Development of an 8 x 8 array of $LaBr_3$(Ce) pixels for a gaseous Compton gamma-ray camera

SHOGUN workshop @ RIKEN, Saitama, JAPAN (2011. 2. 5)

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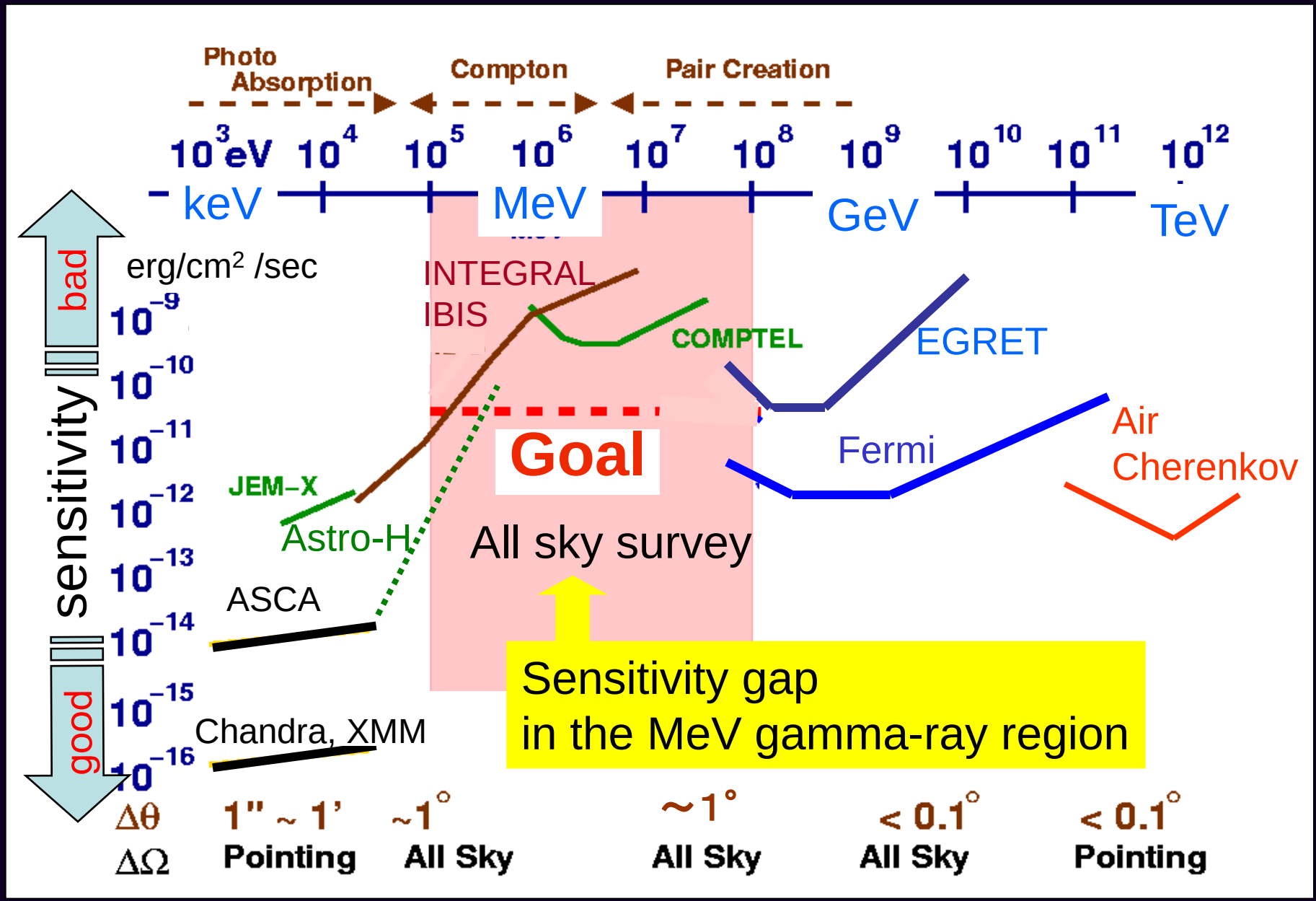
Contents

- Introduction
  - MeV gamma Astronomy / Medical imaging
  - Electron-Tracking Compton Camera (ETCC)
- Improvement of Angular resolution
  - $LaBr_3$ array
  - Application using the ETCC + $LaBr_3$ array
- New readout system for $LaBr_3$ array
- Summary

Sensitivity in X / Gamma-ray Astronomy

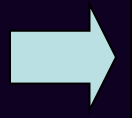


Medical Imaging (functional image)

PET : E = 511keV
SPECT : E < 360keV

Narrow

Wide dynamic energy range



➢New radioactive tracer with new radioisotopes

It is possible that
we obtain various images:
enzyme, protein reaction

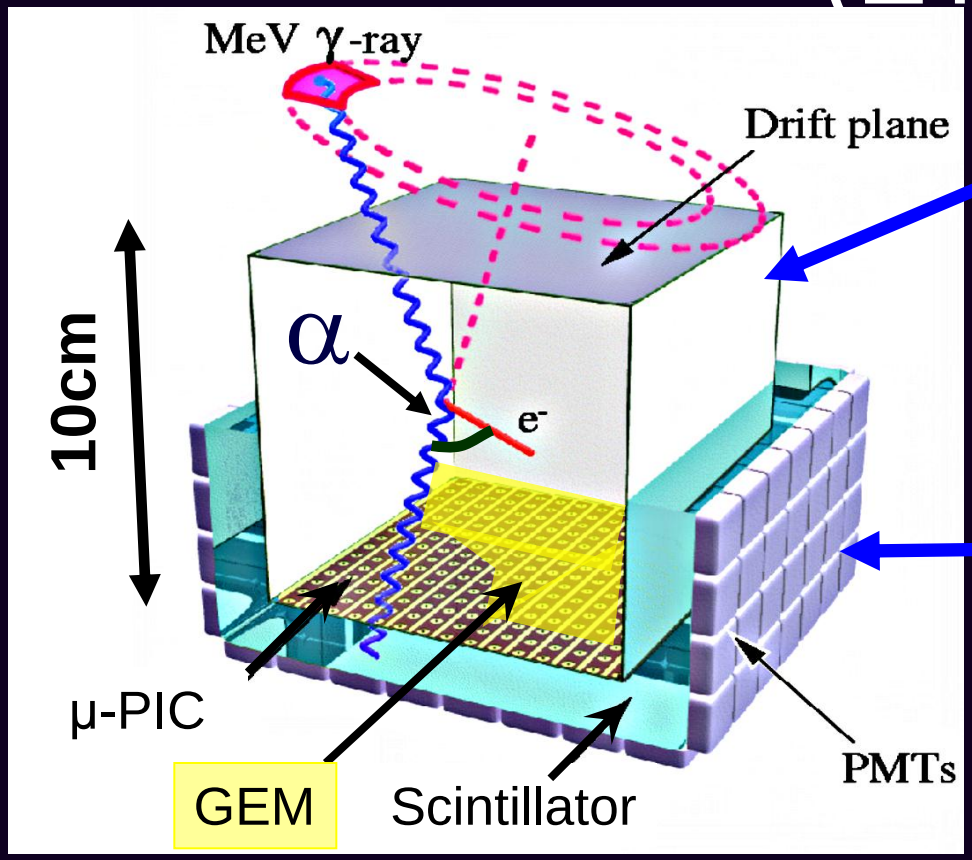
➢Multi-radioisotope Imaging With wide energy range

Simultaneous observation of some metabolisms and interactions

	^{139}Ce	^{133}Ba	^{131}I	^{198}Au	^{22} Na	^{18}F	^{54}Mn	^{65}Zn	^{60}Co
E [keV]	167	354	364	412	511 1275	511	835	1116	1173 1333

SPECT ⟵ ⋯⋯ PET

Electron-Tracking Compton Camera (ETCC)



gaseous TPC
(time projection chamber) :
[containing μ-PIC(MPGD),
GEM (Sauli (1997), Inuzuka *et al.* (2004))]
--- energy and 3-D track of
Compton-recoil electron

Scintillation camera:
[Pixel array Scintillator]
--- energy and position of
scattered gamma ray

- Large FOV (~3str)
- Kinematical background rejection by comparison of two α angles

Reconstruct incident gamma ray event by event

Energy dynamic range: from 0.1 to ~10 MeV

Imaging with ETCC

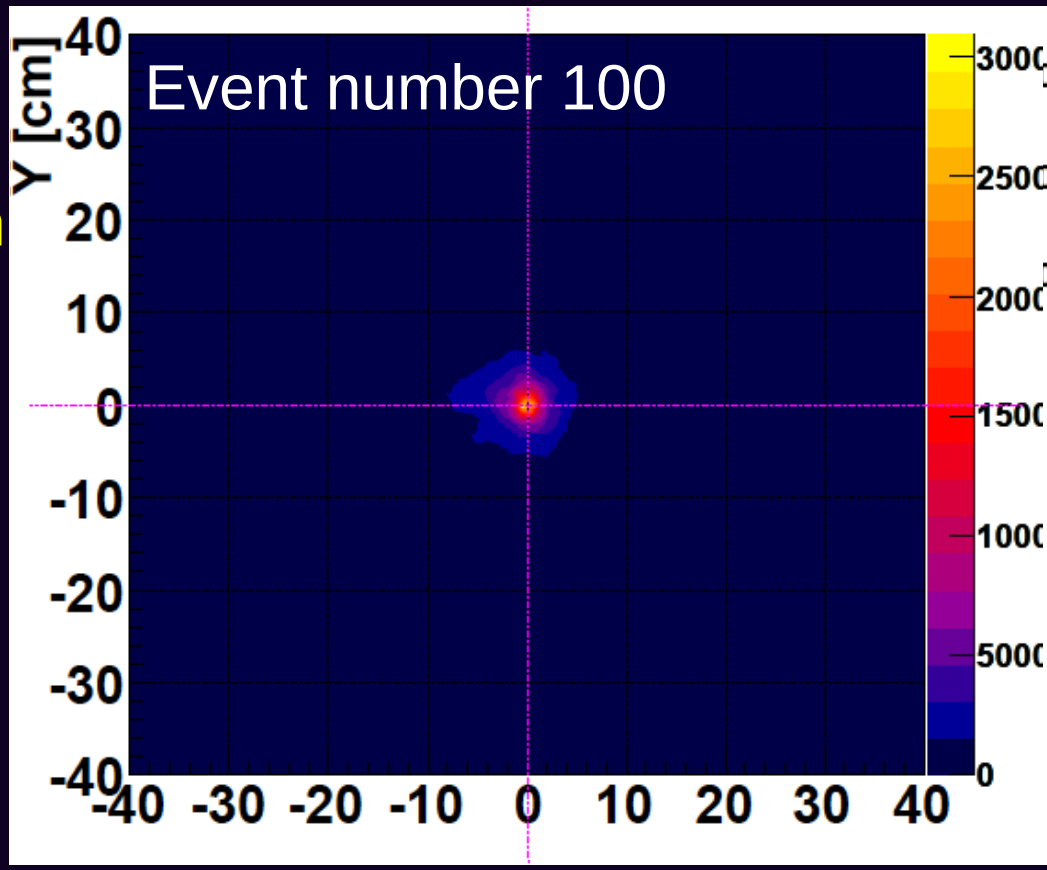
Target

Error region
(arc)

Incident
Gamma rays

Gaseous
TPC

Scintillator



Recoil electron
(Electron cloud)

Scattered gamma rays

Vs. Conventional Compton Camera

Advanced Our ETCC

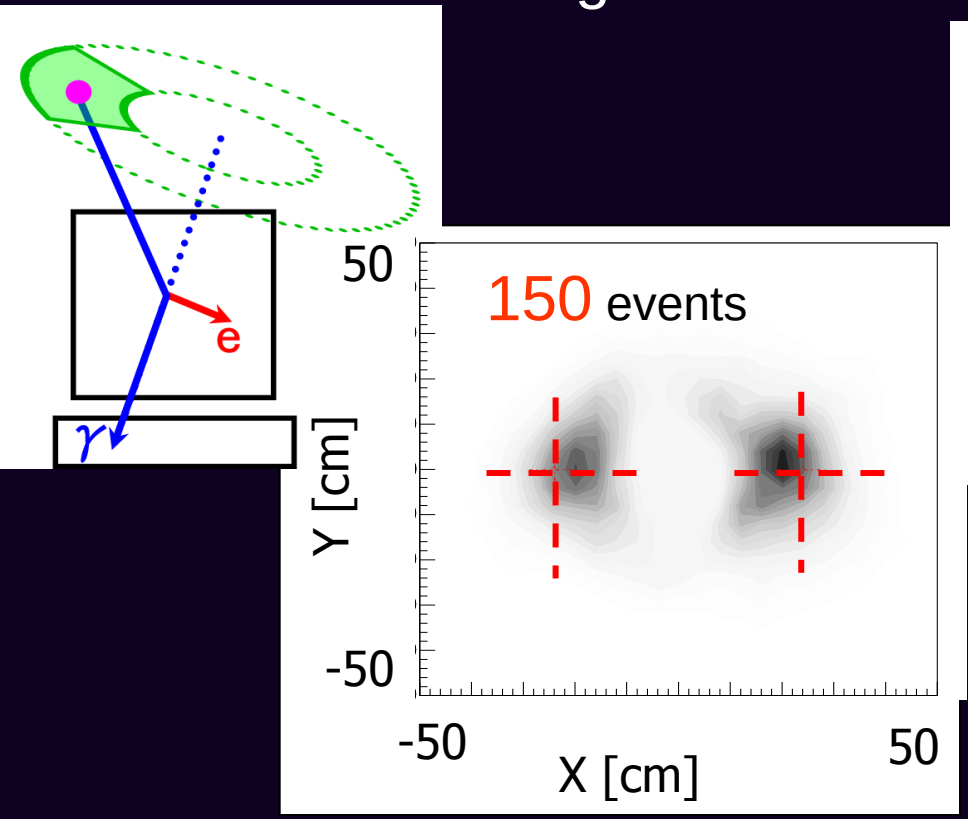
Measure
the 3-D track of a Recoil electron

