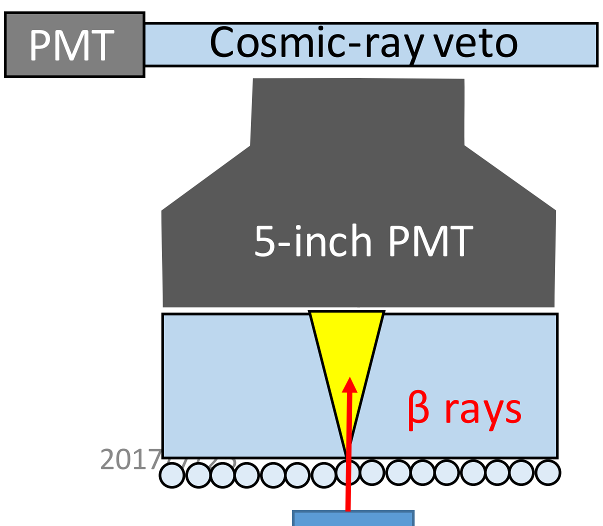
Purpose: measurement of 10 Bq/kg ^{90}Sr at 1 hour in environmental radiation such as ^{40}K.

Precise β rays inspection = Large size detection

e.g. $100\times20\ \mathrm{cm}^2$
Sample 1 kg (5-mm thick)
10 Bq/kg
0.1% eff.

→ BG rate should be less than a few count rate at 1 hour for detection 10-Bq ^{90}Sr significantly.

First Type 1. Direct PMT



Count rate is more than 100 cph.
- PMT thermal noise is a few kHz.
- Accidental γ noises

It is not possible to inspect ^{90}Sr precisely by using a large PMT.

1) Ring Image Cherenkov (RICH)
   … cost, Cherenkov angle=11.4° , noise rate.
2) Reduce the amount of substance of photo-device.
   … using wavelength-shifting fibers, threshold type.

1. Introduction

1.2. This study and motivations

- I developed a threshold-type Cherenkov detector to measure ^{90}Sr concentration using silica aerogel (n=1.041) and wavelength-shifting fibers.
- I studied a basic mechanism of the Cherenkov detector.
- I studied background of environmental radiation, particularly ^{214}Bi as the radon progenies.
- I produced a prototype detector with S=300 cm^2.
- The performance was estimated using radioactive sources.

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Cherenkov radiation

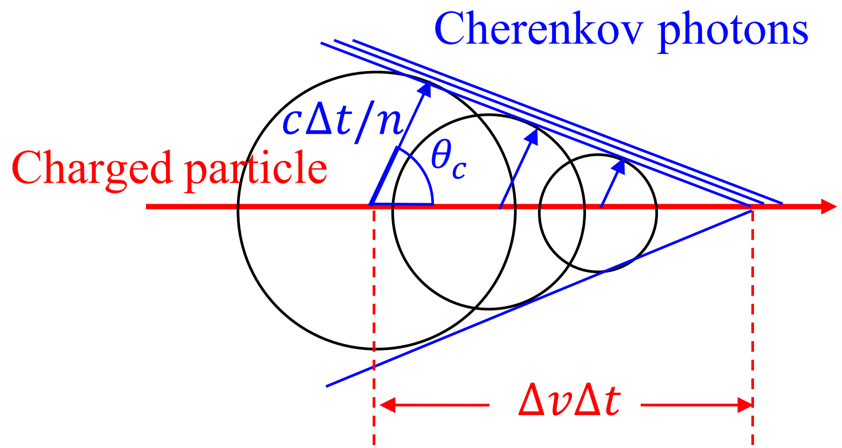
It is required for ^{40}K β rays to not emit Cherenkov photons.

A threshold of refractive index is given as

$$n_{\rm th} = \frac{c}{v} = \frac{E}{pc} = \frac{m_{\rm e}c^2 + K}{\sqrt{(m_e c^2 + K)^2 - m_e^2 c^4}}$$

where $m_{\rm e}$ is electron mass, K is β ray kinetic energy (MeV). In a case of $K = 1.31$ MeV, $n_{\rm th} = 1.041$.

In this index, knocked out e^- by Compton scattering of γ ray with $E\gamma < 1.53$ MeV is not satisfy the Cherenkov condition in the areogel.

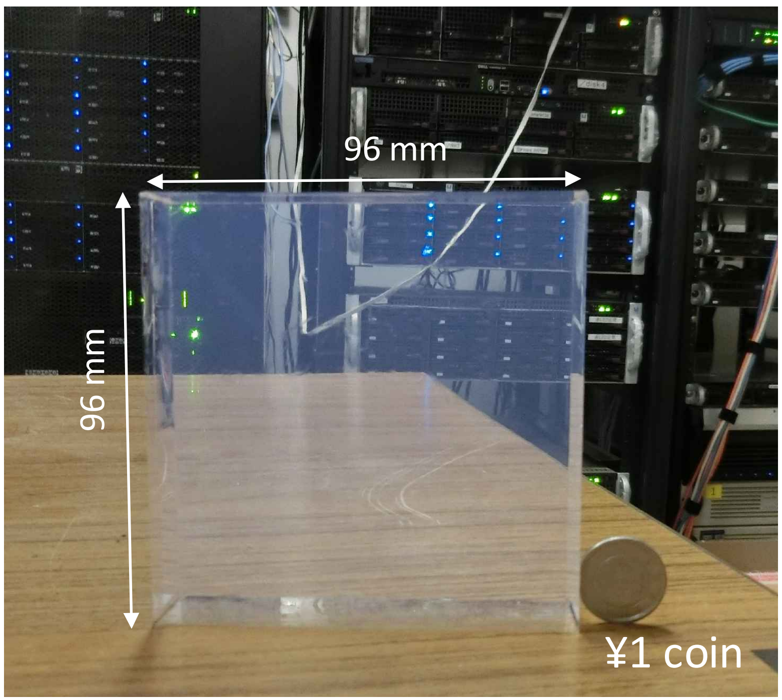


refractive index n

$$\cos\theta_c = \frac{c}{nv} < 1$$

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

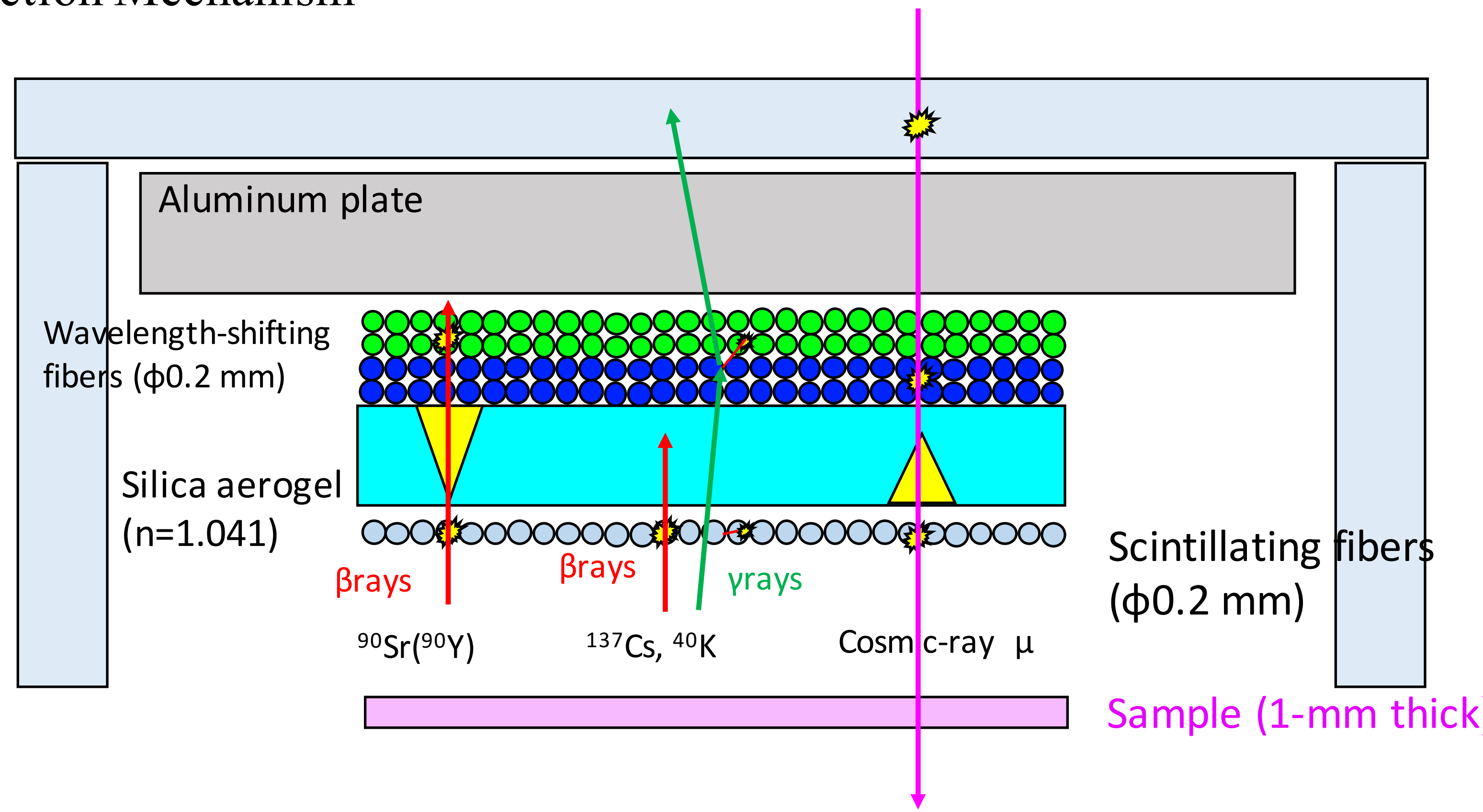
Silica aerogel



- Silica aerogel is a material as SiO_2 + Air.
- Properties:
  (1) Low density (0.1～0.2 g/cm^3)
  (2) Low refractive index
  (3) high transparency for the visible light
- Index control: 1.003 < n < 1.25
- Without a hydrophilic properties by a hydrophobic treatment

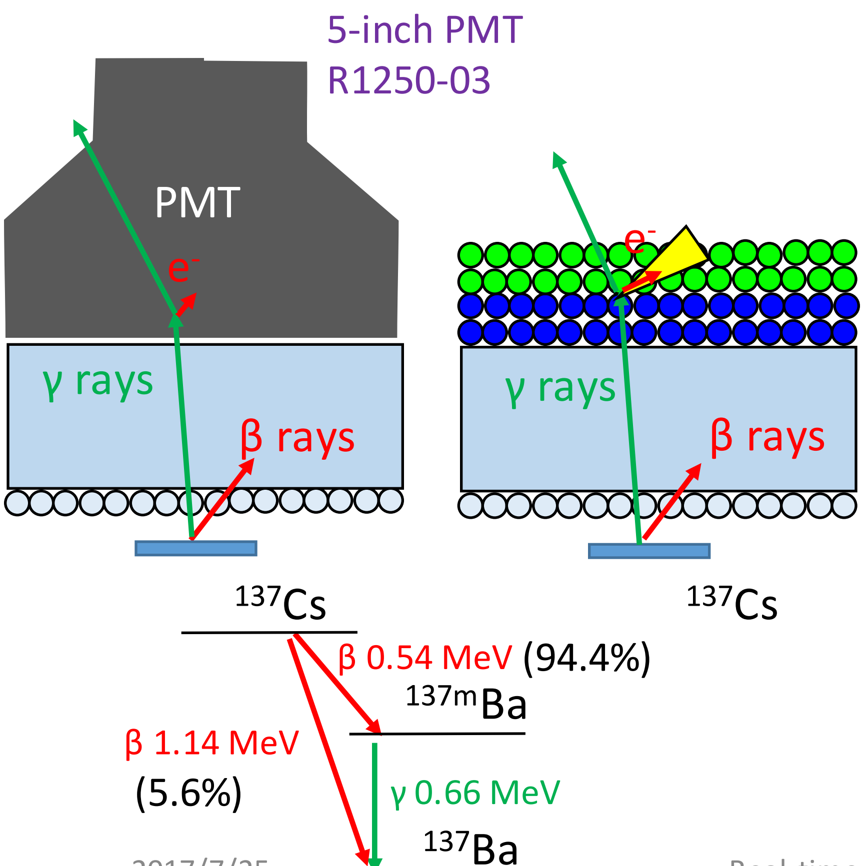
2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

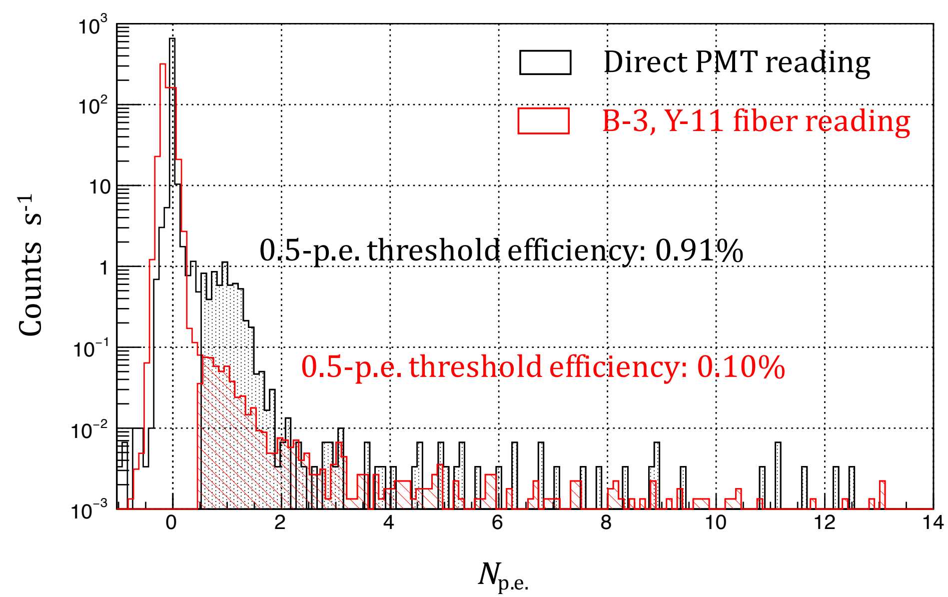
Detection Mechanism



2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

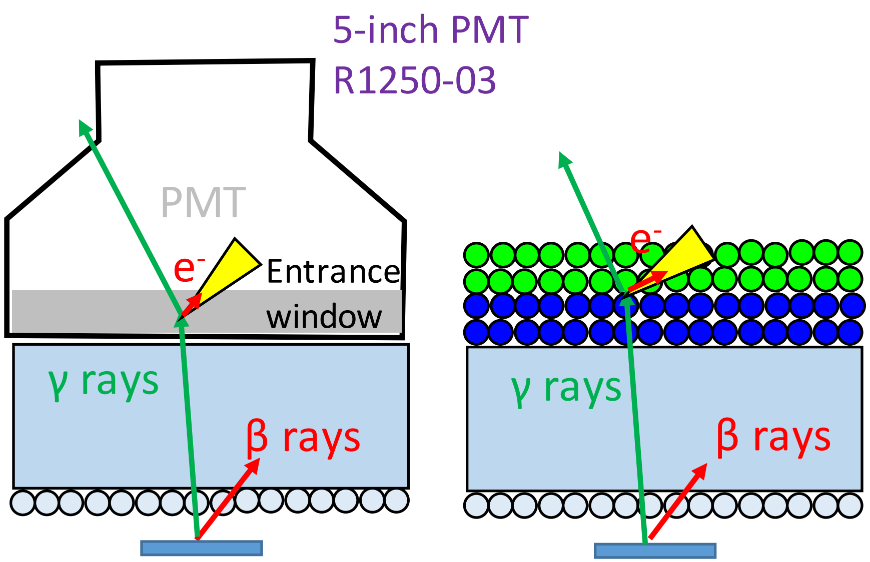
Accidental noise by ^{137}Cs γ rays

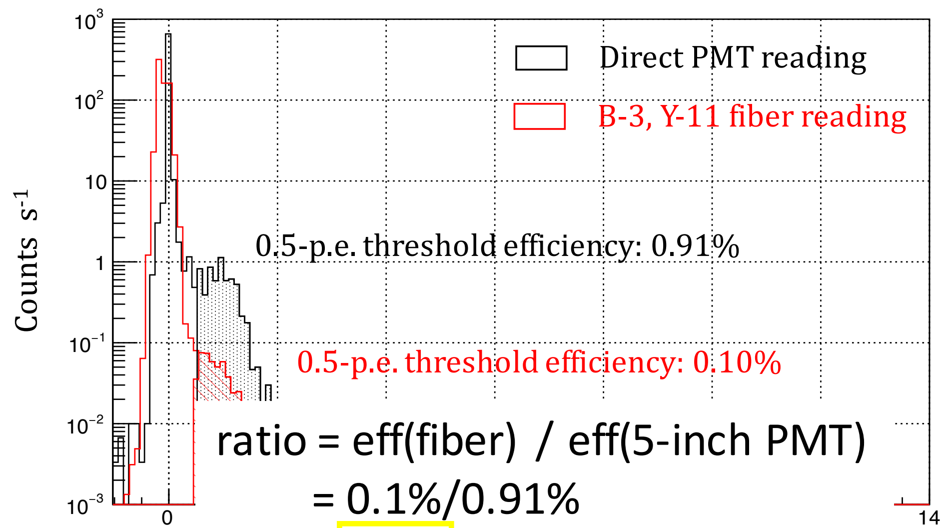




2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Accidental noise by ^{137}Cs γ rays





ratio = eff(fiber) / eff(5-inch PMT)
= 0.1%/0.91%
= 0.11

	Thickness	Density
5-inch PMT entrance window	2-3 mm	2.6 g/cm³
B-3 & Y-11 sheets	0.8 mm	1.06 g/cm³

$$\text{ratio} = \frac{0.8\ \text{mm}}{1.06\ \text{g/cm}^3} \div \frac{2\text{–}3\ \text{mm}}{2.6\ \text{g/cm}^3}$$

= 0.11-0.16

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Optical models
Cherenkov photons

- Optical models were developed to understand wavelength-shifting fibers collection system for Cherenkov photons by reading PMT.
- The model’s parameters fixed with experimental data.
- Collection efficiency of the fibers was estimated using the models.

