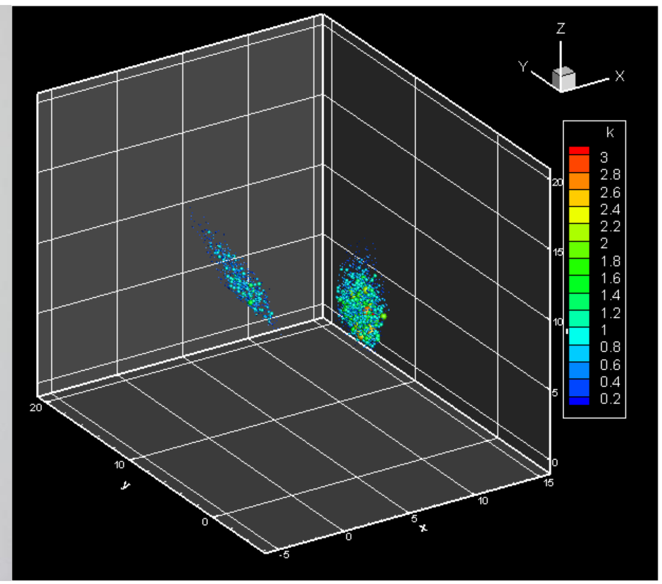
“Stereo Compton cameras” for 3-D localization of radioisotopes



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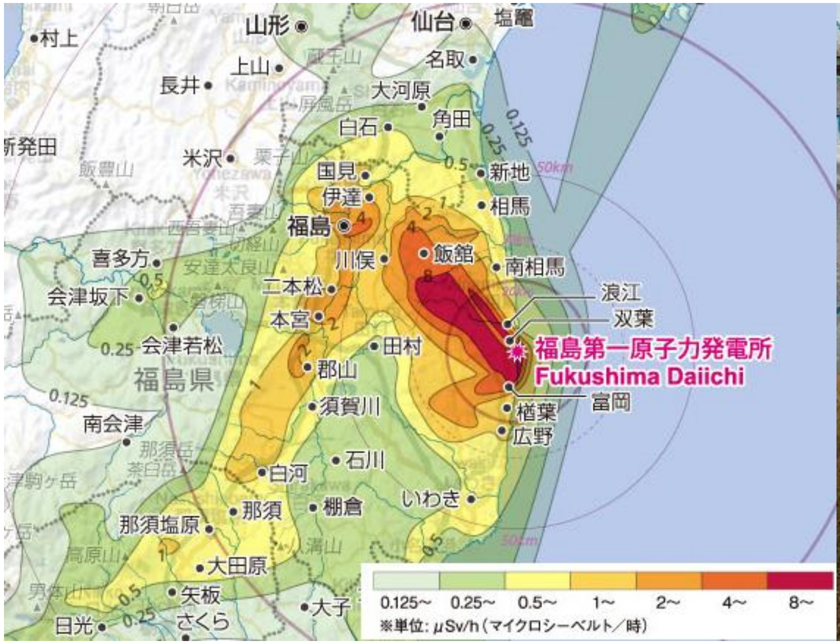
Outline

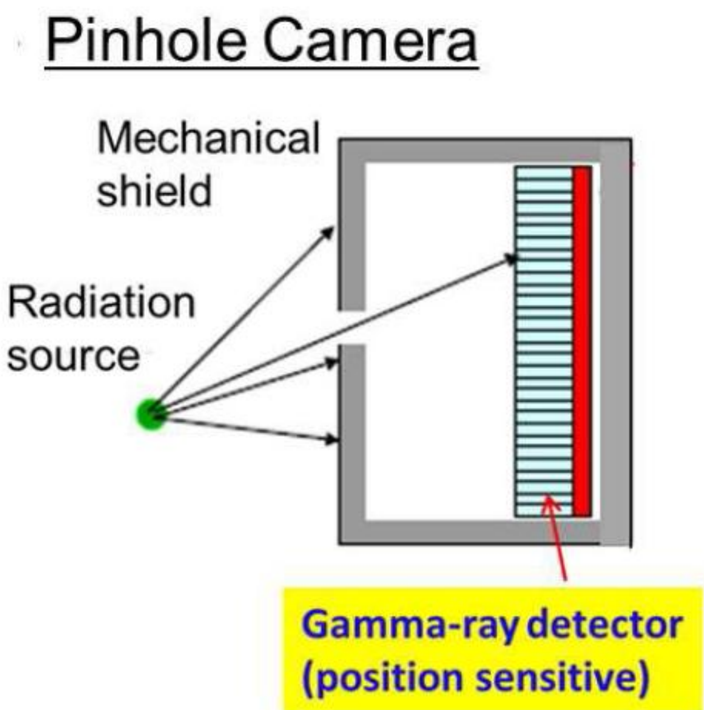
- Background
  - Nuclear disaster and Gamma-cameras
- Novel handy Compton camera
  - Design and prototype's performance
- "Stereo" Compton cameras
  - Method, result of simulation and field-test
- Summary

Nuclear Disaster in Fukushima

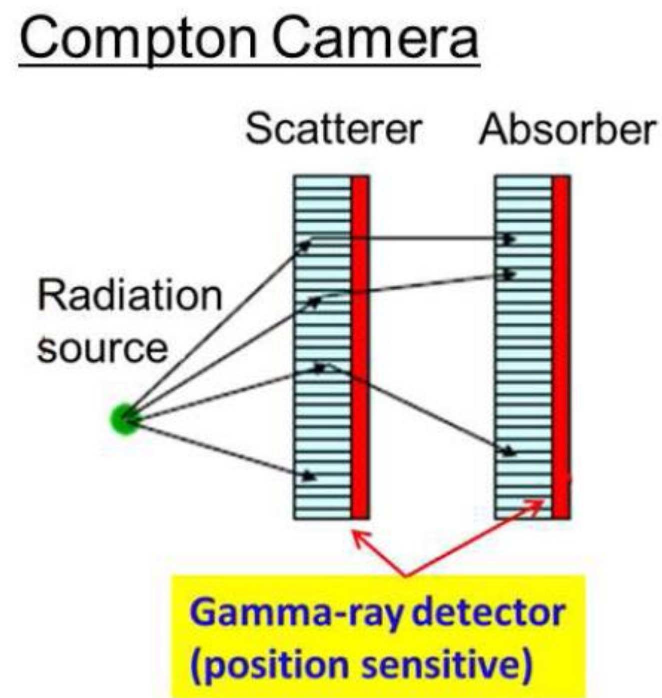


- A huge amount of radioactive isotopes was released and the radiation level around the plant is still high, more than ~20μSv/h
- To help identify radiation hotspots quickly and ensure effective decontamination, various gamma-cameras have been developed and field-tested

Gamma-camera: two approaches

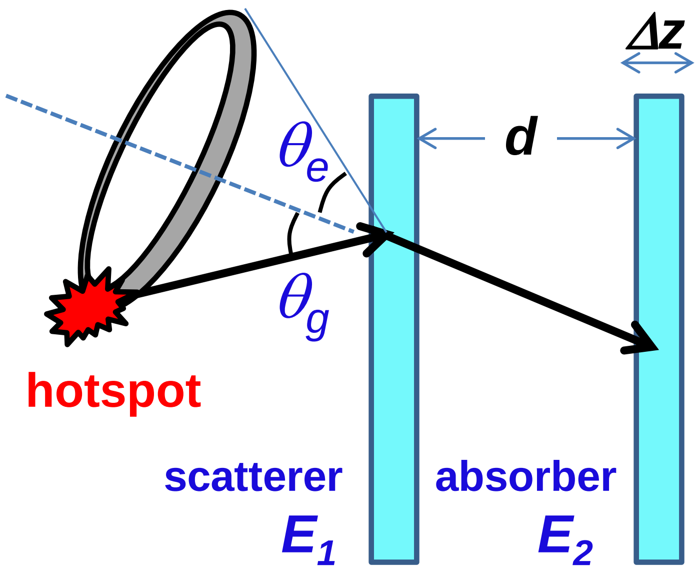


- O Simple structure
- X Heavy, thick collimator (inefficient for 662 keV γ-rays)
- X Limited efficiency ~ pinhole
- O Good angular resolution



- **O No mechanical collimation**
- **O Wide field of view**
- X A bit complicated (needs scatterer and absorber)
- X Difficult to achieve good $\Delta\theta$ …?