- Reconstruction : point
- Direction error region: arc

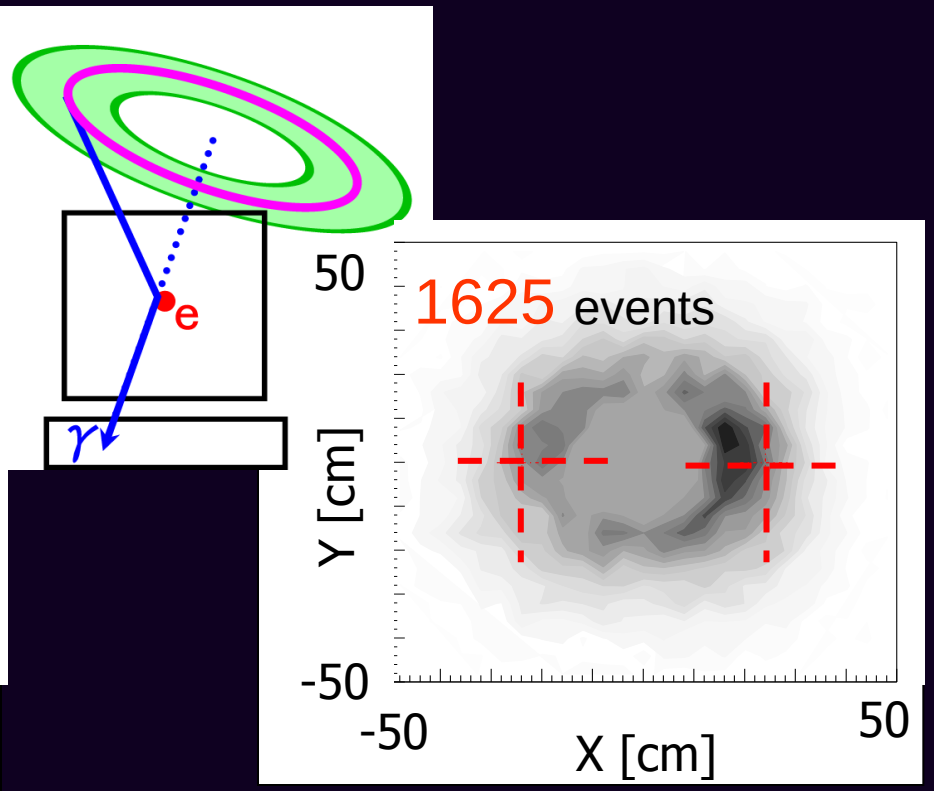
Conventional COMPTEL

DO NOT measure
the track of a Recoil electron

- Reconstruction : circle
- Direction error region : donut

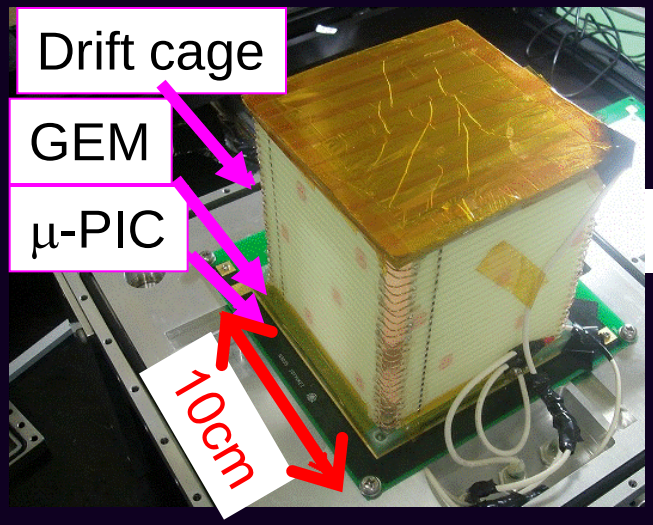


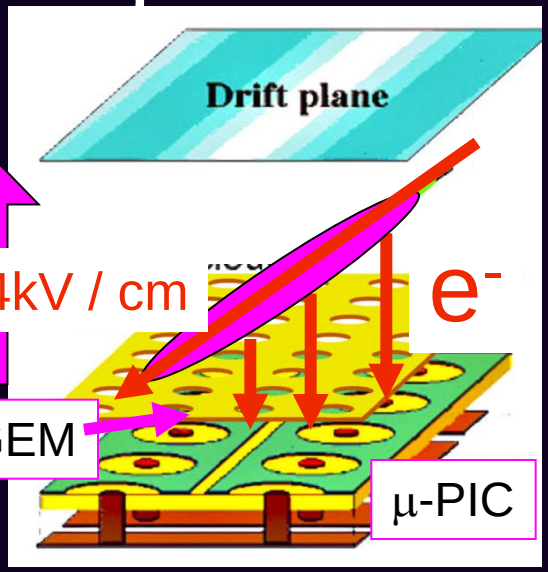
^{137}Cs(1MBq)×2, Advanced Compton

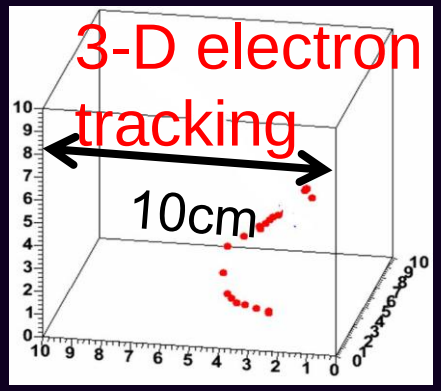


^{137}Cs(1MBq)×2, Classical Compton

Gaseous Time Projection Chamber (TPC)



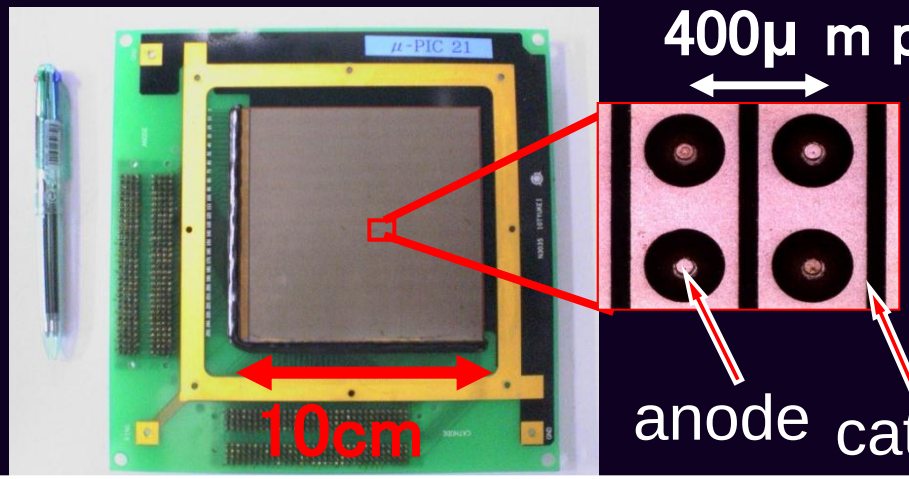




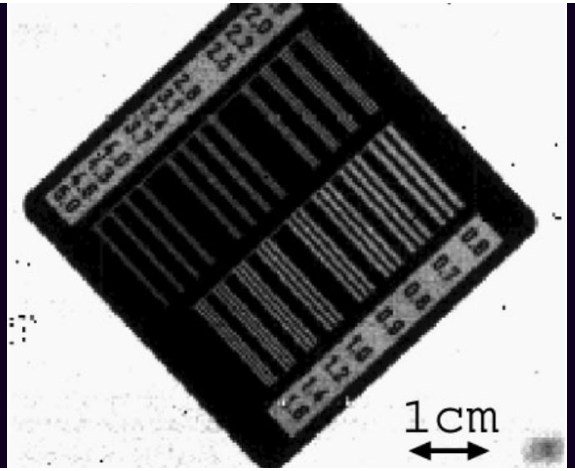
Gas gain: ~30,000
Position Resolution (FWHM) : ~0.4 mm (3-D)

μ-PIC (micro pixel chamber)

- 2-D gaseous detector: ~ 65,000 pixels



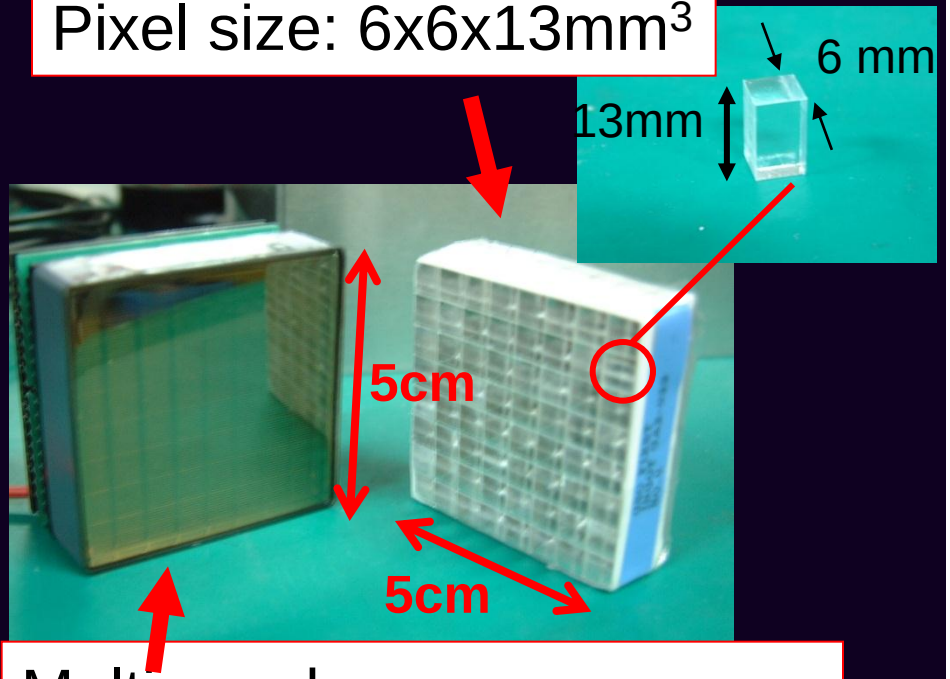
X-ray image with μ-PIC



Position resolution:120 μm

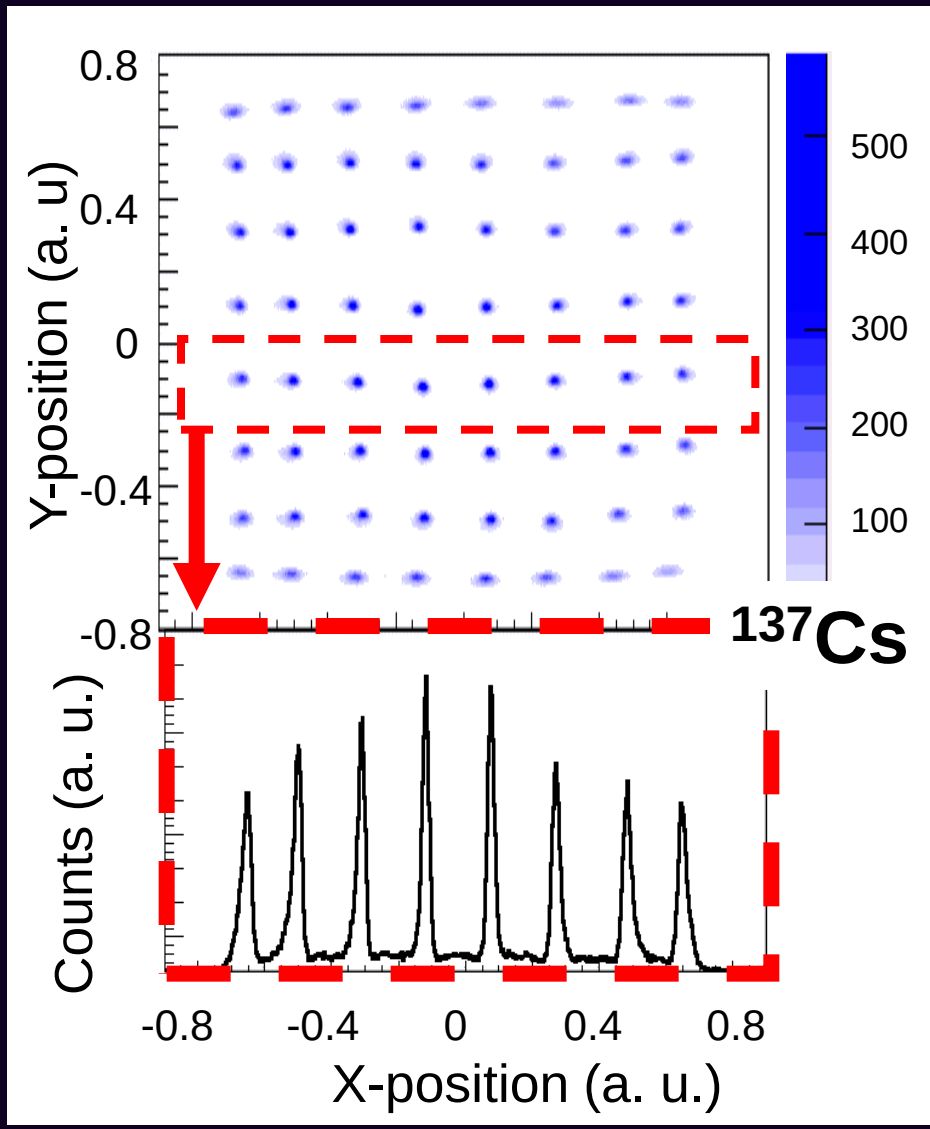
Position-Sensitive Scintillation Camera

GSO(Ce) 8x8 pixels
Pixel size: 6x6x13mm^3



Multi-anode
Photo Multiplier Tube (PMT)
HPK H8500 8x8 anodes

Dynamic energy range: 0.08 -1 MeV
Eng. Resolution: 10.5 % @662 keV



2-D image in flood-field irradiation

SMILE Roadmap

SMILE Project *Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment*

$(10cm)^3$ ETCC (2006) SMILE-I

- Operation test of ETCC @ 35km
- Measurement of Diffuse cosmic and atmospheric gamma rays ~ 3hours (live time)

$(30cm)^3$ ETCC (2013) SMILE-II

Observation of Crab or Cyg X-1 ~ 3hours

$(40cm)^3$ ETCC

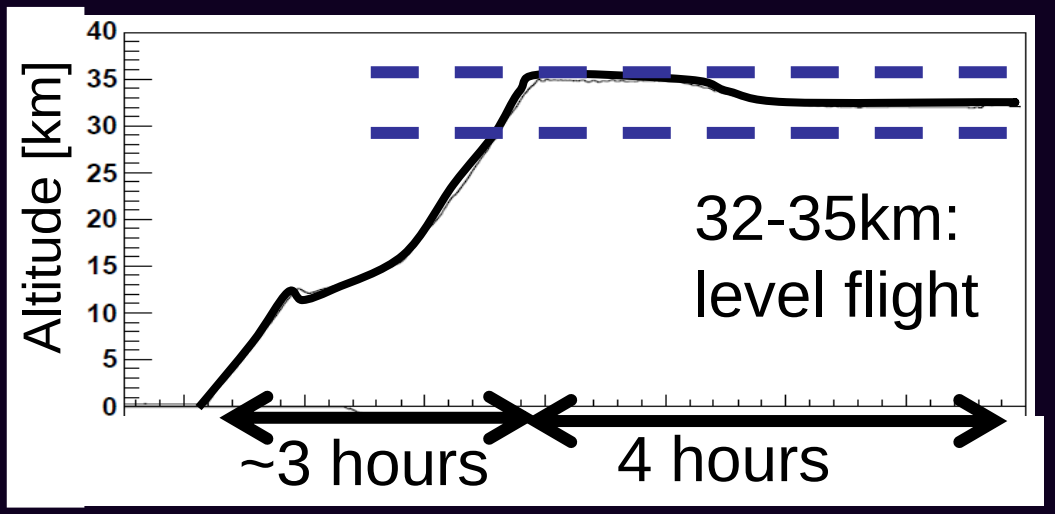
long duration balloon～10days

$(50cm)^3$ ETCC All sky survey

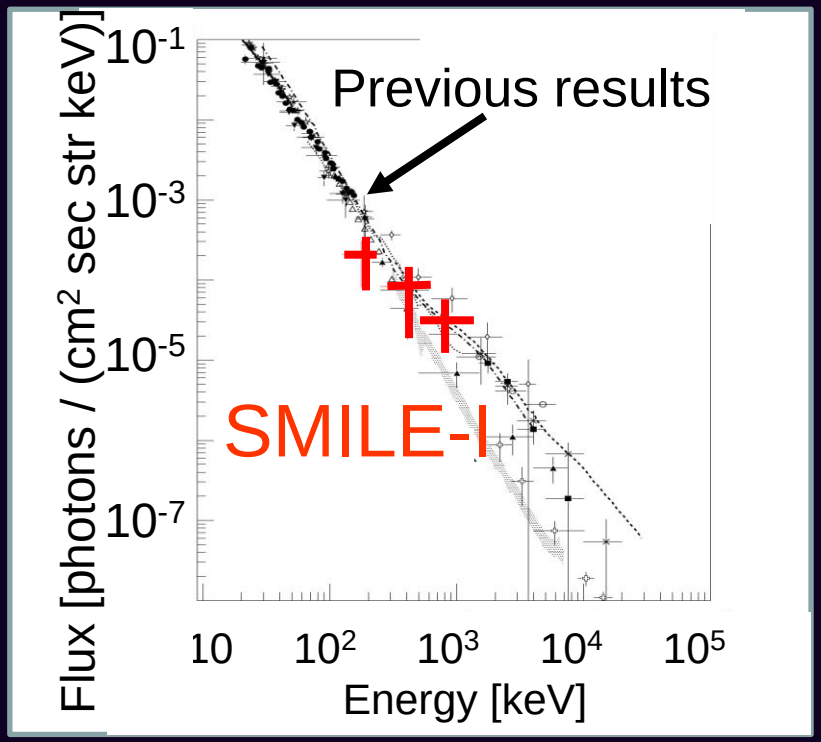
Orbiting balloon (~30days) or satellite

SMILE-I Flight

The balloon was
Launched on Sep. 1, 2006
@ Sanriku Balloon Center
JAXA / ISAS, Japan