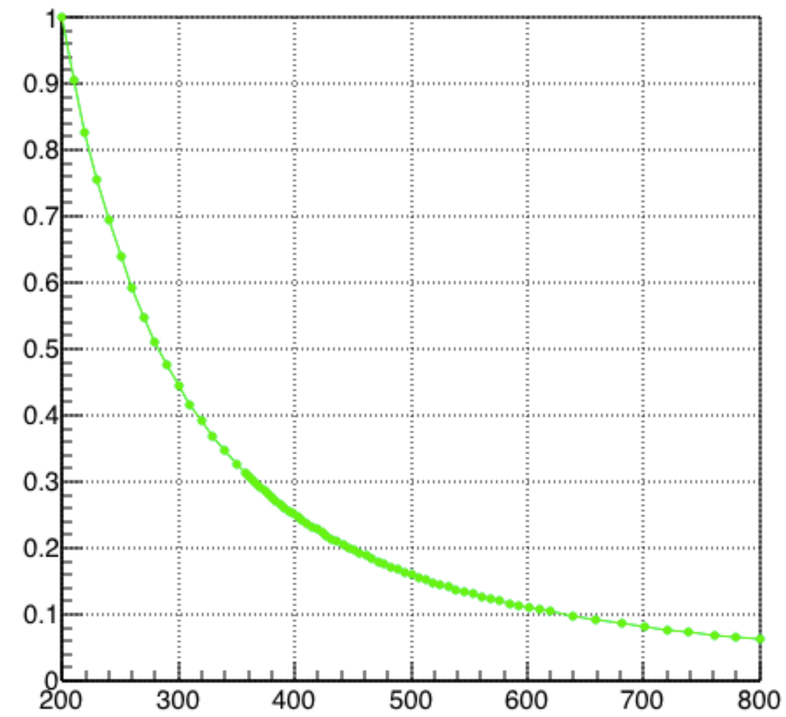
2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Optical models
Cherenkov photons

The number of emitted photons is given as

$$N = 2\pi\alpha L\left(1 - \frac{1}{n^2\beta^2}\right)\int_{200}^{800}\frac{d\lambda}{\lambda^2}$$

where α is fine-structure constant, L is path length of the particle, $\beta = v/c$, λ is the wavelength of emitted photons.



Wavelength λ (nm)

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Optical models

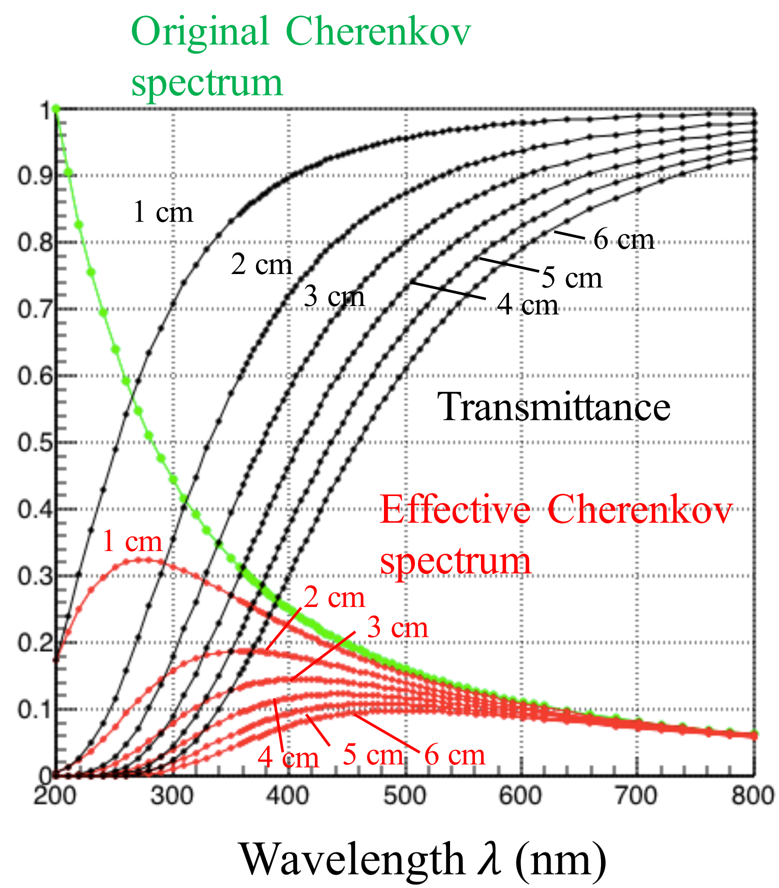
Silica aerogel transmittance

- The transmittance T(λ) is given as

$$\mathrm{T}(\lambda) = A \exp\left(\frac{-Ct}{\lambda^4}\right),$$

where the amplitude is A=1, $\mathrm{C} = 5.33 \pm 0.03$ μm/cm, t =1–6 cm.

- The effective Cherenkov spectrum has a peak at 300–500 nm

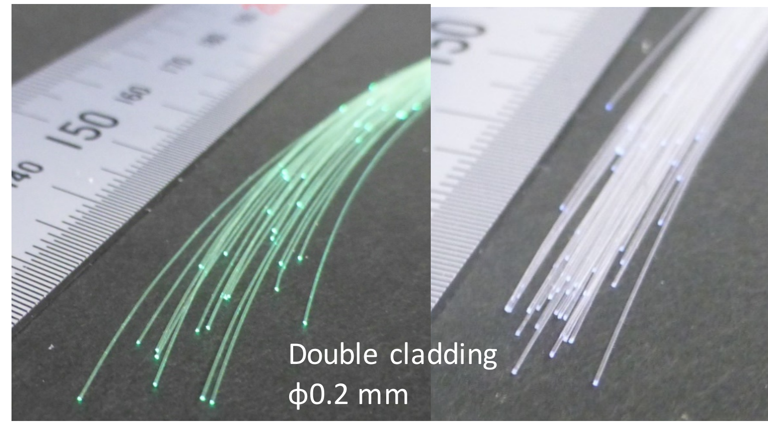


2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Optical models

Wavelength-shifting fibers

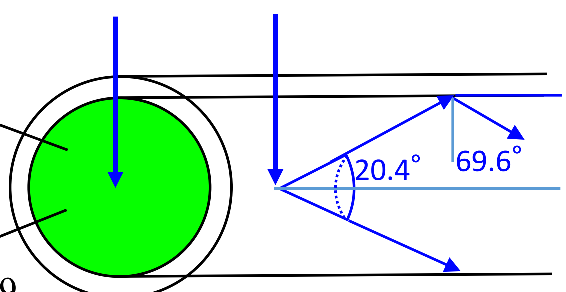
- Optical plastic fibers
- Trapping efficiency determined by a ratio between a refractive indices of core and cladding.



Kuraray Y-11(300)MJ　　B-3(300)MJ

Cladding n=1.49
(Polymethyl-
methacrylate)

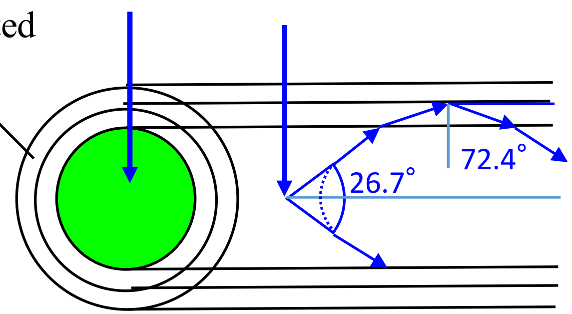
Core n=1.59
(Polystyrene)



3.1%
(one side)

Single cladding

Cladding n=1.42
(Fluorinated
polymer)



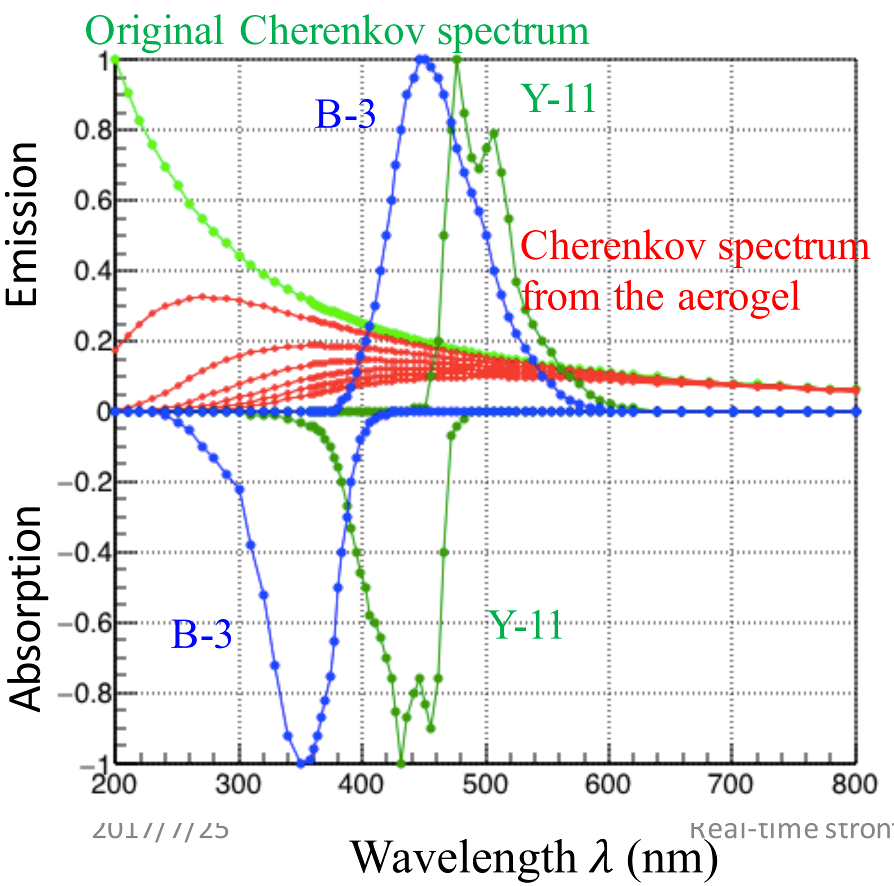
5.4%
(one side)

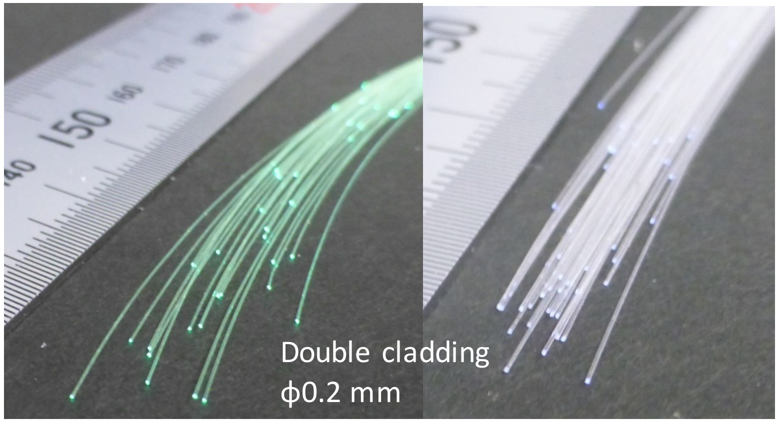
Double cladding

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Optical models

Wavelength-shifting fibers





Kuraray Y-11(300)MJ B-3(300)MJ

- Absorption spectra have peaks at 350 nm (B-3) and 450 nm (Y-11).
- Use of two types of fibers allows to extend wavelength range to absorb Cherenkov photons.

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

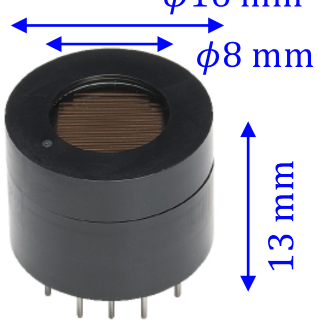
Optical models

PMT

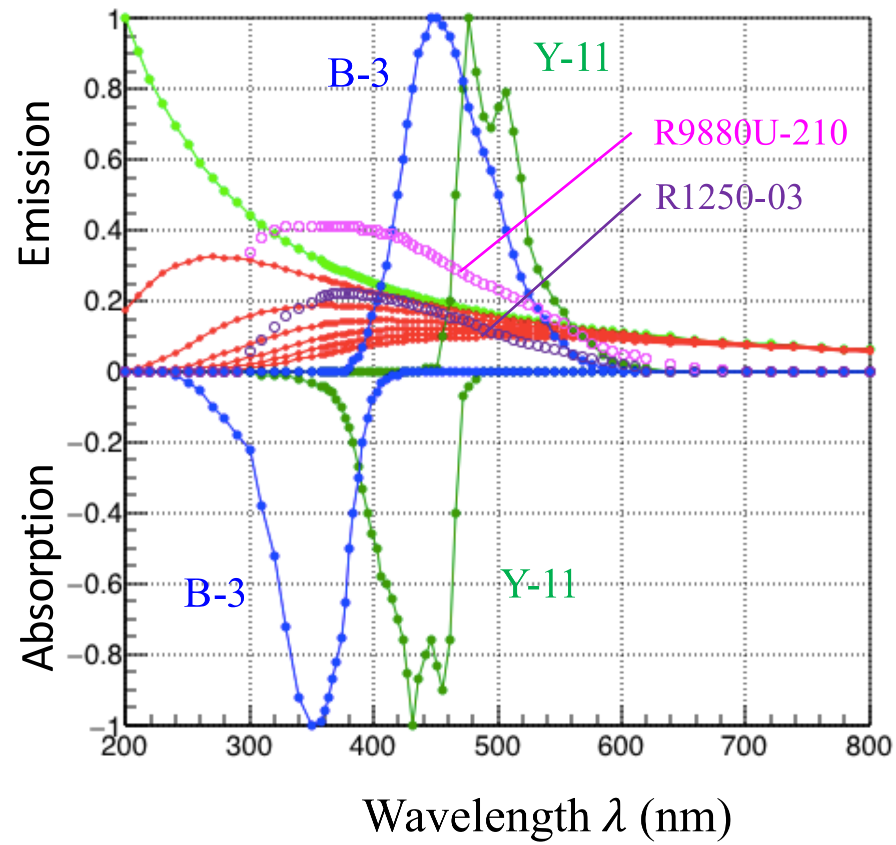
R1250-03

- Head-on Type
- Bialkali photocathode
- Line focused dynode structure

R9880U-210

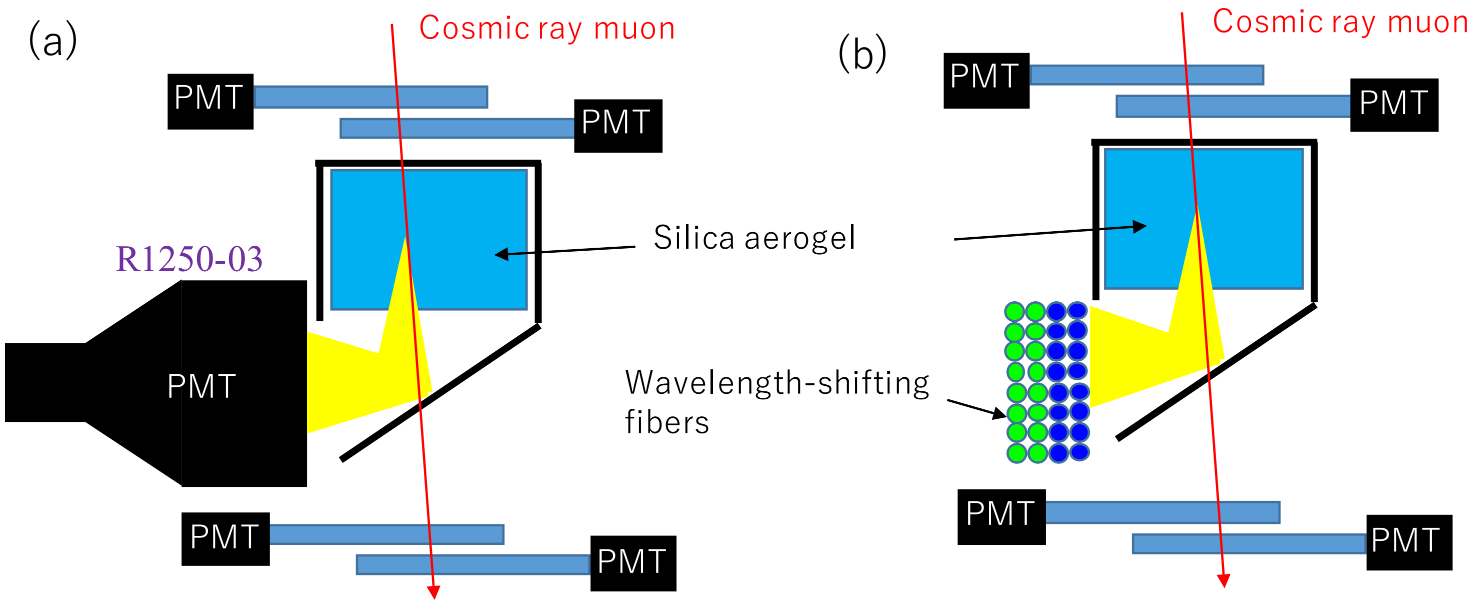


- Head-on Type
- Ultra Bialkali photocathode
- Metal channel dynode structure



2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Measurement of light collection efficiency



