Development of a Gamma Camera Based on an 8×8 Array of $LaBr_3$(Ce) Scintillator Pixels Coupled to a 64-channel Multi-anode PMT

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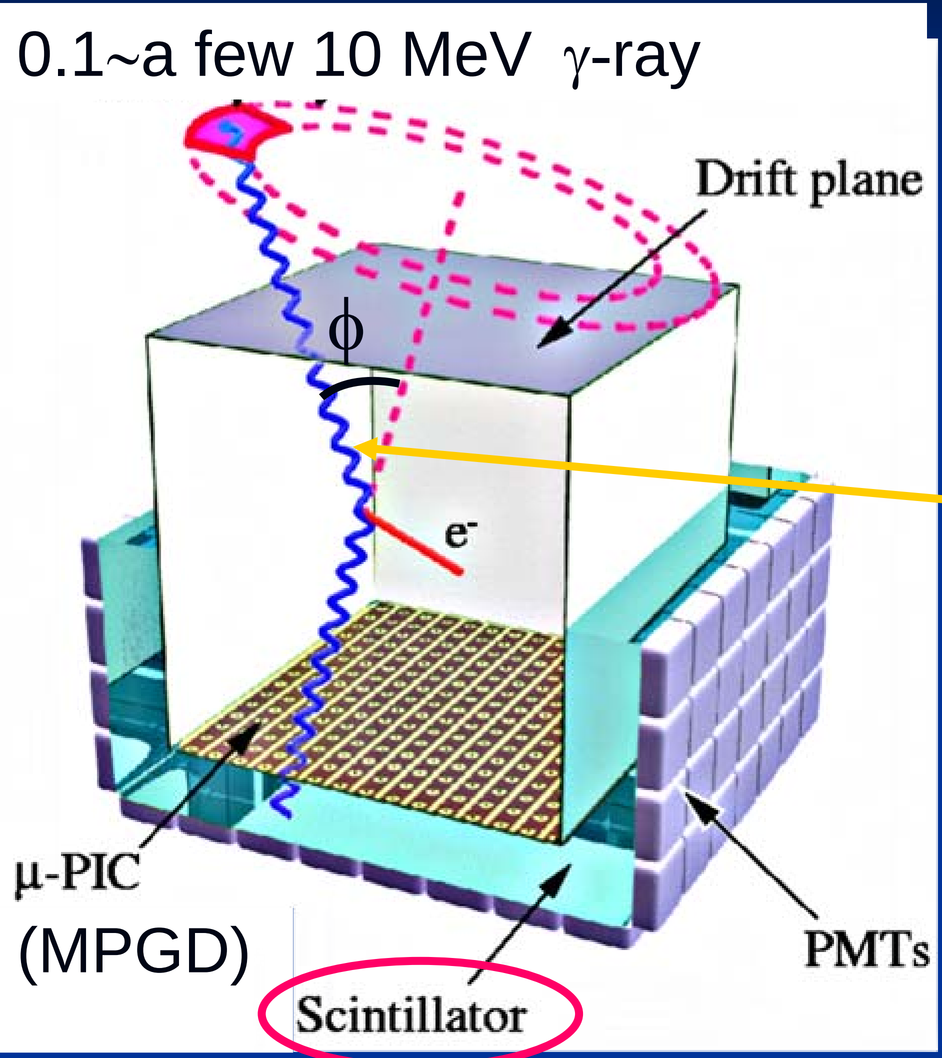
Outline

- Scintillation camera in Compton camera
- Performance of monolithic $LaBr_3$
- Assembly of $LaBr_3$ pixel array
- Performance of $LaBr_3$ pixel array
- Compton camera using $LaBr_3$ pixel array
- Summary

Our Compton Gamma-Ray Camera



- Gaseous TPC
  3D track and energy of recoil electron
- Scintillation camera
  position and energy of scattered γ-ray

$$\cos\phi = 1 - \frac{m_e c^2}{Ee + E\gamma} \cdot \frac{E\gamma}{Ee}$$

Better energy resolution of scintillator $\Delta E\gamma$

Better angular resolution of Compton camera $\Delta\phi$

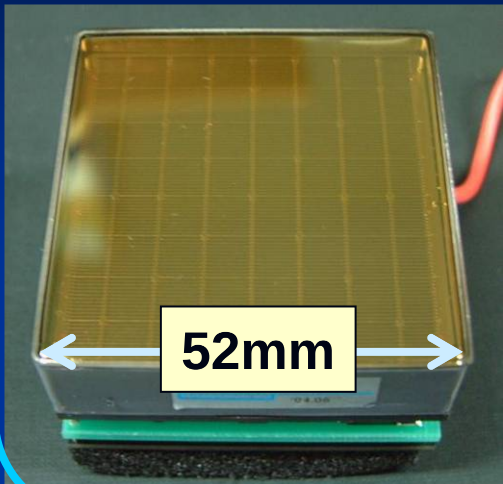
$LaBr_3$ (Ce) has the best energy resolution of all known scintillators.

MP4-1 Tanimori, N33-5 Ueno

GSO Scintillation Camera

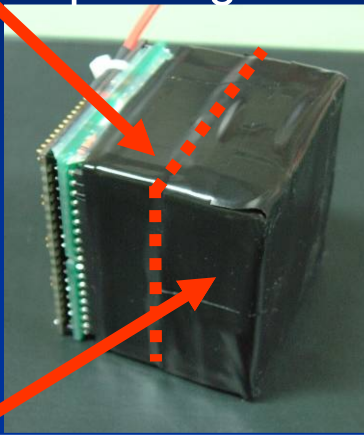
2006 IEEE NSS Kubo et al.,

64ch MAPMT(HPK Flat-panel H8500)



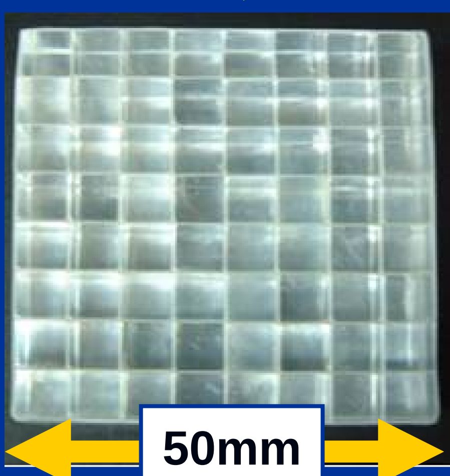
- 8×8 anodes
- anode pitch: **6.1mm**
- 12 stage metal channel dynode
- Size: 52mm×52mm (Photocathode coverage ~89%)
- Anode uniformity: min:max~1:3

Coupled with optical grease



Scintillation camera

PSA (Pixel Scintillator Array)