diffuse cosmic γ rays



Launching

landing

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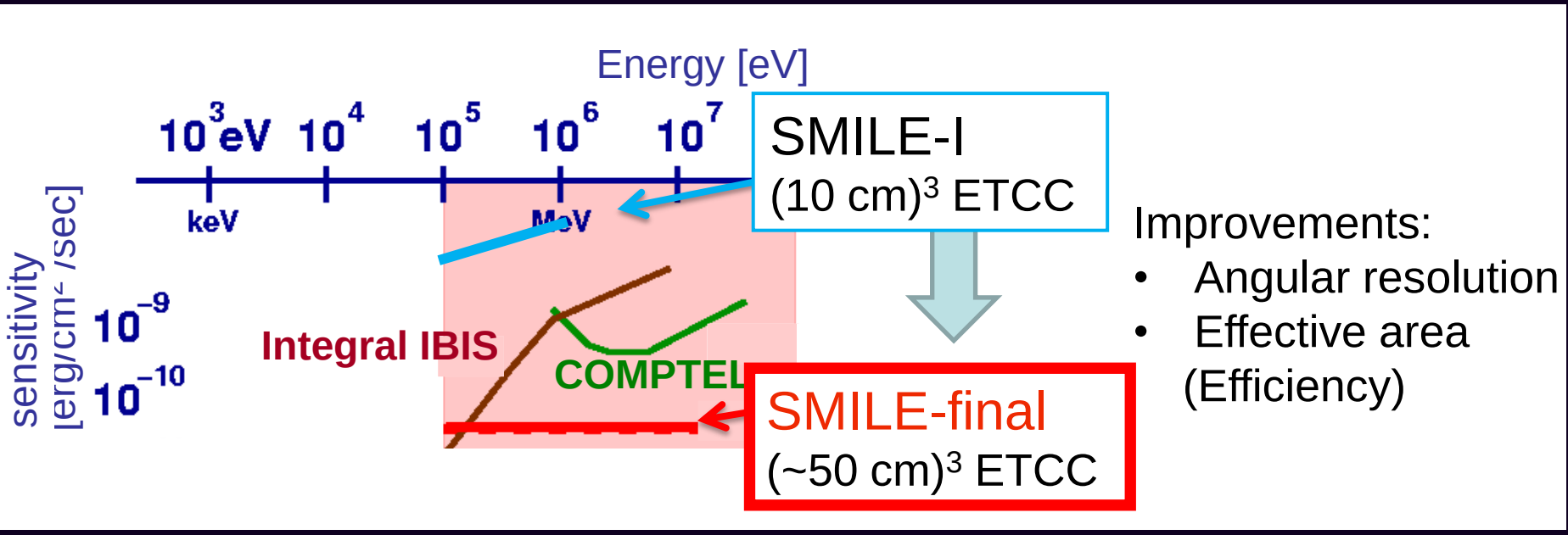
Improvement of Angular Resolution

Goal of angular / spatial resolution (FWHM):

Astronomy ··· < 4.7 deg. @1.3 MeV
(= status of COMPTEL)

Medical imaging ··· < ~1 cm

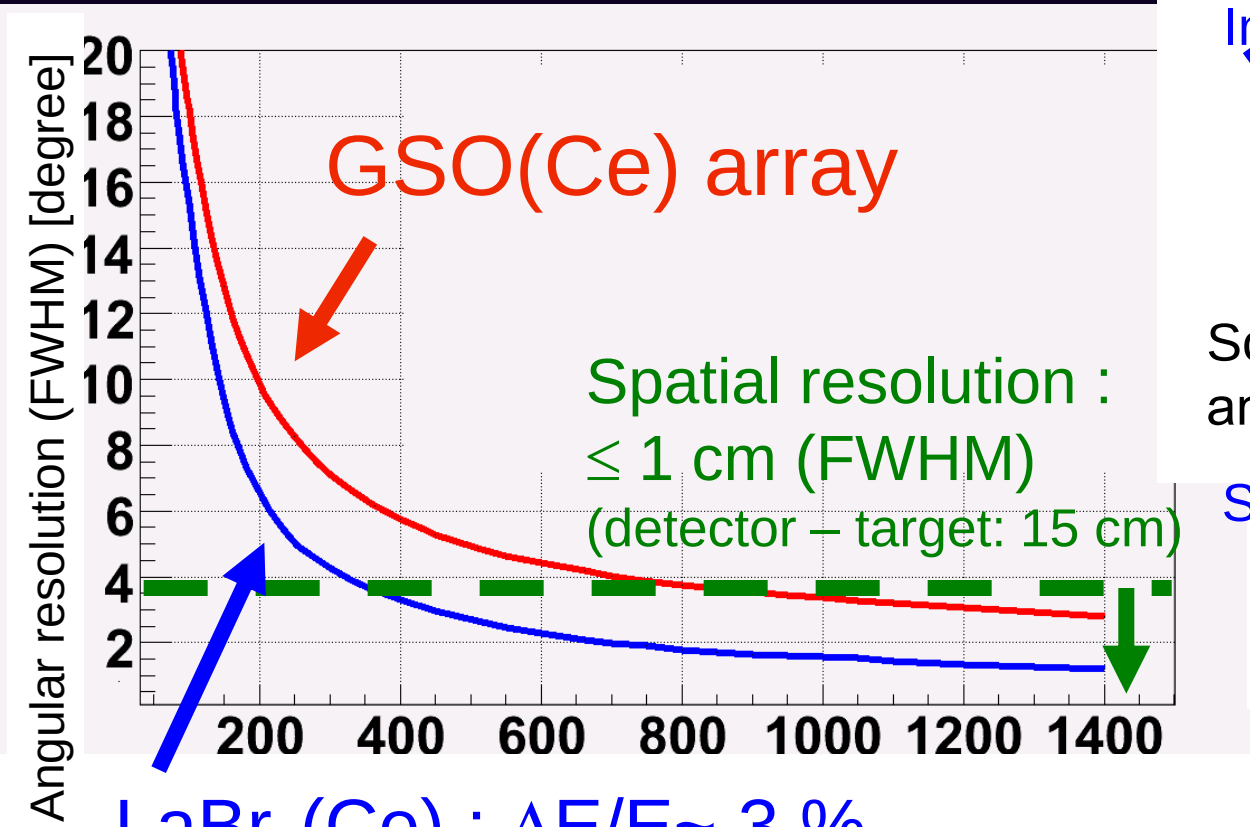


Improvements:

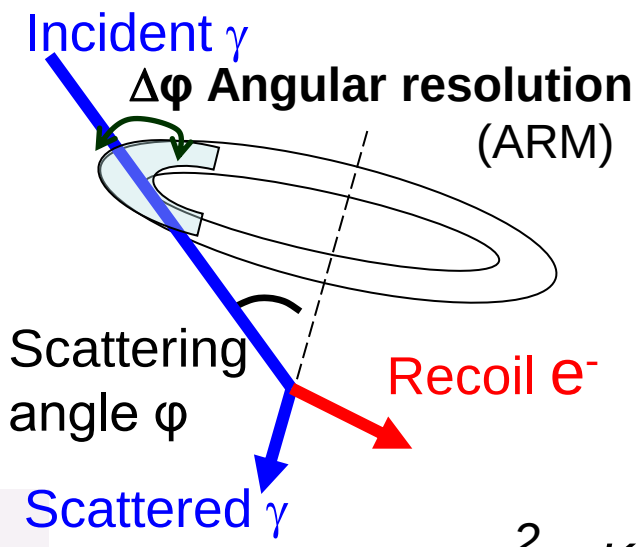
- Angular resolution
- Effective area (Efficiency)

To obtain a higher angular resolution / spatial resolution (≤ 1cm)

Angular resolution of the Compton camera depends on the energy resolution of scintillator



$LaBr_3(Ce)$: $\Delta E/E \sim 3\ \%$ @ 662 keV (FWHM) Loef *et al*. (2001)



$$\cos\varphi = 1 - \frac{m_e c^2}{(E+K)}\frac{K}{E}$$

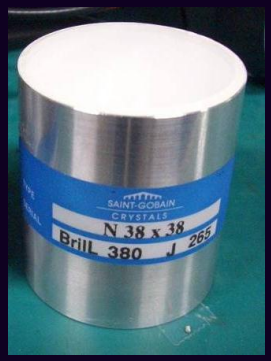
Sci. Eng. Res. @662keV	Com. Angular Res. @662keV
10.5 %	4.2°
3%	2.1°

$LaBr_3(Ce)$ scintillator

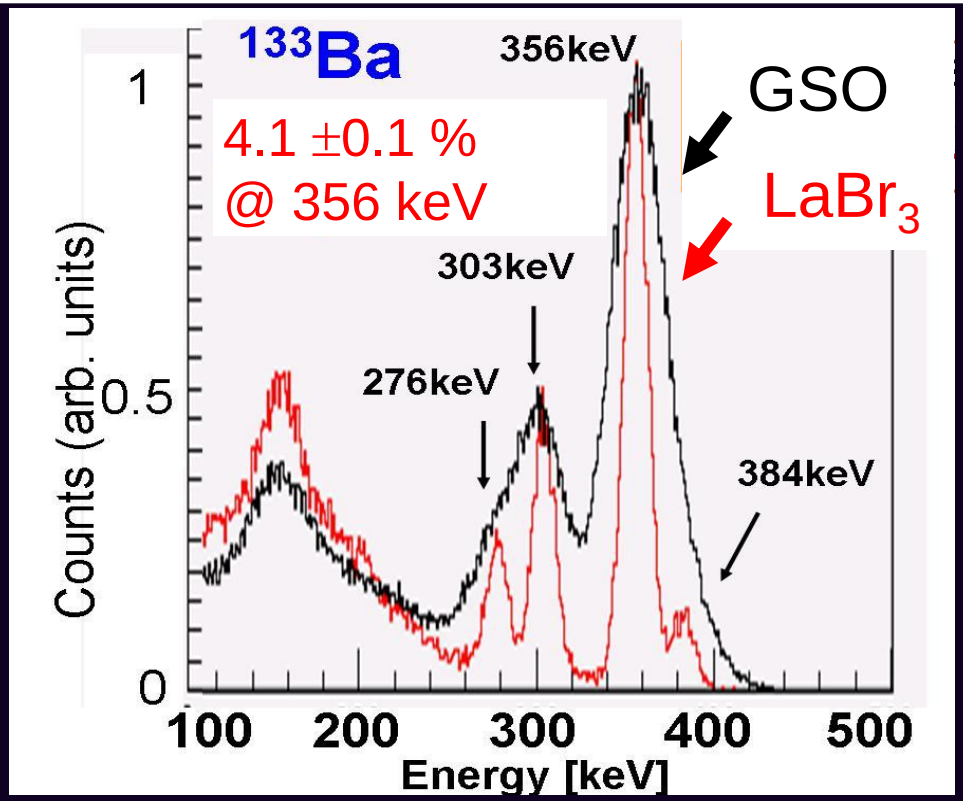
- Excellent energy resolution
- High light yield : 160 NaI%
  [cf. GSO(Ce) : 20 NaI%]
- Fast decay time: ~20 nsec
- hygroscopic

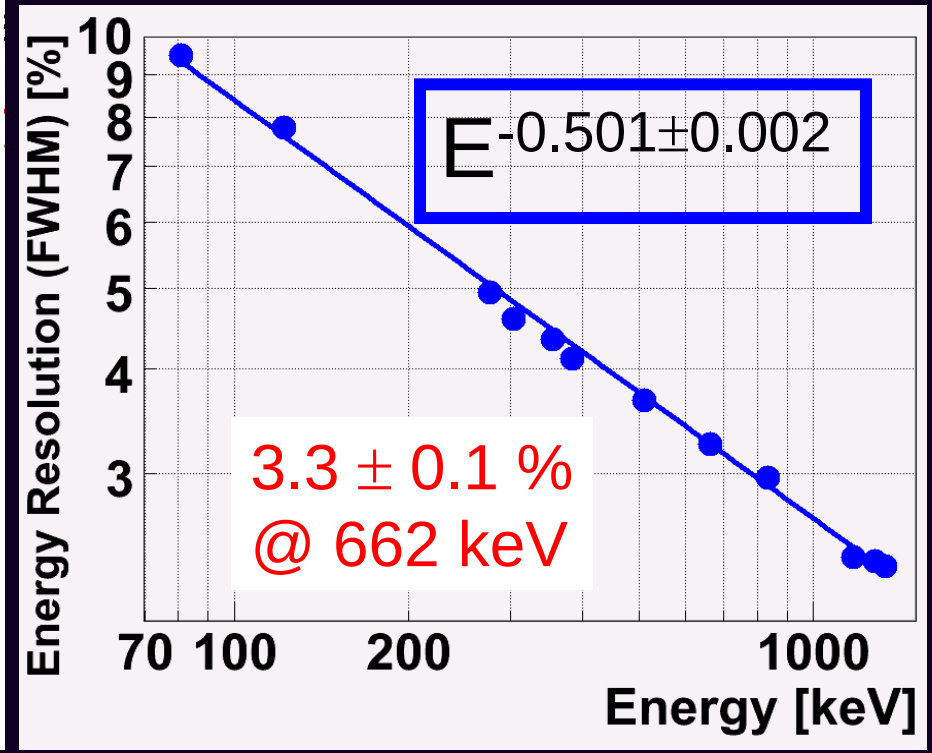
Loef *et al.*, (2000)