$\Delta\theta$ of Compton camera (C.C.)



- Compton Kinematics;

$$E_{\text{in}} = E_1 + E_2,$$

$$cos\theta_e = 1 - \frac{m_e c^2}{E_2} + \frac{m_e c^2}{E_1 + E_2},$$

$$ARM = \theta_e - \theta_g$$

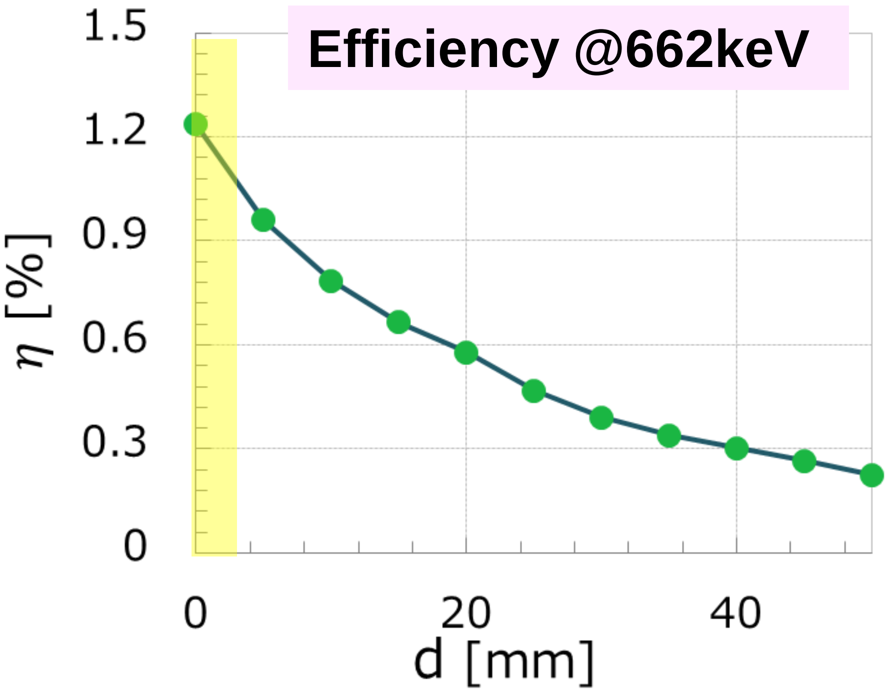
θ_g is calculated from the interaction position and real direction of the source

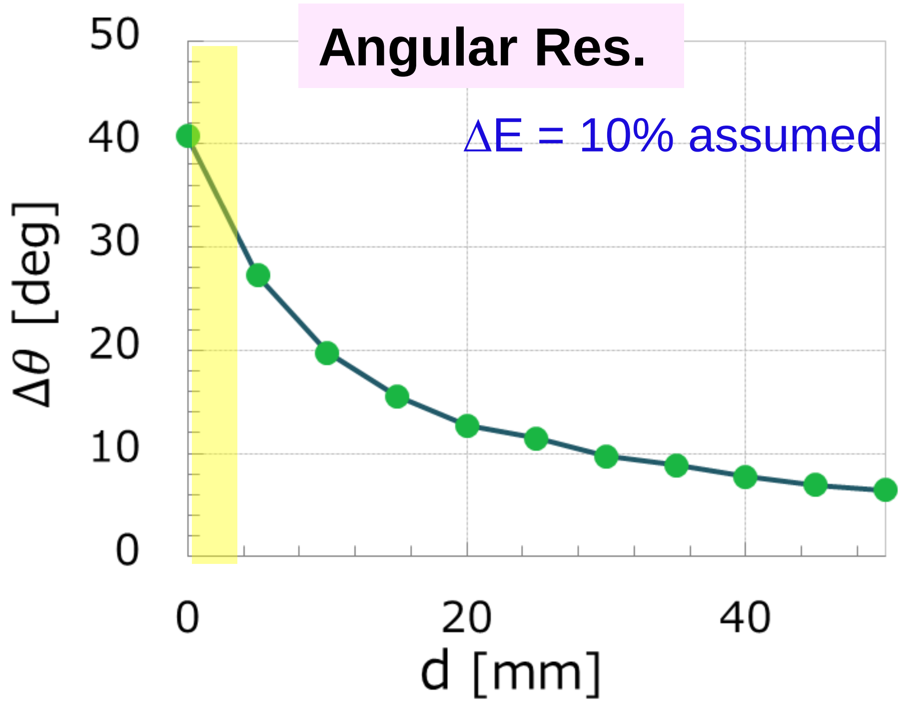
- Angular Resolution: $\Delta\theta \equiv \Delta ARM$

Good $\Delta\theta$	⟺	• thin detectors (Δz) • large distance (d) • good E resolution (ΔE)

In such conditions, very difficult to achieve high η …

Scintillator-based C.C.





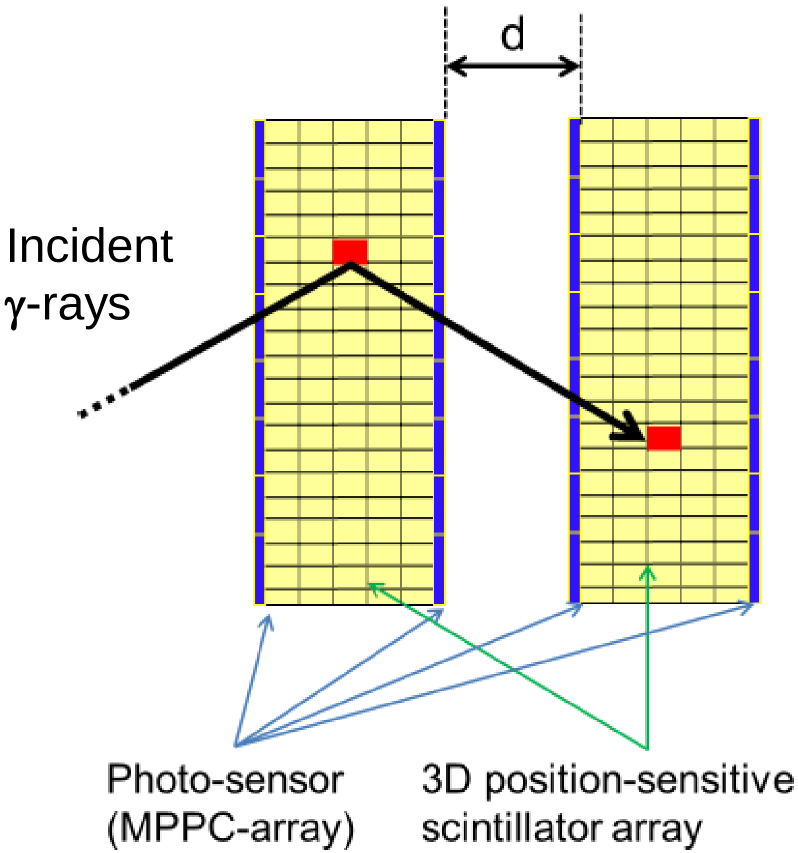
- Assuming 5x5 cm^2 Ce:GAGG plates of t=1 cm (2x2 mm^2 pix)
  - **η as high as 1%** by placing the scatterer and absorber closer together
  - ***However,*** such a config makes Δθ terribly worse, **typically > 30º!**

