茨城大学
Ibaraki University

Development of a Highly-Sensitive and Low-Cost Imaging Gamma-Ray Camera γI (Gamma Eye)

Mika Kagaya

Collage of Science, Ibaraki University

R. Enomoto[3], R. Hanafusa[1], Y. Itoh[1], H. Katagiri[4], H. Muraishi[6], K. Nakayama[4], K. Satoh[5], T. Takeda[6], M. Tanaka[2], T. Uchida[2], T. Watanabe[6], S. Yanagita[4], T. Yoshida[4],

Fuji Electric[1], KEK[2], ICRR Univ. of Tokyo[3], Ibaraki Univ.[4], Shinsei Corporation[5], Kitasato Univ.[6]

COMPTON CAMERA γI

Outline

- **Motivation**
- **Method**
  - Principle of Gamma Eye
  - Design
  - Component and Electronics
  - Data acquisition system
- **Laboratory Experiment**
  - Imaging technique
- **Field test at Fukushima city**
- **Summary**

MOTIVATION

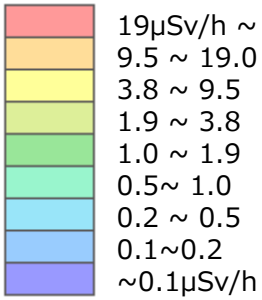
Fukushima Dai-ichi Nuclear Power Plant Accident

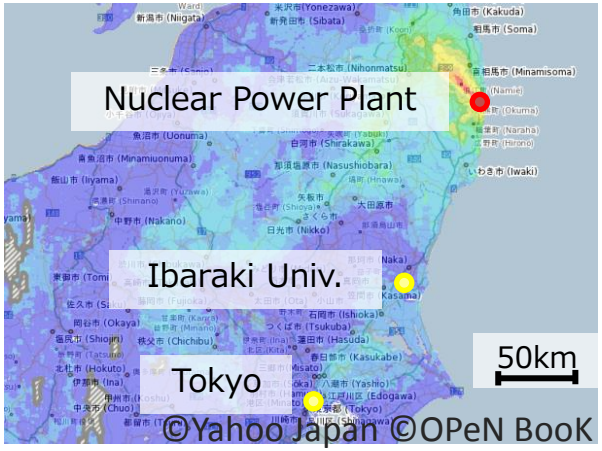
At present, we usually use survey meters to measure gamma-ray level when we do decontamination operation.

< a survey meter >

- **Cannot measure gamma-ray quickly in a wide region although radioactively contaminated area is very large.**

Measurement using a survey meter





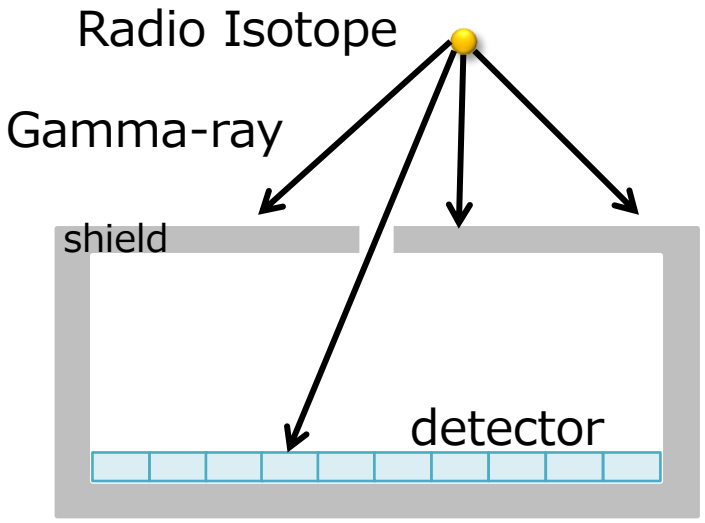
A map of air radiation dose rate

Imaging gamma-ray camera with high efficiency is required.

Visualization of Gamma-Ray – Pinhole Camera

Pinhole Gamma-Ray Camera

- Position sensitive detector which consists of semi-conductor
- A detector is enclosed by Pb shield.
- Detect gamma-rays that pass through a pinhole.



Pros
- Simple

Cons
- Heavy (body is made of Pb)
- Efficiency limited with pinhole size

Visualization Gamma-Ray - Compton Camera

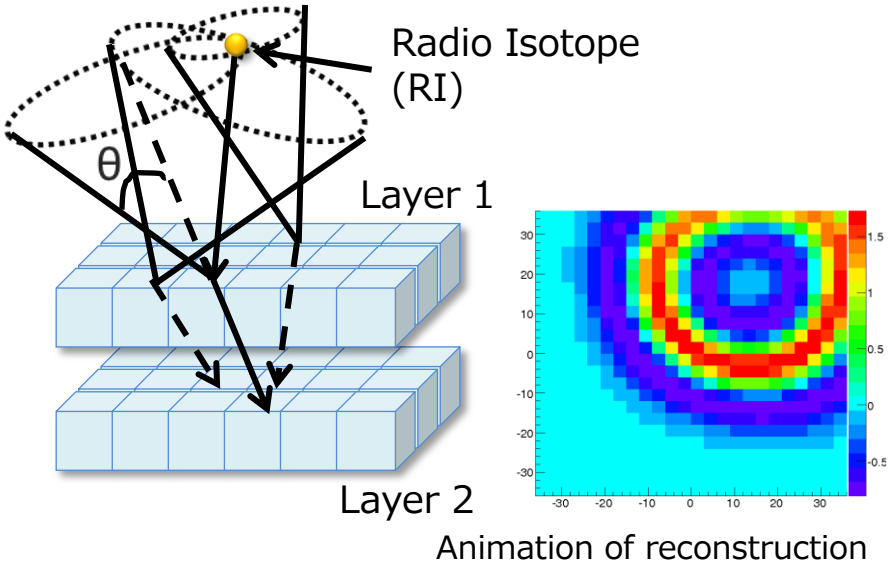
- Measuring deposited energies

Layer 1 : Compton scattering

Layer 2 : Photoabsorption

- Calculate scattering angle

$$\theta = \arccos\left(1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}\right)$$



Animation of reconstruction

- Reconstruction

Each event is mapped by back-projection onto a circle on the 2D-plane

By accumulating some events

→ We can determine the RI position

Pros
- High efficiency
- Wide field of view
- Not use a shield

Various Types of Compton Cameras

Existing detector

Gas detector: cannot have high mass thickness

Semiconductor detector: very high cost to obtain moderate efficiency (> $300,000)

Difficult to measure the low-level contaminated area quickly using existing detector

highly-sensitive and **low-cost** imaging gamma-ray detector using **CsI (Tl) scintillator**

γI (Gamma Eye)