Saint-Gobain
BrilLanCe380
Size:ϕ38×38mm^3



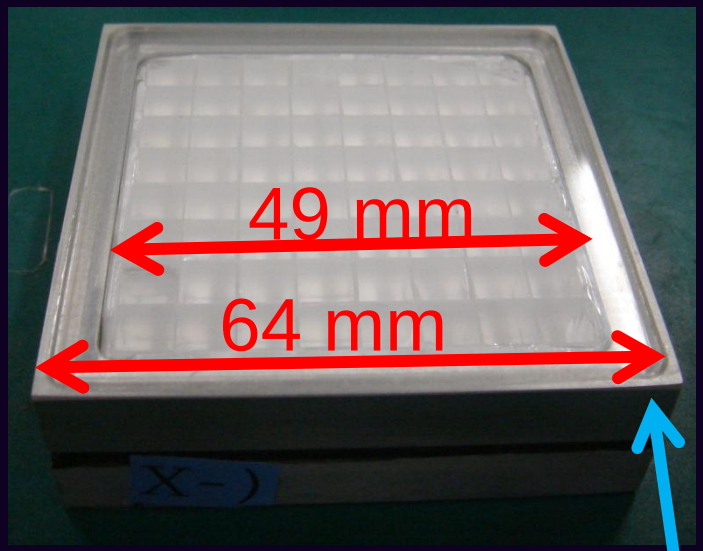
Energy resolution measured with a single-anode PMT (SAPMT) (HPK R6231)

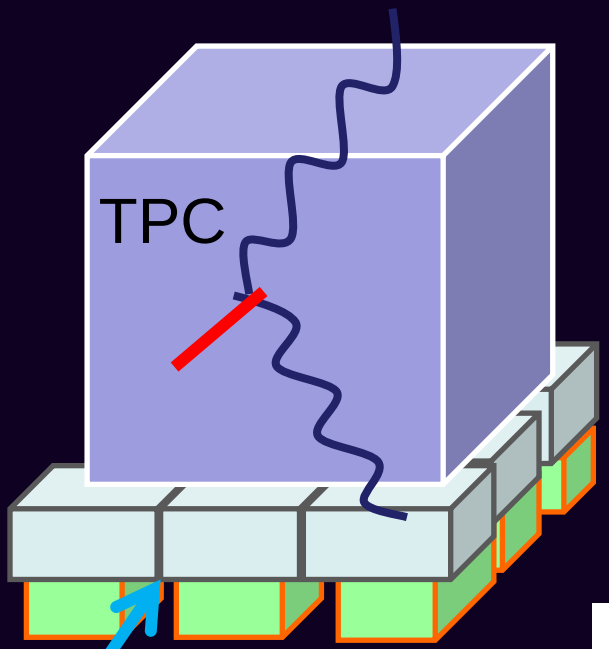




Saint-Gobain $LaBr_3(Ce)$ array

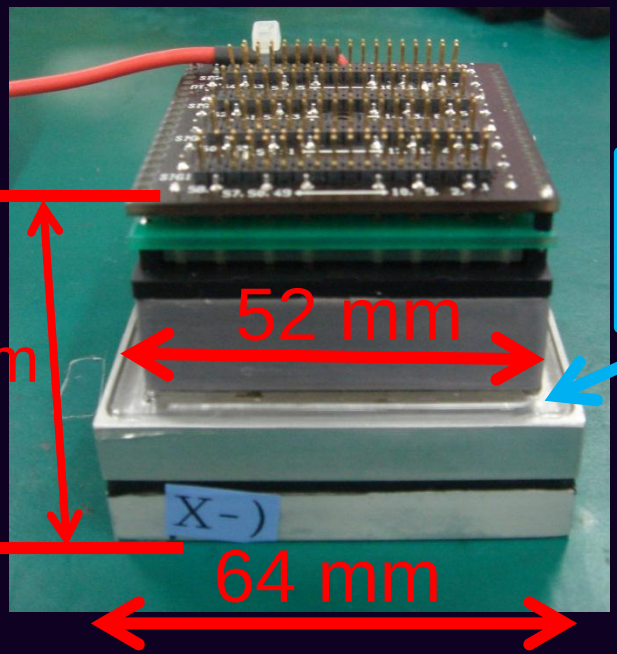
Pixel size: 5.9 mm x 5.9 mm x 15 mm





Scintillator package

PMT



Dead space

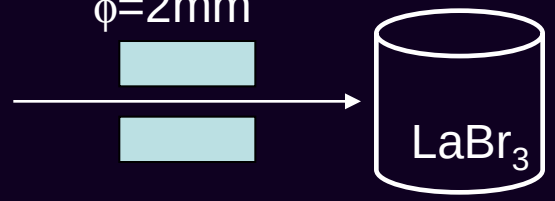
GSO array

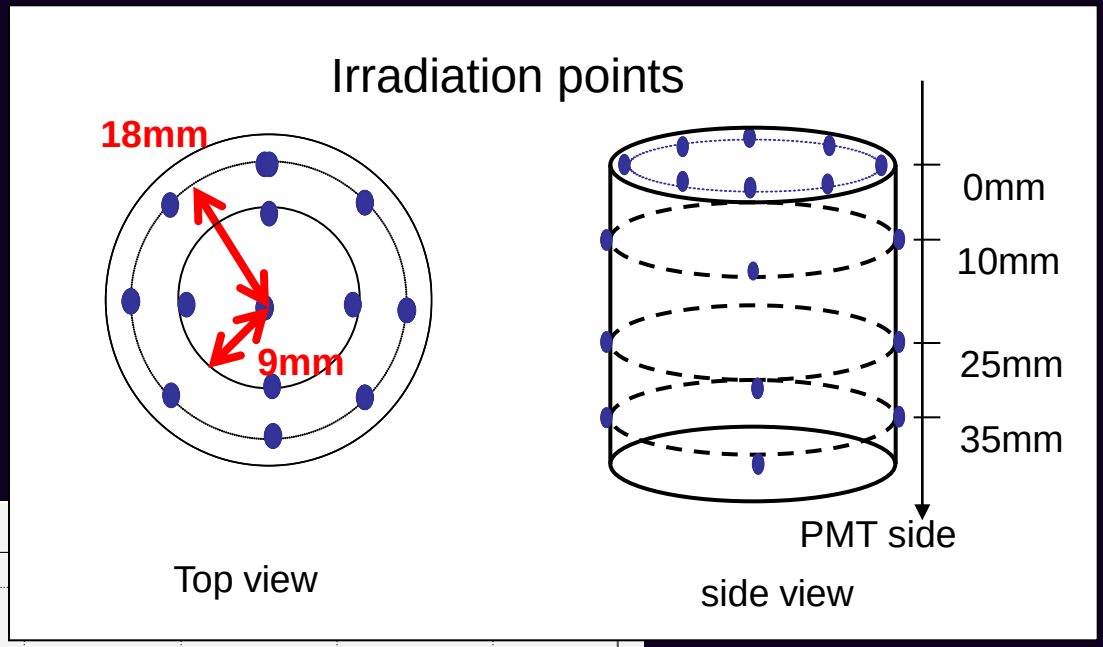
Uniformity

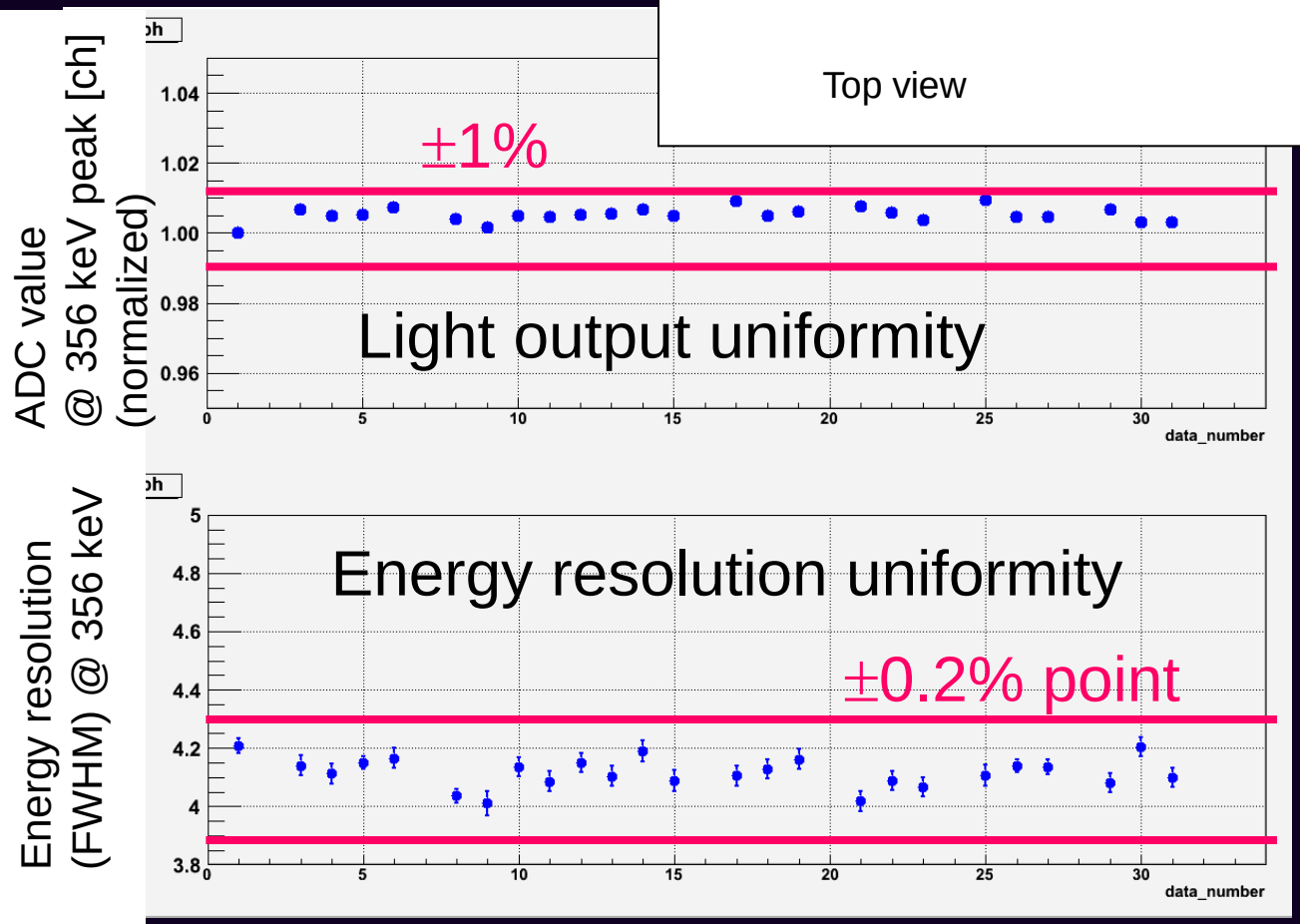
Collimator

ϕ=2mm

^{133}Ba Source







Ave. ± σ
1.005±0.002

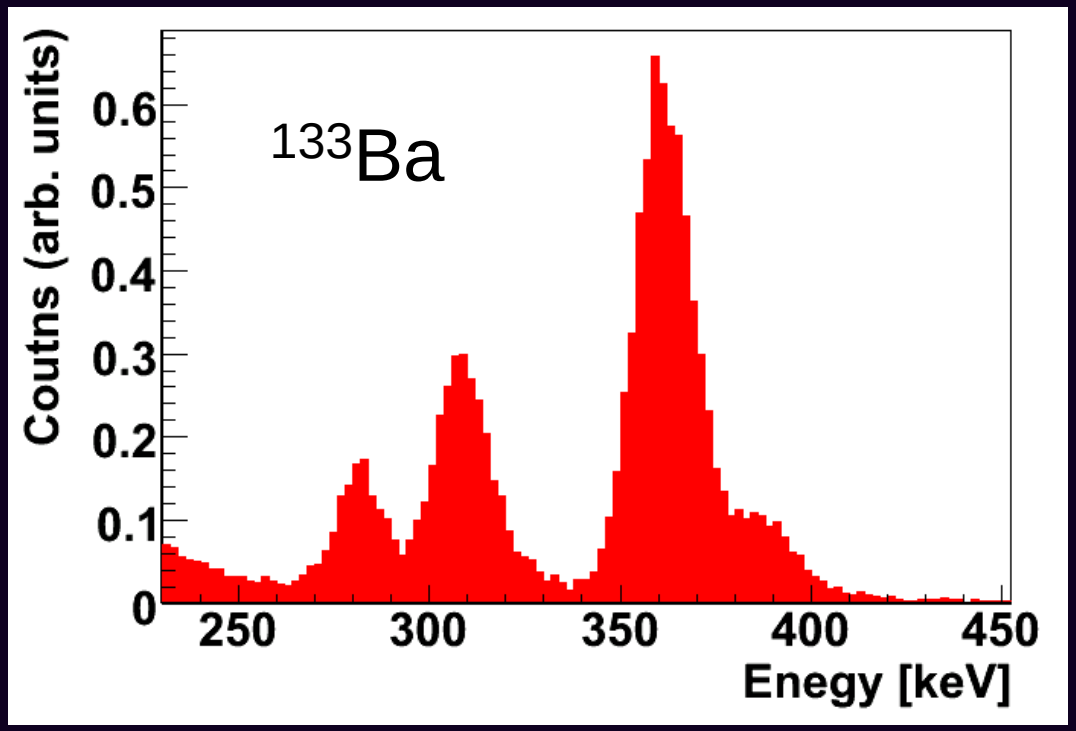
Ave. ± σ
4.11±0.05 %

Naked $LaBr_3$ pixel

Test of our cutting & polishing technique

Saint-Gobain
BrilLanCe380
Size:ϕ38×38mm^3

Size: 6×5×14mm^3 pixel
glass window : none
Hermetic package : none



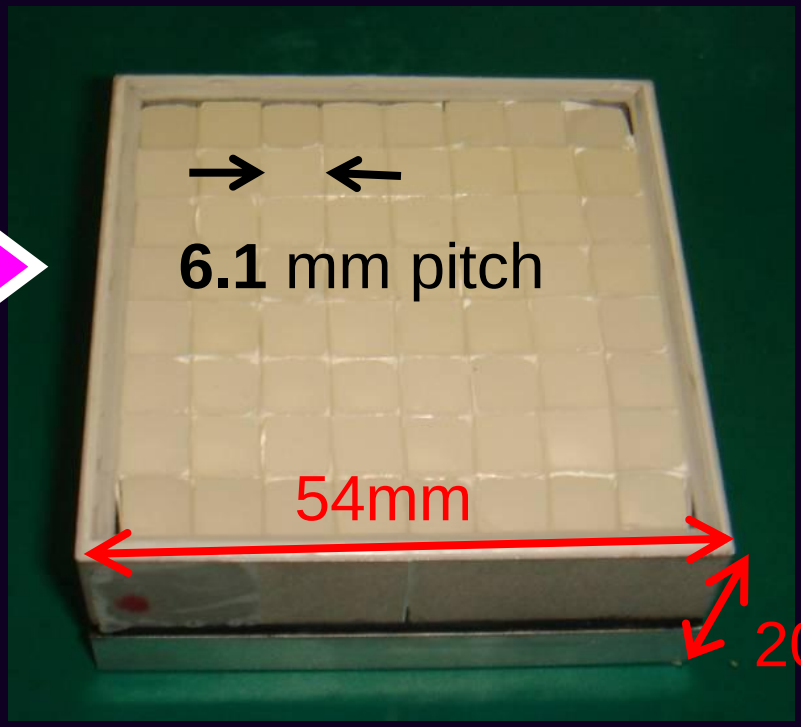
Put the crystal on
single anode PMT (R6231)
directly under the dry condition

Energy resolution (FWHM)
4.5 ± 0.1 @ 356 keV
3.5 ± 0.1 @ 662 keV

Assembly of $LaBr_3$(Ce) array

Using our technique, we cut 5.8×5.8×15.0mm^3 pixels out of two ϕ38×38 mm^3 $LaBr_3$ crystals and assembled an 8×8 array.

