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

TIPP09 @ Epocal Tsukuba, Tsukuba, Japan. (2009.3.14)

Shunsuke KUROSAWA

K. Hattori, C. Ida, S. Iwaki, S. Kabuki, H. Kubo, K. Miuchi, H. Nishimura, J. Parker, A. Takada, M. Takahashi, T. Tanimori, K. Ueno, Y. Yanagida[A]

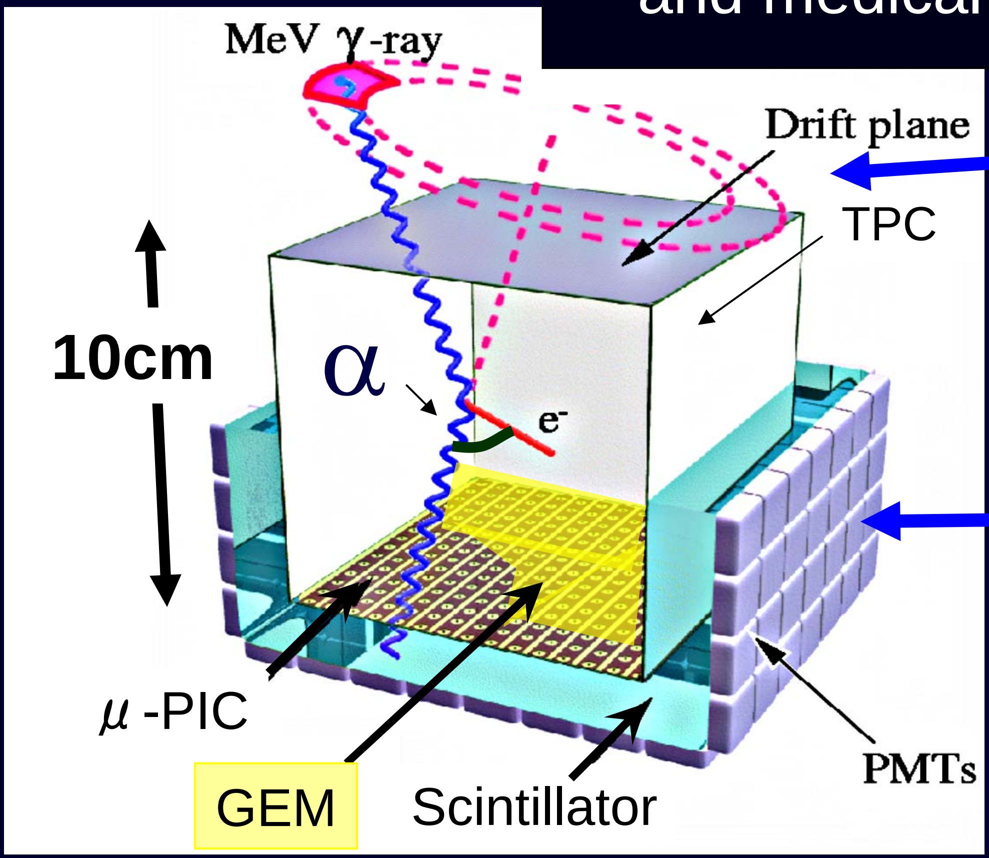
Dept. of Physics, Graduate school of Science, Kyoto University, Kyoto, Japan

[A]World Engineering System, Kyoto, Japan

Contents

Compton gamma camera

Camera is used for astronomy (Ueno's poster id=17),
and medical imaging (Kabuki's talk id=30).



gaseous TPC
(time projection chamber) :
[containing μ-PIC(MPGD), GEM]
--- energy and 3-D track of Compton-recoil electron