METHOD

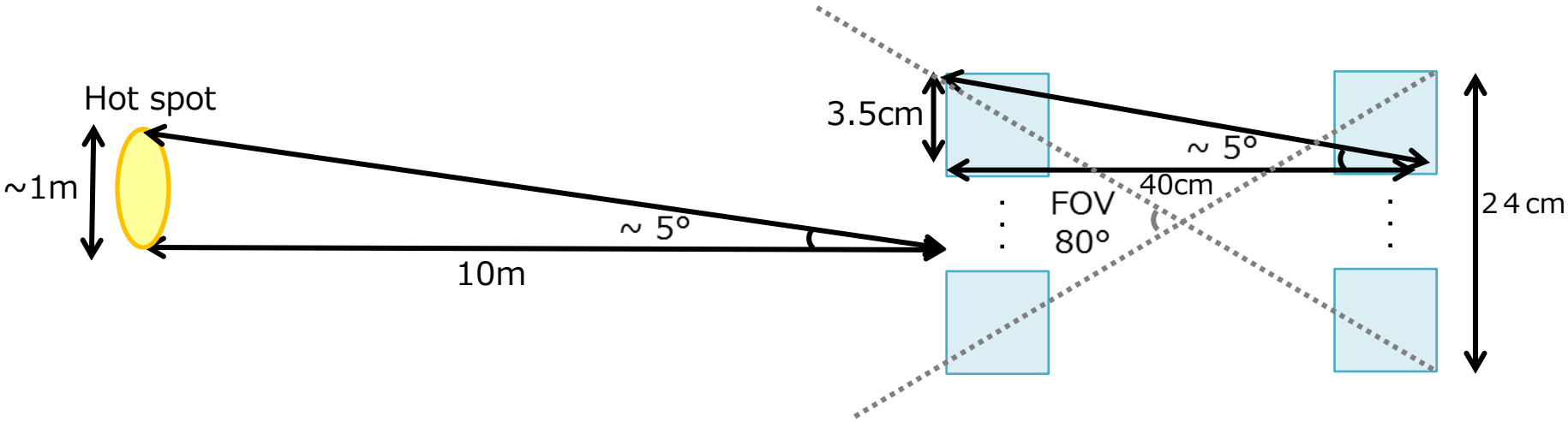
Concept of Gamma Eye

- **Use 2 arrays of CsI (Tl) scintillators**
  Low cost ($50 /1cm^3), Good energy resolution

- The best size for once Compton scattering: **3.5cm**.
- Distance between layer 1 and layer 2 is 40cm.
  → Geometrically, angular resolution **< 5 degrees** (σ) is possible.

(Measurement distance is 10m → can detect ~ 1m wide hot spot)

- A layer size is about 24cm. → Field of view is **80 degrees.**



Energy Constraint

General method

$$\theta = \arccos\left(1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}\right) \Rightarrow \theta = \arccos\left(1 + \frac{m_e c^2}{E} - \frac{m_e c^2}{E_2}\right)$$

E (662keV) = E_1 + E_2

E_1: Compton scattering E_2: photoabsorption

E_1 < 160keV (Energy resolution: 2.3 keV (σ) at 14 keV)

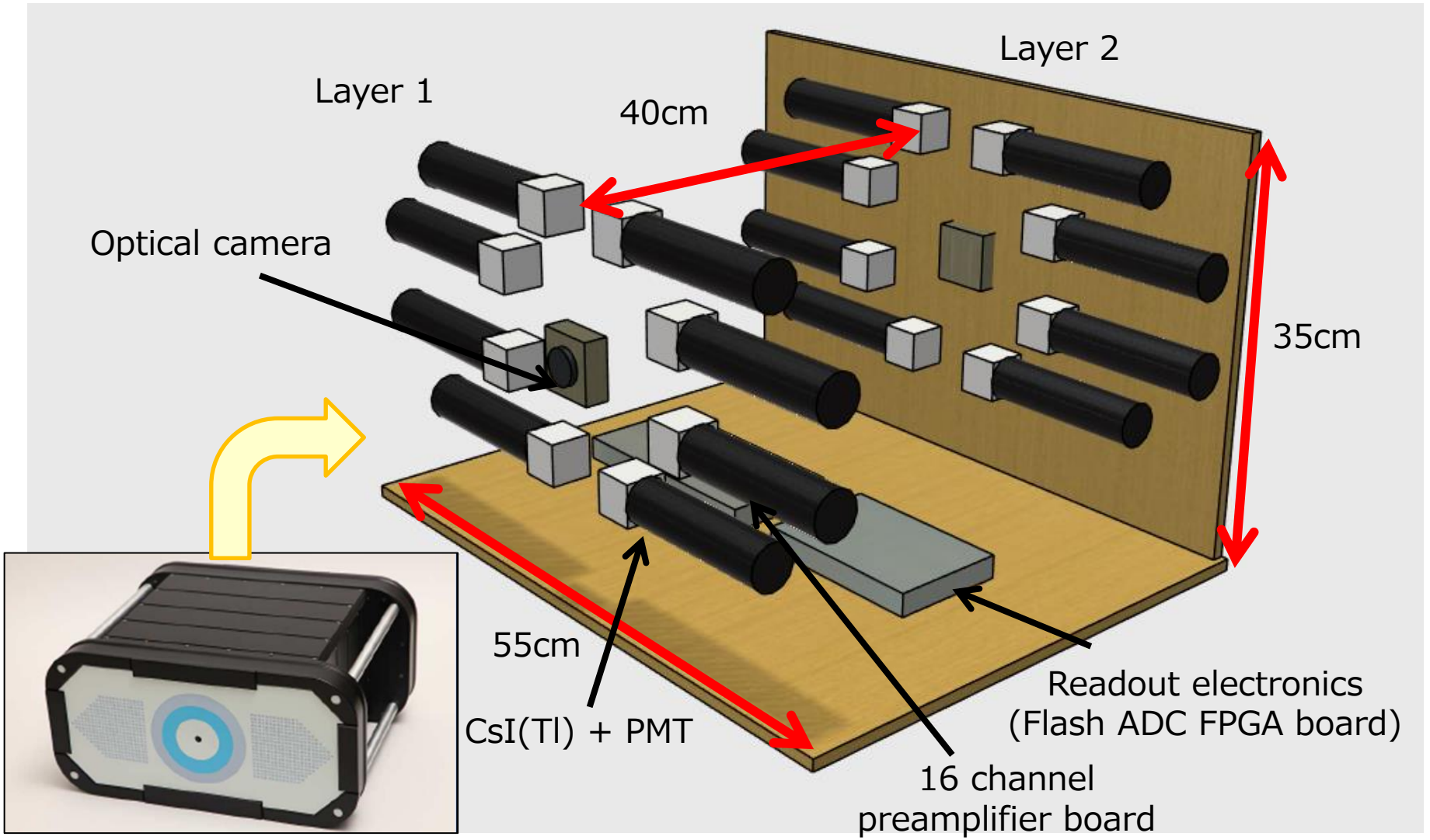
E_2 > 530keV (Energy resolution: 20 keV (σ) at 662 keV)

New method

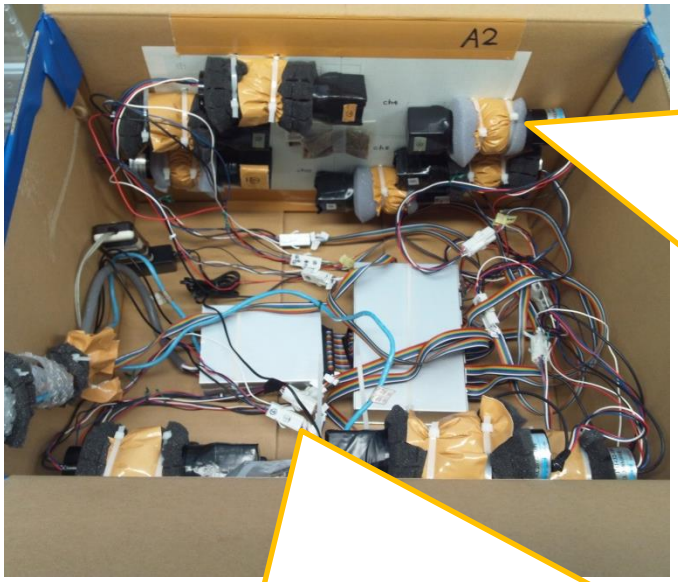
By using energy of layer 1 (E_1) → **Angular resolution < 5 degrees (σ)**

$$\theta = \arccos\left(1 + \frac{m_e c^2}{E} - \frac{m_e c^2}{E - E_1}\right)$$

Design of Detector



Components

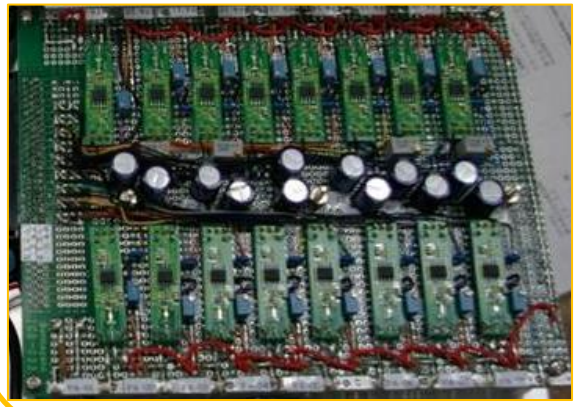


Scintillation detector

CsI (Tl): 3.5cm	PMT (length: 14cm)