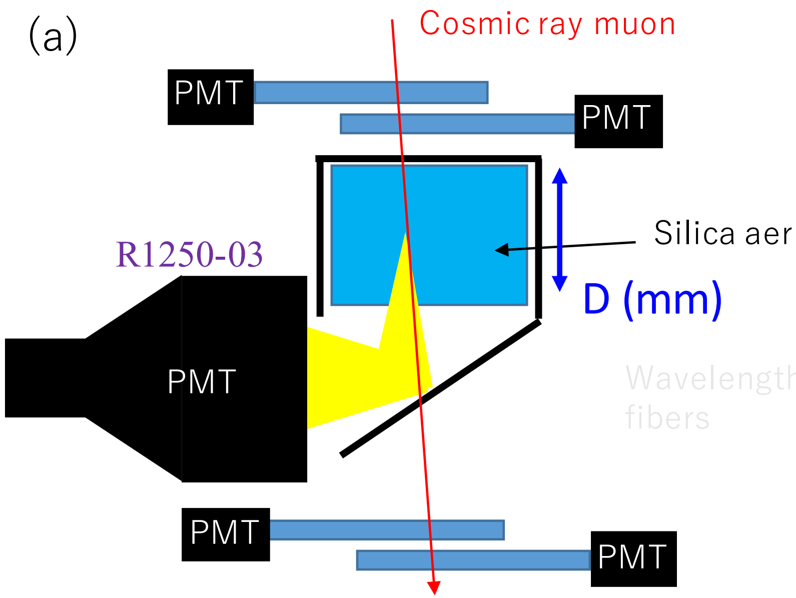
2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

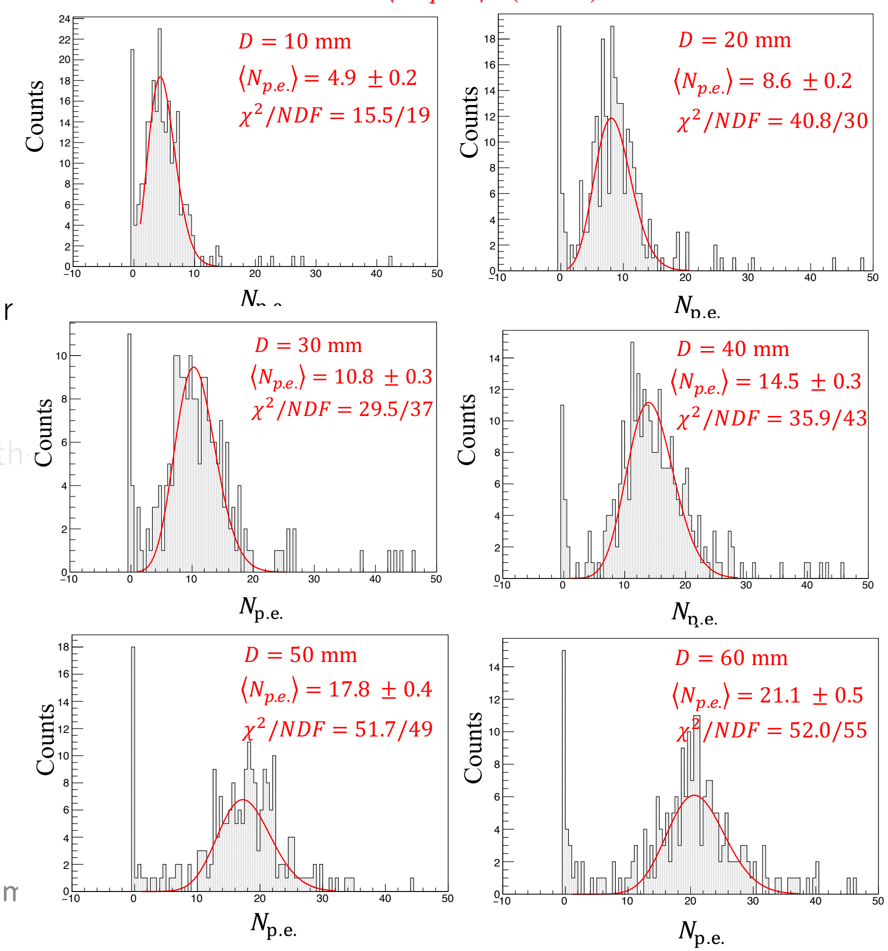
Poisson Function Fitting

$$P(k,\nu) = e^{-\nu}\nu^{k}/k!$$

$$\langle N_{p.e.}\rangle\ (=\nu)$$

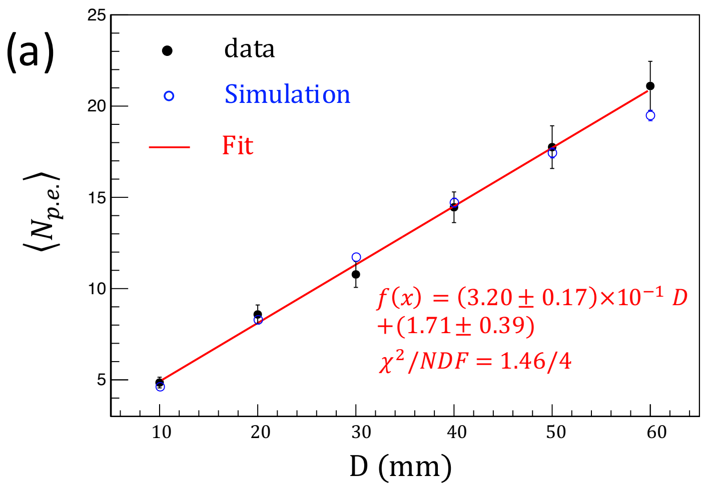
Measurement of light collection efficiency

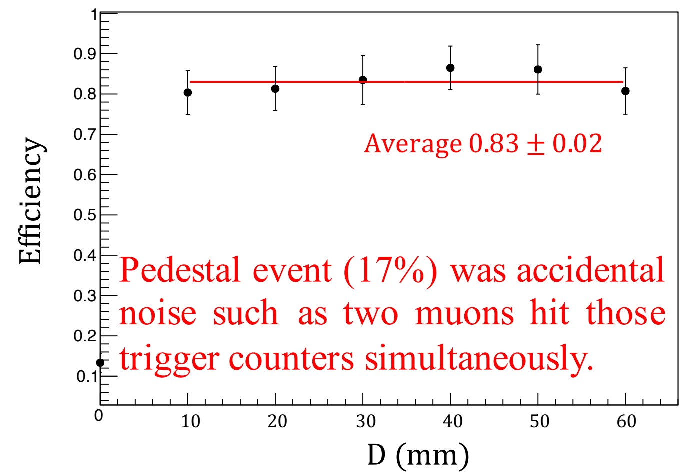




2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Measurement of light collection efficiency





$$N_{\mathrm{p.e.}} = 2\pi\alpha \int d\lambda dL \frac{\varepsilon_{\mathrm{QE}}(\lambda) \cdot T(\lambda, L) \cdot \varepsilon_{\mathrm{ref}}}{\lambda^2} + N_0$$

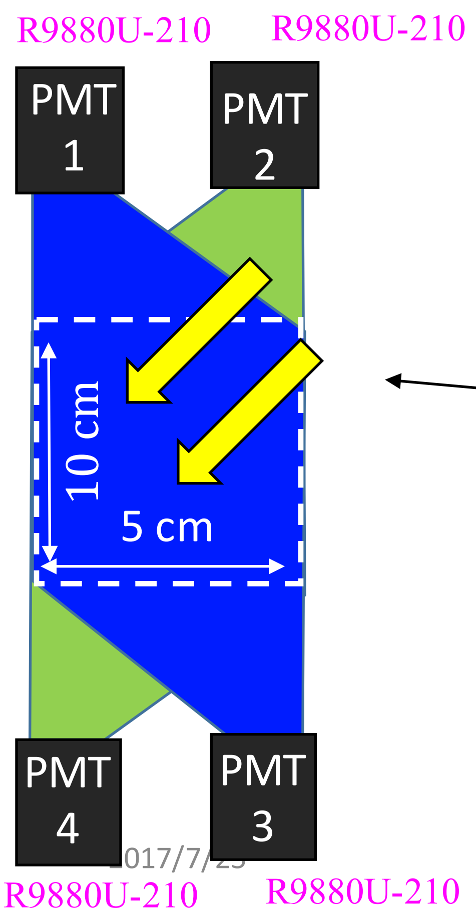
$\varepsilon_{ref} = 0.466 \pm 0.004$

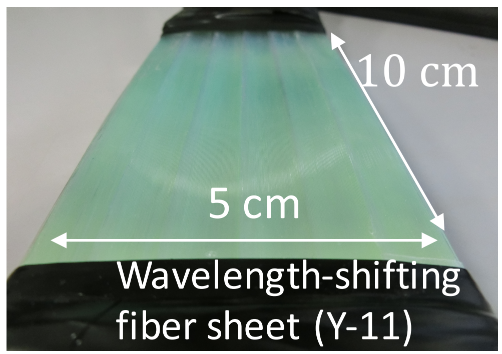
$N_0 = 1.42 \pm 0.03$

with $\chi^2_{\mathrm{min}} = 30.7$

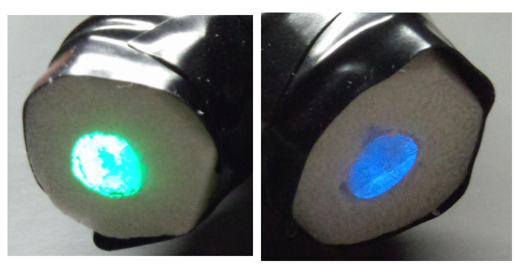
2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

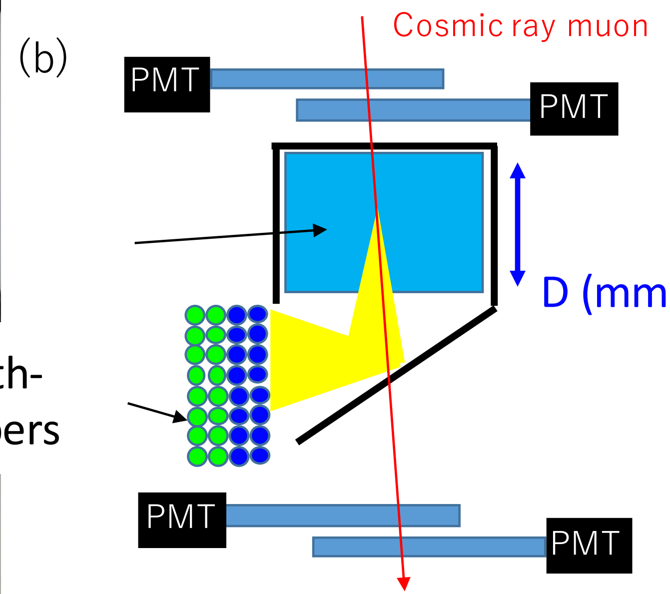
Measurement of light collection efficiency





Wavelength-shifting fibers

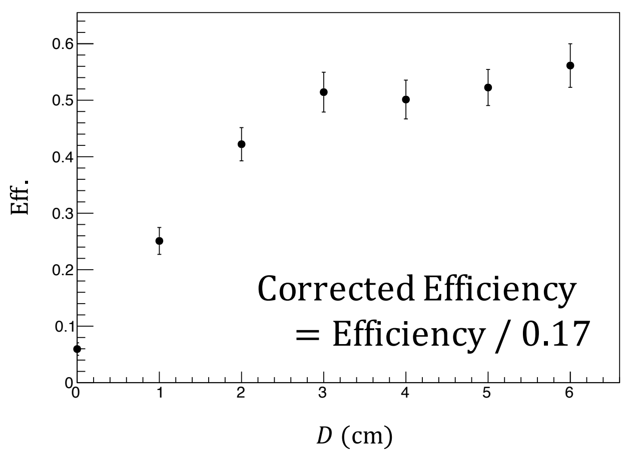


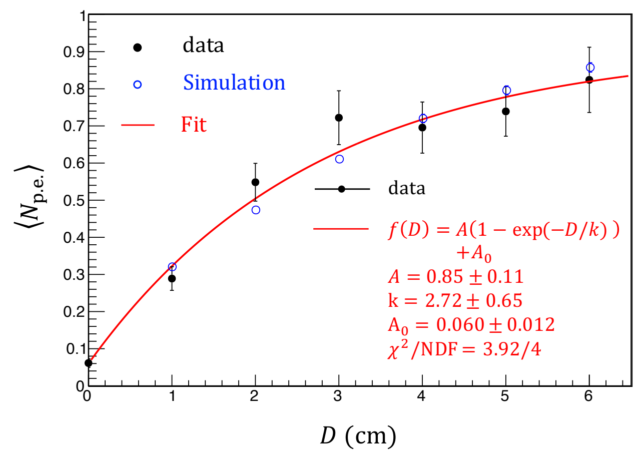


2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Measurement of light collection efficiency

(b)





$$P(k=0,\nu) = \exp(-\nu)$$

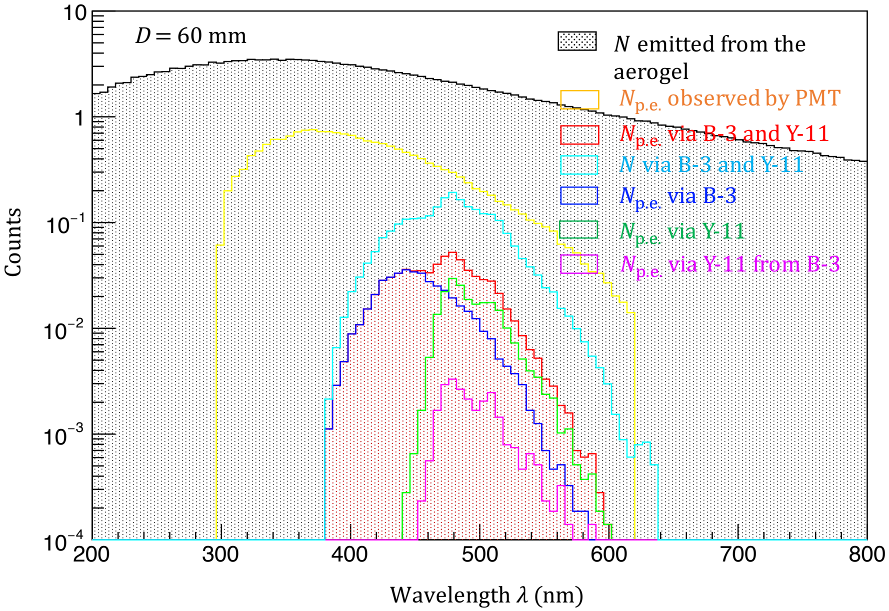
$$\langle N_{\mathrm{p.e.}} \rangle \equiv \nu = -ln(\mathrm{inefficiency})$$

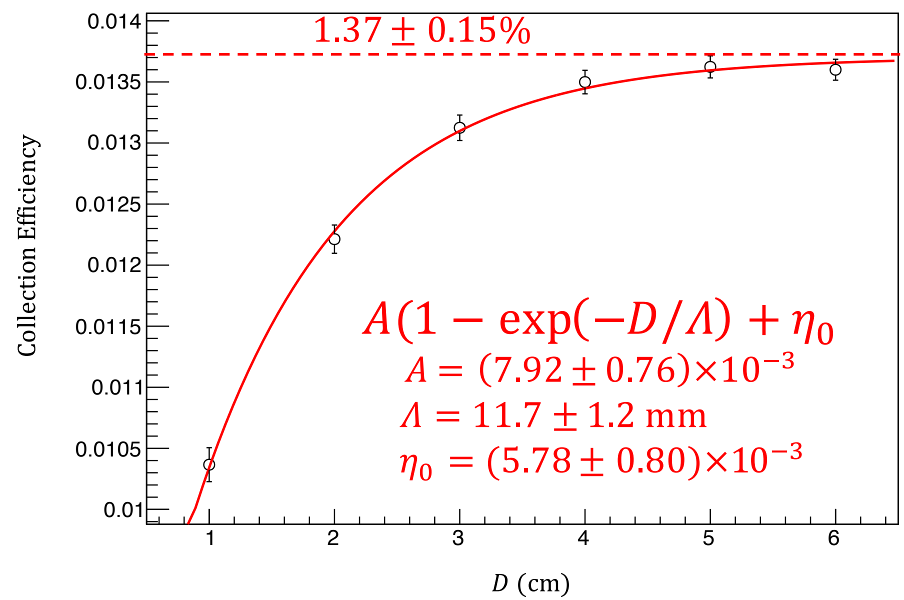
$$\begin{aligned} N_{\mathrm{p.e.}} &= 2\pi\alpha \int d\lambda dL \frac{T(\lambda, L)\cdot\varepsilon_{\mathrm{ref}}}{\lambda^2} \\ & \Big\{ \; g_{\mathrm{core}}^{\mathrm{B-3}}(\lambda,\lambda')\varepsilon_{\mathrm{trap}}\varepsilon_{\mathrm{QE}}(\lambda')d\lambda' \\ &+ \frac{1}{2} g_{\mathrm{core}}^{\mathrm{B-3}}(\lambda,\lambda') g_{\mathrm{core}}^{\mathrm{Y-11}}(\lambda',\lambda'')(1-\varepsilon_{\mathrm{trap}})\varepsilon_{\mathrm{trap}}\varepsilon_{\mathrm{QE}}(\lambda'')d\lambda'' \\ &+ (1-g_{\mathrm{core}}^{\mathrm{B-3}}) g_{\mathrm{core}}^{\mathrm{Y-11}}(\lambda,\lambda'')\varepsilon_{\mathrm{trap}}\varepsilon_{\mathrm{QE}}(\lambda'')d\lambda'' \Big\} \\ &+ N_0, \end{aligned}$$

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Measurement of light collection efficiency