⇨ **Can achieve good Δθ w/o reducing** η**?**

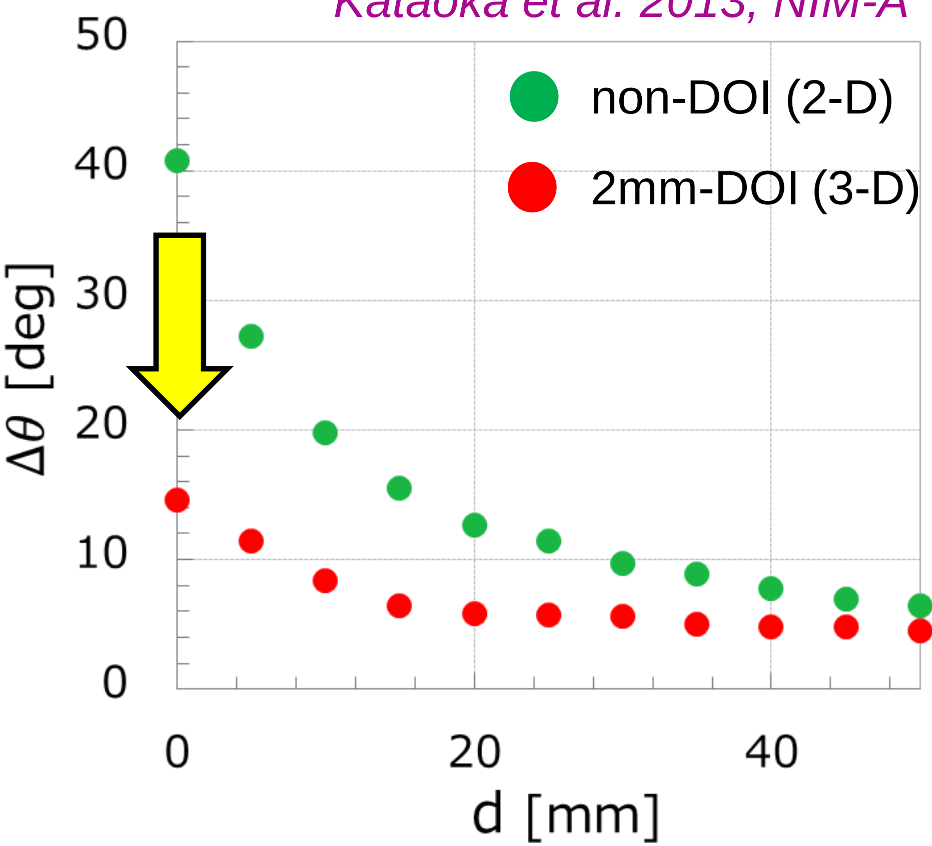
New Concept : "DOI"-Compton Camera

Japanese patent application 2012-157920 (Waseda Univ., HPK)

- Achieve excellent η and good Δθ ***at the same time***
- Needs compact, thin light sensor (unlike PMTs,,,)



Kataoka et al. 2013, NIM-A

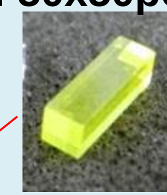


Handy C.C. by HPK

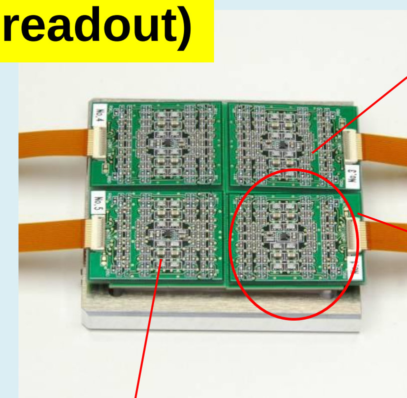
Weight 1.9 kg!!!

Fish-eye visible camera

Ce:GAGG (1x1x10mm 50x50pcs)



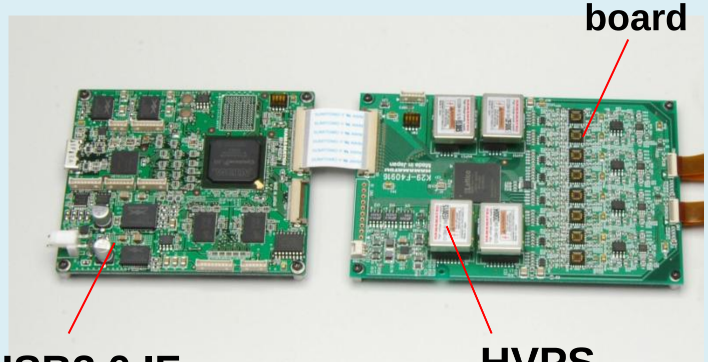
d = 15mm (2-D readout)



8x8 MPPC Array board

resistive charge division network

AMP ADC board

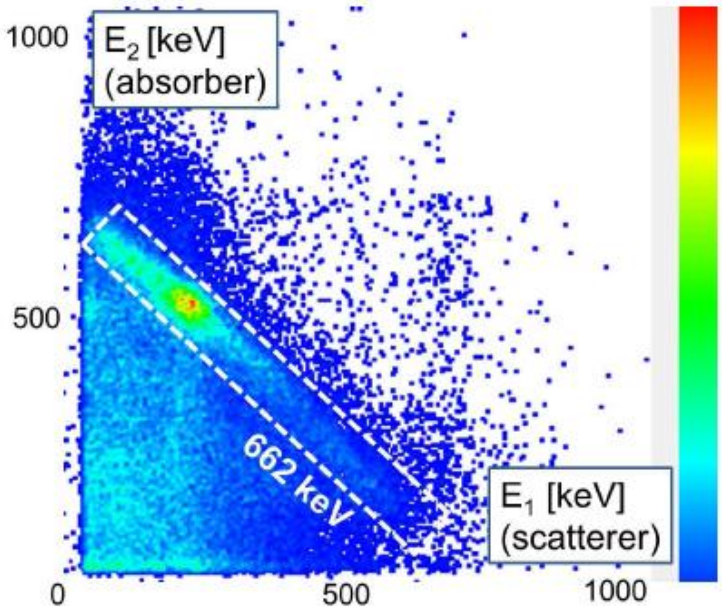


USB3.0 IF board

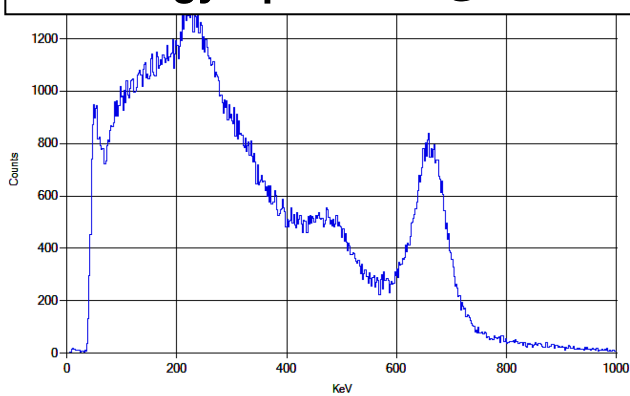
HVPS (C11204-01)