A CsI (Tl) scintillator cube: 3.5cm on a side
A PMT: H11432-100 (2 inch, super bialkali, Cockcroft-Walton high-voltage)

Preamp board (16ch)



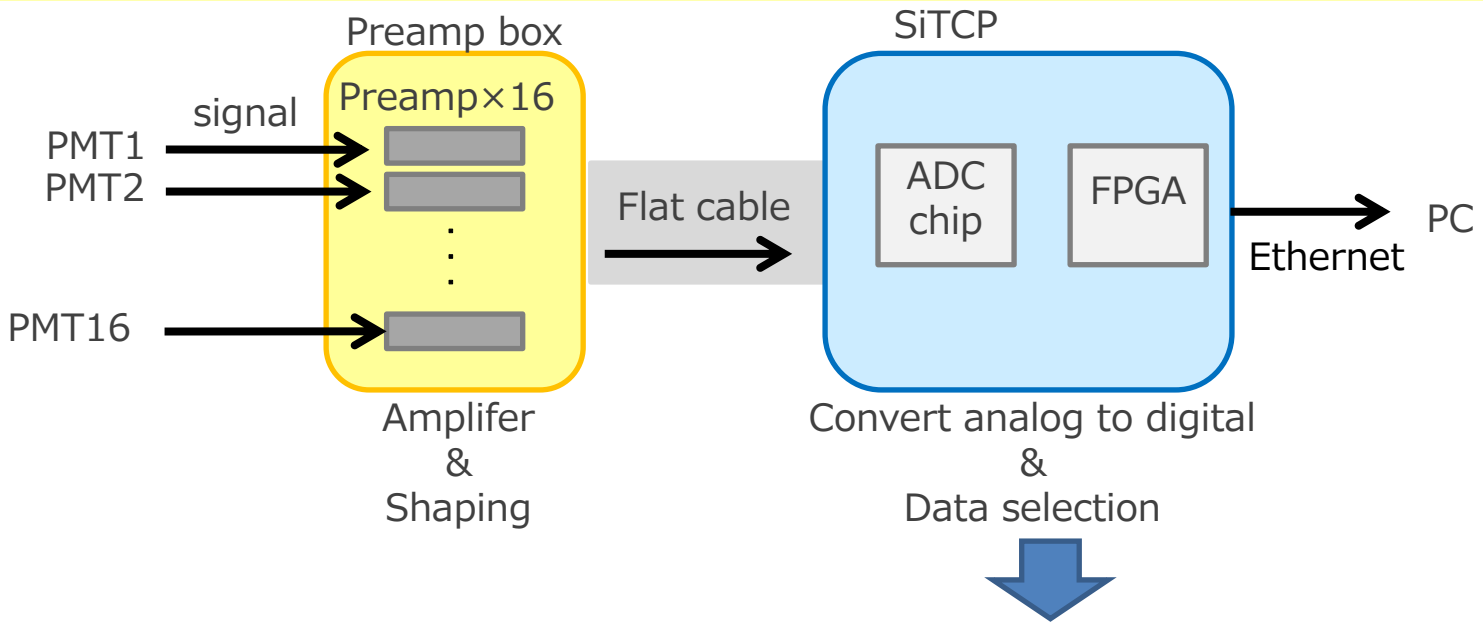
SiTCP board (16ch)

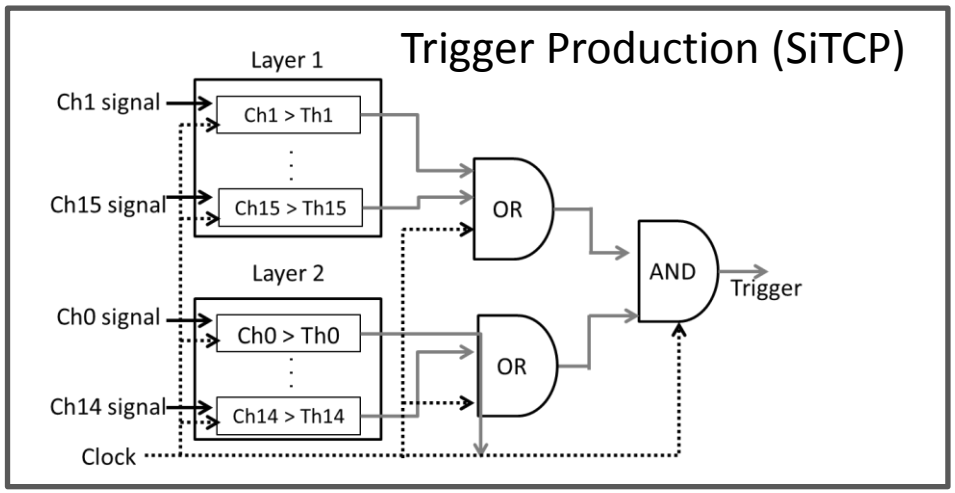
Wath's SiTCP Board?

Adopt a flash ADC board by controlled by FPGA with a SiTCP technology

- Fast readout (1Gbps)
- Small (13cm x 10cm)
- Light weight (97g)

Schematics of Data Acquisition System





Selection of Gamma-Ray Data

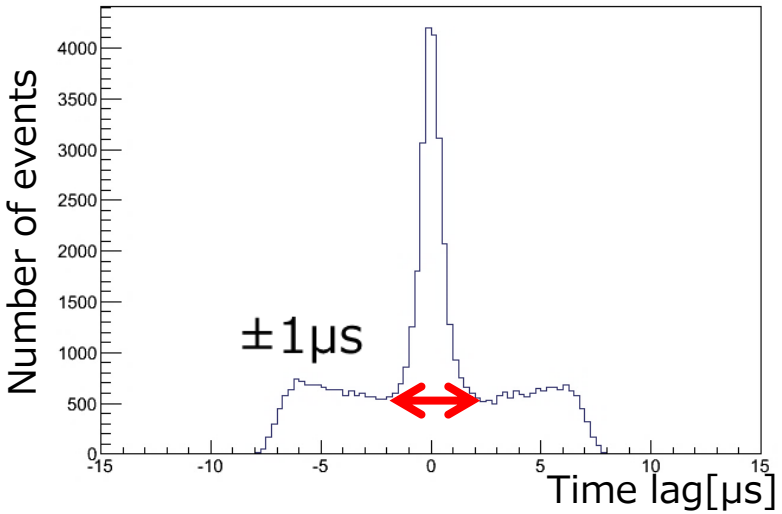
Hot spots exist everywhere at radioactively contaminated area.
A lot of accidental events are detected.