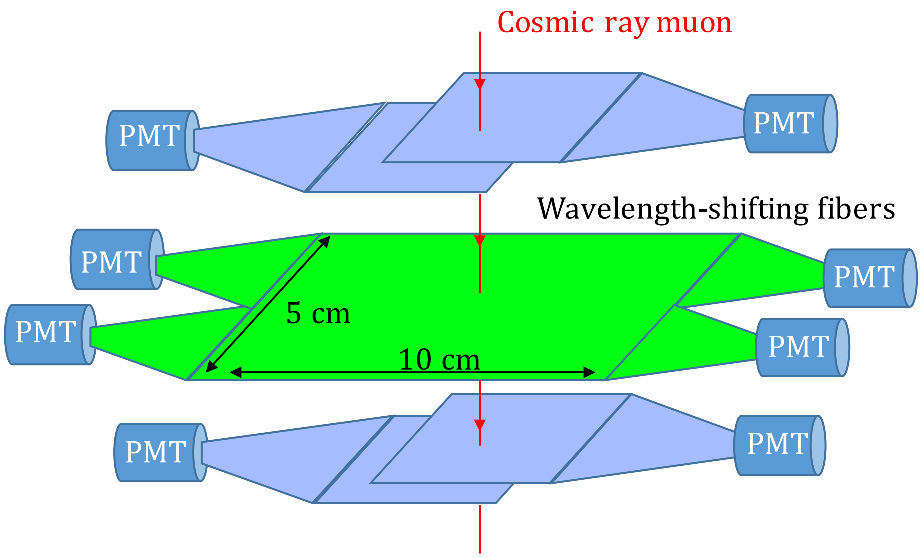
(b)

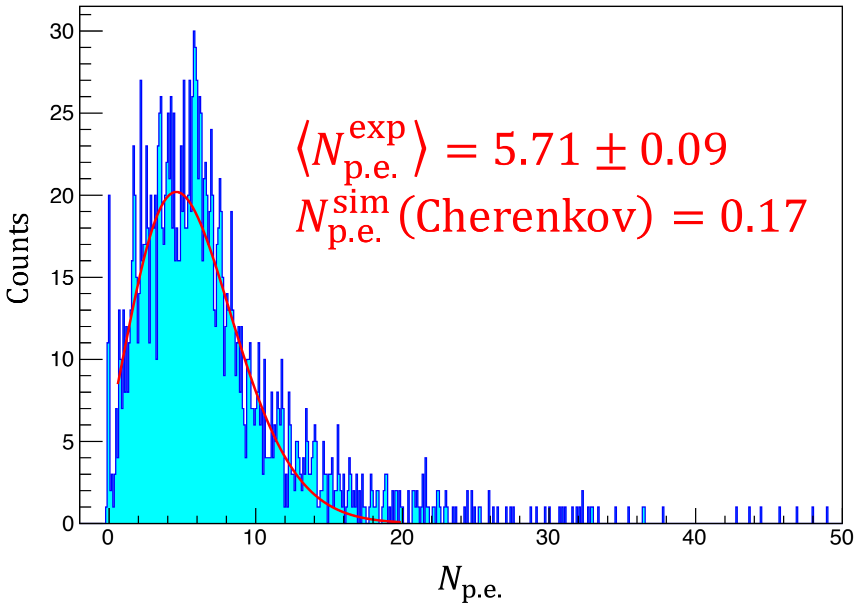




2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Impact of charged particles passing though the fibers

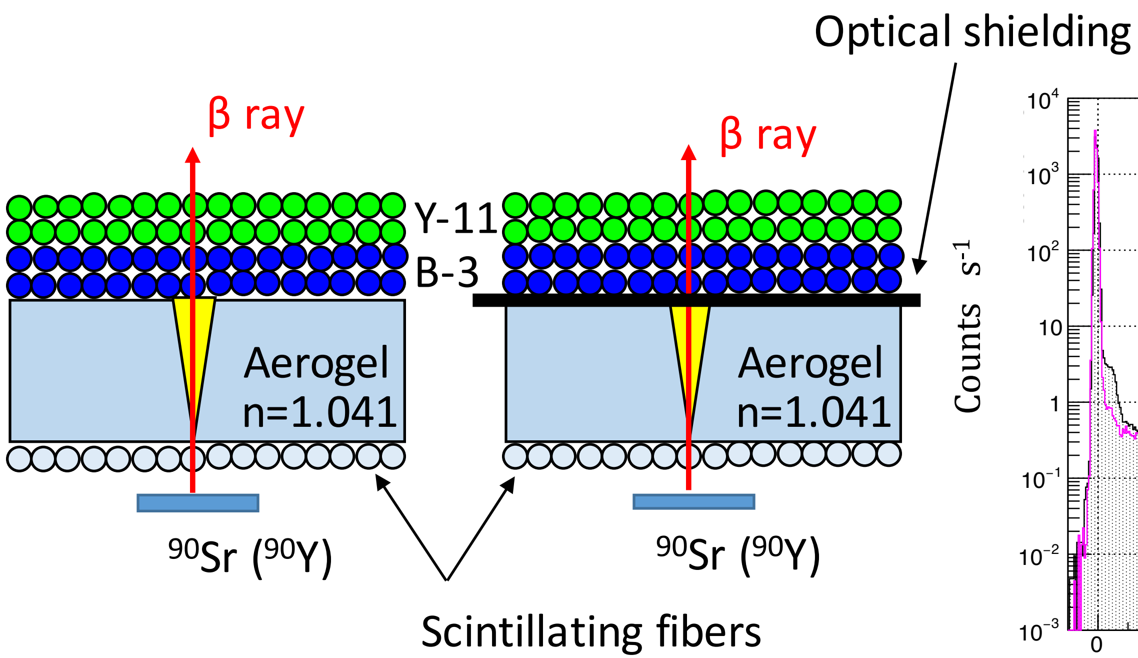


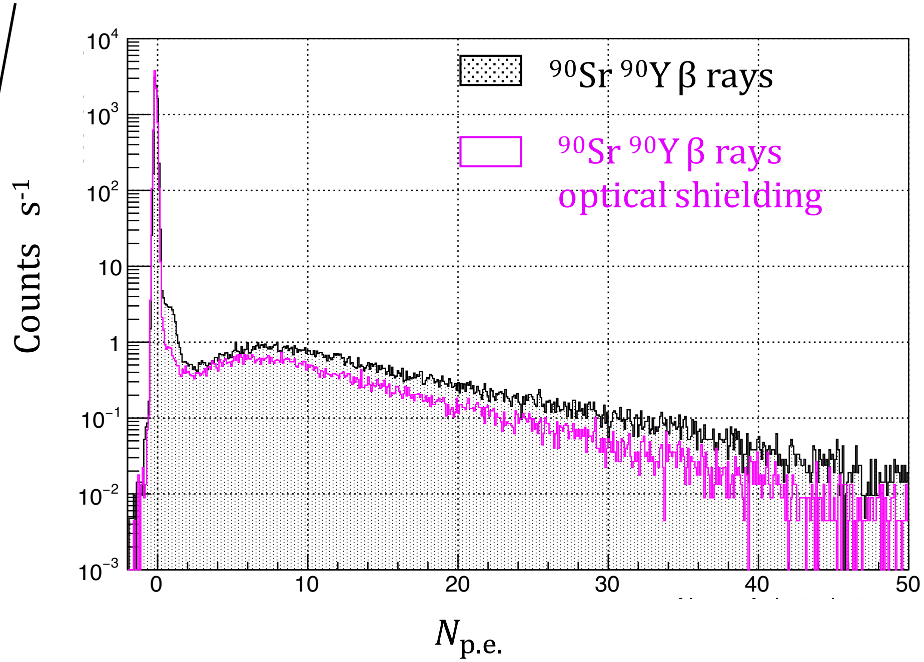


It was considered that wavelength-shifting fiber has a property of scintillation radiation.

2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

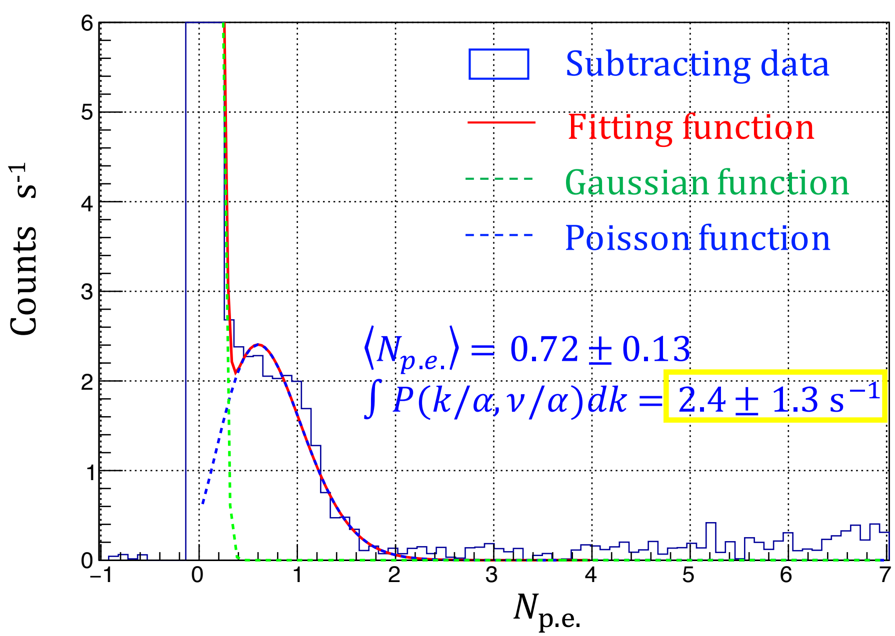
Cherenkov photons from ^{90}Sr and ^{90}Y β rays





2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

Cherenkov photons from ^{90}Sr and ^{90}Y β rays



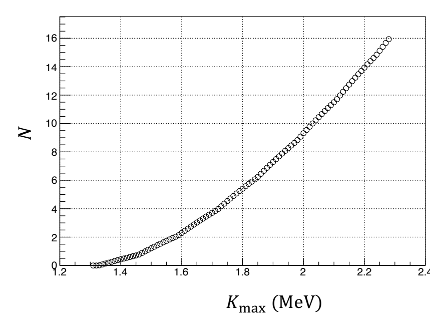
Count rate

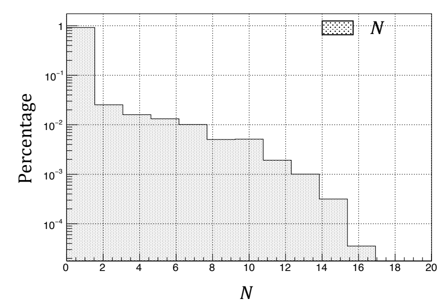
$=A_{\mathrm{Sr+Y}}\cdot\Omega\cdot\eta$

$= 2\times 23.6\ \mathrm{kBq}\cdot 0.099\cdot 5.04\times10^{-4}$

$= 2.35\ \mathrm{s}^{-1}$,

where $\eta = \int dN\, dN_{\mathrm{p.e.}} \exp\left(-\delta(N)\varepsilon(N\to N_{\mathrm{p.e.}})\right)$





2. Basic concept an aerogel Cherenkov detector using wavelength-shifting fibers

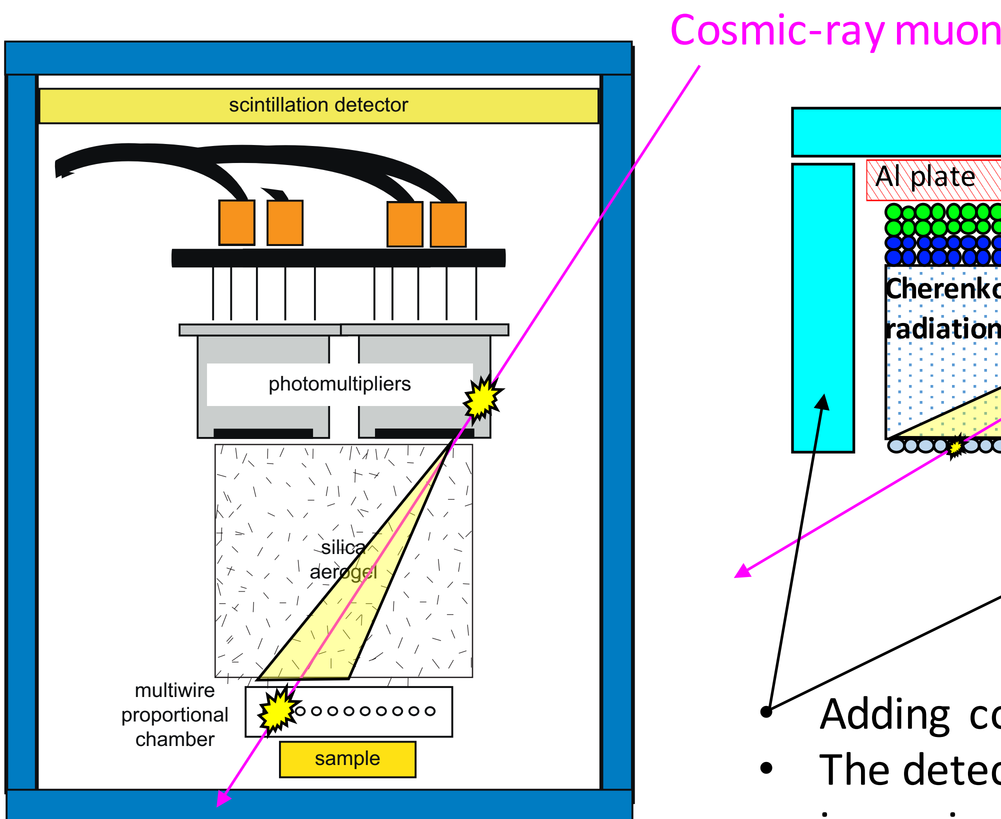
Results

- Aerogel (n=1.0411): K_{th}=1.31 MeV, $E\gamma^{(thr.)}$=1.53 MeV.
- Accidental noise can be reduce to 11% using the fibers than 5-sinch PMT reading.
- Optical models were developed for the Cherenkov detector.
  1. Cherenkov spectrum
  2. Silica aerogel transmittance
  3. Wavelength-shifting fibers absorption & emission spectrum
  4. PMT quantum efficiency
  5. Fix with cosmic-ray test
- Light collection efficiency was determined to be 1.0-1.4%.
- Cherenkov photons by ^{90}Y β rays were observed using the aerogel and B-3 & Y-11.

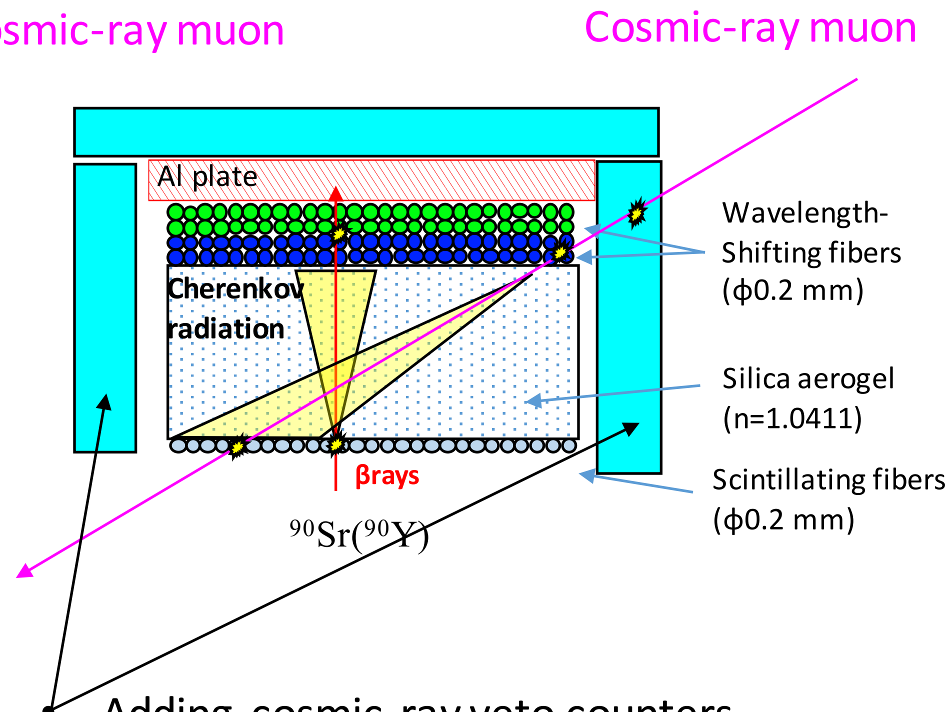
3. Background study of environmental radiation

3. Background study of environmental radiation

3.1. Cosmic-ray muons



NIMA 595 (2008) 278.



- Adding cosmic-ray veto counters.
- The detection efficiency of 99.9% or more is required for cosmic-ray muons.

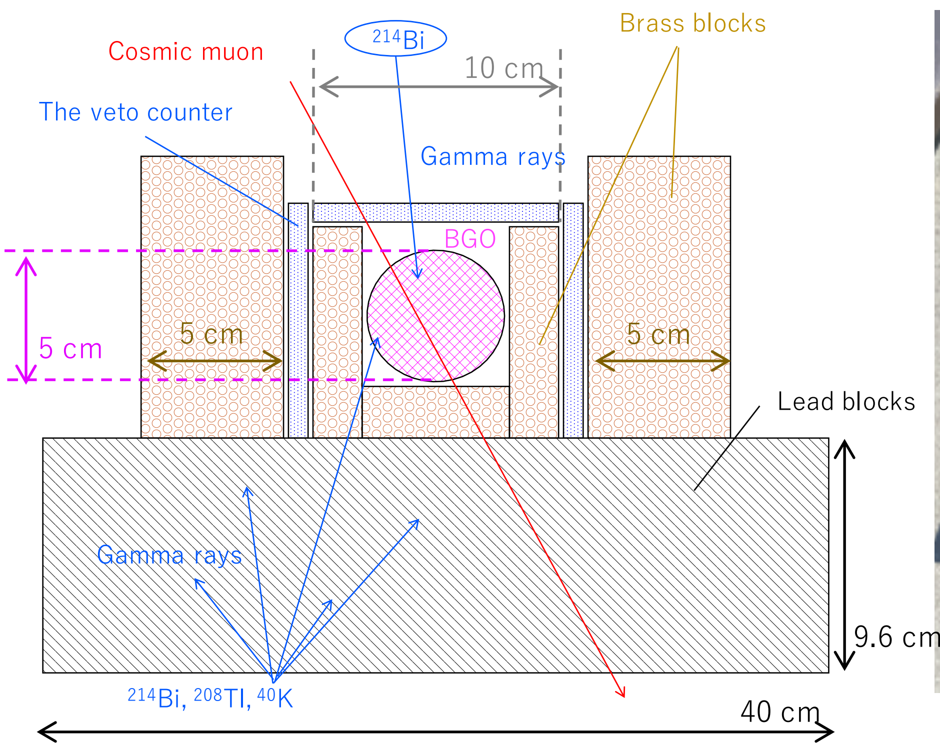
3. Background study of environmental radiation

3.2. γ-rays energy spectroscopy of the air

- It was considered that ^{40}K is not to be background because knocked out e^- from γ ray (1.46 MeV) dose not satisfy the Cherenkov condition in the aerogel (n=1.041).
- Thorium include in the concrete blocks of the buildings. Radon progenies attach on surface in the environmental.
- Knocked out e^- from γ rays (Eγ>1.53 MeV) emitted from ^{214}Bi and ^{208}Tl can satisfy the Cherenkov condition there.
- Average of radon (^{222}Rn) concentration in the air is 45 Bq/m^3.
- Here, radon progenies (particularly ^{214}Bi) in the air were focused by the study.
- ^{214}Bi emits β rays (max. 3.27 MeV).