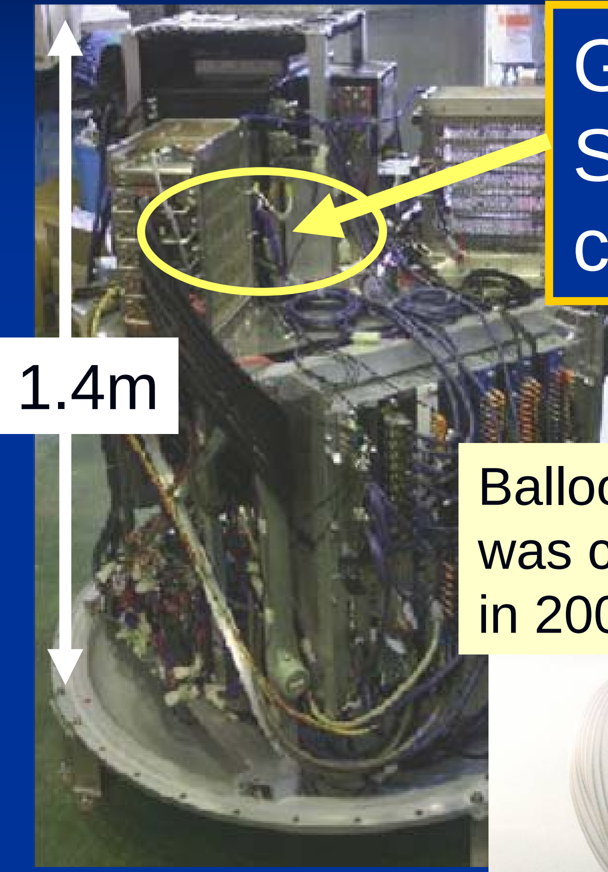
- GSO (Ce) crystal (Hitachi Chemical)
  no hygroscopic: it is easy to assemble
  radiation hard
- 8×8 pixels
- Pixel size: 6mm×6mm×13mm
  fits the anode-pitch of H8500
- Pixels are optically isolated with the 3M ESR film (65 μm thick)

6×6 PMTs

~2000 GSO pixels

Applications of Compton camera

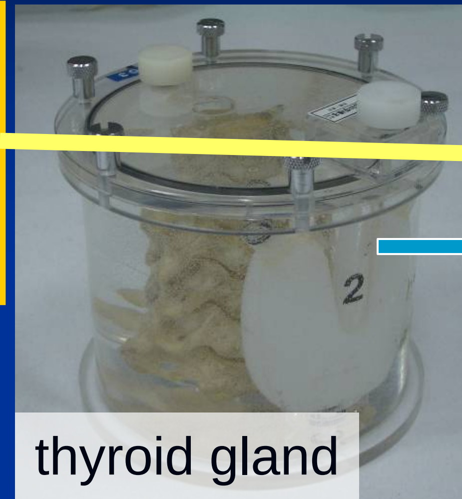
- MeV gamma-ray Astronomy
- Medical Imaging



GSO Scintillation camera

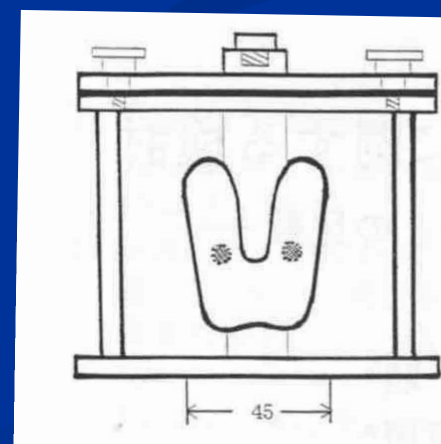
Balloon experiment was conducted in 2006

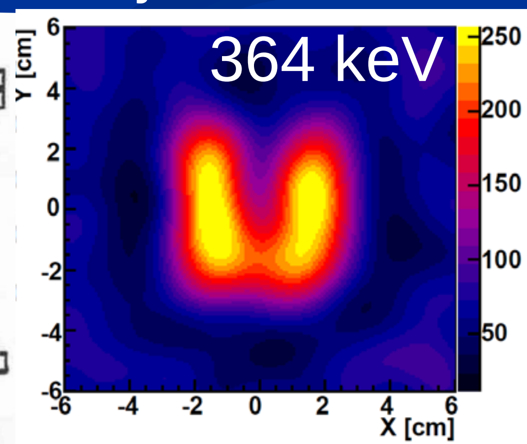
N59-8 Takada



thyroid gland phantom

^{131}I injection



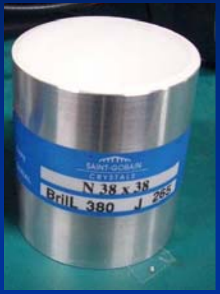


M18-110 Kabuki, M13-141 Kohara, M18-150 Shirahata

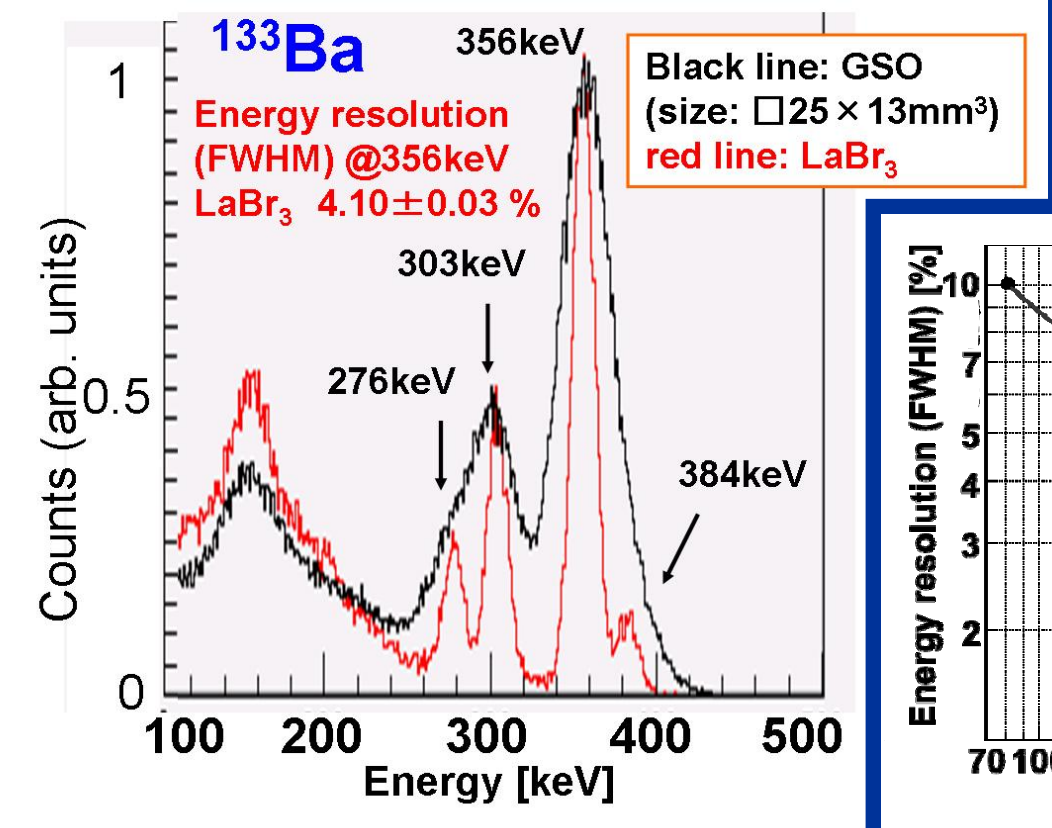
$LaBr_3(Ce)$ scintillator

- High light yield (NaI%):160%
  cf.GSO(Ce):20%
- Fast decay time: 26 nsec
- hygroscopic
  it is difficult to assemble

E.V.D. van Loef, et al., (2000)