Saint-Gobain BrilLanCe380
Size:ϕ38×38mm^3



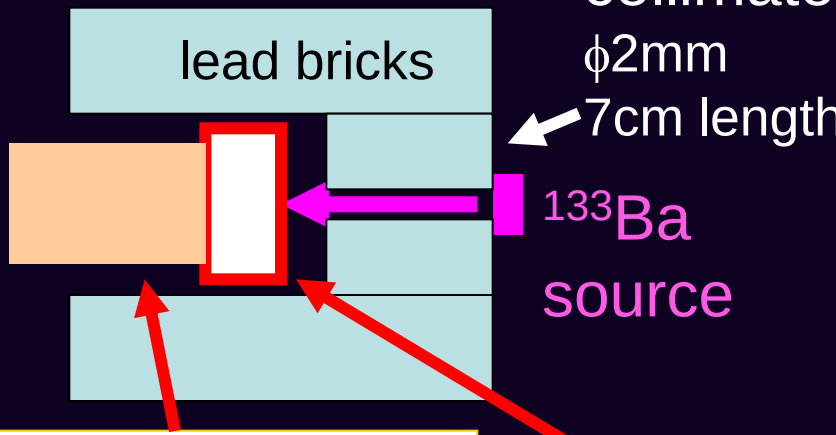
Dead space
1,700 mm^2 (S. G.)
⇓
500 mm^2 (Ours)

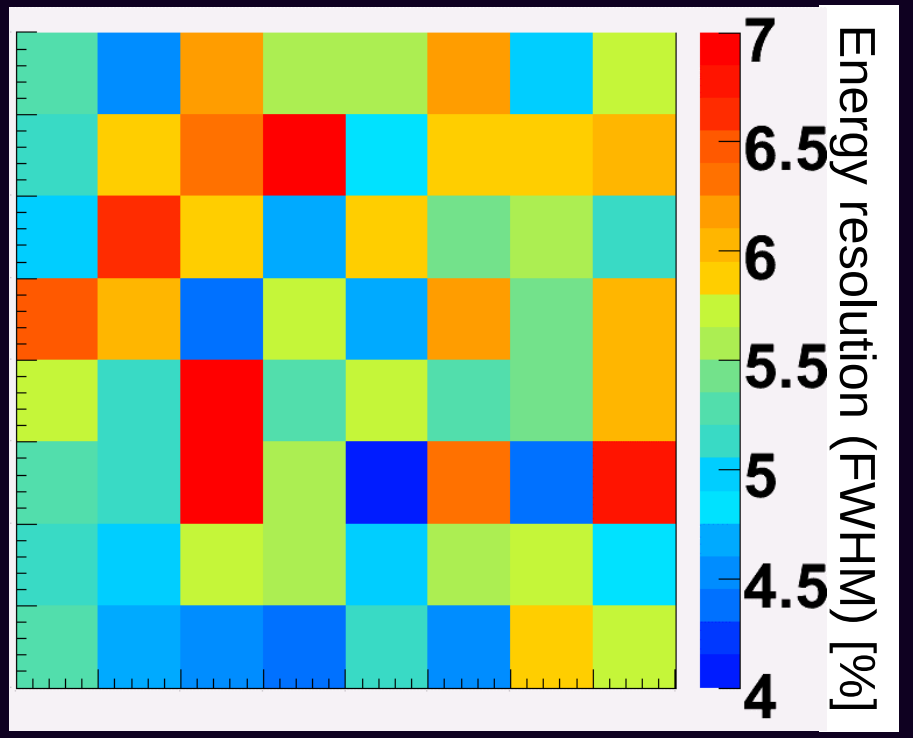
Effective area : 49 × 49 mm^2
(=PMT photocathode)
Glass window : Quartz (t 2.3 mm)
Hermetic package : Aluminum (t 0.5 mm)

Performance of each pixel

To estimate the performance without the effect of gain uniformity (~3) among 64 anodes of Multi-Anode PMT (H8500)