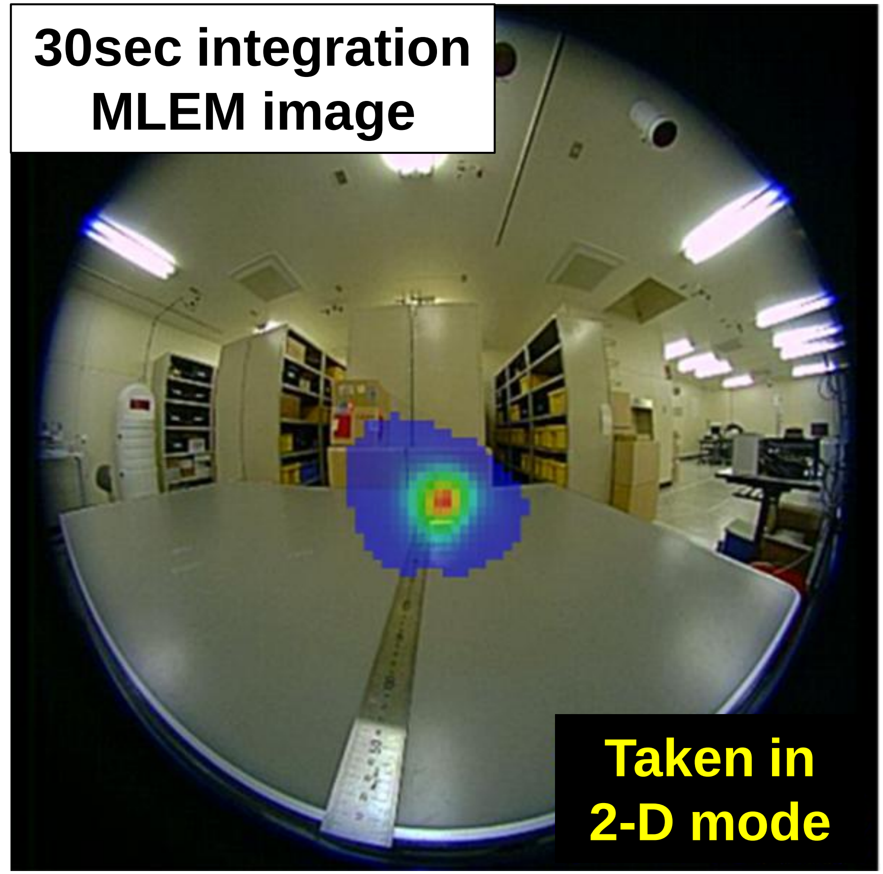
Prototype Testing (2-D)

Energy map @^{137}Cs



Energy Spectrum @^{137}Cs





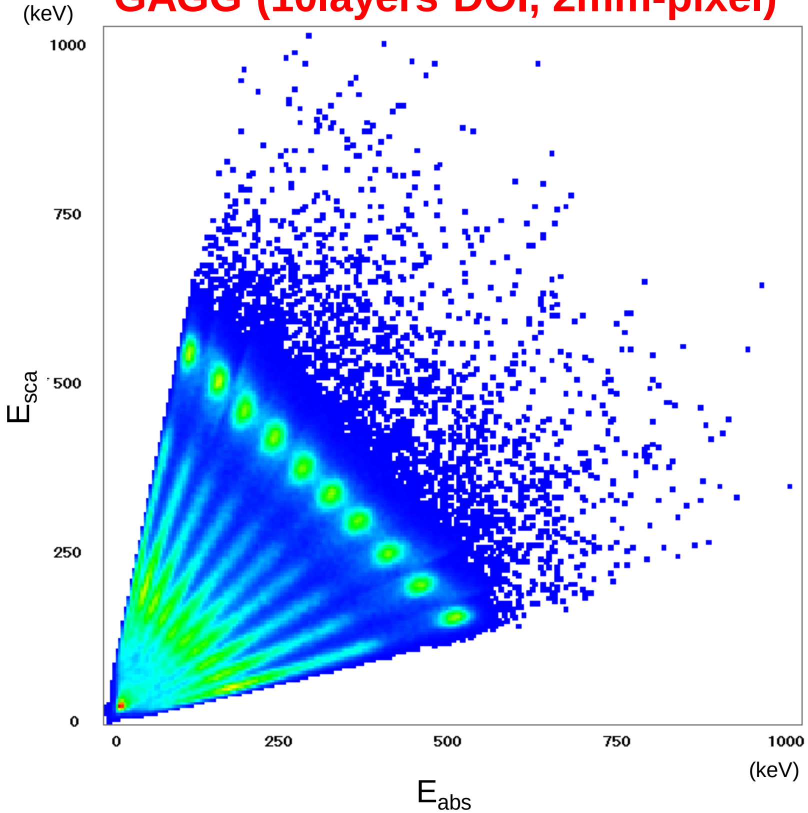
Distance to the isotope: 30cm

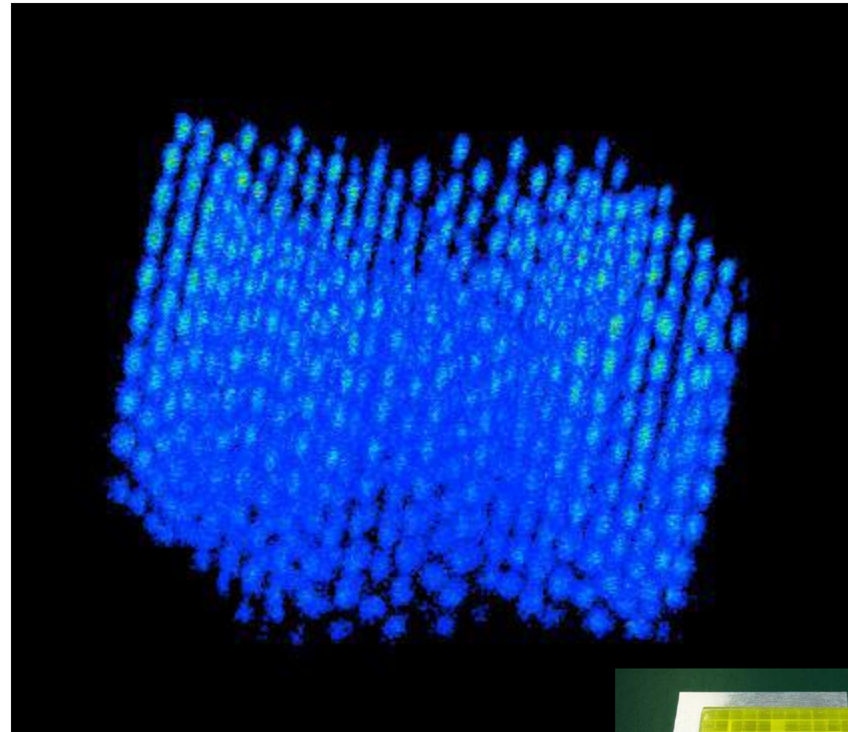
Rad dose :~6μSv/h@^{137}Cs

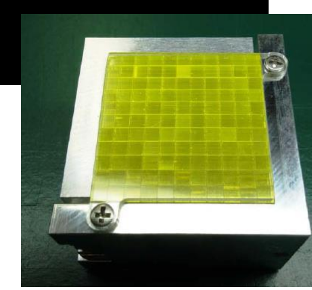
Integration time: 30 sec

Prototype Testing (3-D)

GAGG (10layers DOI, 2mm-pixel)