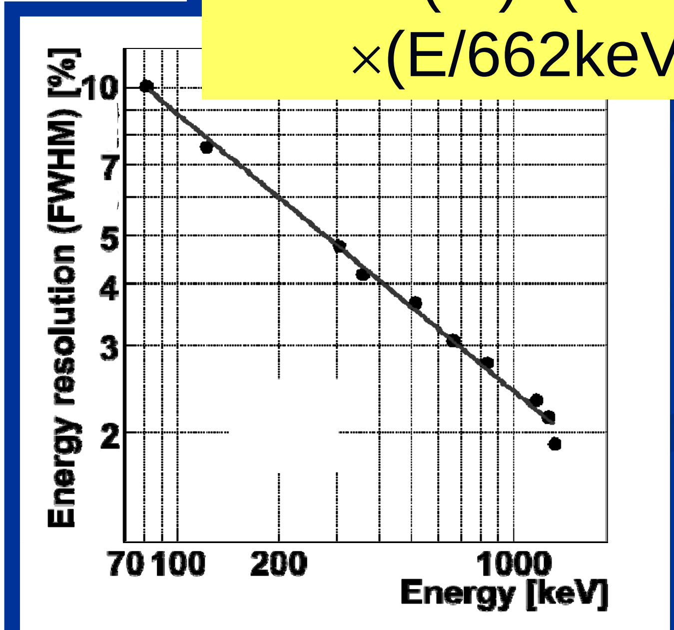


Saint-Gobain
BrilLanCe380
Size:$\phi 38 \times 38 mm^3$

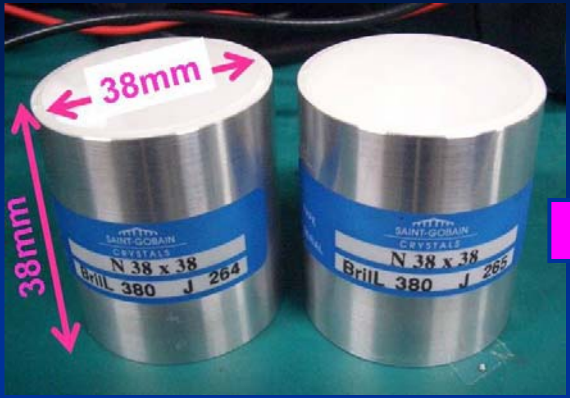


Energy resolution measured with a single-anode PMT(HPK R6231)

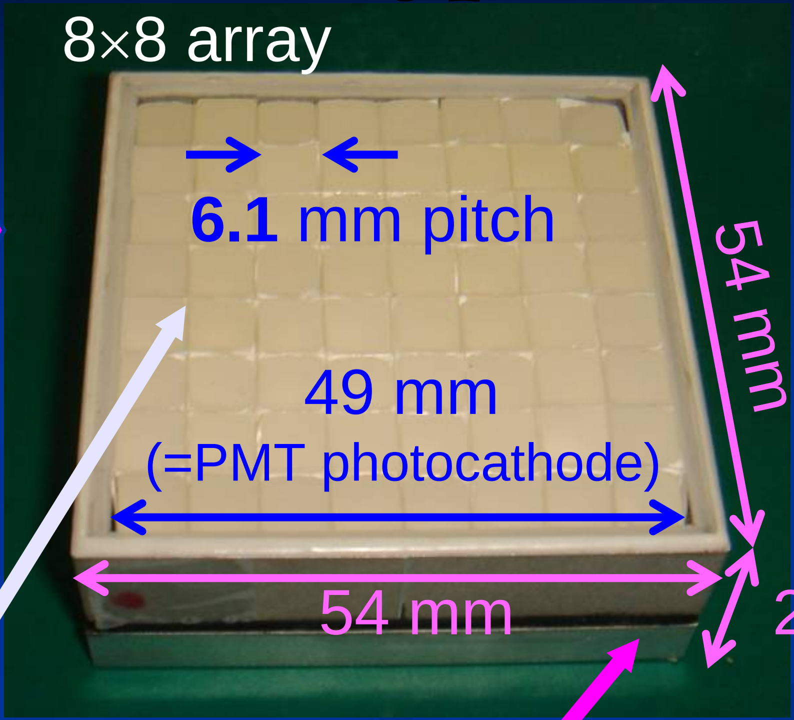
$$FWHM(\%) = (3.1 \pm 0.3) \times (E/662keV)^{-0.53 \pm 0.02}$$



Assembly of $LaBr_3$ pixel array



$LaBr_3$
(Saint-Gobain
BrilLanCe380)
Size:$\phi 38\times 38 mm^3$



PMT package: 52×52 mm^2

Area ratio:
Crystal/package
$(5.8\times 8/54)^2$
=74%

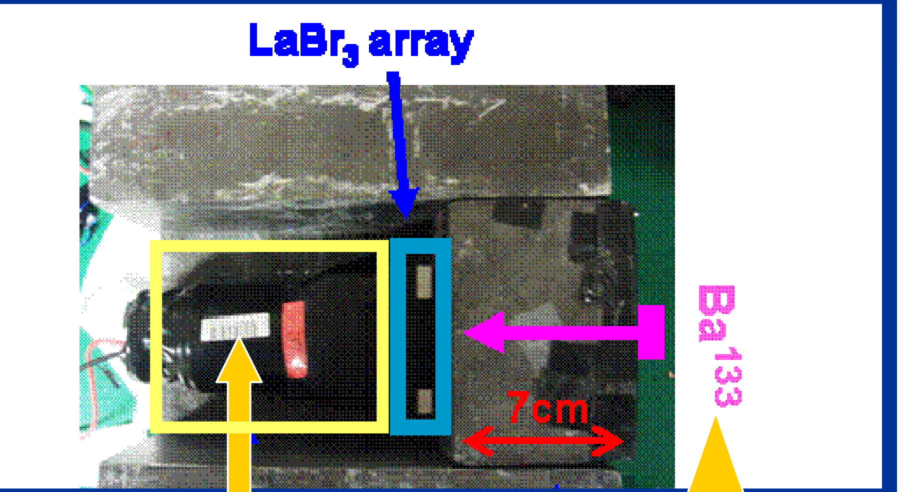
Glass window(2.3mm t)

Hermetic package of aluminum(0.5mm t)

We quarried two $\phi 38\times 38$ mm^3 $LaBr_3$ crystals to 5.8x5.8x15.0mm^3 pixels and assembled an 8×8 array
with a pitch of 6.1 mm (=anode pitch of H8500 PMT)
by our technique. The crystal with an area of 49×49 mm^2 is sealed in a compact aluminum package with glass window.

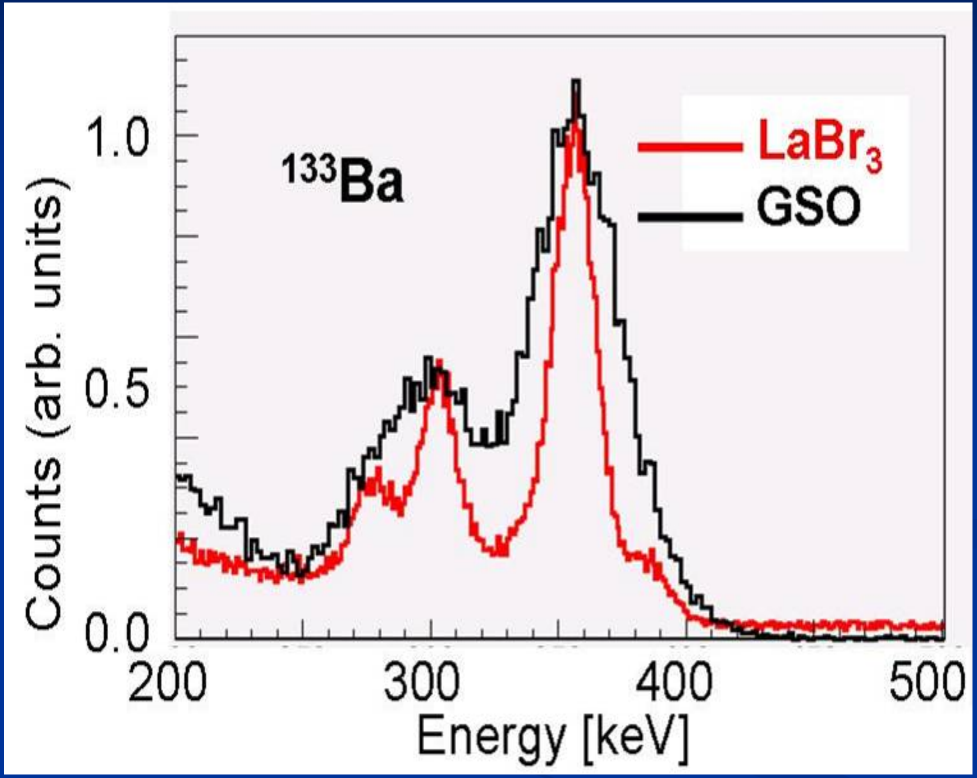
Energy resolution of $LaBr_3$ pixel array coupled to single-anode PMT