irradiation of collimated gamma rays to a pixel one by one



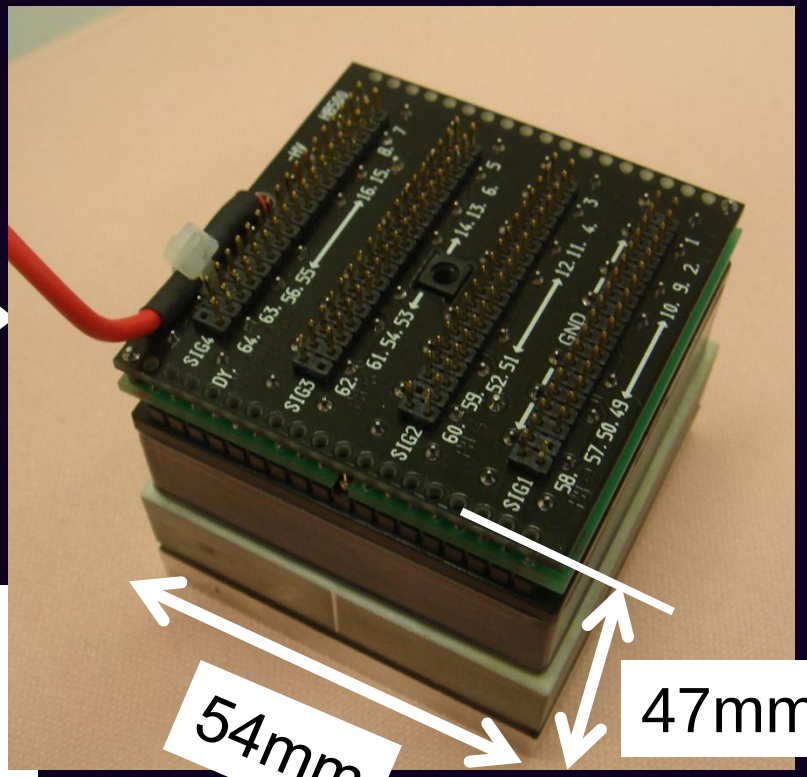


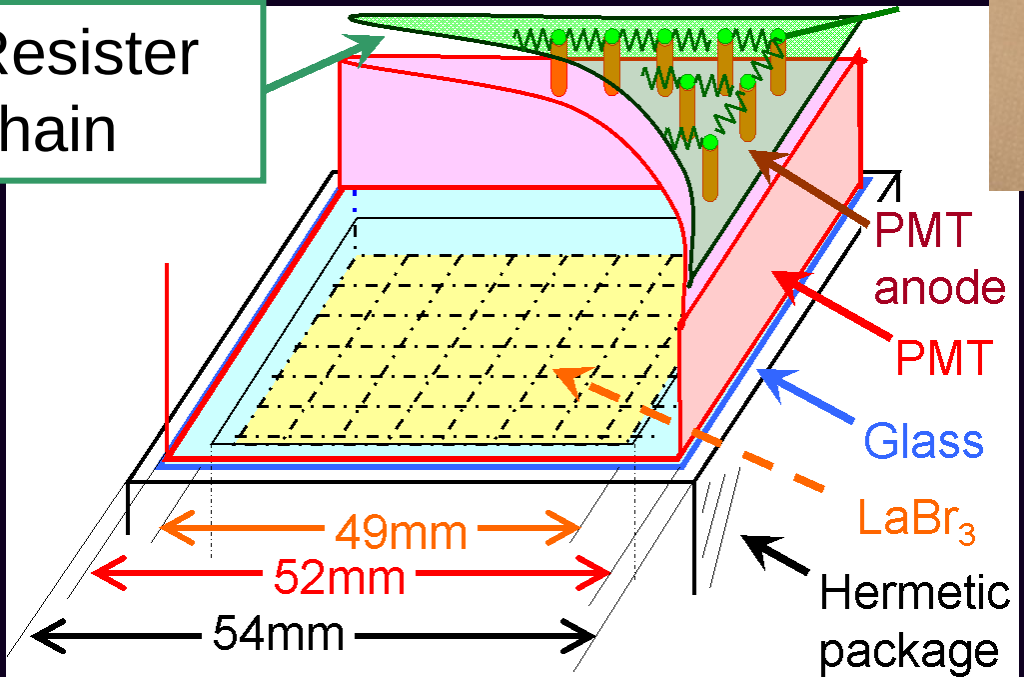
Map of energy Res. of 8 × 8 pixels

Energy resolution (FWHM)
@ 356 keV
Ave. $\pm\sigma$ = 5.5 $\pm$ 0.7 %

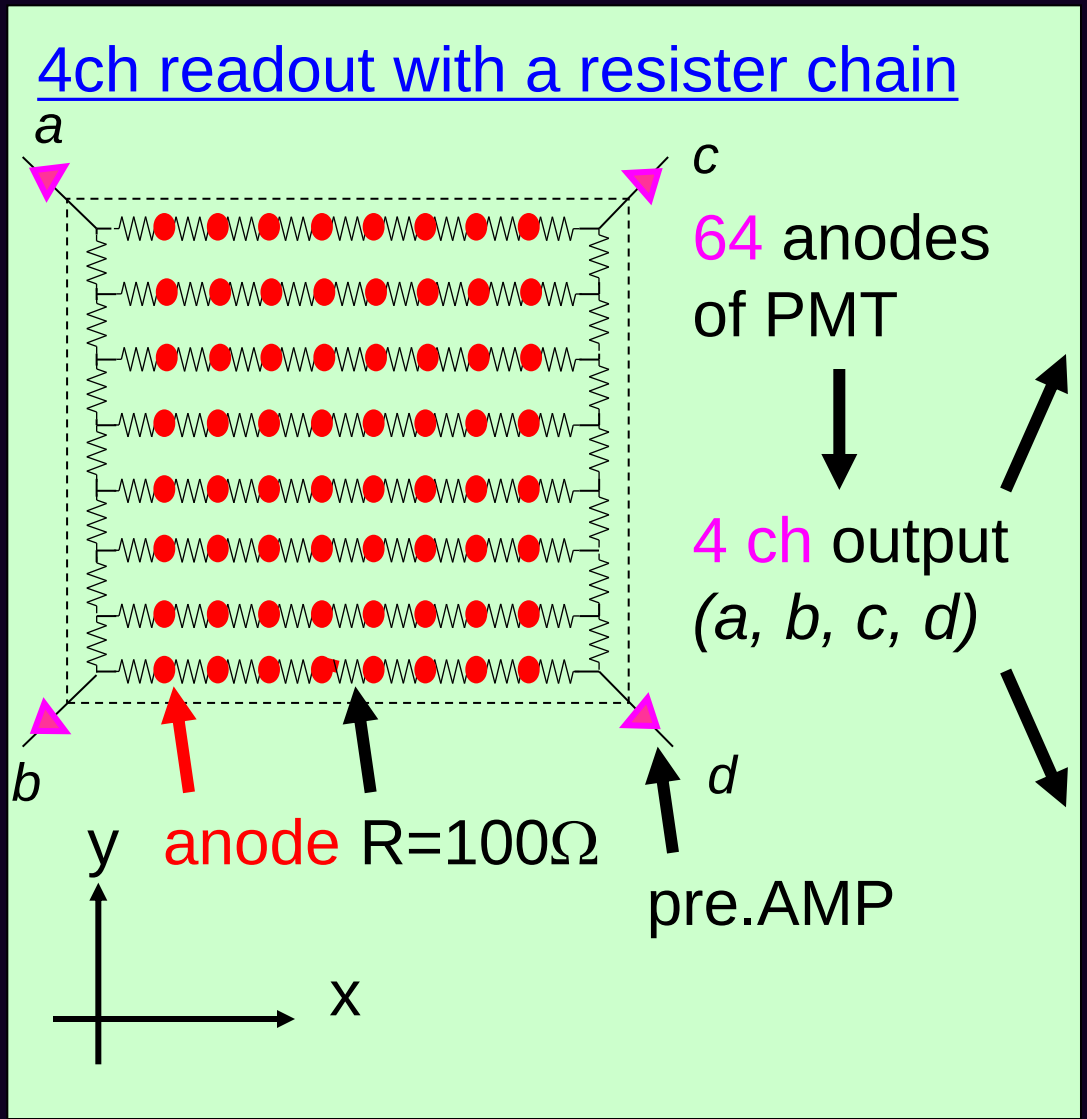
4ch readout with H8500

$LaBr_3$ array MAPMT HPK H8500





Readout of an array camera



Charge-division method

$$x = \frac{c + d - a - b}{a + b + c + d}$$

$$y = \frac{a + c - b - d}{a + b + c + d}$$

→ X, Y position

Sum

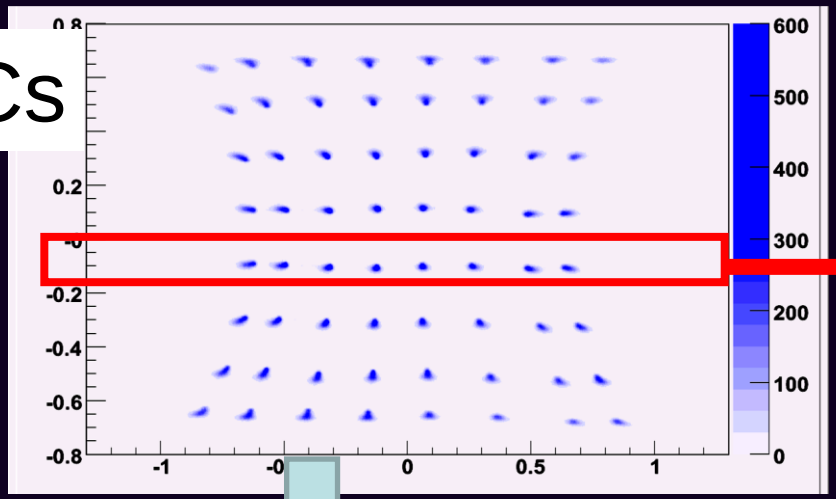
$$E = a + b + c + d$$

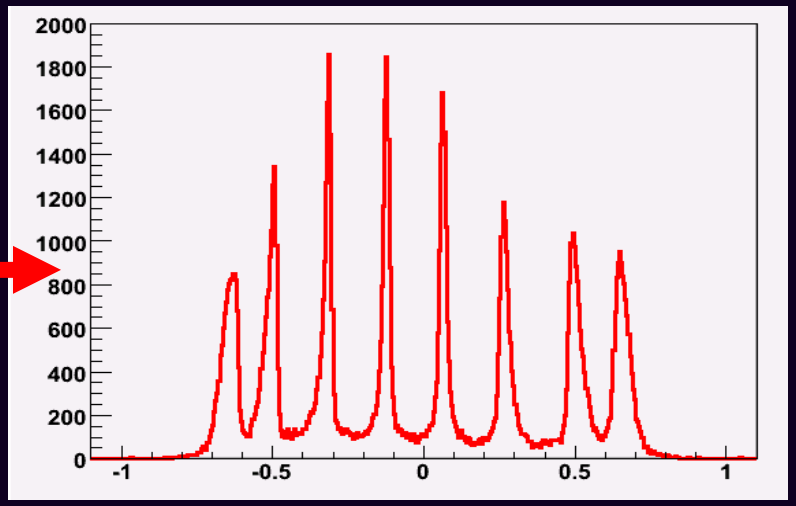
→ Energy

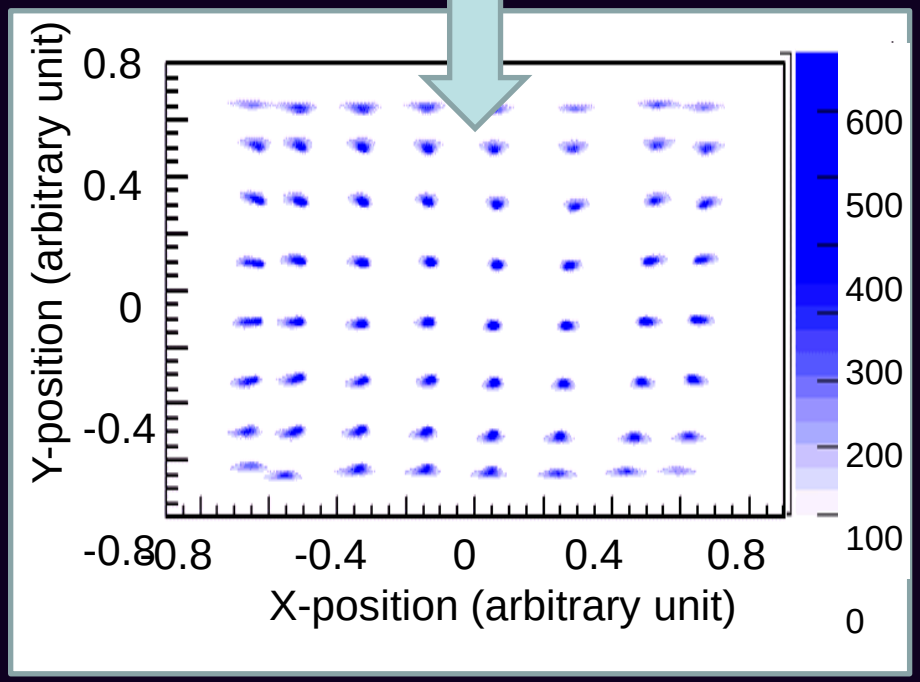
Image and energy spectrum

- Flood field irradiation image

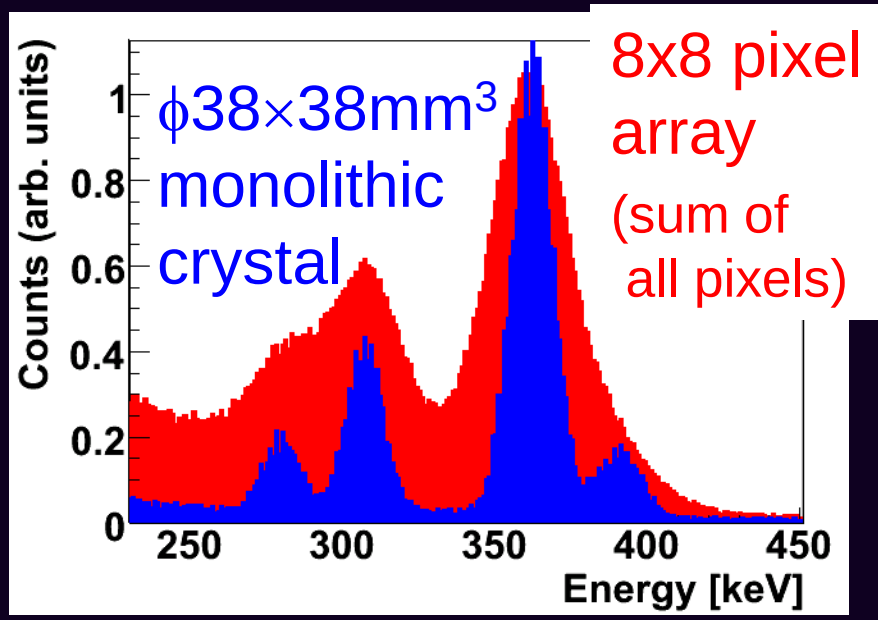
^{137}Cs







- Energy spectrum (^{133}Ba)



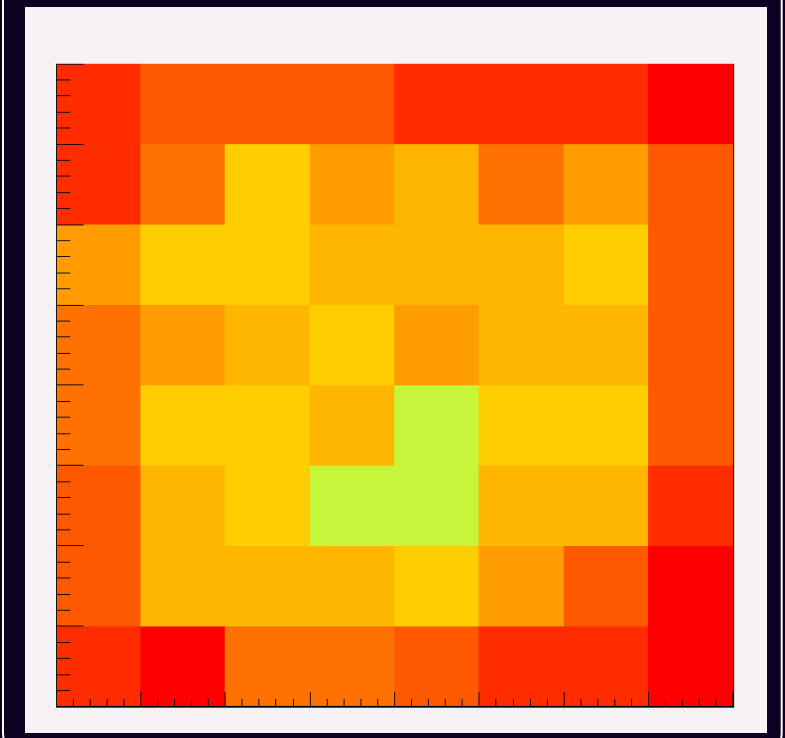
Energy resolution (FWHM) of each pixel @ 662 keV (^{137}Cs)

GSO

6×6×13 mm^3 8×8 array

Ave. ± RMS :

10.8 ± 1.0%

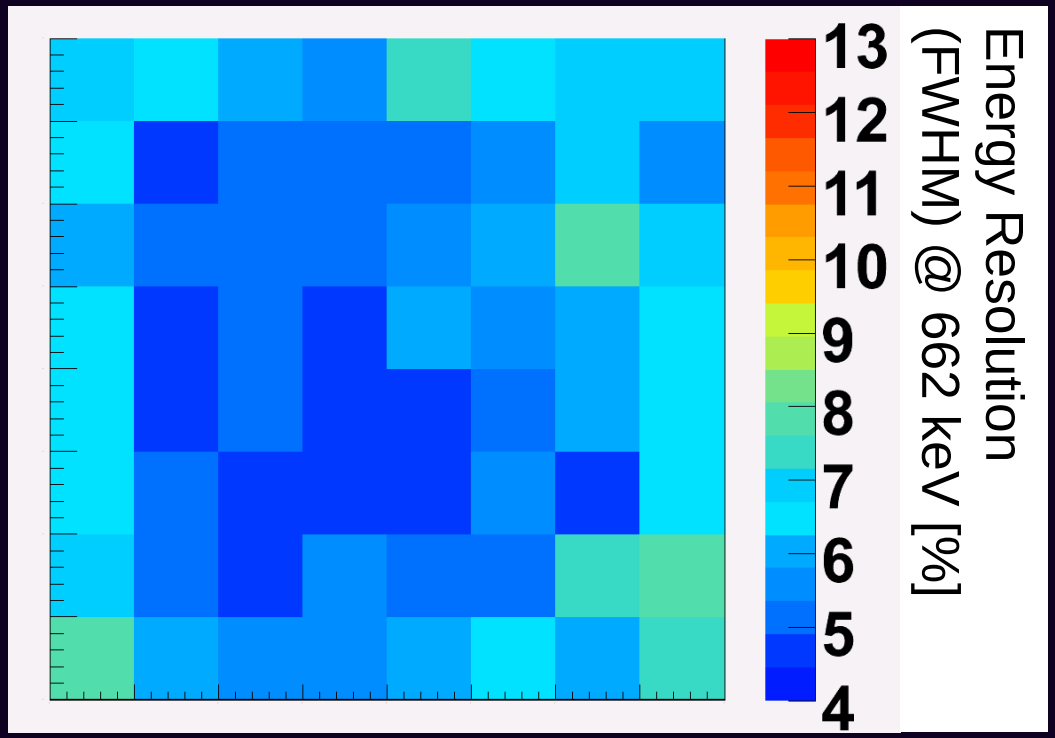


$LaBr_3$

6×6×15 mm^3 8×8 array

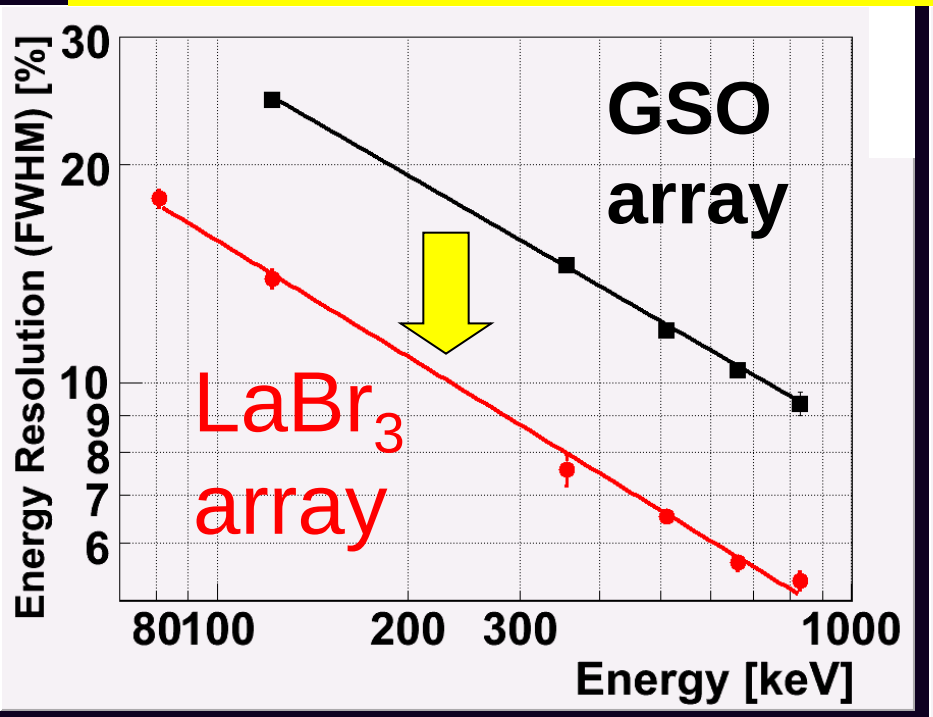
Ave. ± RMS :

5.8 ± 0.9%



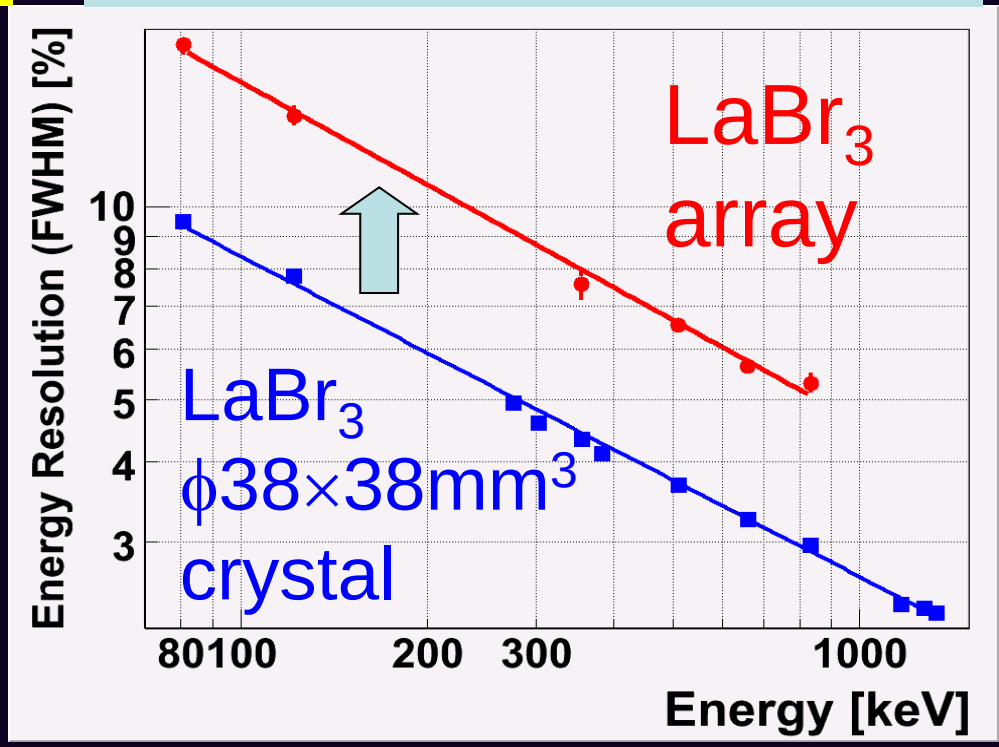
Energy Resolution (2)

Improved by factor ~2



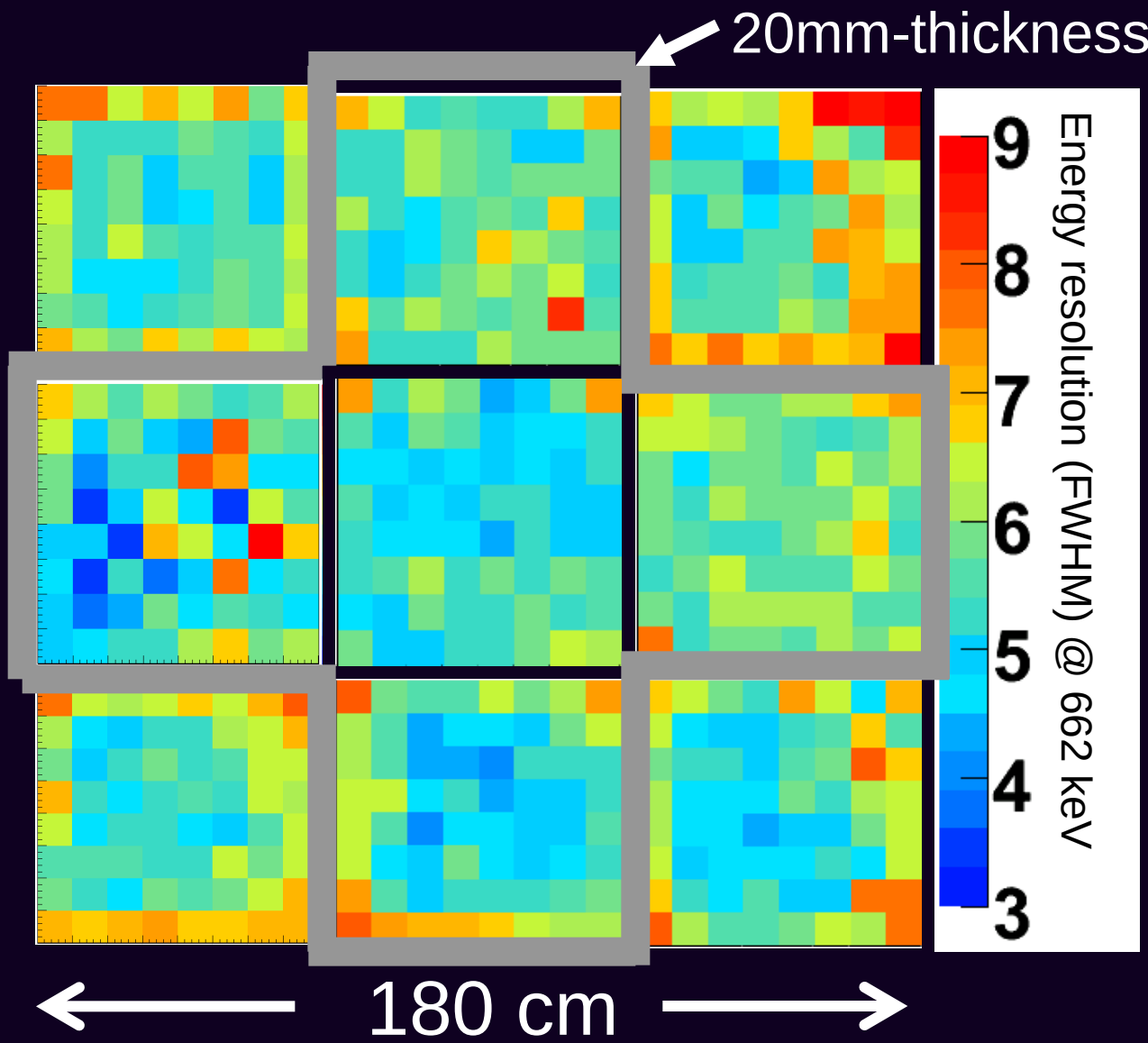
GSO
6×6×13 mm³ 8×8 array:
FWHM(%)=(10.4±0.3)
×(E/662keV)$^{-0.51\pm0.01}$