To select signals from layer 1 and layer 2 within a narrower time window by software

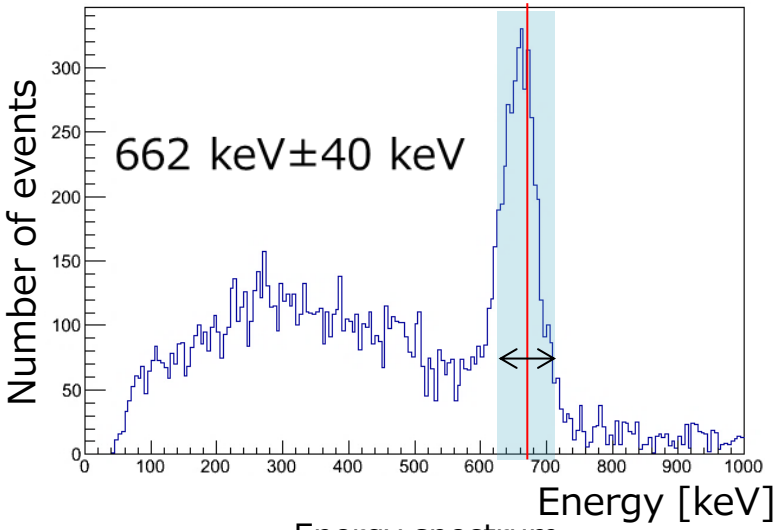
$dt = t_1$ (Layer 1) $- t_2$ (Layer 2) $< 1\mu s$

& (< decay time of CsI (Tl))

Energy cut : 662 keV ± 40 keV



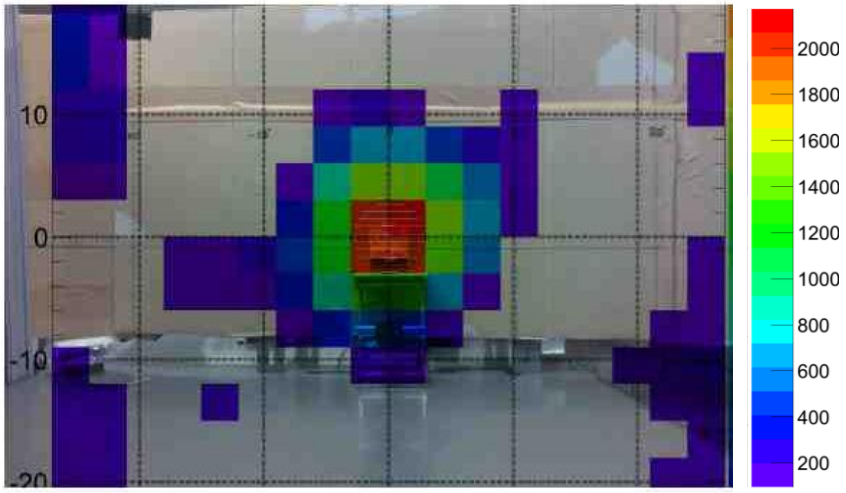
Difference time



Energy spectrum

LABORATORY EXPERIMENT

Laboratory Experiment



Radio Isotope: ^{137}Cs (1MBq)
Measurement distance: 1m
Measurement time: 60 min

< Color range >
Maximum: red
Just above the average: blue
Below average level: transparent

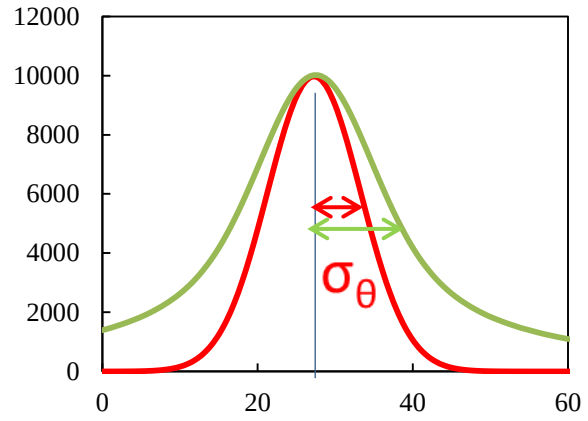
Number of counters	Size of detector	Weight of Detector	Sensitivity	FOV	Angular resolution
8 + 8 (16 counters)	56 cm x 40 cm x 35 cm	15kg	6cps/(1μSv/h)	±40°	3.5° (※)

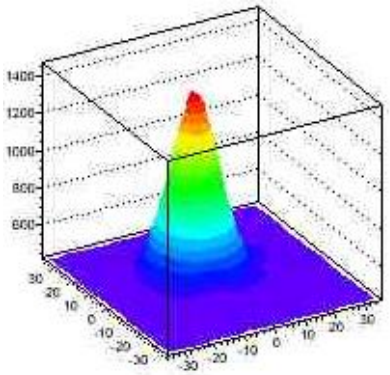
※using an image filter

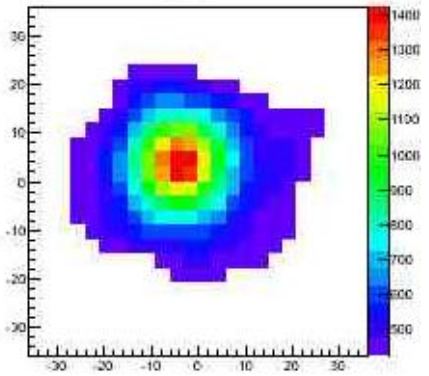
Image sharpening technique

Filtered back-projection : one of the way to sharpen images

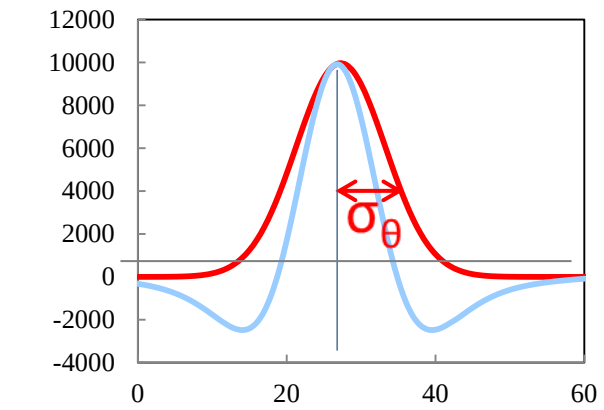
H. Muraishi et al : JJMP 33(3),124(2013))