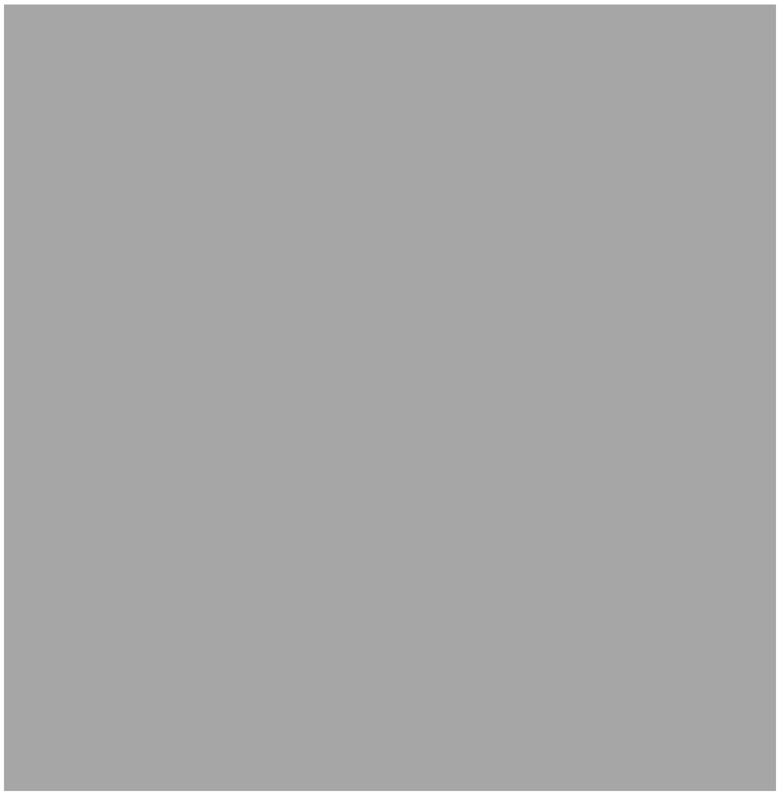


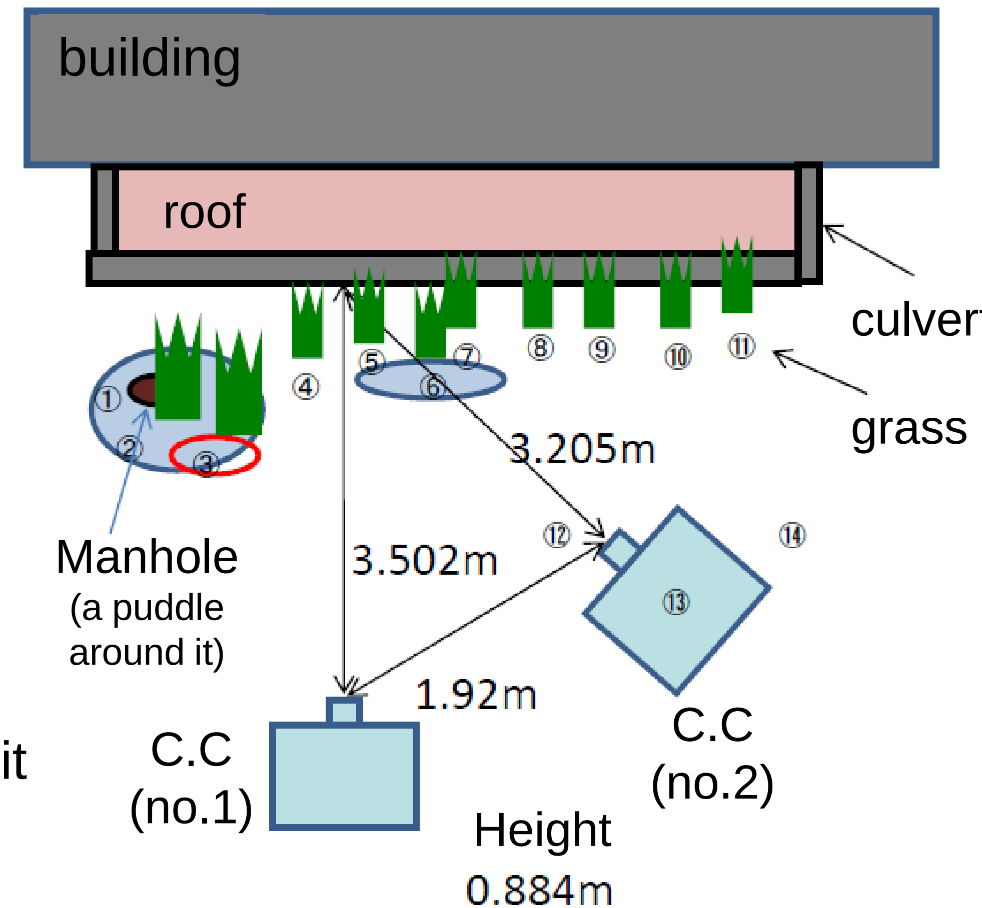
- d ~ 8-10 mm → η ~ 150% cf. 2-D mode
- 2mm-DOI structure → Δθ ~ 7-8 deg (FWHM)

Improving and prototype testing

Field Test in Fukushima

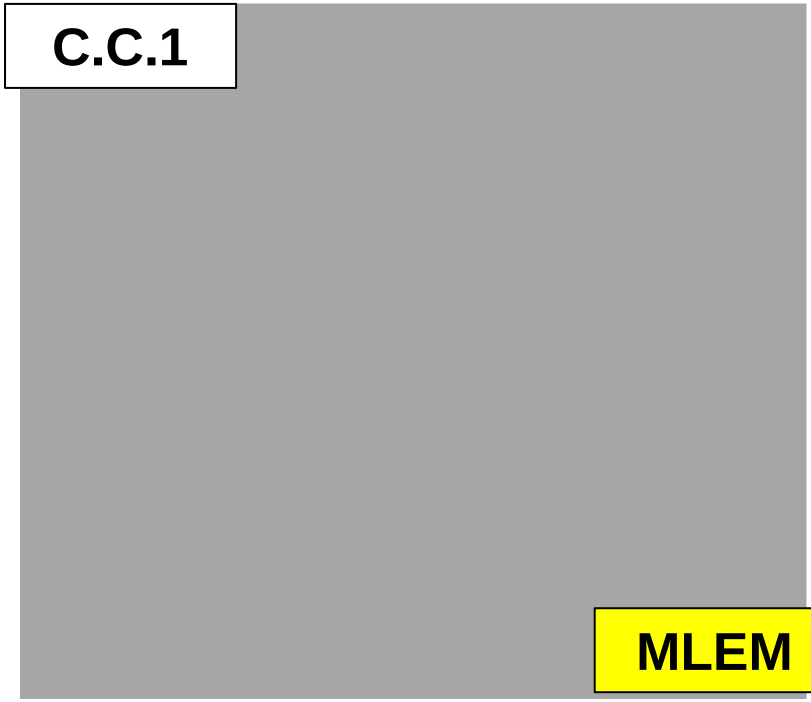
position	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪
dose (μSv/h)	34	23	50	15	35	63	50	35	30	20	30