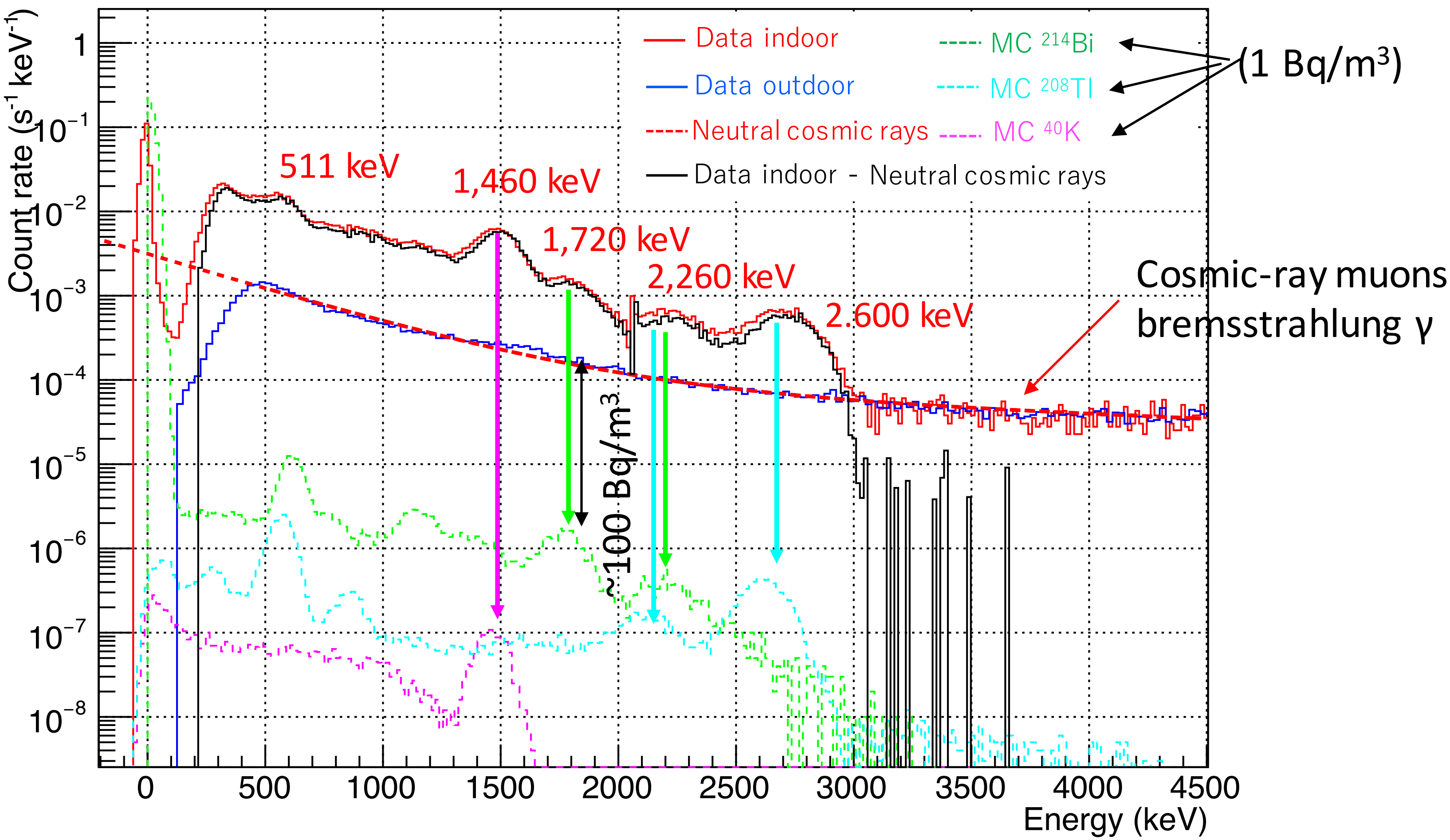
3. Background study of environmental radiation

3.2. γ-rays energy spectroscopy of the air



3. Background study of environmental radiation

3.2. γ-rays energy spectroscopy of the air



3. Background study of environmental radiation

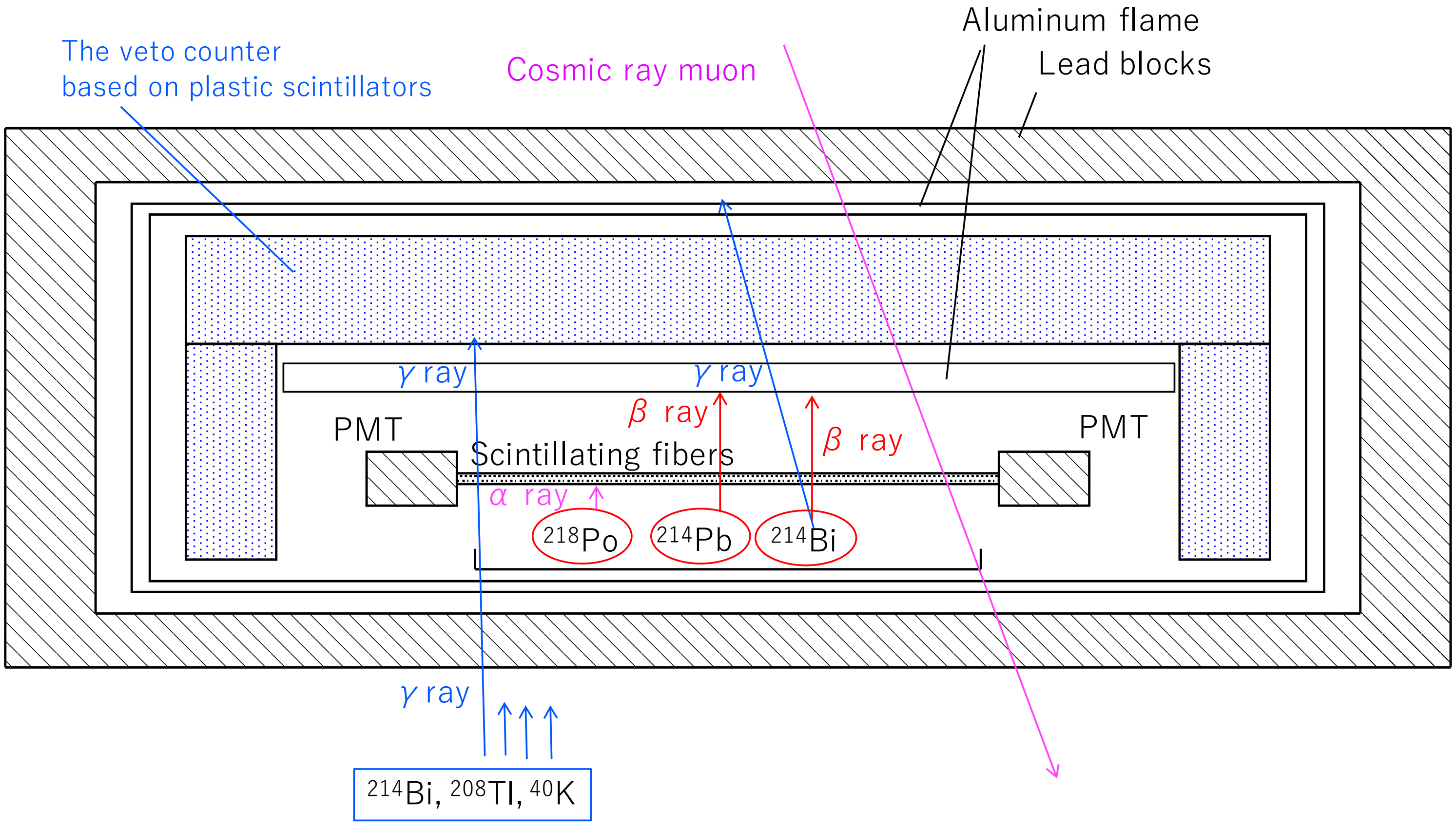
3.2. γ-rays energy spectroscopy of the air

Results

- ^{214}Bi concentration in the air is less than 100 Bq/m^3.
- Gap between sample and trigger counter should be less than 1 cm.
- The air in space under the sample should be removed out.

3. Background study of environmental radiation

3.3. β rays surface inspection of sample sheets adsorbing radon progenies



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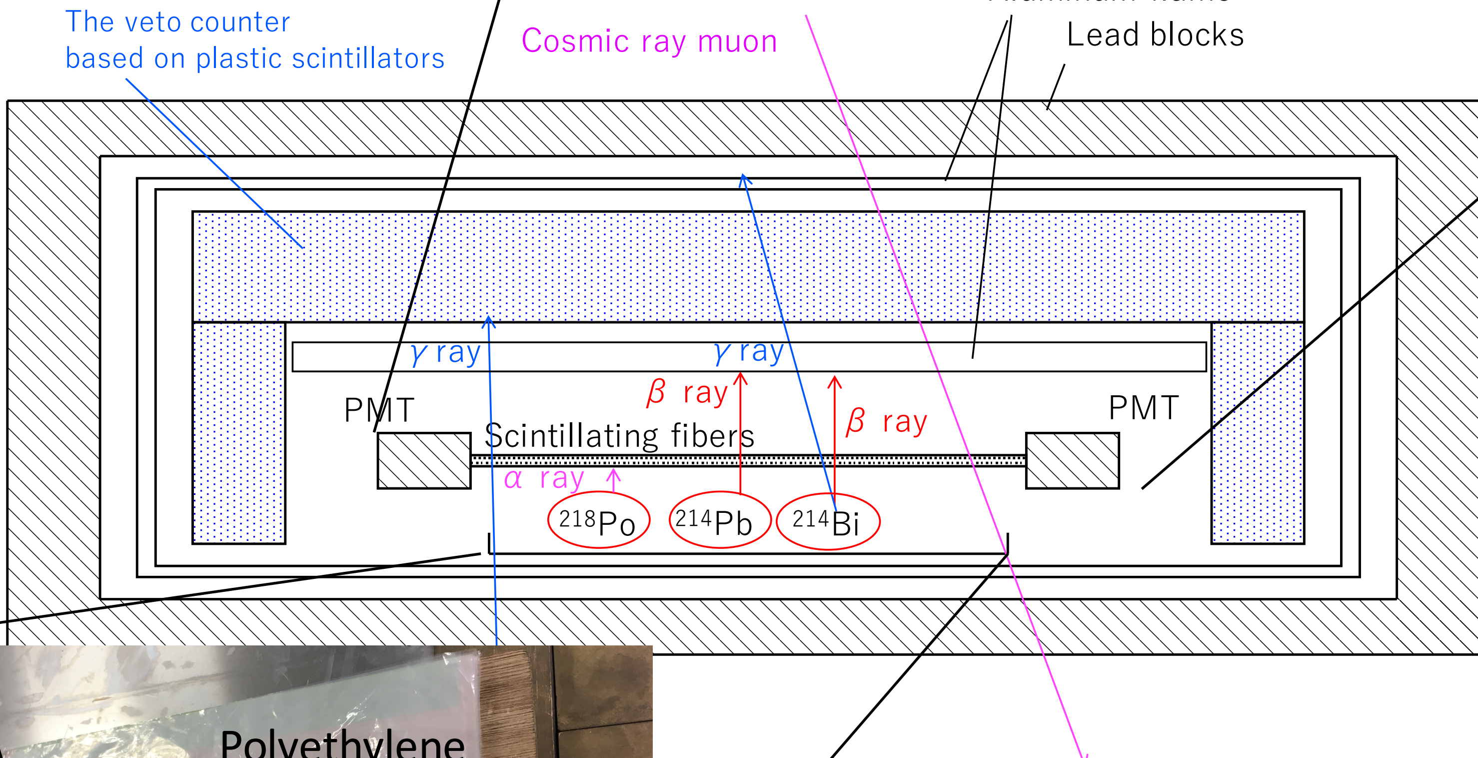
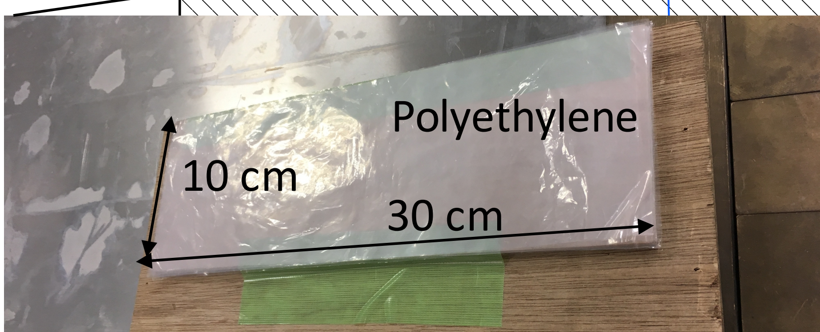
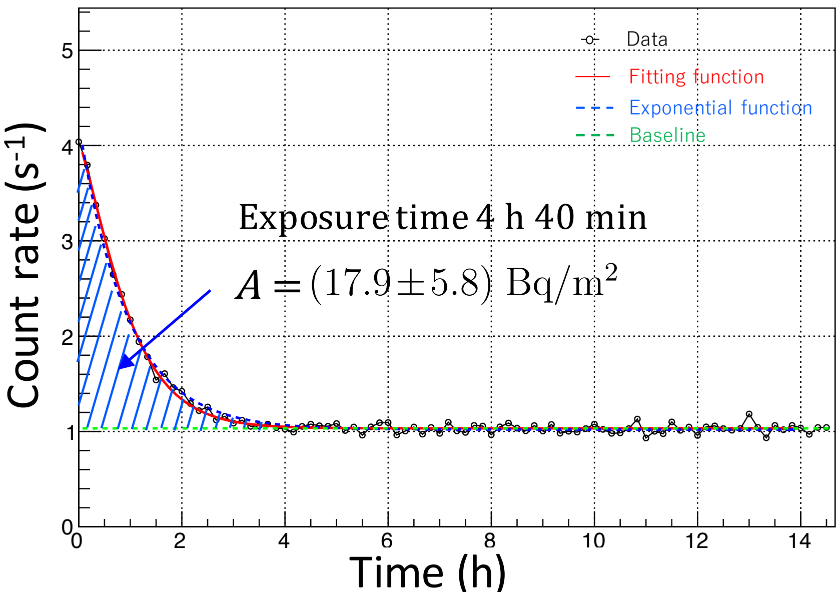
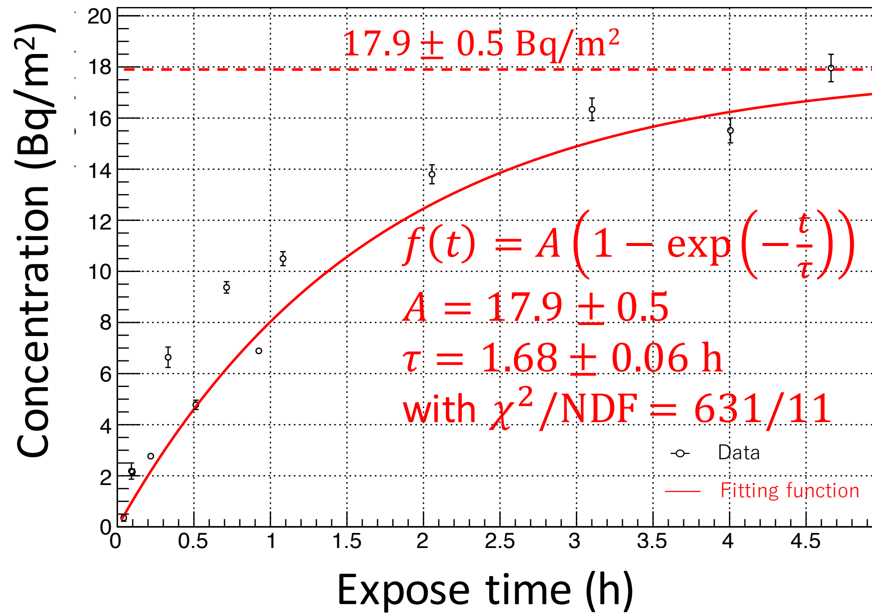




3. Background study of environmental radiation

3.3. β rays surface inspection of sample sheets adsorbing radon progenies





Concentration

$$A = \sum_j \left(C(t_j) - R_{\mathrm{BG}}\right) \Delta t_j \frac{\eta_\varepsilon k_\rho}{\varepsilon_{\mathrm{Sr}} S}$$

$C(t_j)$: counting rate

R_{BG}: background rate

$\Delta t = 10$ min

$\varepsilon_{\mathrm{Sr}}$: ^{90}Sr eff. = $(8.68 \pm 0.01) \times 10^2$ Bq^{-1} h^{-1}