To remove the effect of gain-uniformity (~3) among 64 anodes of MAPMT(H8500)



2 inch square single-anode PMT (HPK R6236)

collimated gamma rays were irradiated to one pixel

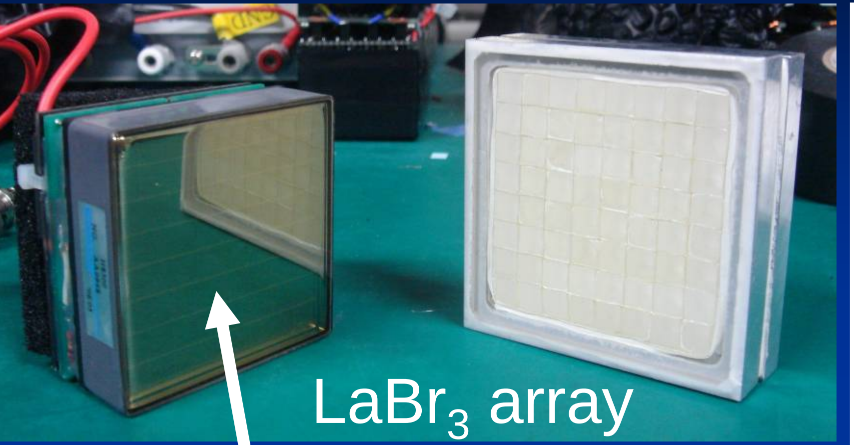


Energy resolution (FWHM) of 64 pixels:

5.8±0.9% at 356keV

4.9±0.7% at 662keV

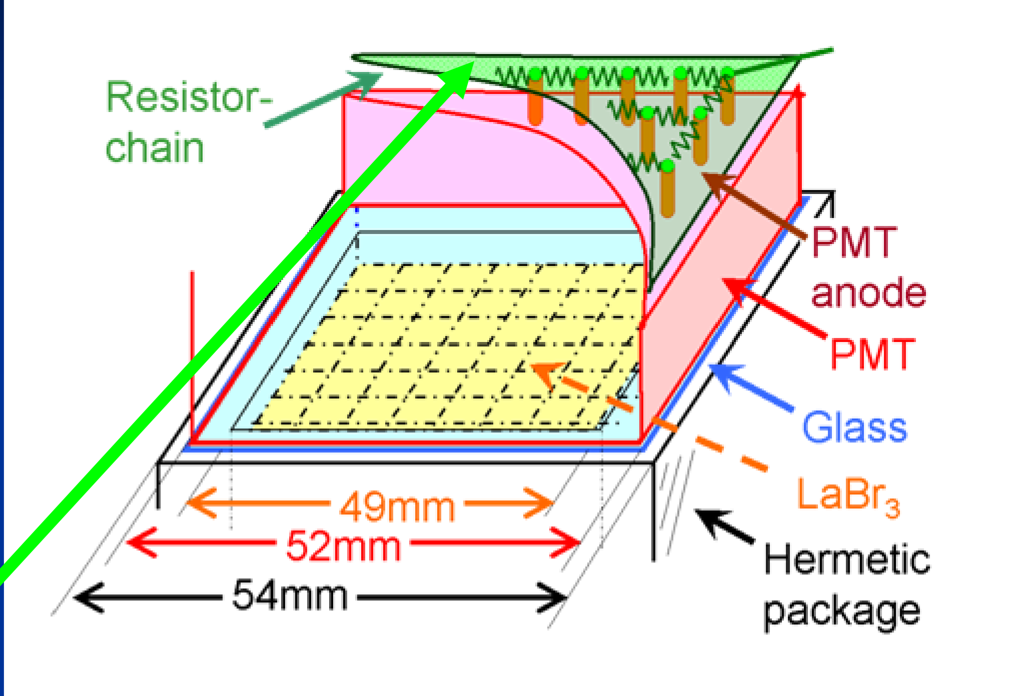
Readout of a 64ch Multi-anode PMT

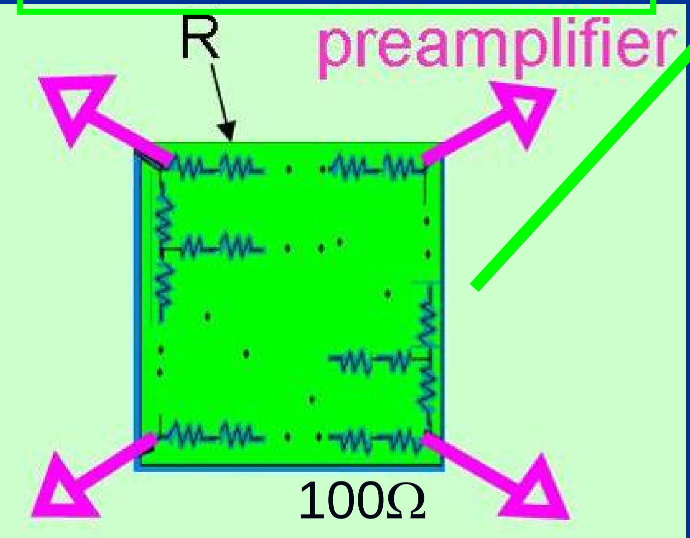


64ch MAPMT

HPK Flat-panel H8500

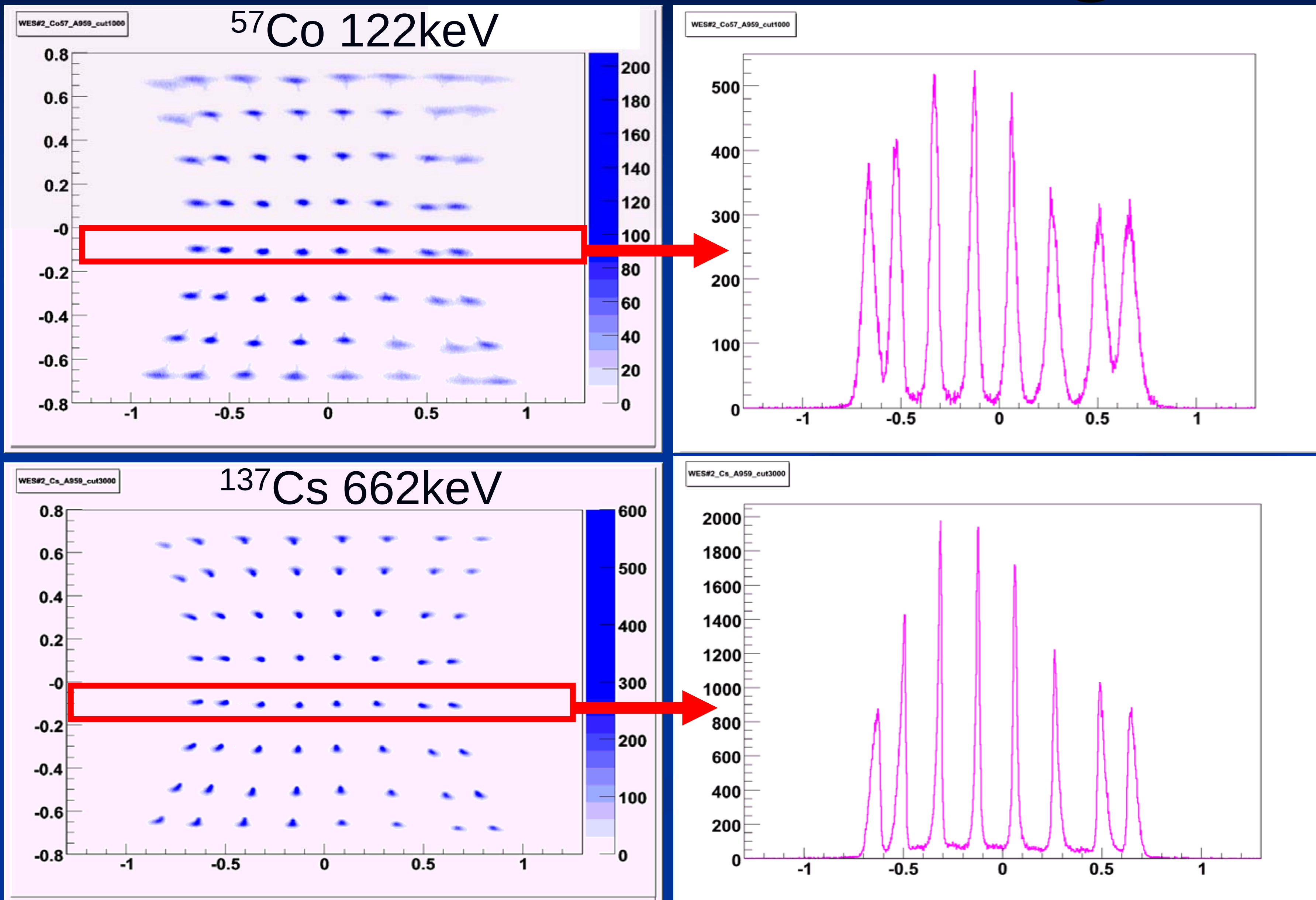
Resistor chain board





- Each anode is connected to resistors, and 4 ch at the corners in resistor chains are read.
- X, Y positions of 64 anodes are obtained in the charge-division method.