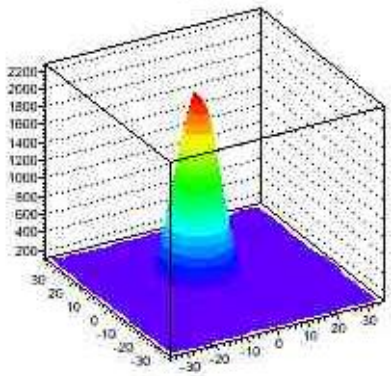


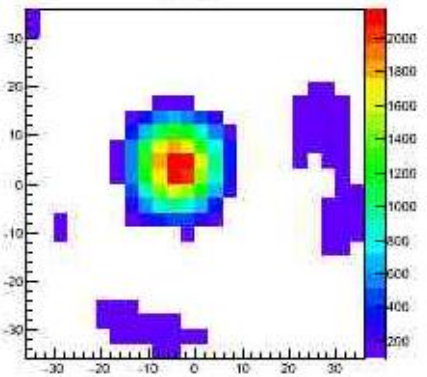


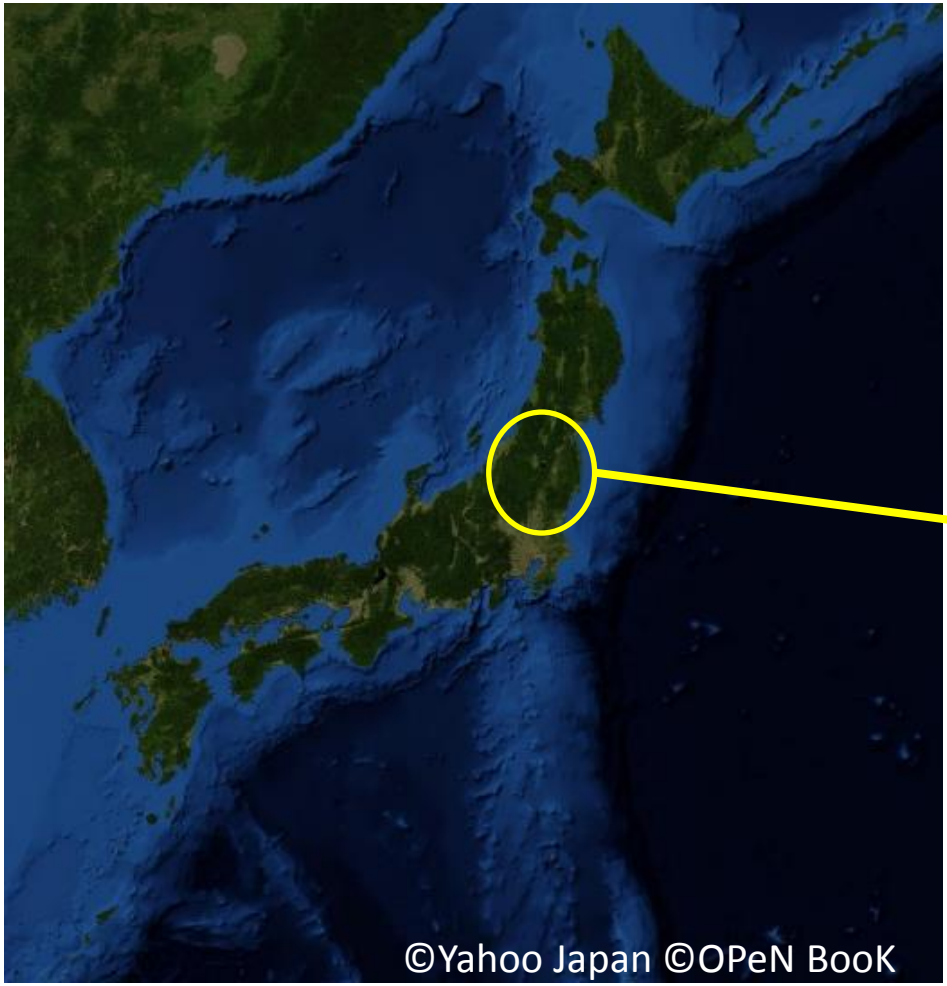


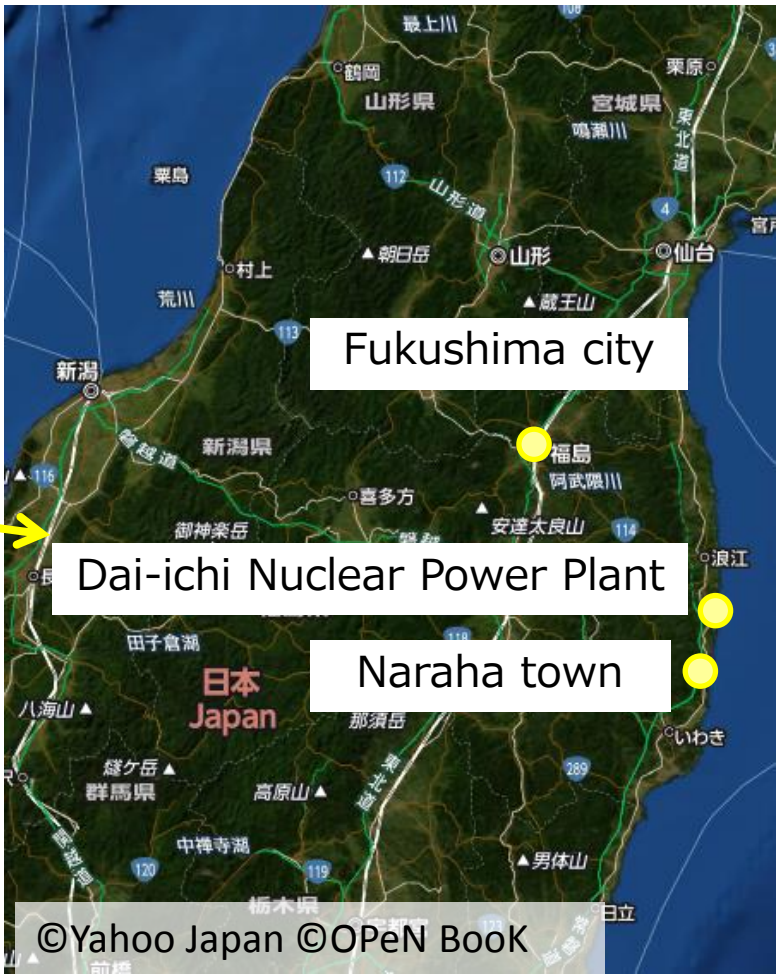
By using a high path filter → Image sharpening