η_ε: ratio of ^{90}Sr eff. to radon prog. eff. = 0.37

k_ρ: correction coefficient = 1.15

S: 0.03 m^2

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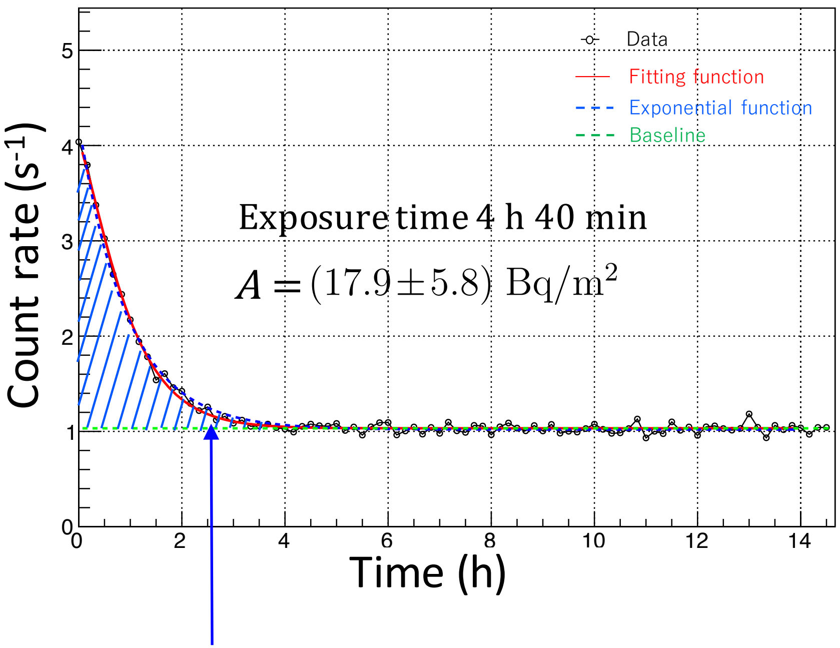
Interpretation

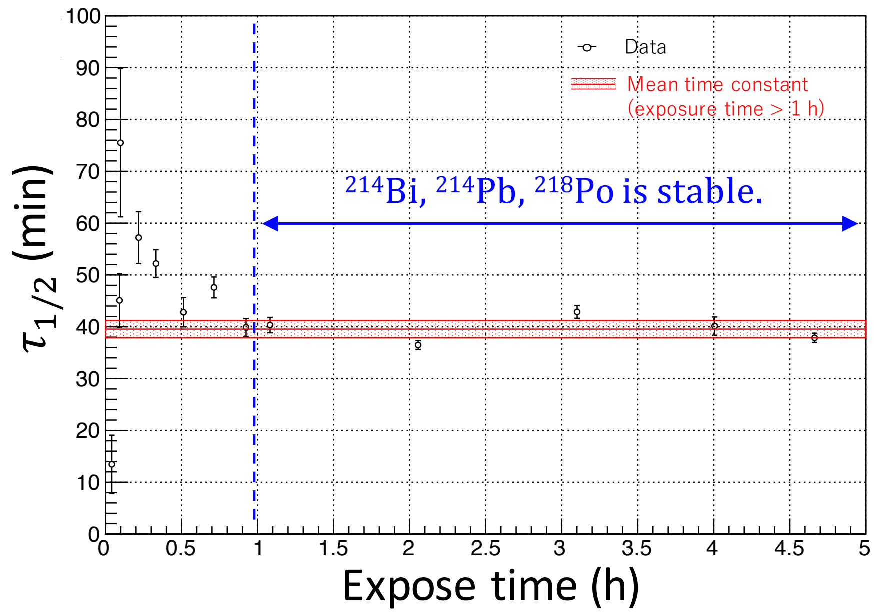
(1) ^{218}Po only falls on the sample after the radon decay in the air. ^{214}Pb and ^{214}Bi produced at the sample.

(2) ^{218}Po, ^{214}Pb, and ^{214}Bi in the air fall the sample after the radon decay in the air.

3. Background study of environmental radiation

3.3. β rays surface inspection of sample sheets adsorbing radon progenies





Simple exponential function fit

$$f(t) = A \exp(-t \ln 2 / \tau_{1/2}) + R_{\mathrm{BG}}$$

$$A = 3.22 \pm 0.04$$

$$\tau_{1/2} = (0.95 \pm 0.02)\ \mathrm{h}$$

$$R_{\mathrm{BG}} = (1.02 \pm 0.01)\ \mathrm{s}^{-1}$$

with $\chi^2/\mathrm{NDF} = 0.32/69$

Interpretation

(1) ^{218}Po only falls on the sample after the radon decay in the air. ^{214}Pb and ^{214}Bi produced at the sample.

(2) ^{218}Po, ^{214}Pb, and ^{214}Bi in the air fall the sample after the radon decay in the air.

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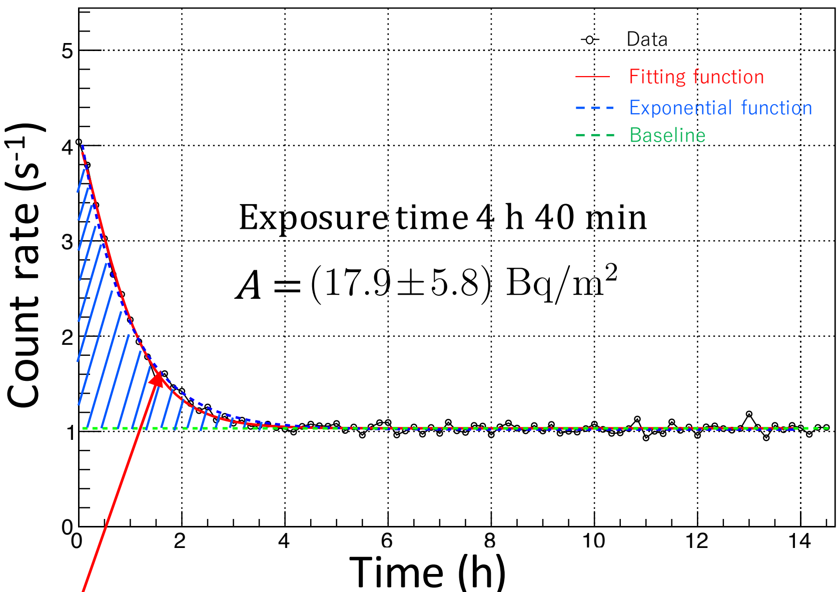
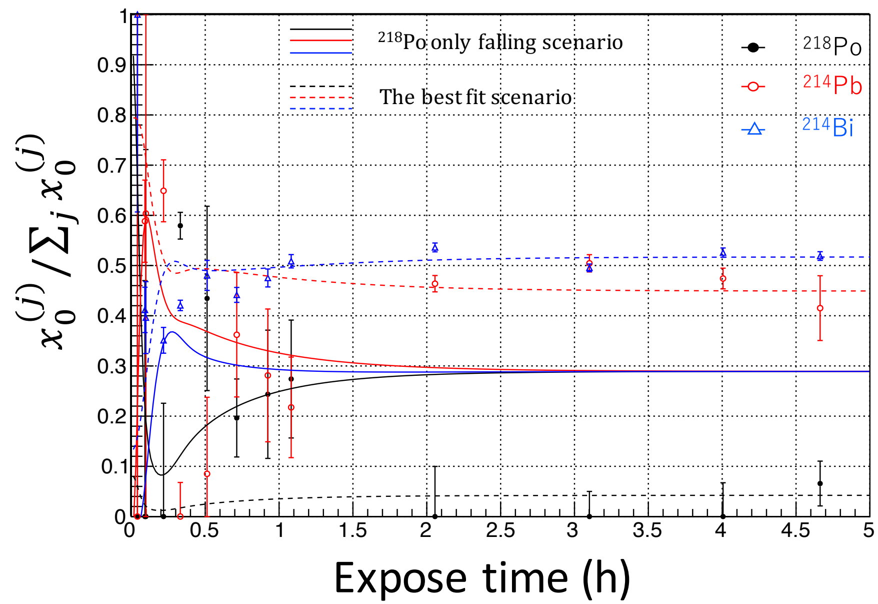
3. Background study of environmental radiation

3.3. β rays surface inspection of sample sheets adsorbing radon progenies





$$f(t) = \frac{\lambda_1 \lambda_2 x_0^{(1)}}{(\lambda_1 - \lambda_2)(\lambda_1 - \lambda_3)} \exp(-\lambda_1 t) + \left(\frac{\lambda_1 \lambda_2 x_0^{(1)}}{(\lambda_2 - \lambda_1)(\lambda_2 - \lambda_3)} + \frac{\lambda_2 x_0^{(2)}}{\lambda_3 - \lambda_2} \right) \exp(-\lambda_2 t) + \left(\frac{\lambda_1 \lambda_2 x_0^{(1)}}{(\lambda_2 - \lambda_1)(\lambda_2 - \lambda_3)} + \frac{\lambda_2 x_0^{(2)}}{\lambda_3 - \lambda_2} + x_0^{(3)} \right) \exp(-\lambda_3 t) + R_{BG},$$

free parameters

Isotope $j = 1, 2, 3$ are ^{218}Po, ^{214}Pb, ^{214}Bi, respectively.

$\lambda_j = \tau_j^{-1}$: inverse of life time of isotope j

$x_0^{(j)}$: initial intensity of isotope j

R_{BG}: background rate

)0 counters

3. Background study of environmental radiation

3.3. β rays surface inspection of sample sheets adsorbing radon progenies

Result

- It was found that radon progenies of $(17.9 \pm 0.5)\ \mathrm{Bq/m^2}$ were attached to the sample sheets.
- ^{214}Bi on the sample is not negligible, and it is required to not expose sample into the air.
- This result suggested to reject the scenario in the case of ^{218}Po only falling on the sample after the radon decays in the air.
- Therefore, it is suggested that there are the radon progenies in the air Indirectly.
- The suggestion could be a clue for a search of the lung cancer occurring in non-smokers from the impact and exposures by inhalation of the radon progenies.

4. Design of a prototype detector

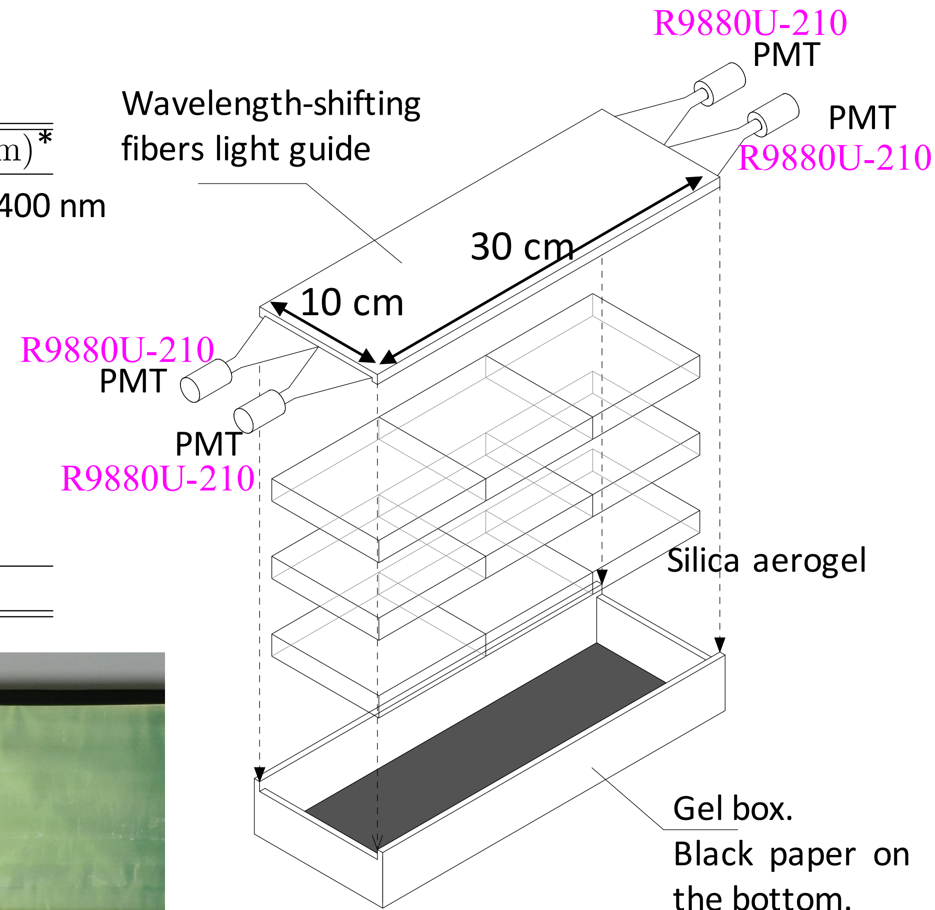
4. Design of a prototype detector

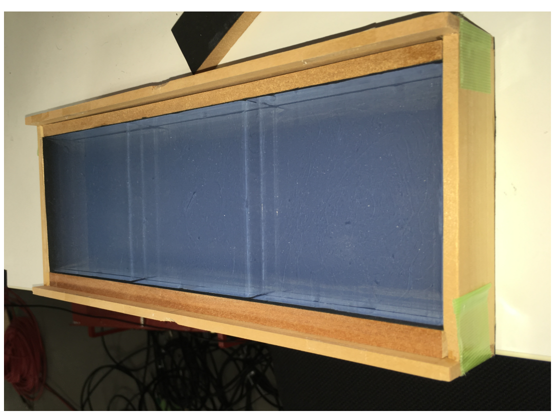
4.1. Threshold-type Cherenkov counter

Properties of the aerogel tiles

Tile	Refractive index	Transmission length (mm)*
MEC4-1a	1.0408	41.0
MEC4-1b	1.0411	38.6
MEC4-1c	1.0412	39.2
MEC4-2a	1.0414	40.9
MEC4-2b	1.0414	41.2
MEC4-2c	1.0414	41.7
MEC4-3a	1.0408	41.7
MEC4-3b	1.0410	41.4
MEC4-3c	1.0411	41.7
Mean	1.0411±0.0002	40.8±1.1