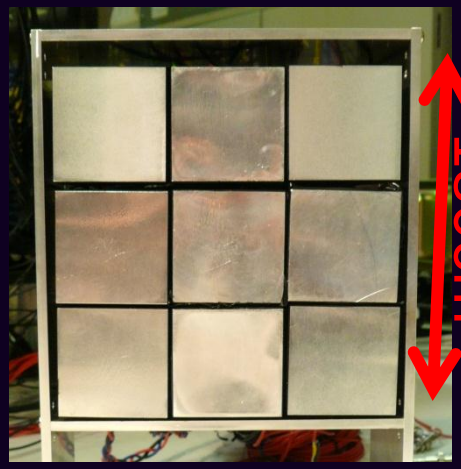
Worsened by factor ~2



$LaBr_3$
6×6×15 mm³ 8×8 array:
FWHM(%)=(5.7±0.4)
×(E/662keV)$^{-0.53\pm0.01}$

9 arrays: Energy Resolutions (FWHM) @ 662keV





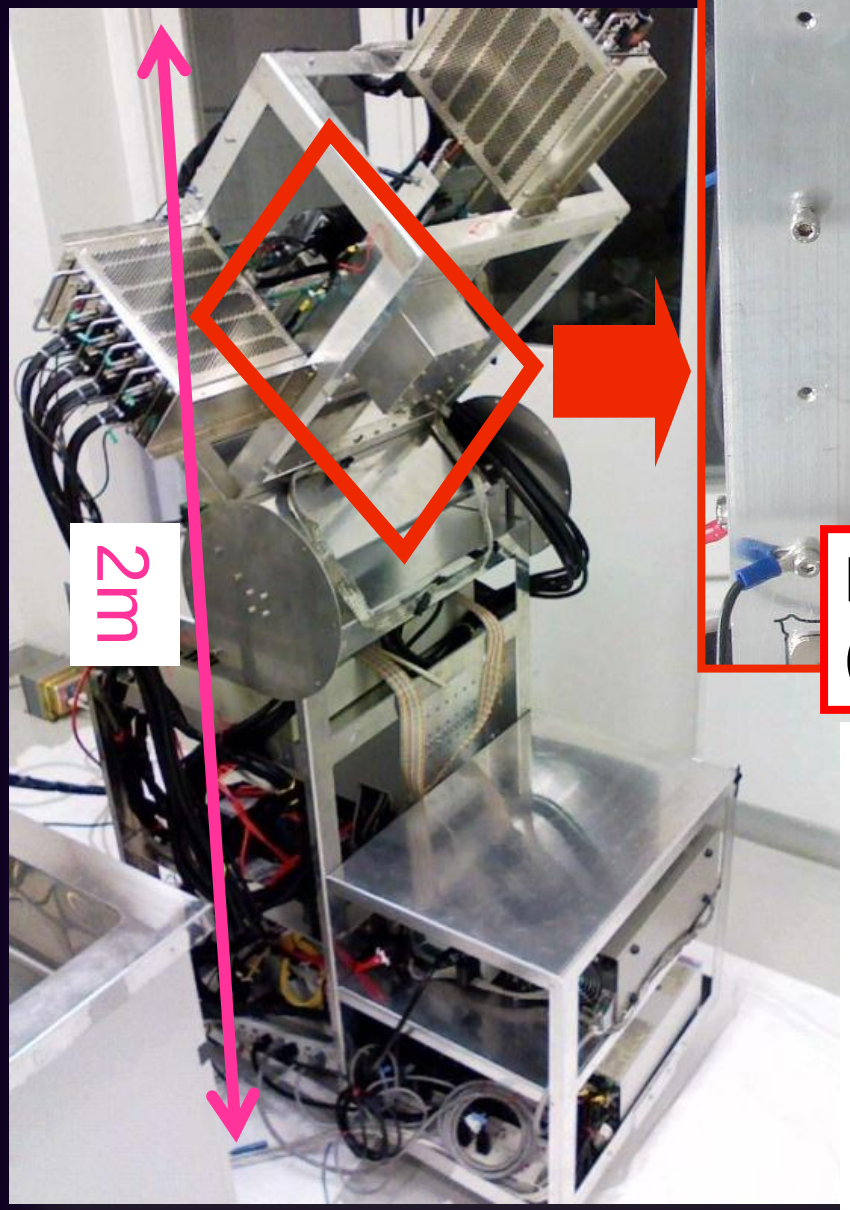
Eng. Res. (FWHM)
@ 662 keV
Ave. ± σ :

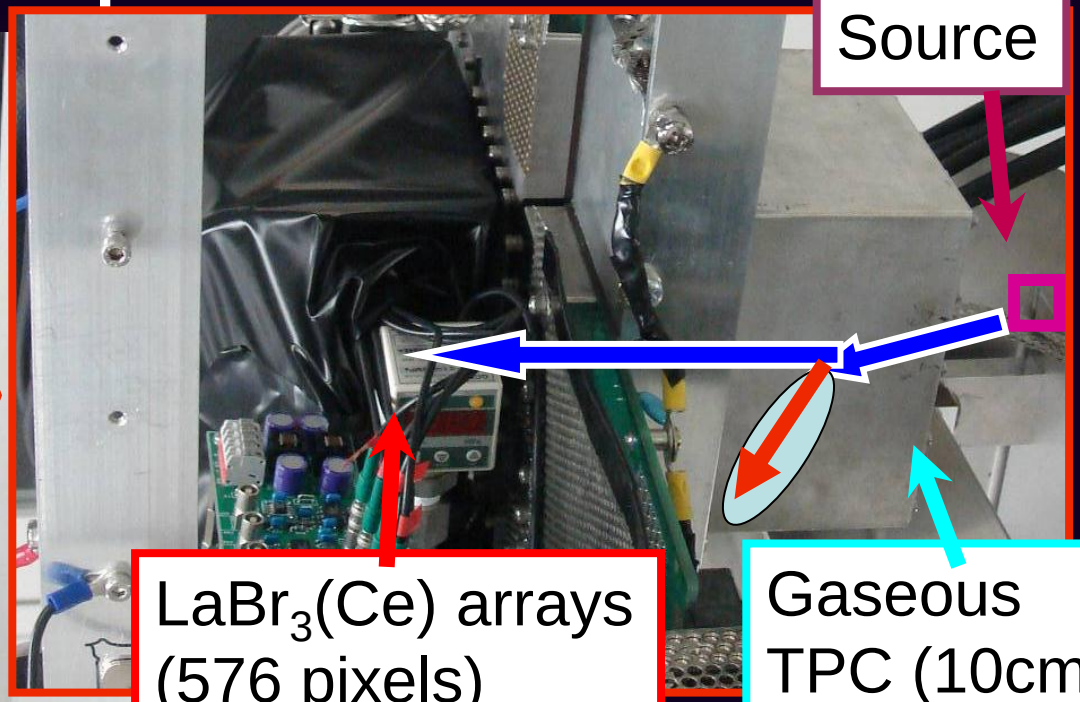
6.0 ± 1.0%
(15mm-thickness)

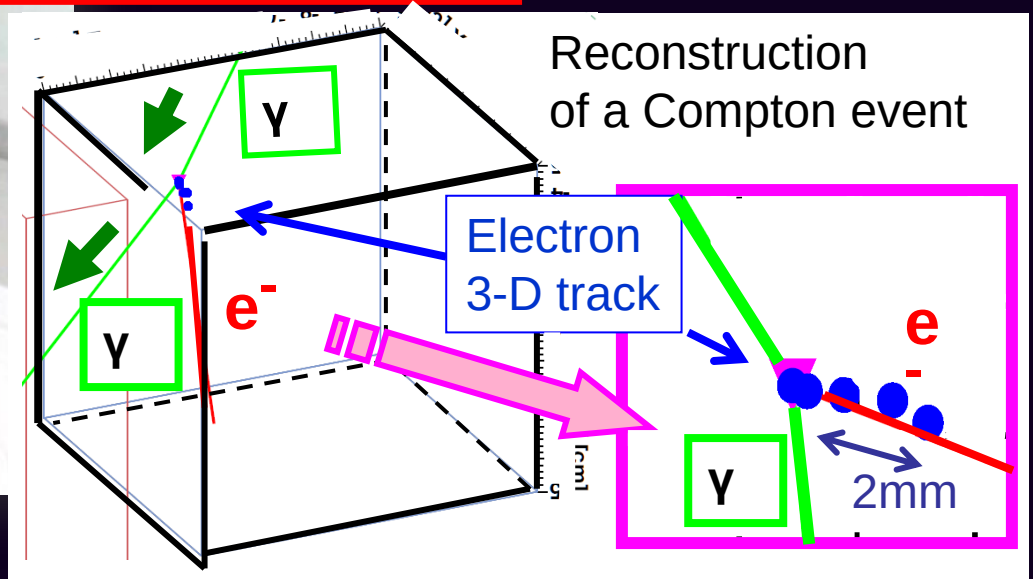
5.6 ± 0.8%
(20mm-thickness)

5.8±0.9%
(Total, 576 pixels)

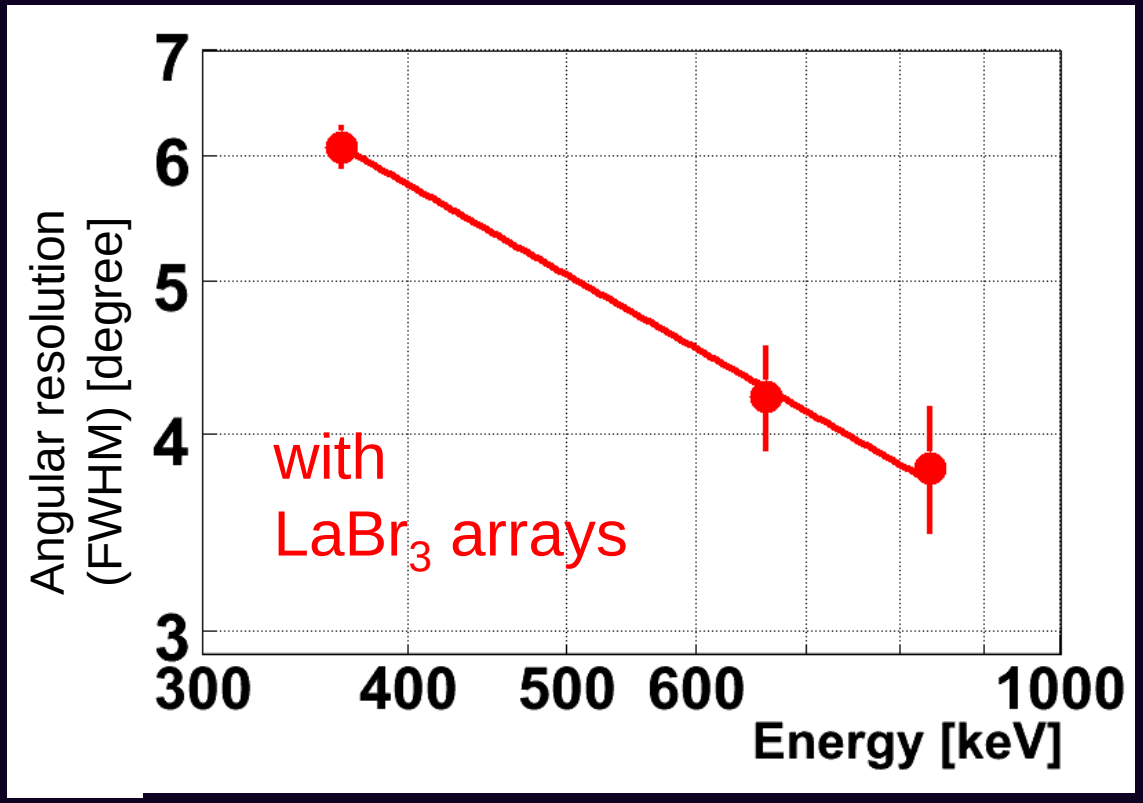
Setup of ETCC







Angular resolution



Angular resolution (FWHM) @662 keV [degree]

5.0±0.2 (GSO)

improved

4.2±0.3 ($LaBr_3$)

3.5 deg. (FWHM) @1.3 MeV (expected)
(cf. 4.7 deg. for COMPTEL)

Spatial resolution (FWHM) @ 662 keV:
1.1 cm (detector – target: 15 cm)

Contents

- Introduction
  - MeV gamma Astronomy / Medical imaging
  - Electron-Tracking Compton Camera (ETCC)
- Improvement of Angular resolution
  - $LaBr_3$ array
  - Application using the ETCC + $LaBr_3$ array
- New readout system for $LaBr_3$ array
- Summary

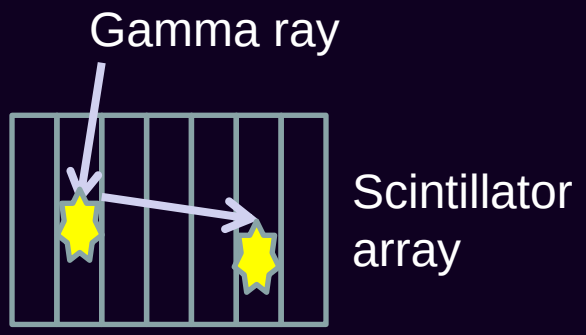
Improvement of Reading System

Charge-division method
(Anger logic)