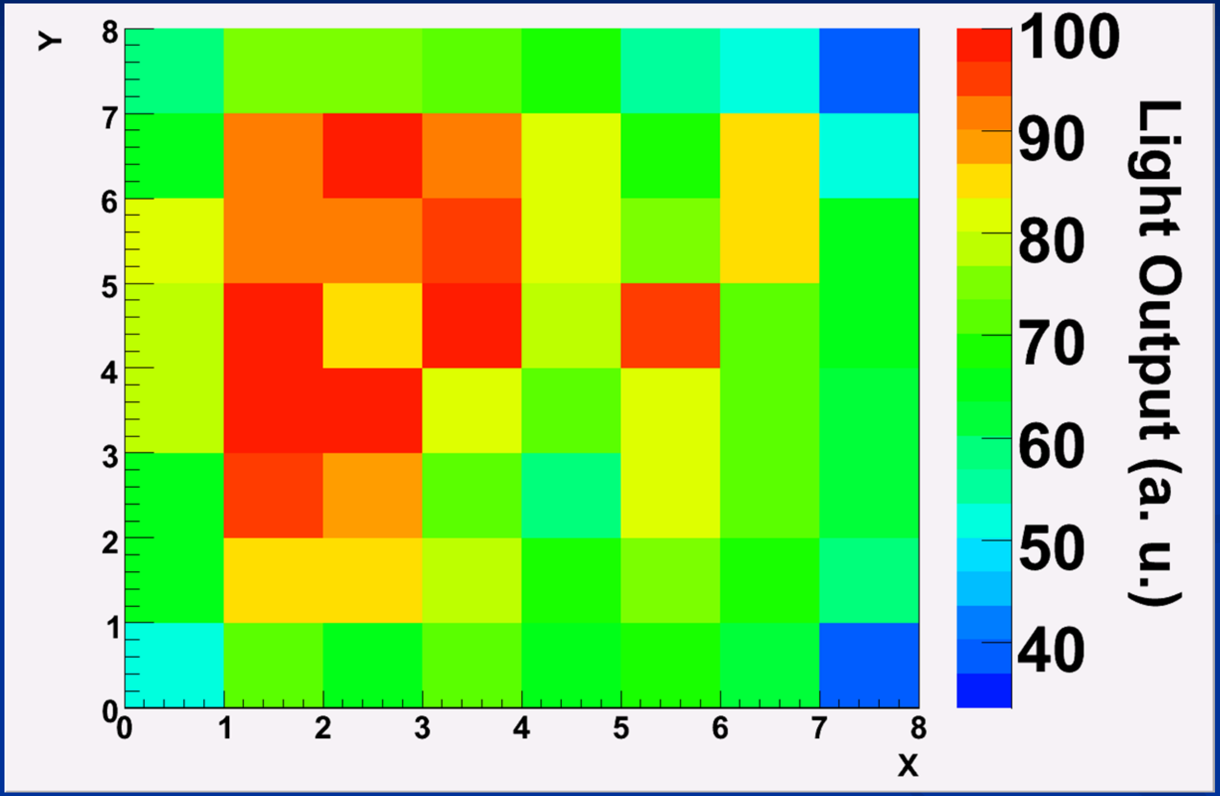
Flood field irradiation image



Light output uniformity

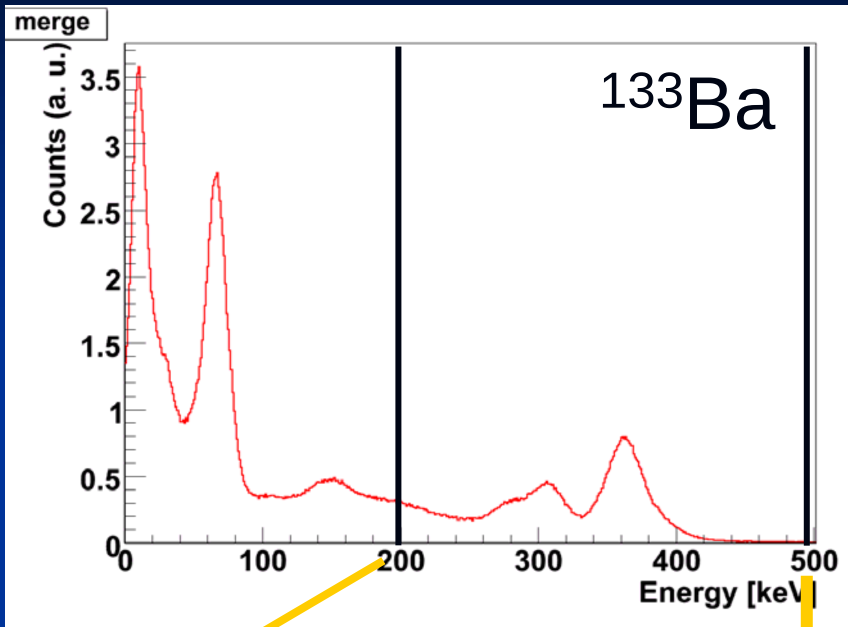
$LaBr_3$
8x8 pixel array

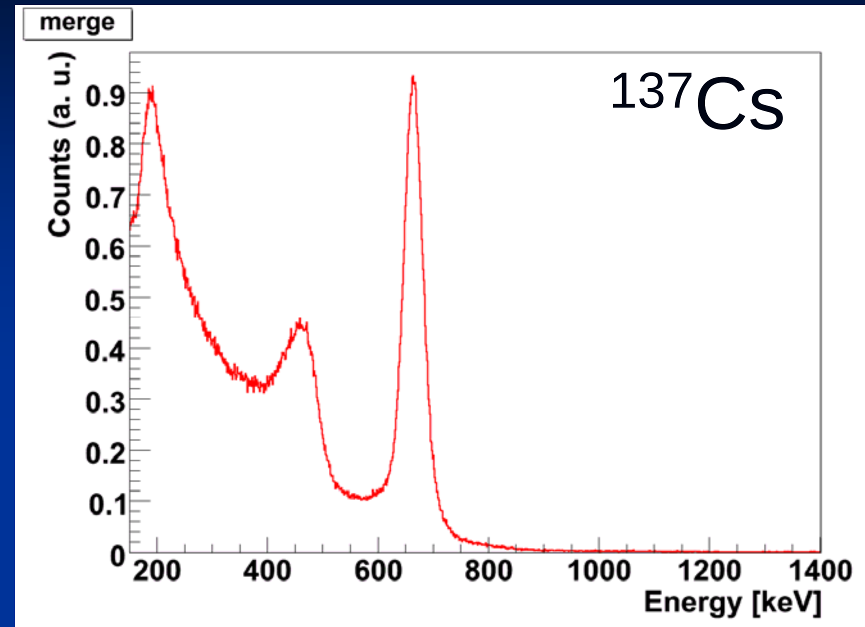
Average : 71.3
RMS : 14.5
RMS/Av.=20%

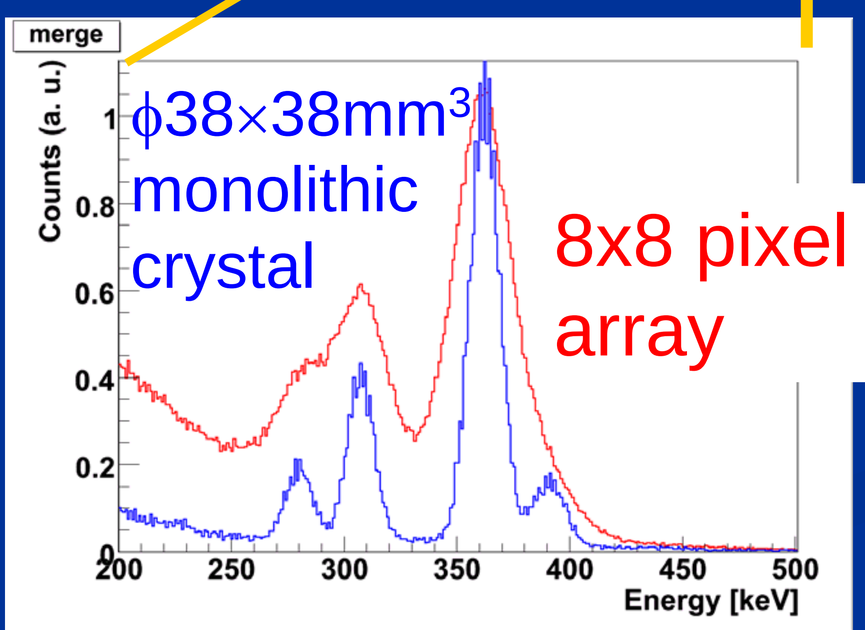


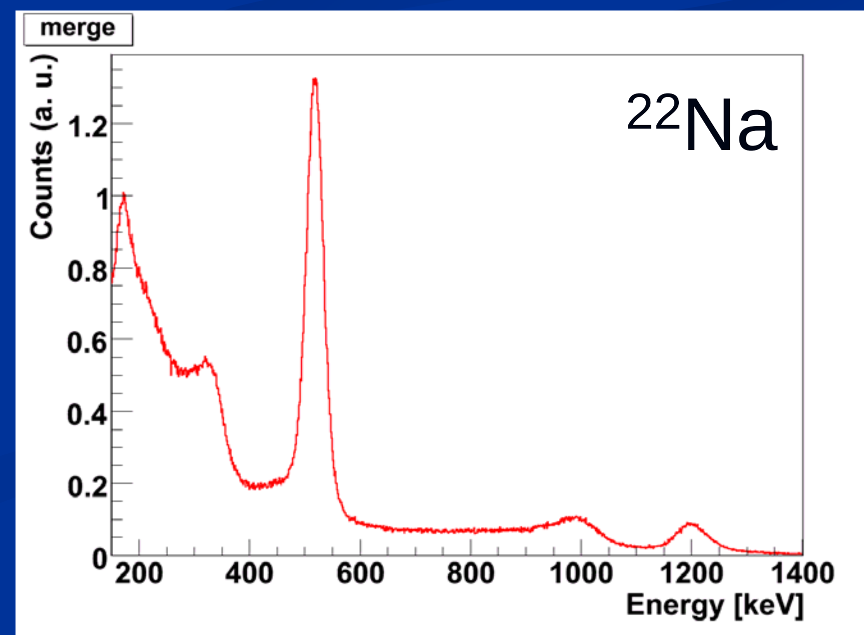
corrected with PMT-anode gain
Maximum value is normalized to 100.