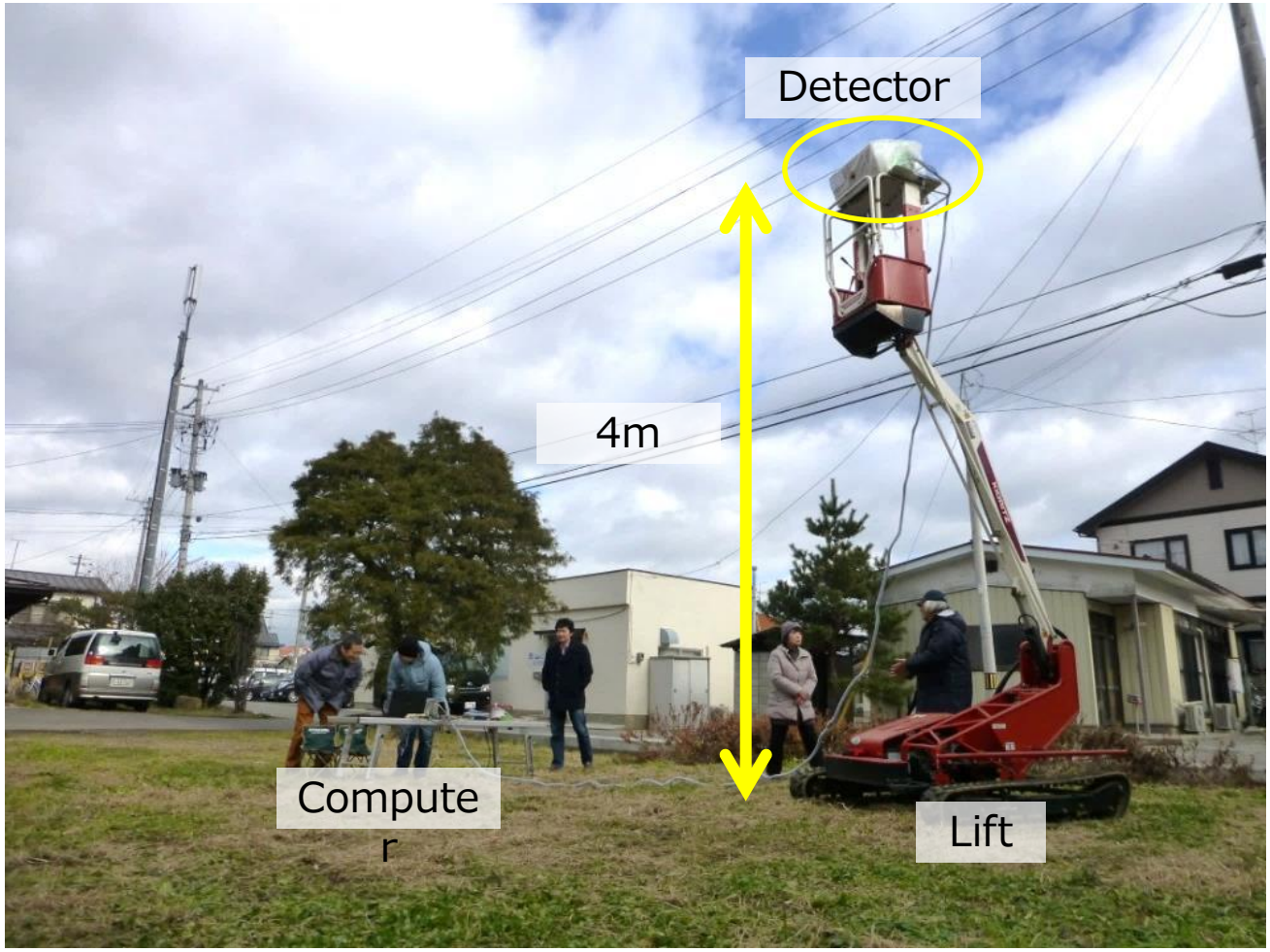






FIELD TEST IN FUKUSHIMA

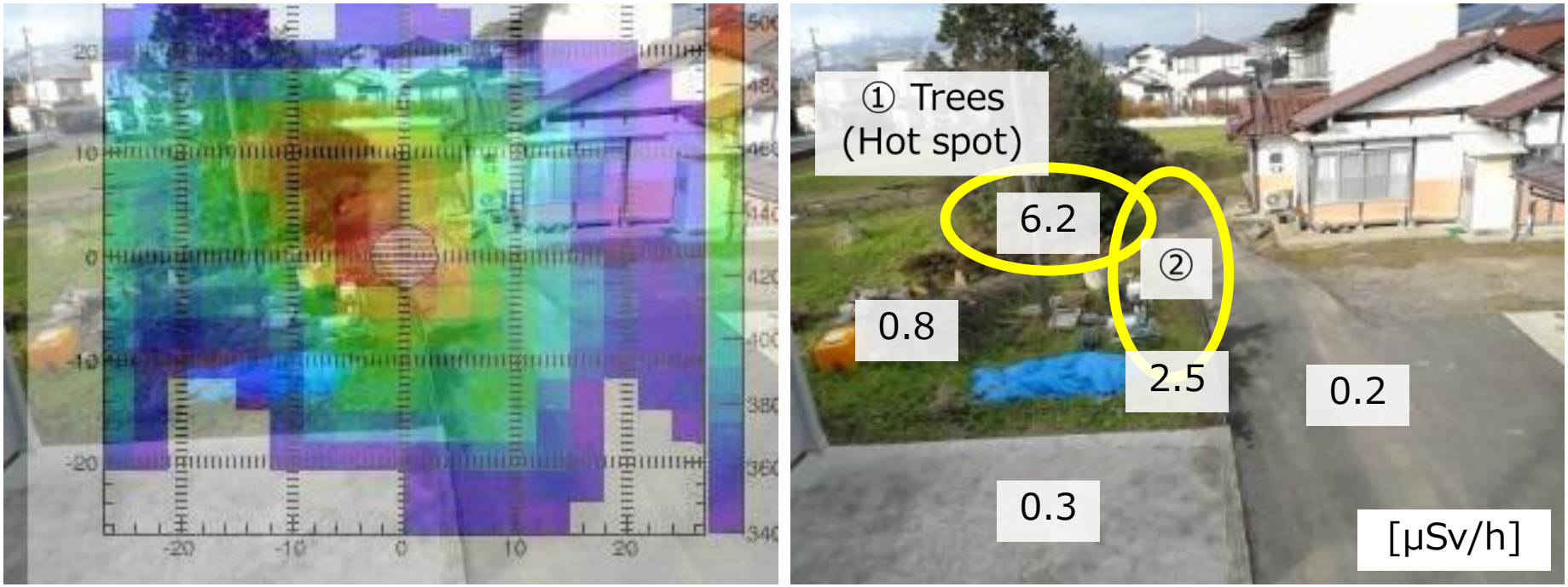
Setup of the detector



at a height of 4 meters in order to cover a wide area

Result of Field Test

Measurement time: 90min, distance:15m



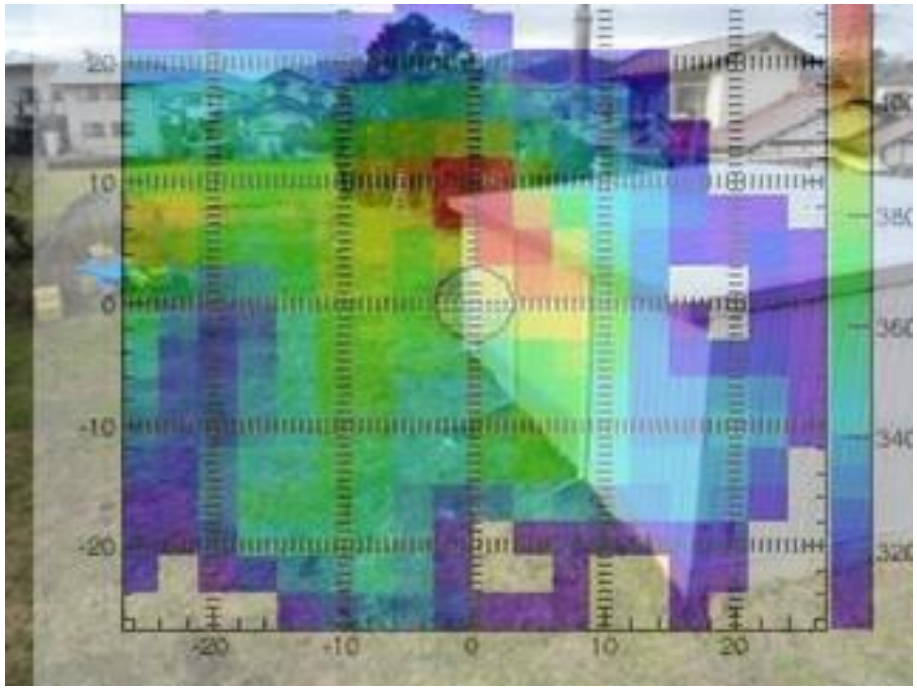
① Detected a hot spot at the bottom of trees (6.2 μSv/h)

② Area between trees and road is a hot spot (2.5 μSv/h) where rainwater collected.

The distributions detected with Gamma-Eye are consistent with the measurements by using a survey meter.