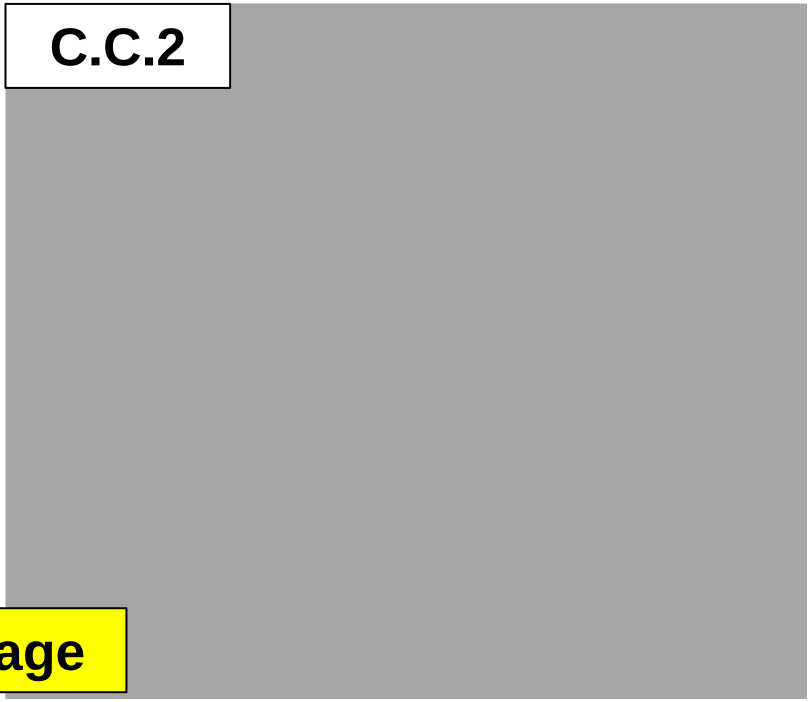




- Surveying the puddles which emit gamma-rays with two C.C.s

Field Test in Fukushima



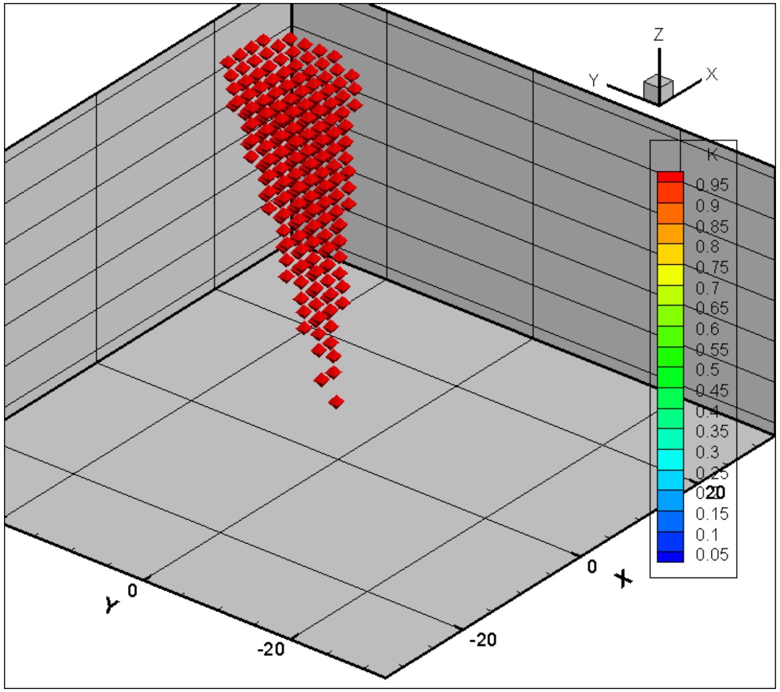


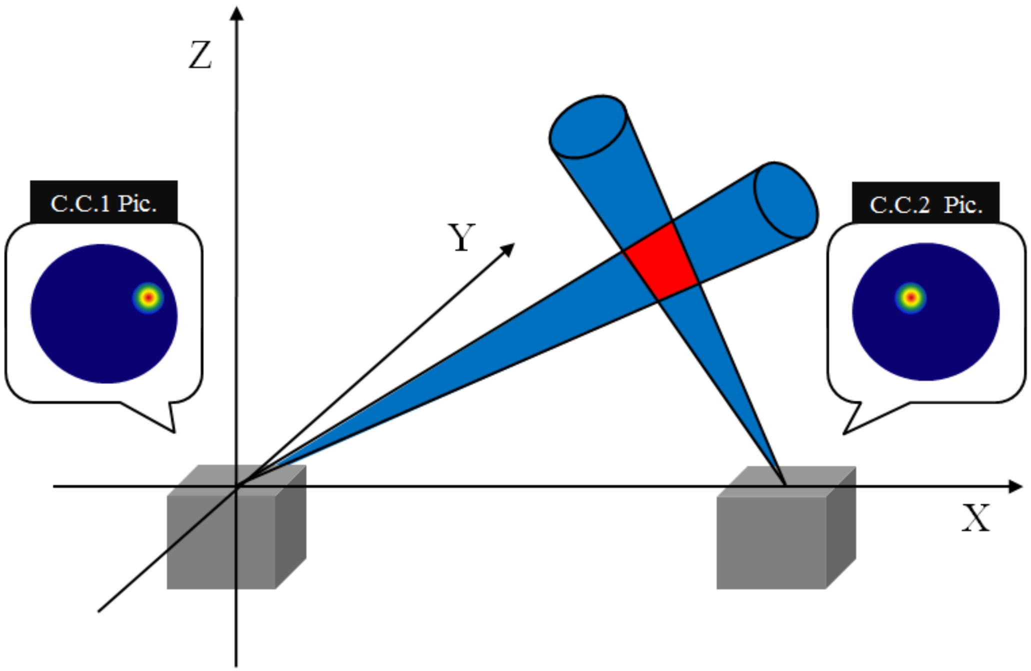
MLEM image

- Reconstructed images correctly reflect high-dose region measured by the survey-meters

➡ **Can we identify the localization of unknown sources by using two Compton camera images?**