Energy spectrum of $LaBr_3$ pixel array





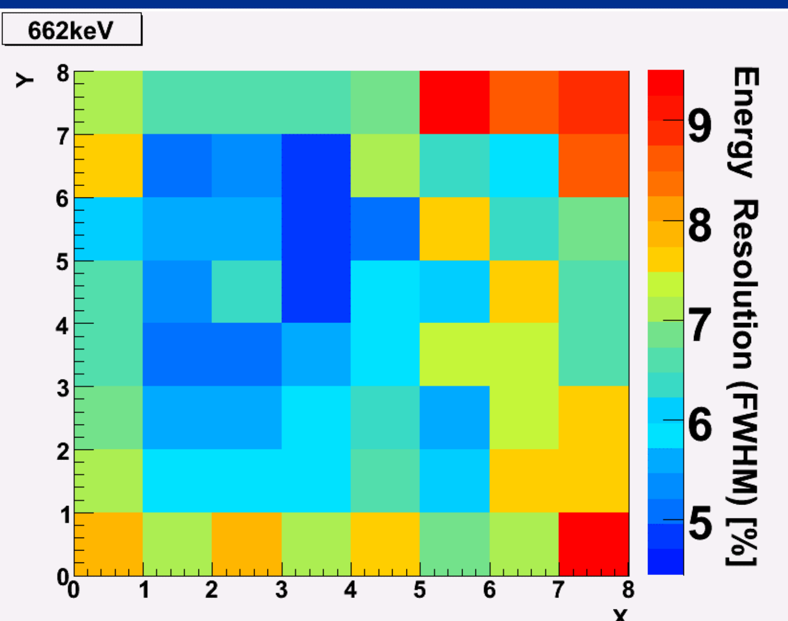




Energy resolution

LaBr$_3$ 8x8 pixel array

^{137}Cs 662 keV

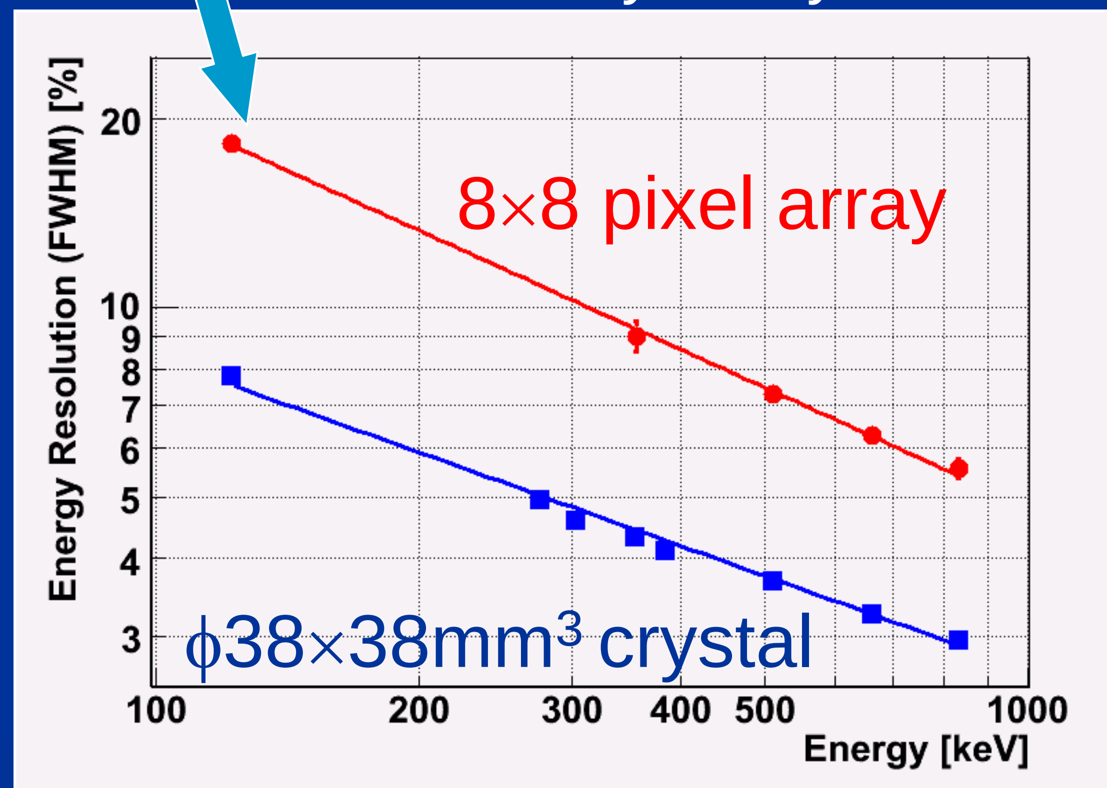


Average 6.3%

RMS 1.2%

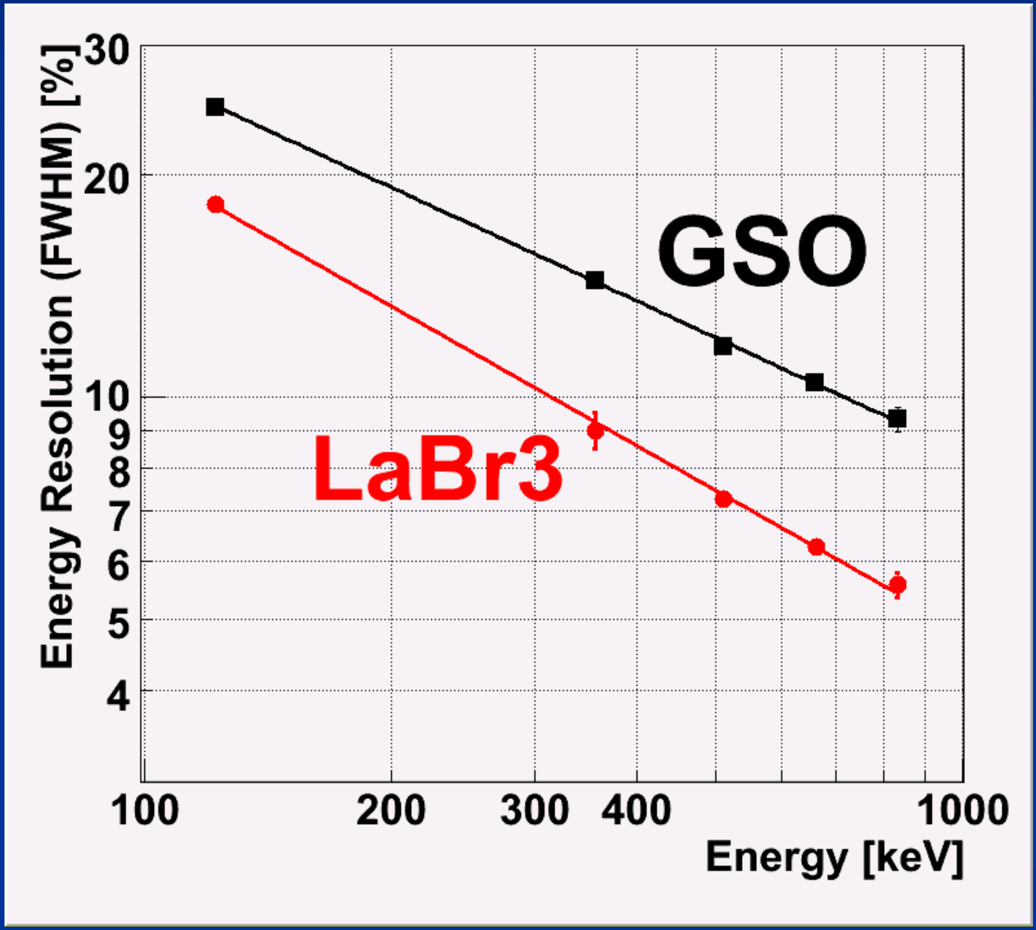
$\mathrm{FWHM}(\%) = (6.2 \pm 0.4) \times (E/662\mathrm{keV})^{-0.63 \pm 0.01}$

worse than the $\phi 38 \times 38\mathrm{mm}^3$ monolithic crystal by factor 2



GSO array vs. $LaBr_3$ array

Energy resolution



GSO

$6 \times 6 \times 13$ mm^3 8x8 array:

FWHM(%)=$(10.4 \pm 0.3) \times (E/662keV)^{-0.51 \pm 0.01}$

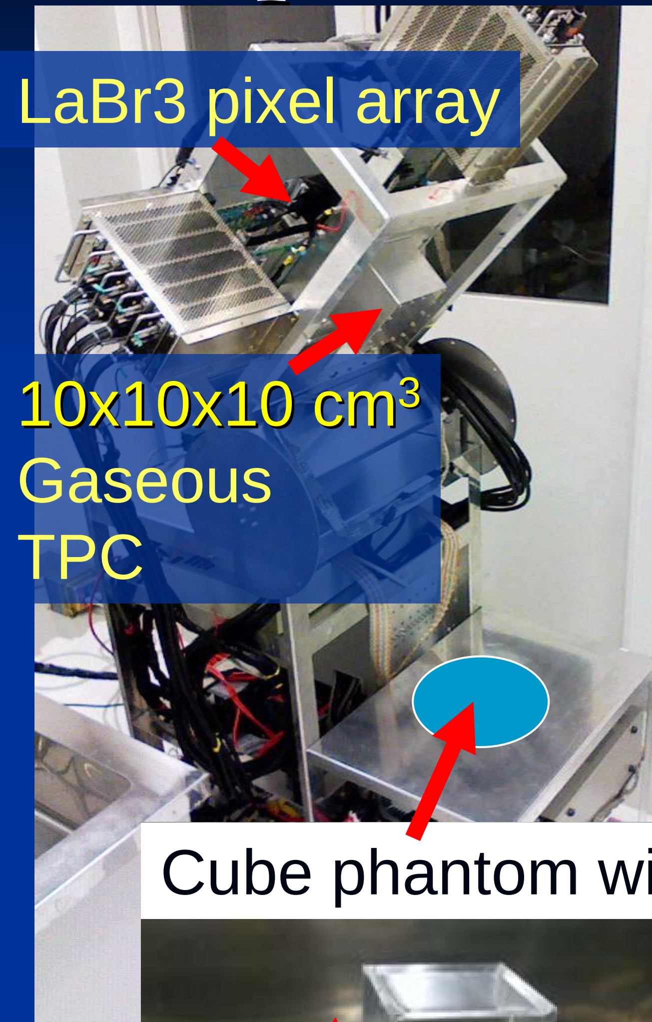
better by factor 1.7

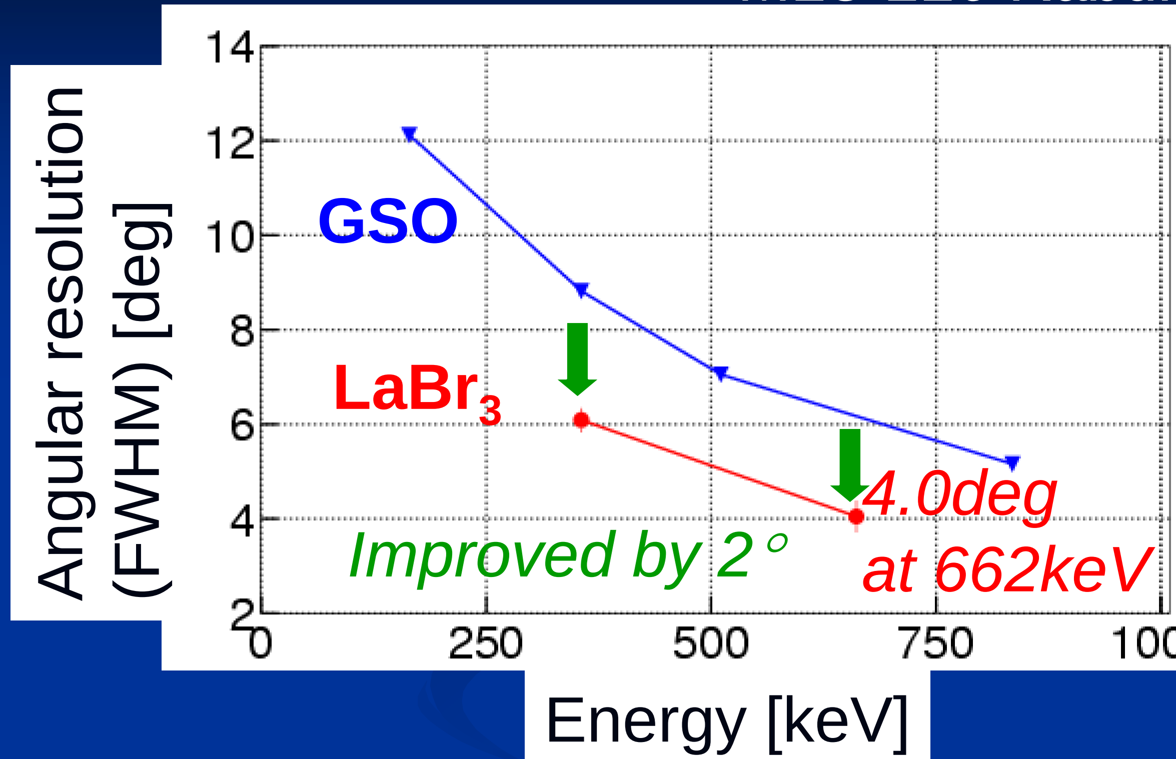
$LaBr_3$ array:

FWHM(%)=$(6.2 \pm 0.4) \times (E/662keV)^{-0.63 \pm 0.01}$

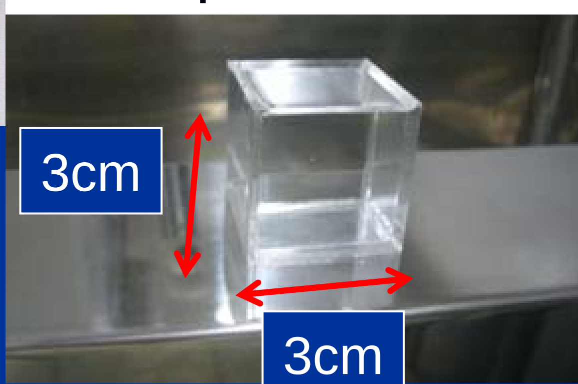
Compton camera using $LaBr_3$ pixel array

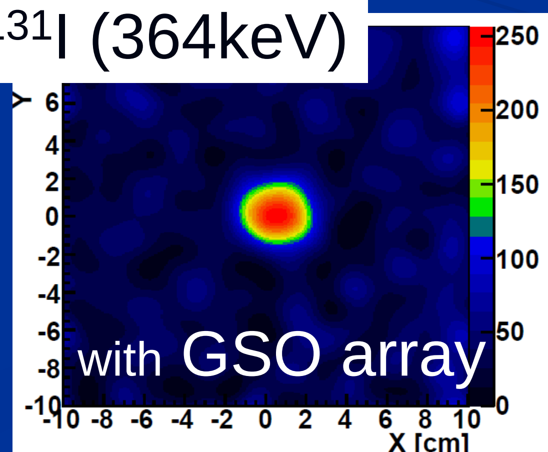
M18-110 Kabuki

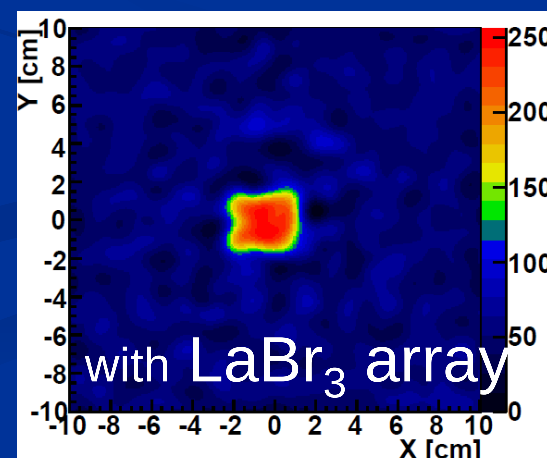




Cube phantom with ^{131}I (364keV)







Summary

- In order to improve the angular resolution of the Compton camera, we have developed an 8x8 array of LaBr3(Ce) pixels with a size of 6x6x15mm^3 , sealed in a compact package, and a gamma camera based on the array coupled to a 64ch MAPMT(HPK H8500).
- Light output uniformity among 64 pixels is 20%(RMS).
- Energy resolutions (FWHM) at 662 keV are

  ϕ38×38mm^3 monolithic: 3.1±0.3%

  8×8 array with SAPMT: 4.9±0.7%

  8×8 array with MAPMT by resistor-chain readout:

  6.3(Av. of 64 pixels)±1.2(RMS)%
- Angular resolutions (FWHM) of the Compton camera using the $LaBr_3$ array are 6.1° and 4.0 ° at 364 keV and 662 keV, respectively.
- For future work, we will make four arrays to cover an area of 10x10 cm^2, and develop a readout system by which each anode is read individually to improve the energy resolution.