From Another Angle

Measurement time: 60min, distance:12m

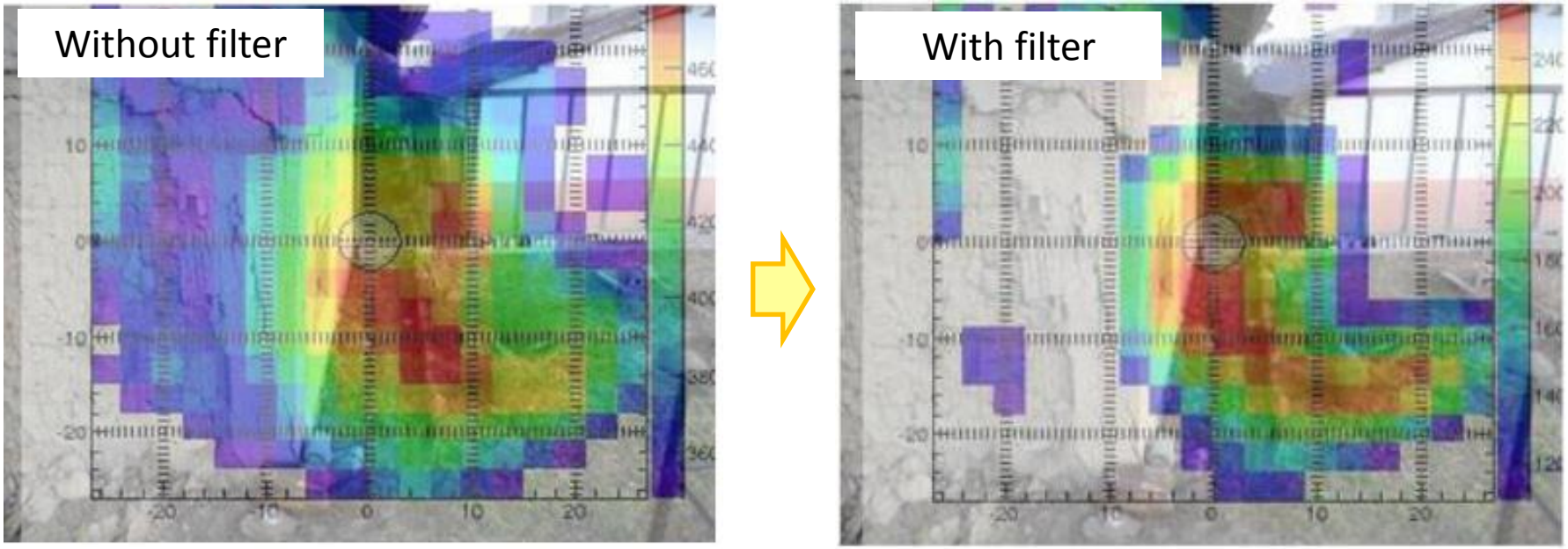


The hot spot (tree) is again detected from another angle.

We confirmed the ability to detect a hot spot
under the dose rate of ~1μSv/h.

Using Filtered Back Projection for Small Hot Spot

Measurement time: 60min, distance: 10m



In this measuring case → a hot spot is small

The image gets sharper by using the filtered back-projection.

Summary

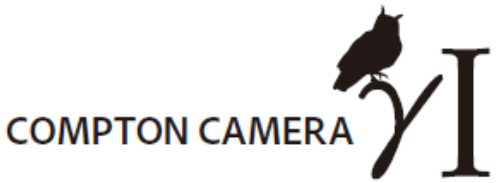
- We developed a new Compton camera “Gamma Eye”.
  - By using CsI (Tl)
  - Angular resolution: σ = 3.5 degree (using Filtered back-projection)
  - Good sensitivity: 6 cps / (1μS/h)
  - Wide field of view: ±40 degrees
  - Low-cost (~ $80,000)
- We demonstrated the capability of Gamma-Eye for measurement of arrival direction of gamma-rays in the environment even with the dose rate ~1μSv/h.
- The mass production will be done soon.

(Fuji Electric and Shinsei Cooperation)

<future plan>

- Development of 360 degrees panorama monitoring detector
- Measuring environment of nuclear medical facilities
- Measuring gamma-ray lines (e.g. 511keV) for astrophysics

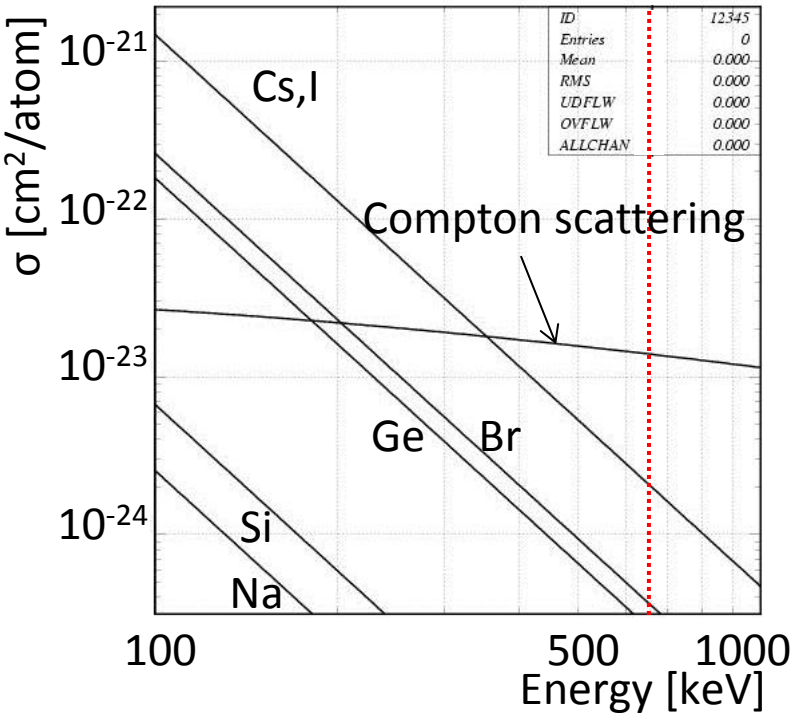
BACKUP SLIDE



CsI (Tl) scintillators

We select events as following.

Compton scattering (E_1): once
Photoabsorption (E_2): once
$E = E_1 + E_2 = 662keV$



- CsI (Tl): can use it at 662 keV
- Low- cost
- The best size: 3.5cm on one side for once Compton scattering.

※$LaBr_3$, $Bi_4Ge_3O_{12}$: expensive, can not be mass product

What's SiTCP?

- A flash ADC board with Silicon Transmission Control Protocol board (SiTCP) developed by KEK institute.
- Be able to transfer of the data between a readout circuit and a computer via Ethernet.
- Users can develop the trigger logic by myself and input a program to FPGA

Bee Beans Technology BBT-X044

- Readout speed: 1Gbps
- 40MHz sampling ADC (16ch)
- $2,200 ($140/channel)
- Small (13 cm x 10 cm), light (97g)