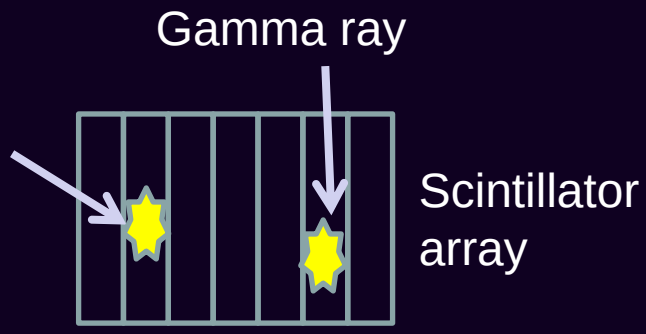
Individual reading of each pixel

- Multi-hit event rejection
  - Random coincidence rejection
- Simpler position capitulation

- Compton scattering

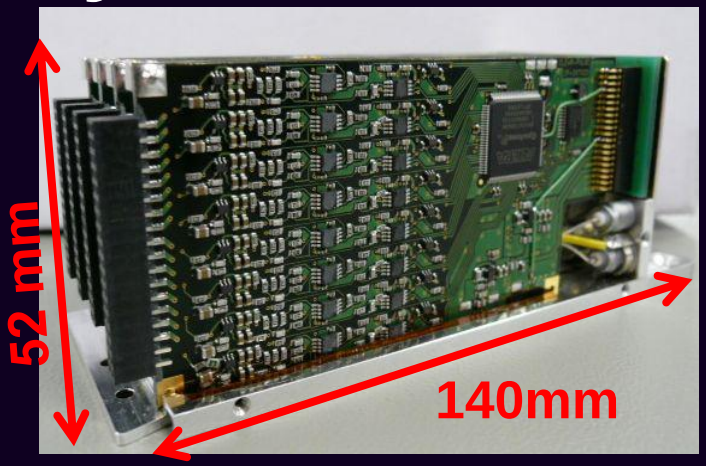


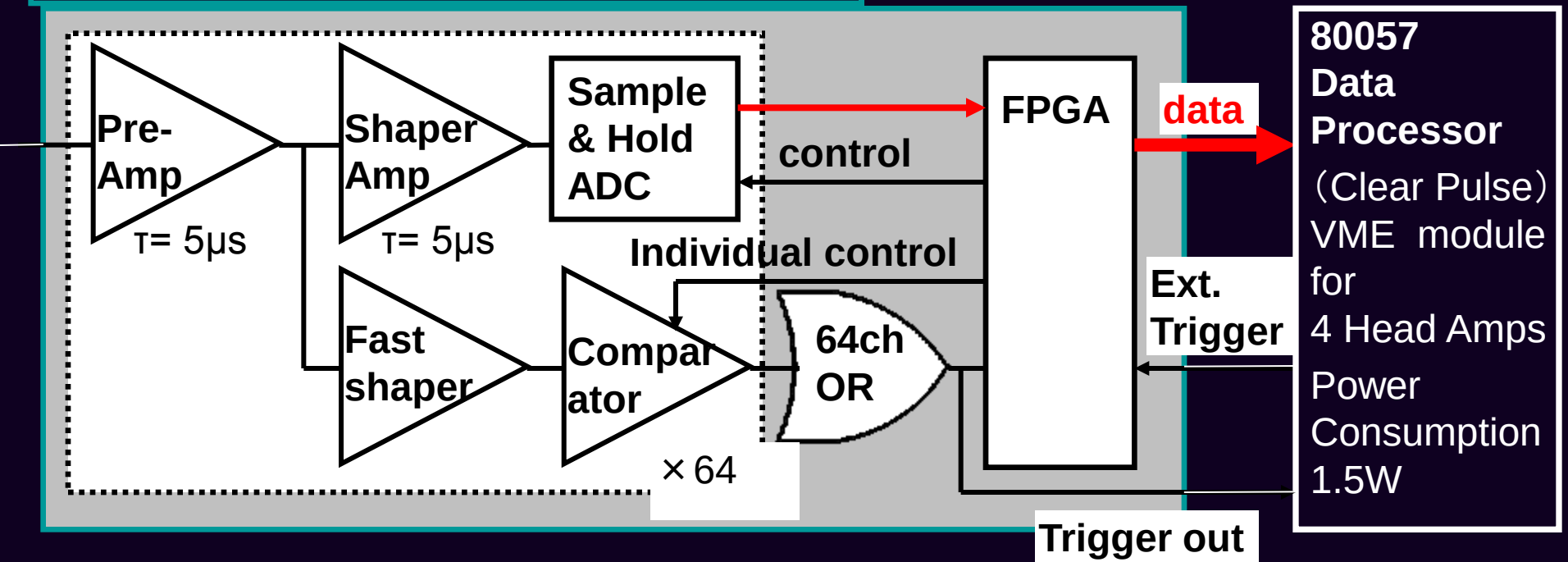
- Random coincidence



New Readout System

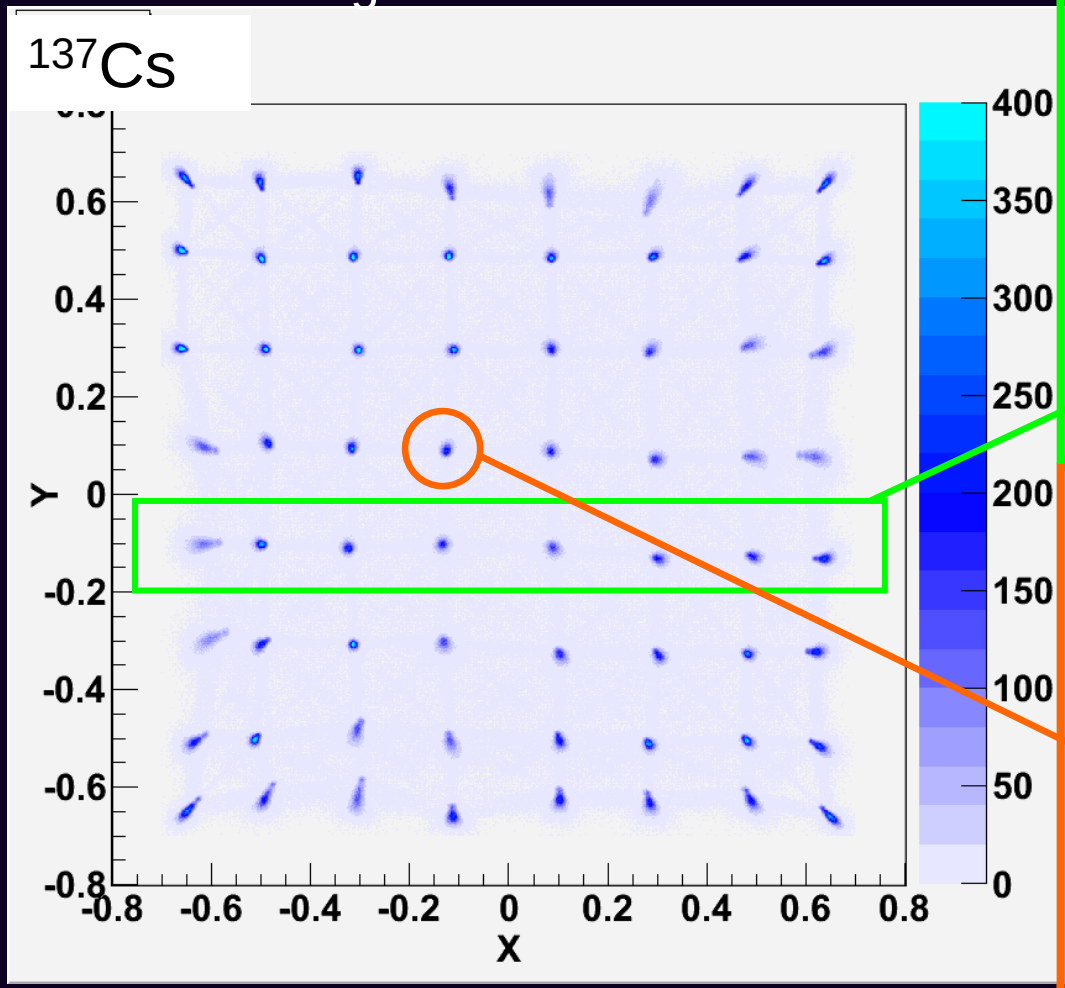
Head Amp Unit CP80190(Clear Pulse)
- 64ch readout
- Using only discrete devices.
- Input dynamic range is variable by replacing feedback capacitor. (Adjusted to <750pC)
- Power Consumption：1.2W
- 20us/64ch to read out

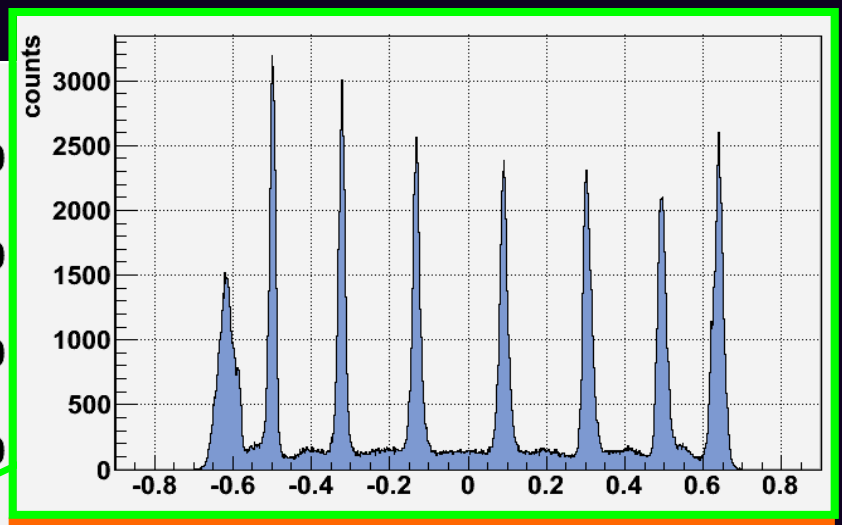


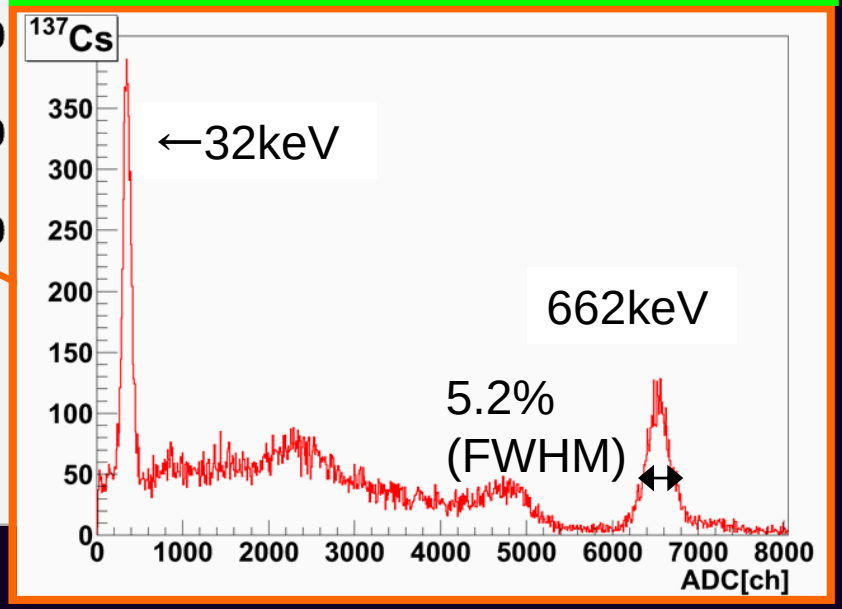


$LaBr_3$ Array 64 ch reading

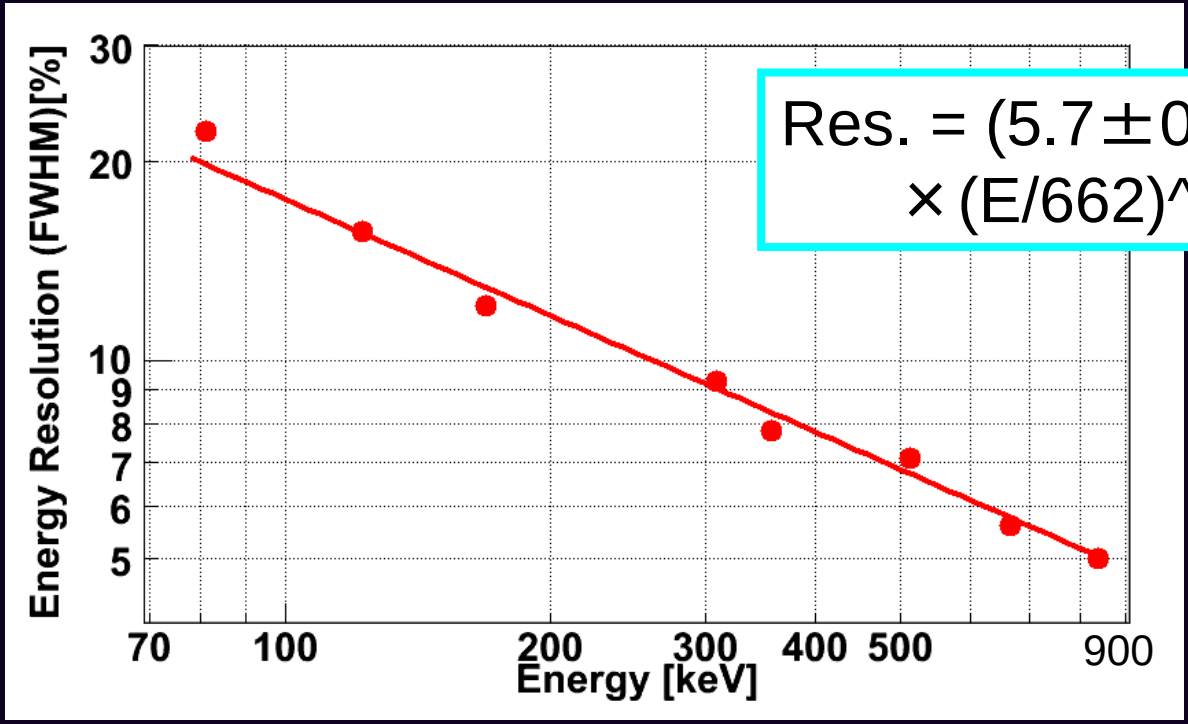
2-D image in flood-field irradiation







Energy resolution, Power Consumption



Res. = (5.7±0.4)
×(E/662)^(-0.58±0.07)

	$LaBr_3$ array ΔE / E (FWHM @ 662 keV)	Power (/PMT)
Conventional system	5.7 ± 0.4%	2.7 W (for 4 ch)
New system	5.7 ± 0.4%	1.5 W (for 64 ch)

summary

- Assembly of an 8×8 $LaBr_3$ pixel array
  for improvement an angular resolution of Compton Camera.
  - Pixel size : 5.8 ×5.8 ×(15 or 20) mm^3
  - Pixel pitch: 6.1mm (the same as that of MAPMT H8500)

- Energy resolution of the array with MAPMT（FWHM、@662keV）
  - $LaBr_3$ array　　5.8 ± 0.9 %
  - GSO array　　10.8 ± 1.0%

- Angular resolution of Compton gamma camera (FWHM)
  - With $LaBr_3$ array　　4.2±0.3 deg. @ 662 keV
    3.5 deg. @ 1.3 MeV (expected)
    (COMPTEL 4.7 deg. @ 1.3 MeV)

- Individual readout system for each anode channel.

Tank you

for your attention

Special thanks to
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Mr. T. Kadono

The Last Shogun: Yoshinobu Tokugawa
http://www.kanko-chiyoda.jp/tabid/841/Default.aspx