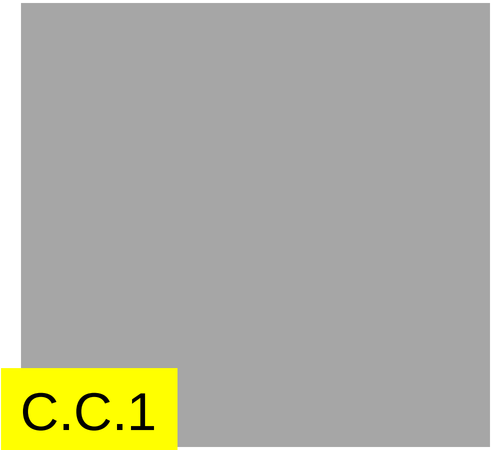
Stereo C.C. : Concept and method

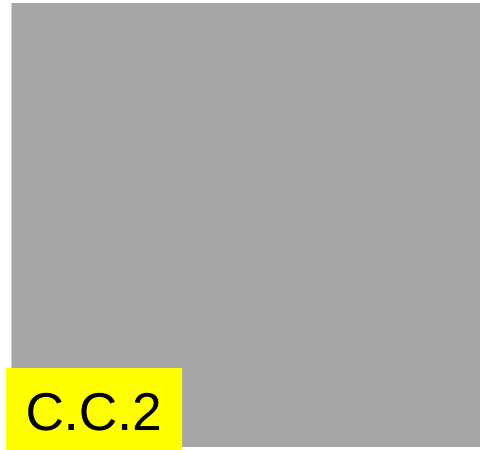


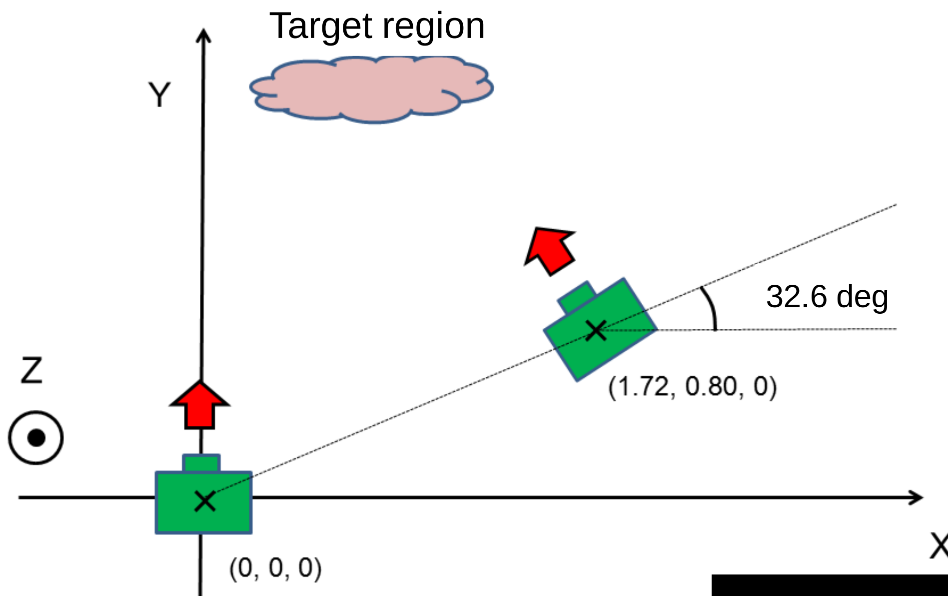


- A single cone with its angular resolution can be drawn
- Simply by gathering these cones of two images, 3-D localization image of radioisotopes can be achieved

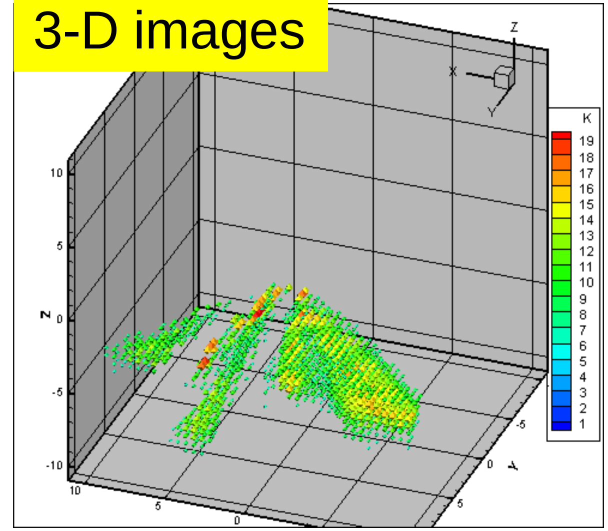
Stereo measurement : field data imaging

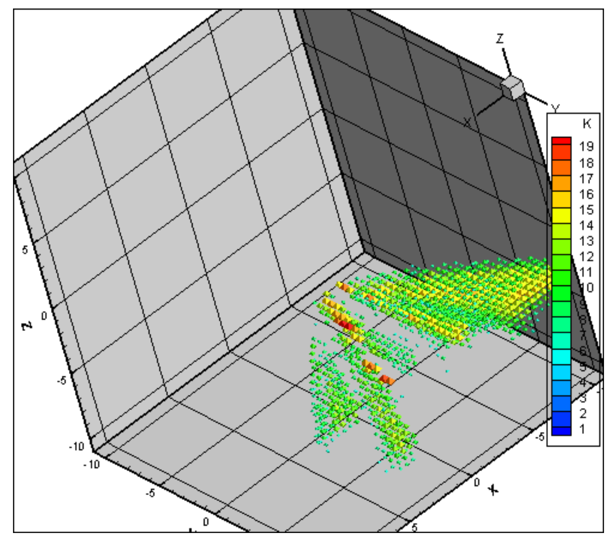






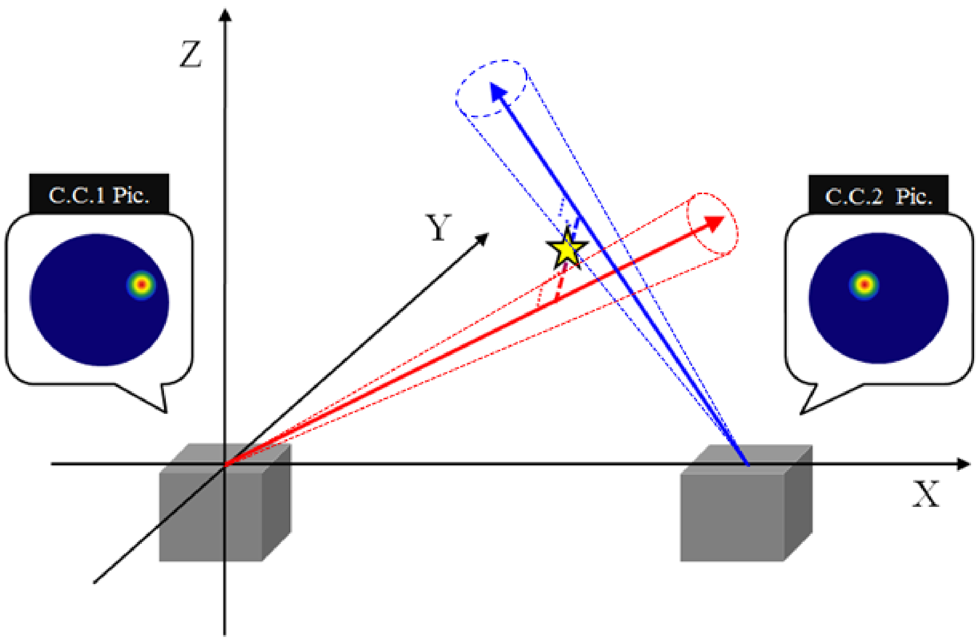
3-D images





How can we get more clear images…?

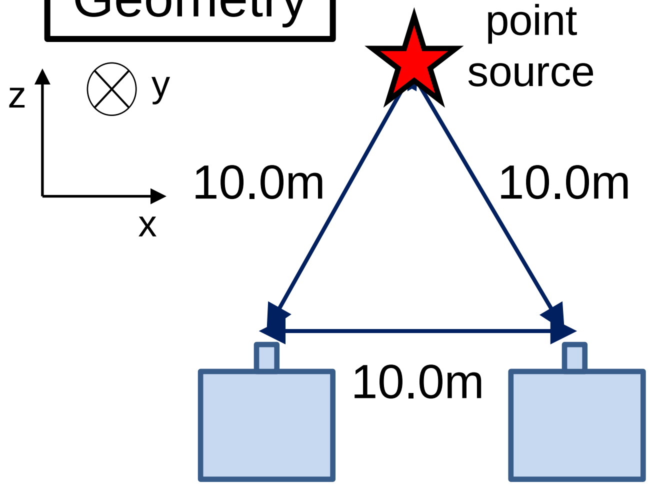
Alternative method



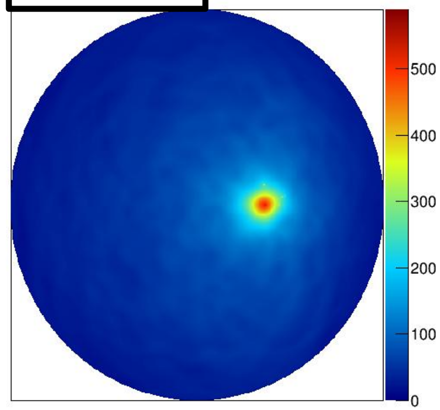
- The point nearest to two lines corresponding to the axis of two cones is decided to the source position with probability based on two pixels' values
- Find the "truly" source position by repeating this routine