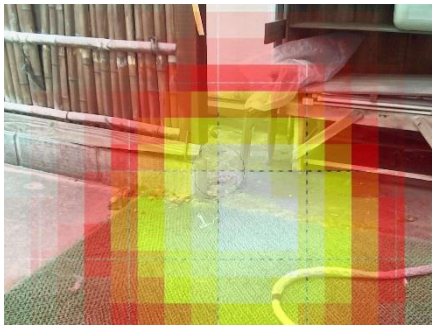
Back

The effect of Decontamination

Measurement a hot spot (15μSv/h) decontamination

Measurement time : 1 hour

Distance form detector : 2m



Before decontamination

Remove a moss

Remove artificial turf

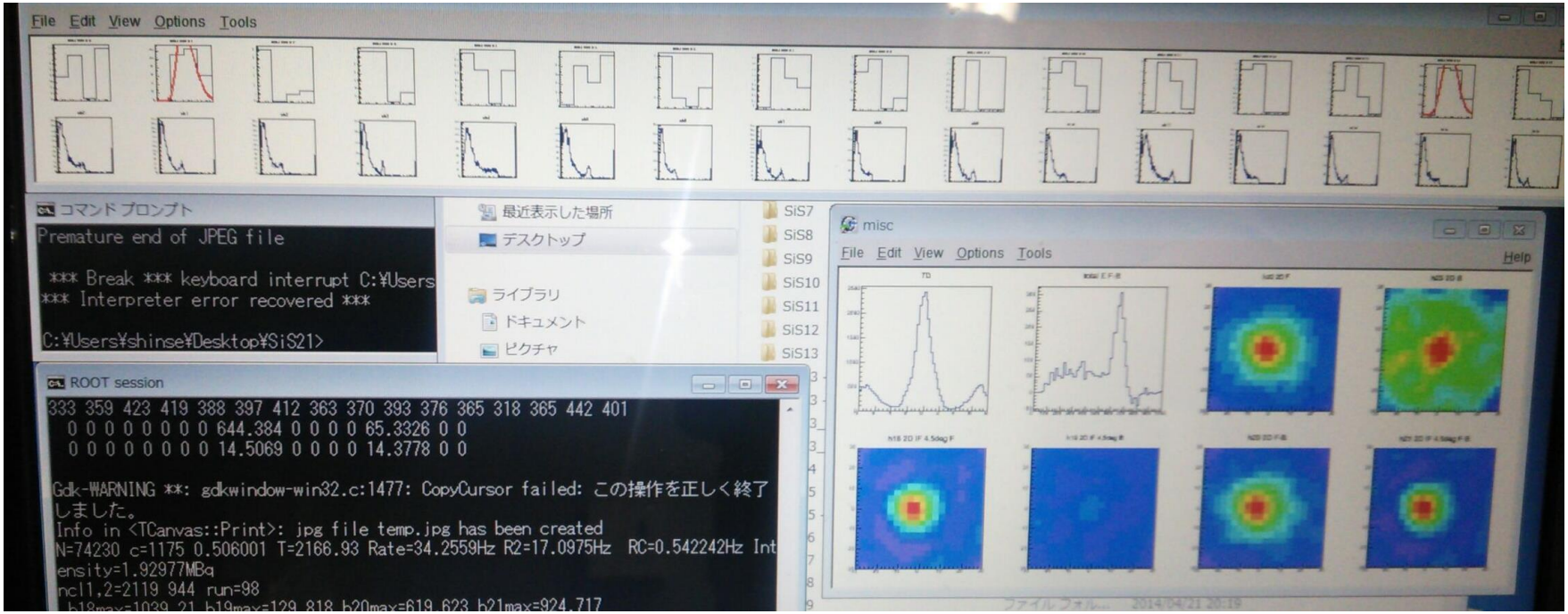
Remove dust

- Can confirm the effect of decontamination.

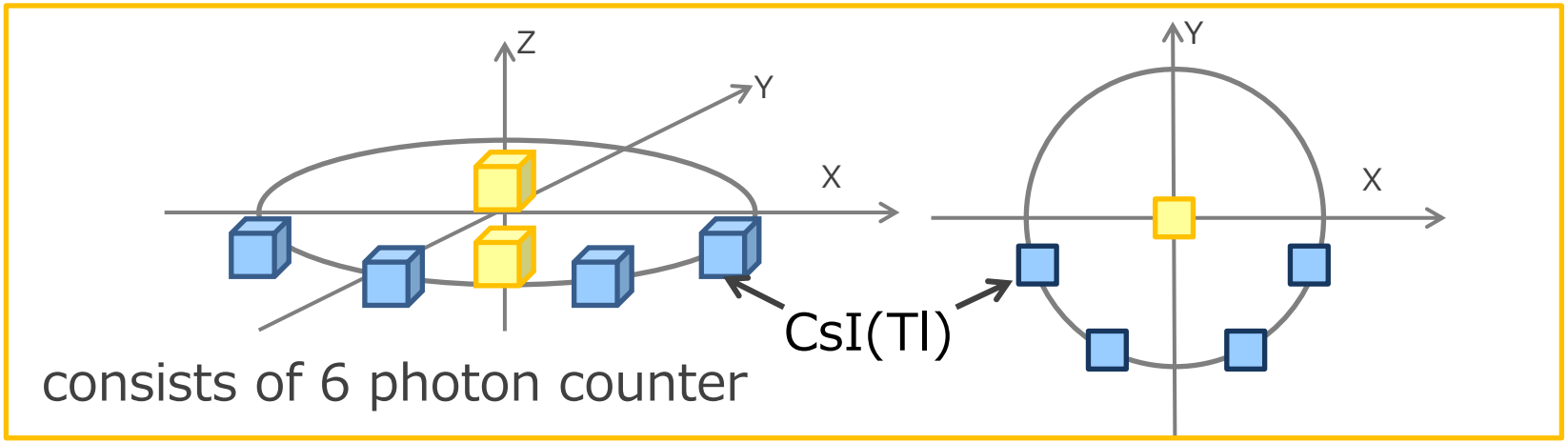
※Maximum level is shown white.
Just above the average level is shown red.

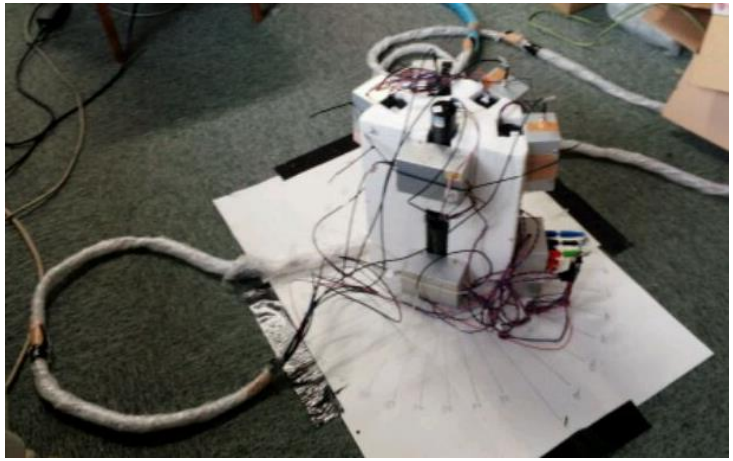
Online monitoring

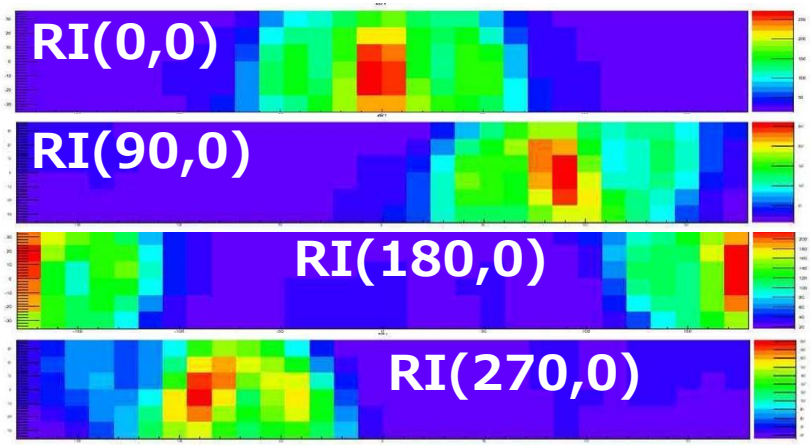
We check the result of measurement by using online analysis program.



Development of 360° panorama monitor







- Change the position of photon detector
- Detect the location of the radiation source in the horizontal direction
- Angular resolution is 12 degree.

Development schedule

Year	Detector type	Data Acquisition System	Online Analysis Program	Field tests
2012	3 + 3	NIM CAMAC	VC++ ROOT (Windows)	Nov: Fukushima city
2013	6 + 6	SiTCP		Apr: Fukushima city May: Fukushima city June: Fukushima city Aug: Fukushima city Aug: Naraha town Oct: Naraha town Oct: Naraha twon Nov: Naraha town Dec: Naraha town
2014	8 + 8			Feb: Naraha town Mar: Naraha town