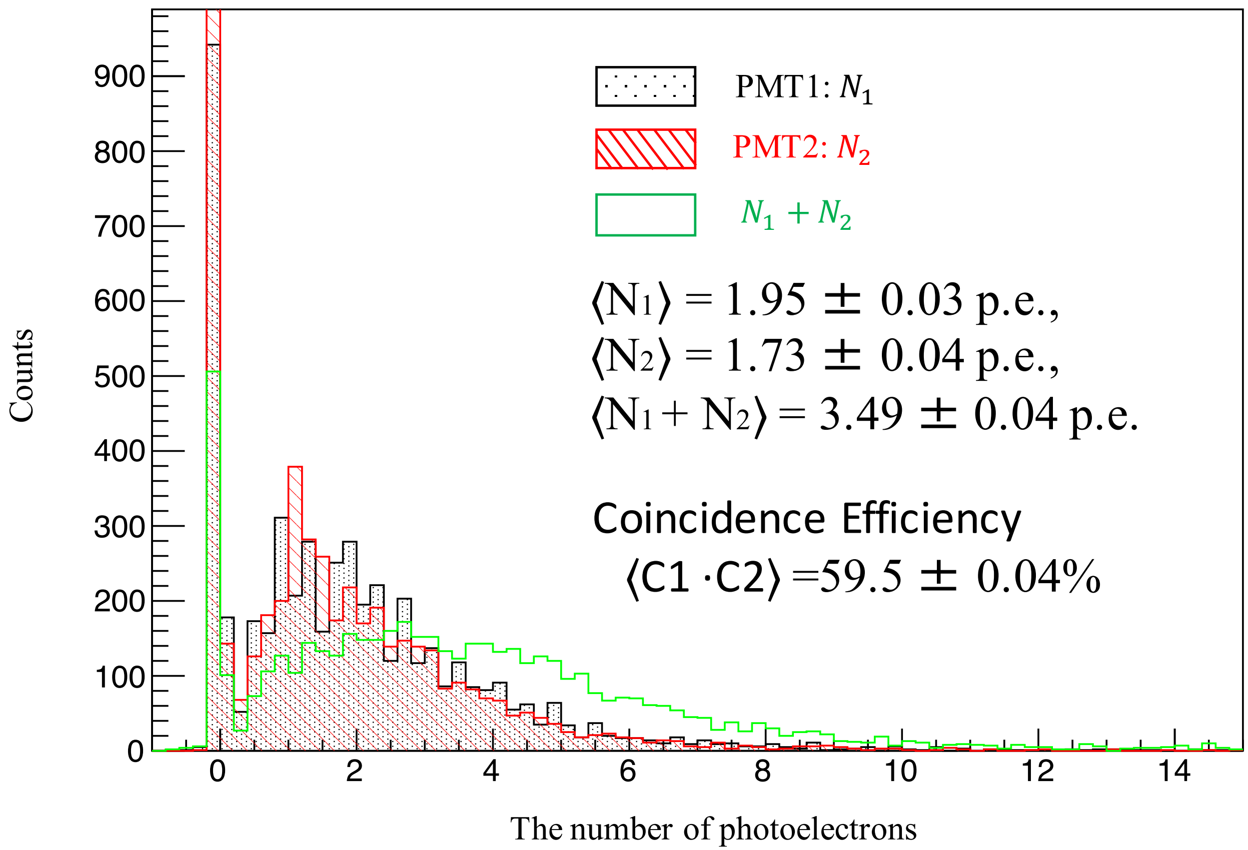
* at 400 nm





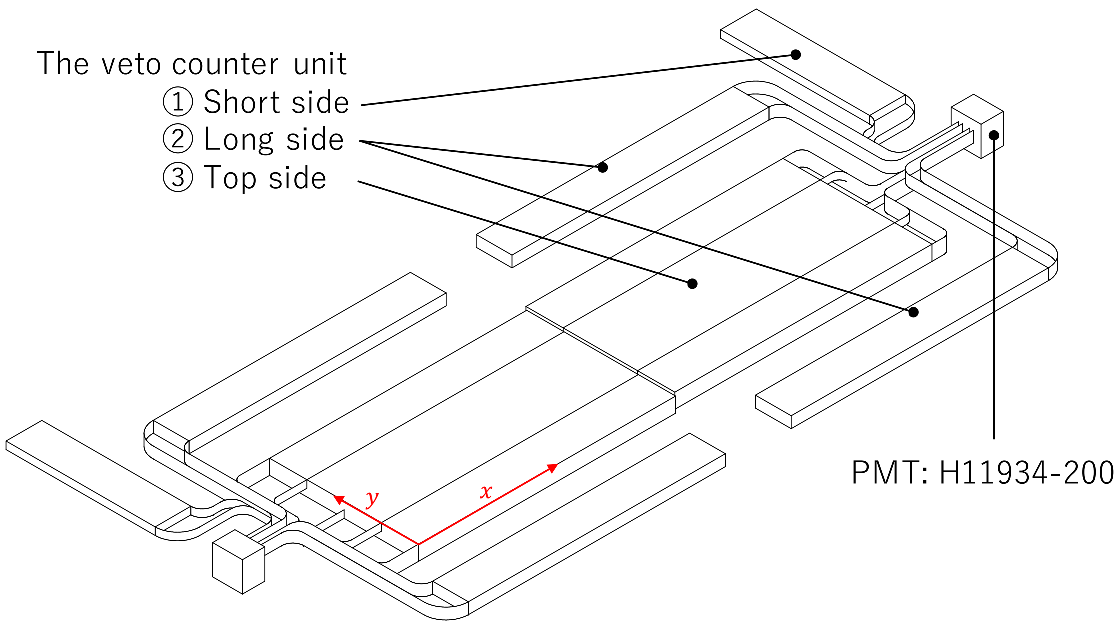
4. Design of a prototype detector

4.2. Trigger counter

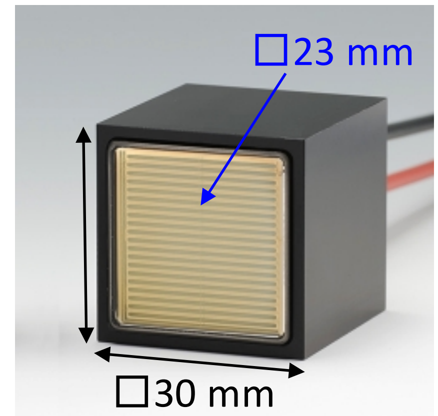


4. Design of a prototype detector

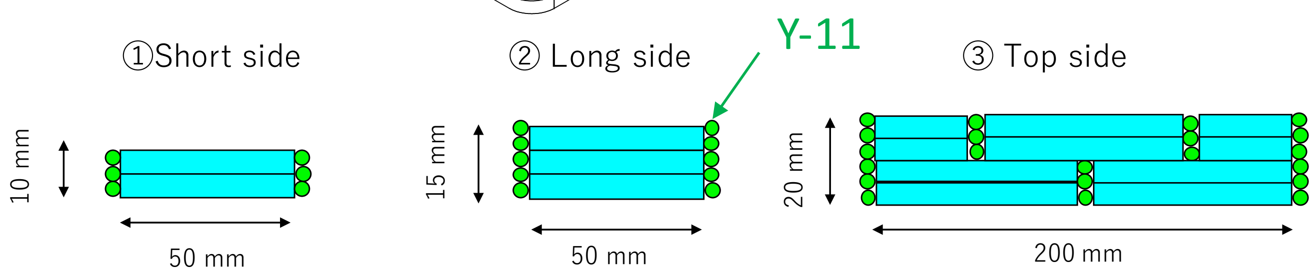
4.3. Veto counter



H11934−200

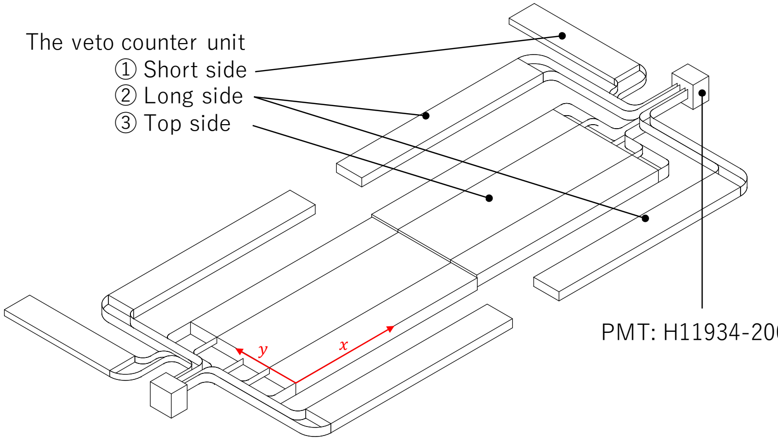


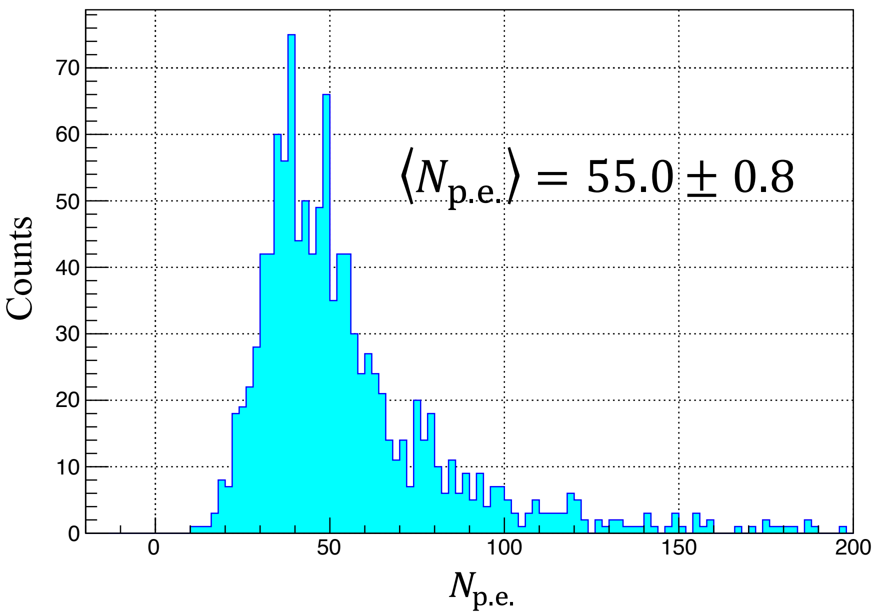
- Photocathode
  - □23 mm
  - Ultra Bialkali
- Metal Channel Dynode

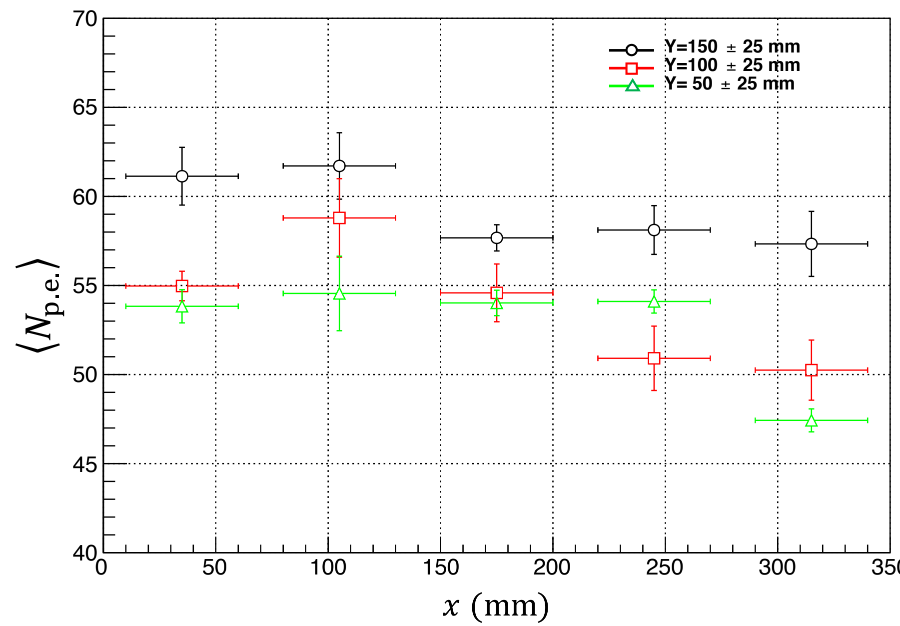


4. Design of a prototype detector

4.3. Veto counter

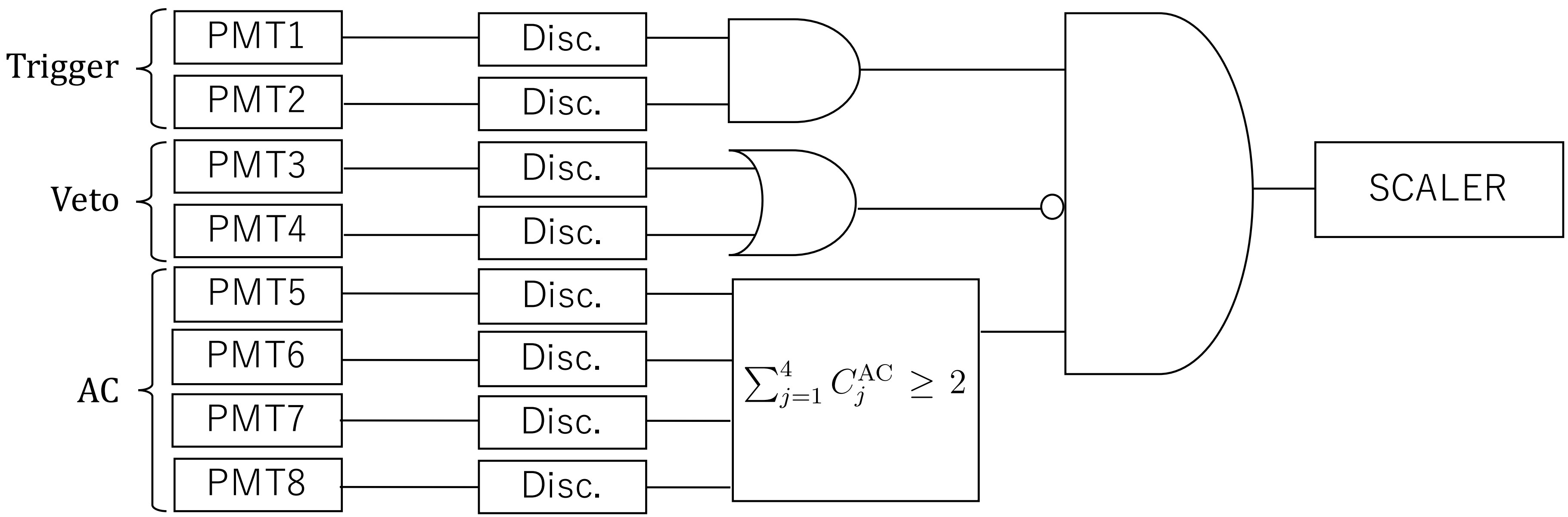






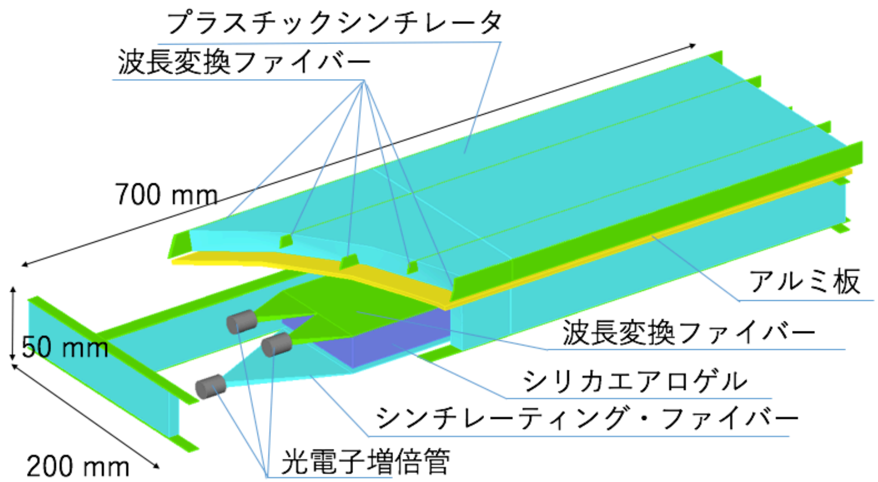
4. Design of a prototype detector

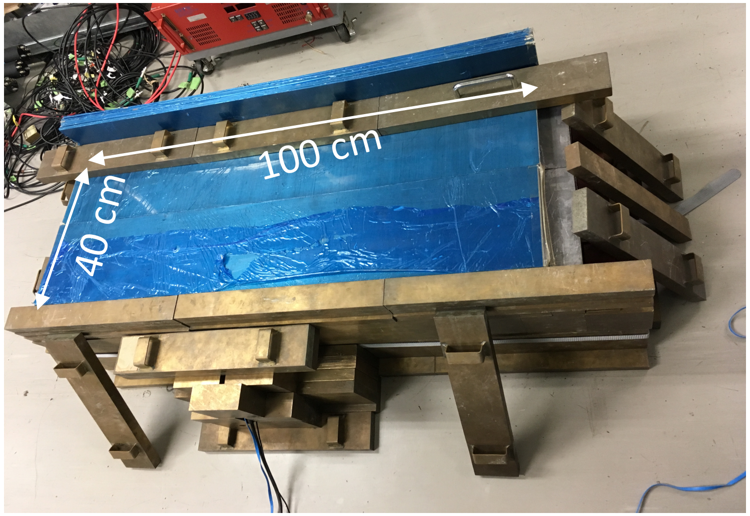
4.4. Electronics

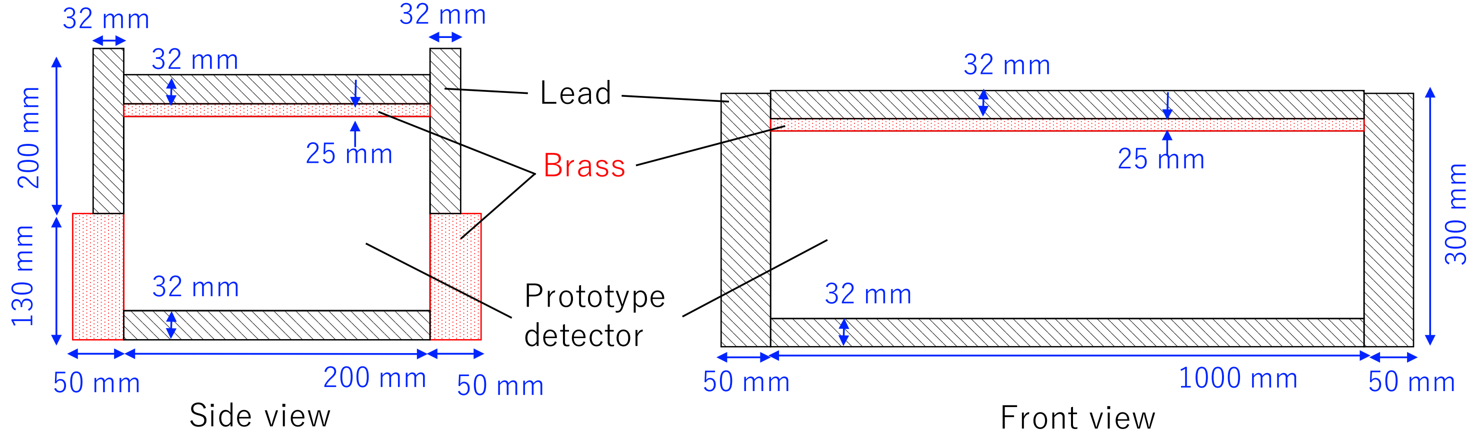


4. Design of a prototype detector

4.5. Shielding by lead and brass blocks







5. Performance of the prototype detector

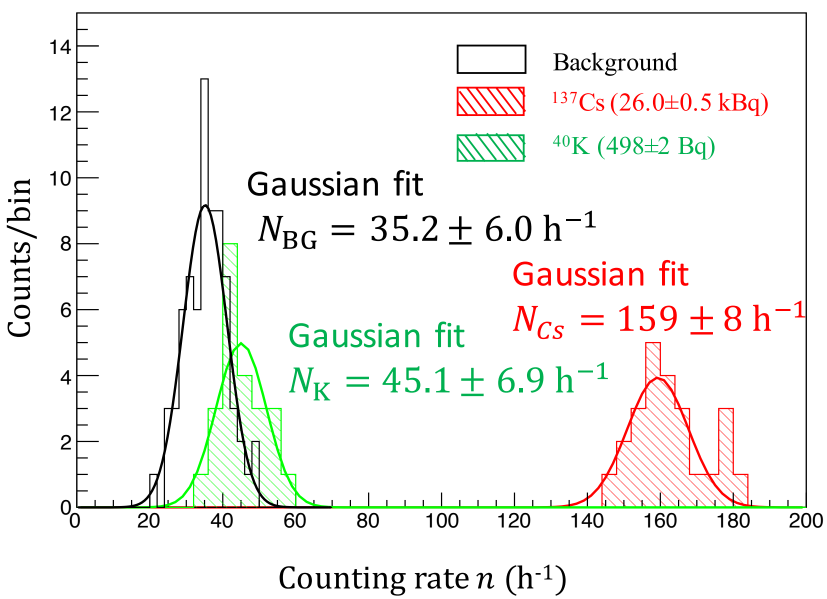
5. Performance of the prototype detector

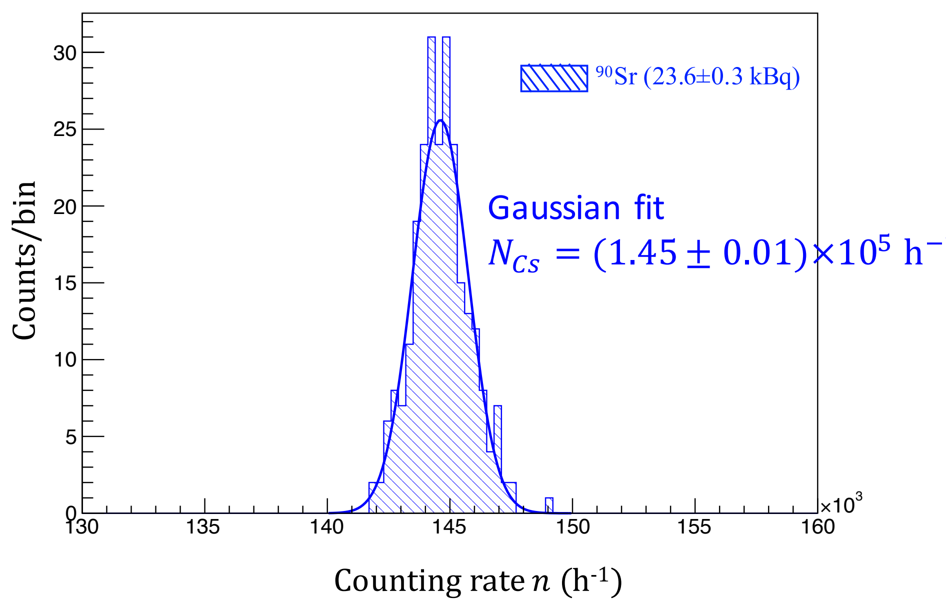
5.1. Radioactivity of sources

^{90}Sr source ... 23.6 ± 0.3 kBq
^{137}Cs source ... 26.0 ± 0.5 kBq
delivered by Japan Radioisotope Association .