Stereo measurement : 1-source simulation

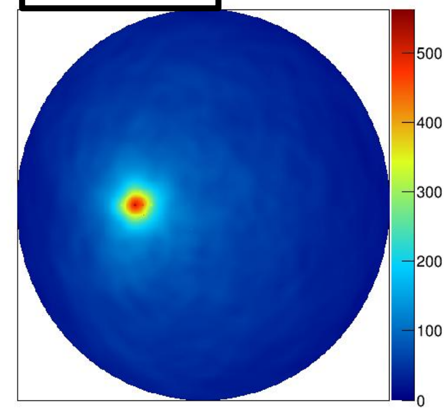
Geometry



C.C.1

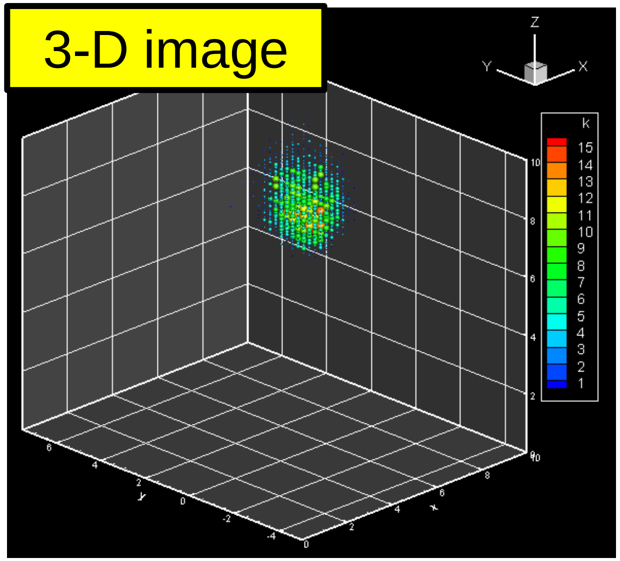


C.C.2

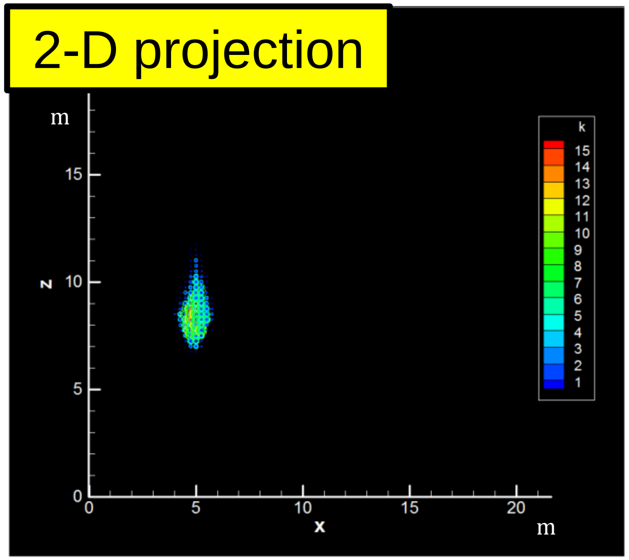


※ **Back-projection images**

3-D image



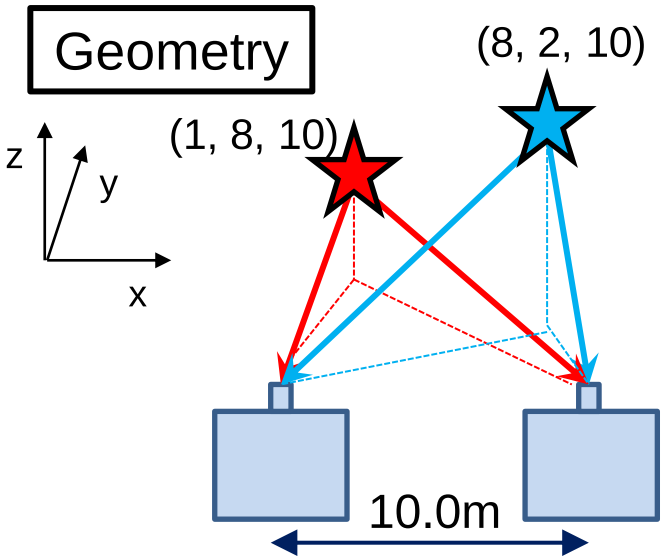
2-D projection

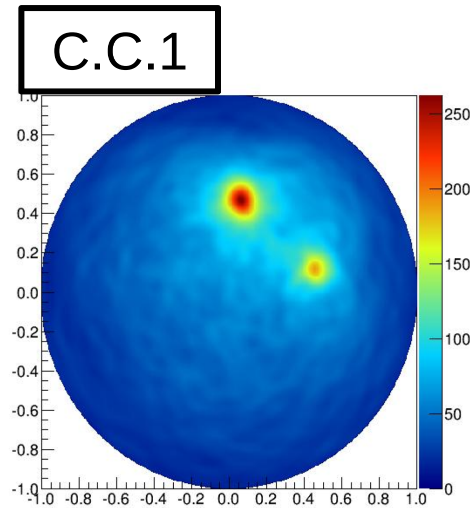


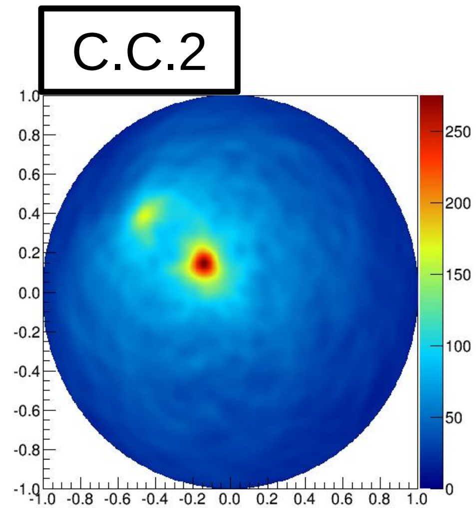
Spatial Resolution

Δx ~ 1.1m
Δy ~ 1.6m
Δz ~ 1.9m
(FWHM)

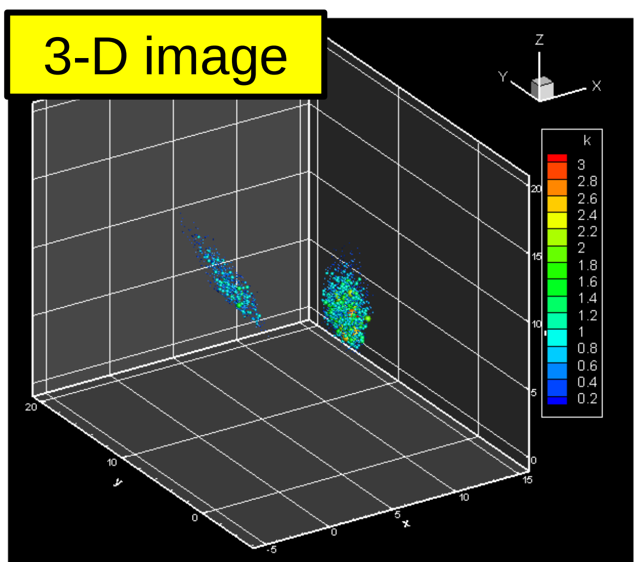
Stereo measurement : 2-sources simulation







※ Back-projection images



- Two sources clearly distinguished
- Spatial resolution becomes a little worse for y-direction and z-direction

Reconstruction from more than 3 images can be a solution for it …?

Summary

- To realize high h (~ 1% for 662 keV) , good $\Delta\theta$ (~ 10^o) and portablity (~ 1-2 kg), we are developing a novel handy Compton camera using 3-D position sensitive scintillators.

- Our prototype Compton camera performs very well on field-test in Fukushima, and more complete version of "DOI"-Compton camera is now being developed by Hamamatsu Photonics K.K.

- We showed that the method of stereo measurement is applicable to the Compton camera and indicated the first results of both simulations and field-tests.

Thank you for your kind attention!