^{40}K source ... 498 ± 2 Bq in potassium chloride (KCl).
The KCl with a mass of 30.0 ± 0.1 g.
A purity of $\gtrsim 99.5\%$.

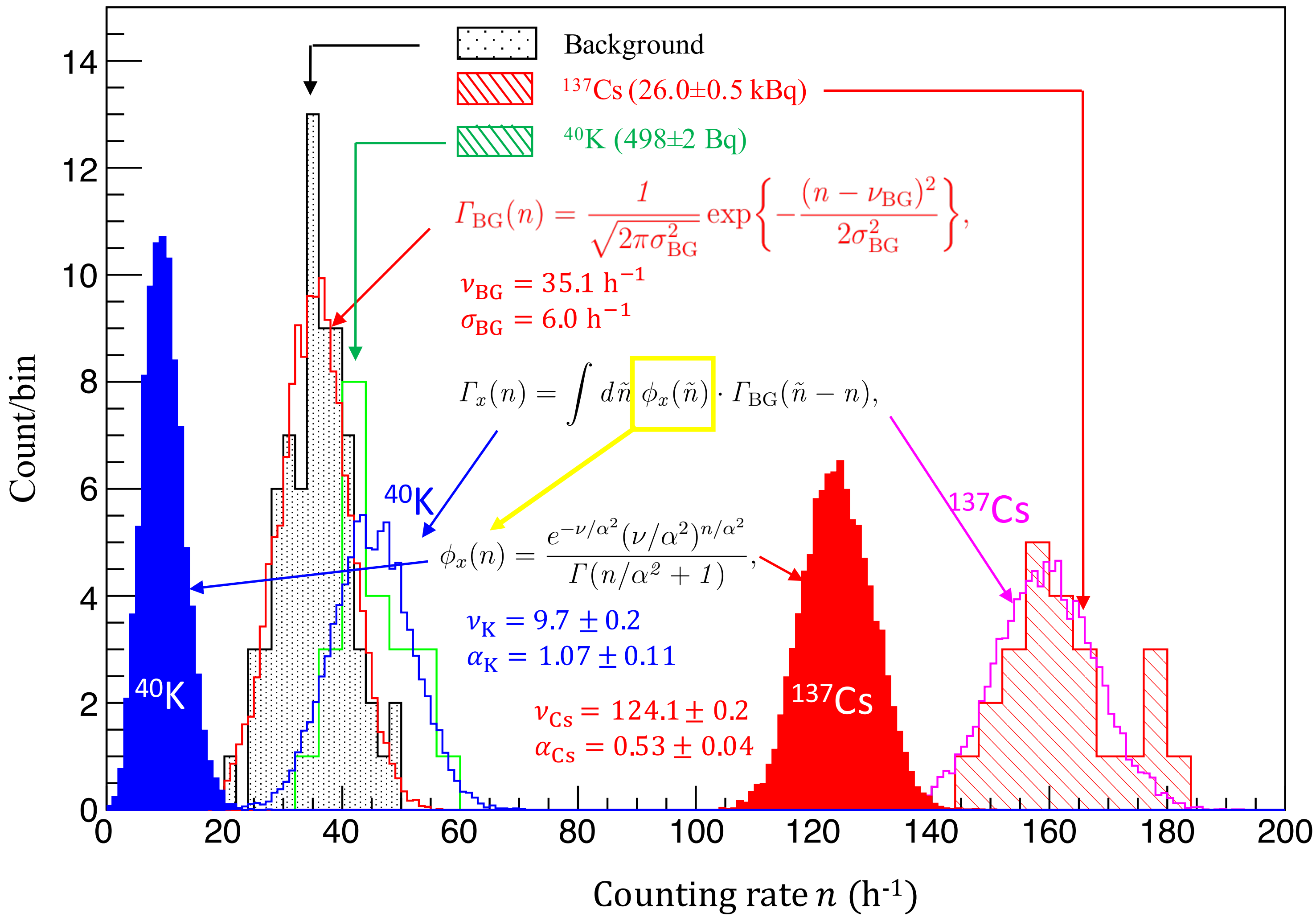
5.2. Counting rate





5. Performance of the prototype detector

5.3. Signal model



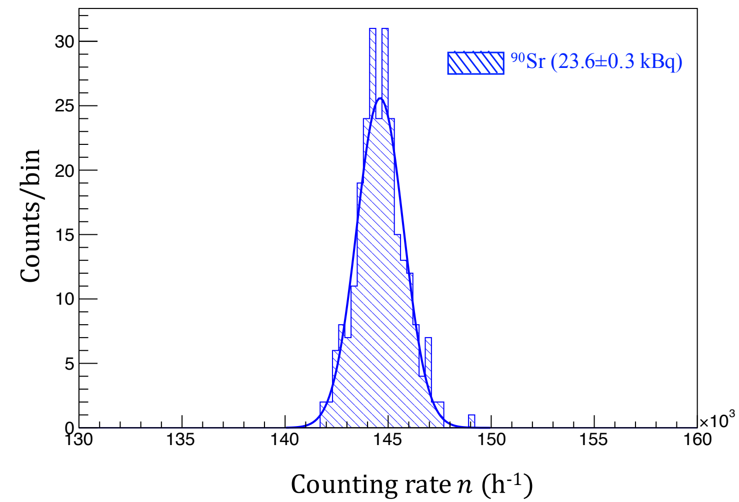
5. Performance of the prototype detector

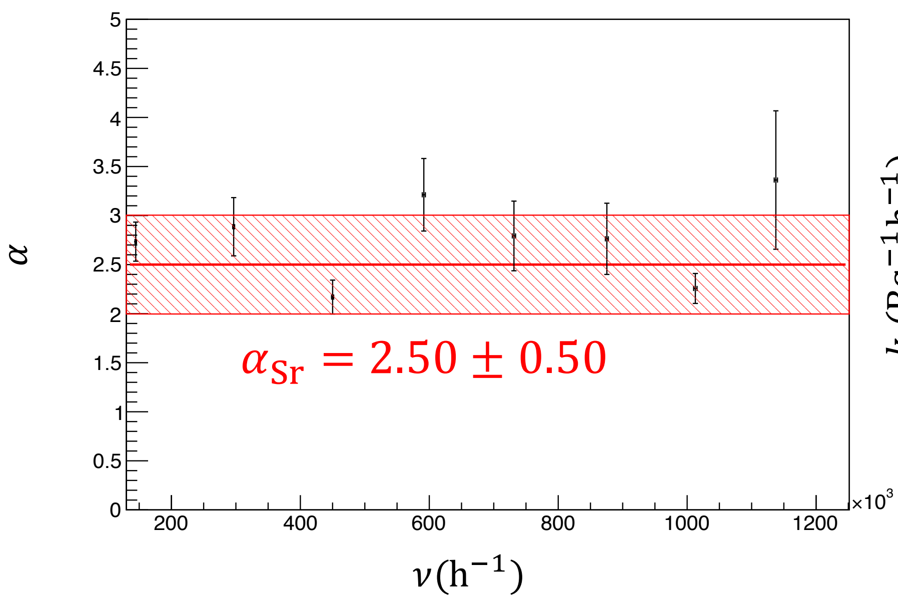
5.3. Signal model

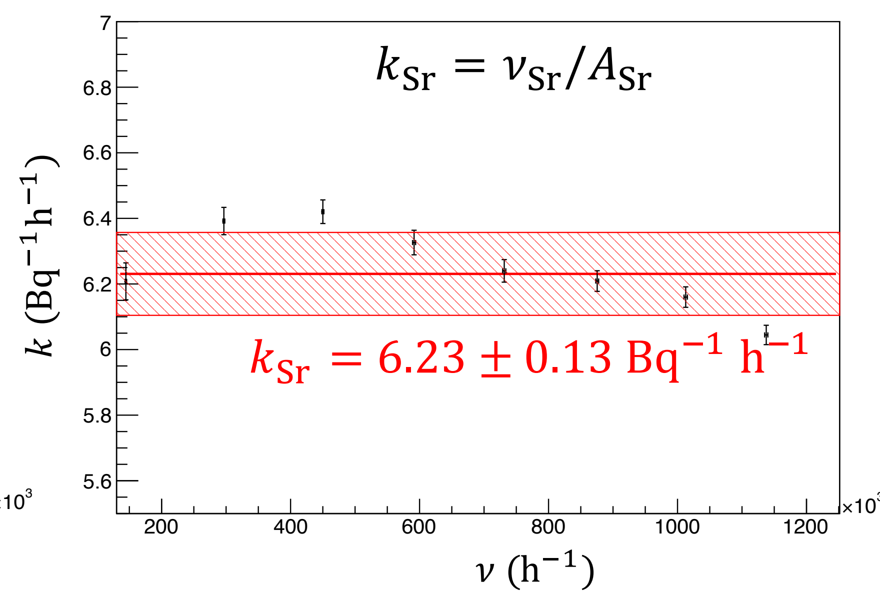
$\langle \Gamma_{BG}(n) \rangle \ll \langle \phi_{Sr}(n) \rangle$ => $\Gamma_{Sr}(n) \approx \phi_{Sr}(n)$

$$\phi_x(n) = \frac{e^{-\nu/\alpha^2}(\nu/\alpha^2)^{n/\alpha^2}}{\Gamma(n/\alpha^2 + 1)}, \quad (x = \mathrm{Sr})$$

Source	α	k (Bq^{-1} h^{-1})
^{90}Sr	2.50 ± 0.50	6.23 ± 0.13
^{137}Cs	0.532 ± 0.044	$(4.77 \pm 0.09) \times 10^{-3}$
^{40}K	1.067 ± 0.106	$(1.95 \pm 0.04) \times 10^{-2}$

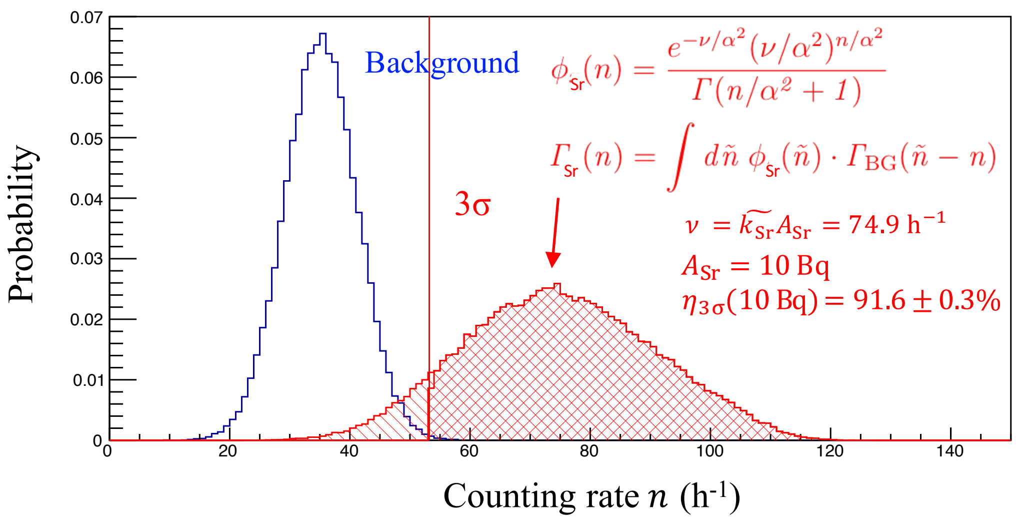




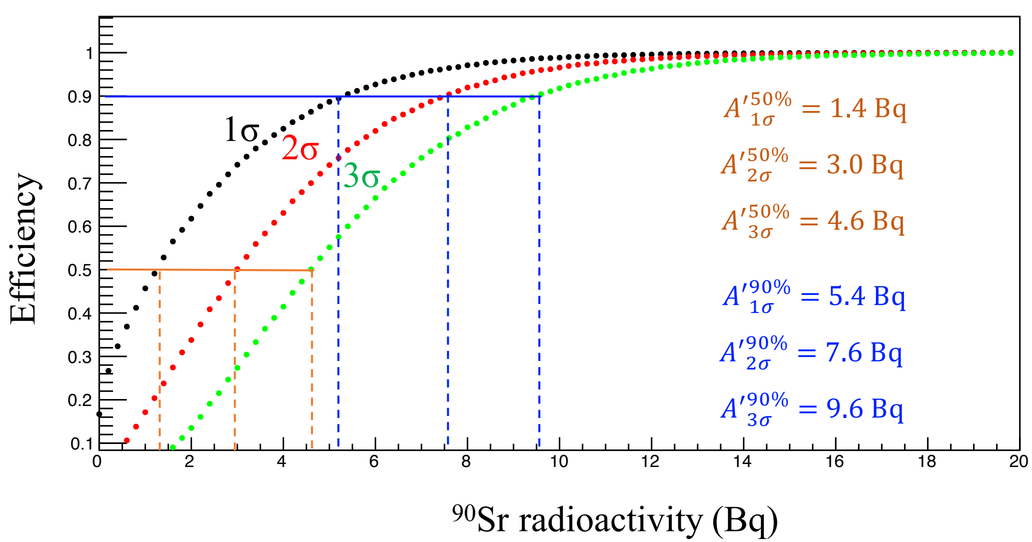


5. Performance of the prototype detector

5.5. Detection efficiency and limit



- Mean counting rate is 74.9 h^{-1} using 10-Bq ^{90}Sr in the signal model.
- The source position dependence for the coefficient k was corrected.
- In a case of 3σ threshold setting, this detection eff. is estimated to be 91.6 ± 0.3% for 10-Bq ^{90}Sr.



- These curves show relations between ^{90}Sr radioactivity and the efficiency for 1, 2, 3σ threshold condition.
- Typical detection limit is determined to be $A^{50\%}_{3\sigma}$ satisfying $\langle \Gamma_{Sr}(n) \rangle > \langle \Gamma_{BG}(n) \rangle + 3\sigma$.
- $A^{50\%}_{3\sigma} = 4.6$ Bq at 1-hour measuring.

5. Performance of the prototype detector

5.6. Concentration

Detection limit of surface concentration is $A_{3\sigma}^{50\%}/S = 0.0153\ \mathrm{Bq/cm^2}$, where $S = 300\ \mathrm{cm^2}$.

Here, it is assumed that

- Density of sample is 1 g/cm^3
- Sample was dried.
- Compression factor is $\varepsilon = 0.3$
- Sample thickness is 1 mm
- Sample weight is m = 30 g (corresponding to the original of m/ε = 100 g).

$$A_{3\sigma}^{50\%}\ m\ \varepsilon^{-1} = 46\ \mathrm{Bq/kg}$$

at 1-hour measurement.

The food contamination permissible limit of 100 Bq/kg defined by Ministry of Health, Labour and Welfare, Japan, in 2012.

$A \propto S^{-1}$; it expected to be 8.4 Bq/kg @S=1 m^2

Furthermore, in the case of seawater, the lower limit of dried seawater in 1-hour measurement is estimated to be $A_{3\sigma}^{50\%}\ m\ \varepsilon^{-1} = 1.5\ \mathrm{Bq/L}$, where ε = 0.01.

5. Performance of the prototype detector

5.6. Results

- Signal models were developed based on experimental test using the sources.
- The efficiency curves were estimated as the detector performance.
- The detection limit was estimated to be 4.6 Bq.
- The detection limit of surface concentration was estimated to be 0.0153 Bq/cm^2.
- The detection limit of weight concentration was estimated to be 46 Bq/kg (seafood) and 1.5 Bq/kg (seawater) at 1-hour measurement in the prototype detector.

6. Summary

- It is important to measure ^{90}Sr concentration in food because intake of ^{90}Sr is dangerous than ^{137}Cs, and the method of measuring ^{90}Sr rapidly is focused.
- Wavelength-shifting fiber system was adopted because it is not possible to inspect 10-Bq/kg ^{90}Sr by a large PMT reading Cherenkov photons directly.
- The light collection efficiency was estimated to be 1.0-1.4% for Cherenkov photons.
- The Cherenkov photons by ^{90}Y β rays was observed using the fibers.
- ^{214}Bi as the radon progenies in the air was not observed in the limit of 100 Bq/m^3. The radon progenies on the sample sheets was not observed 18 Bq/m^2. It was found that the detector design should be performed the care for these ^{214}Bi.
- I produced a prototype detector with an effective area of $30\times10\ \mathrm{cm}^2$.
- The detection limit of weight concentration at 1-hour measurement was estimated to be 46 Bq/kg (seafood) and 1.5 Bq/kg (seawater). By extending to effective area of 1 m^2, it is expected to be 8.4 Bq/kg (seafood).

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