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

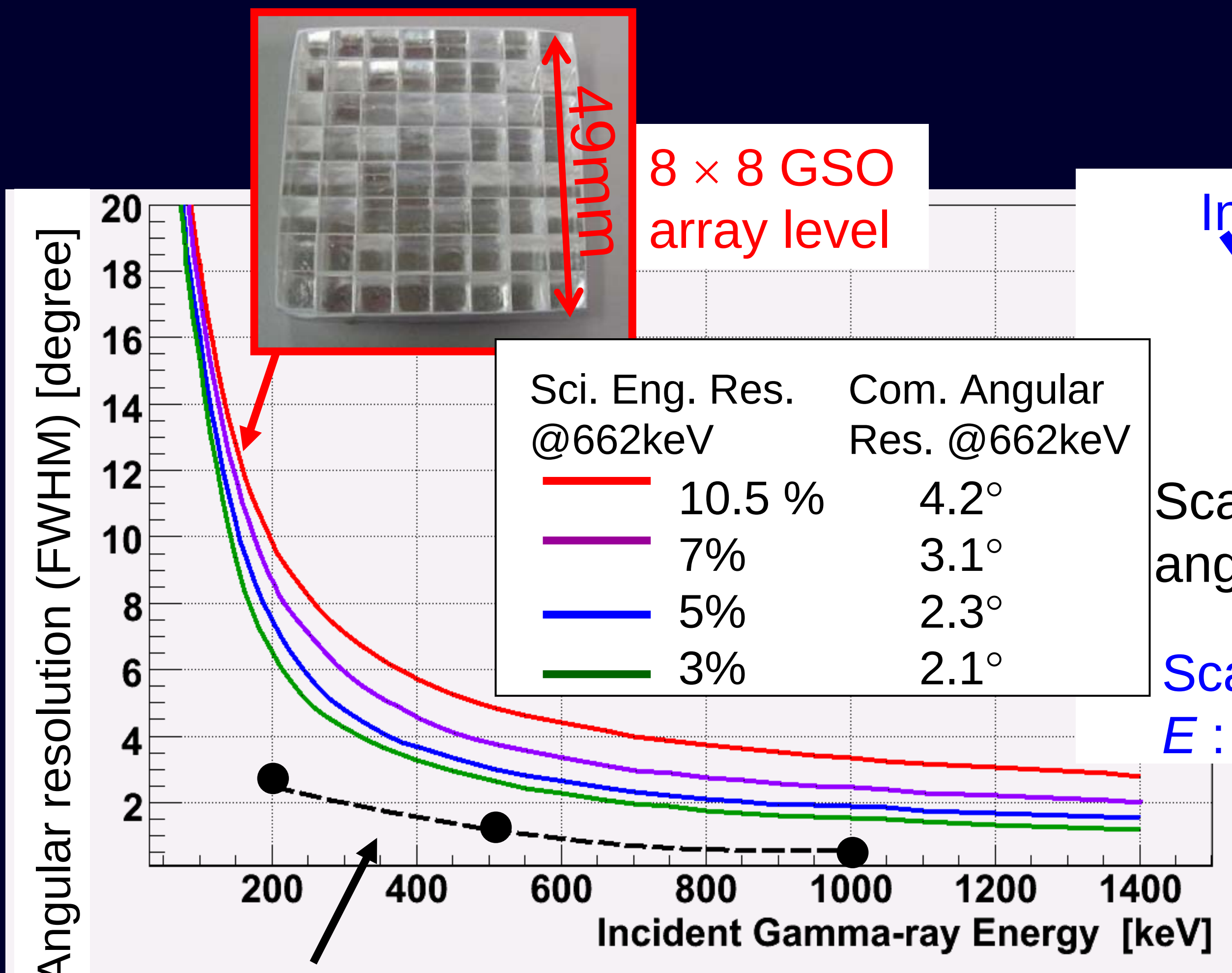
Reconstruct incident gamma ray event by event

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

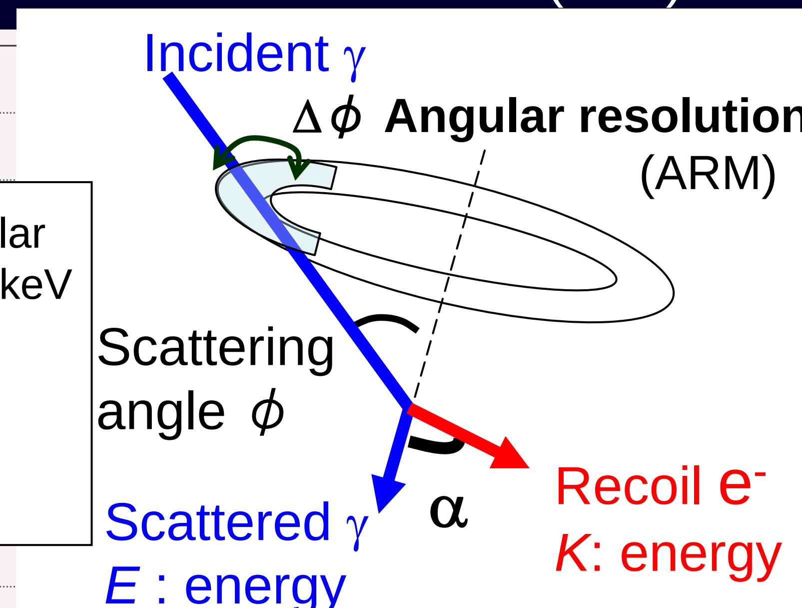
To obtain a higher angular resolution

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

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



Doppler broadening (Ar)
Zoglauer *et al.* (2003)



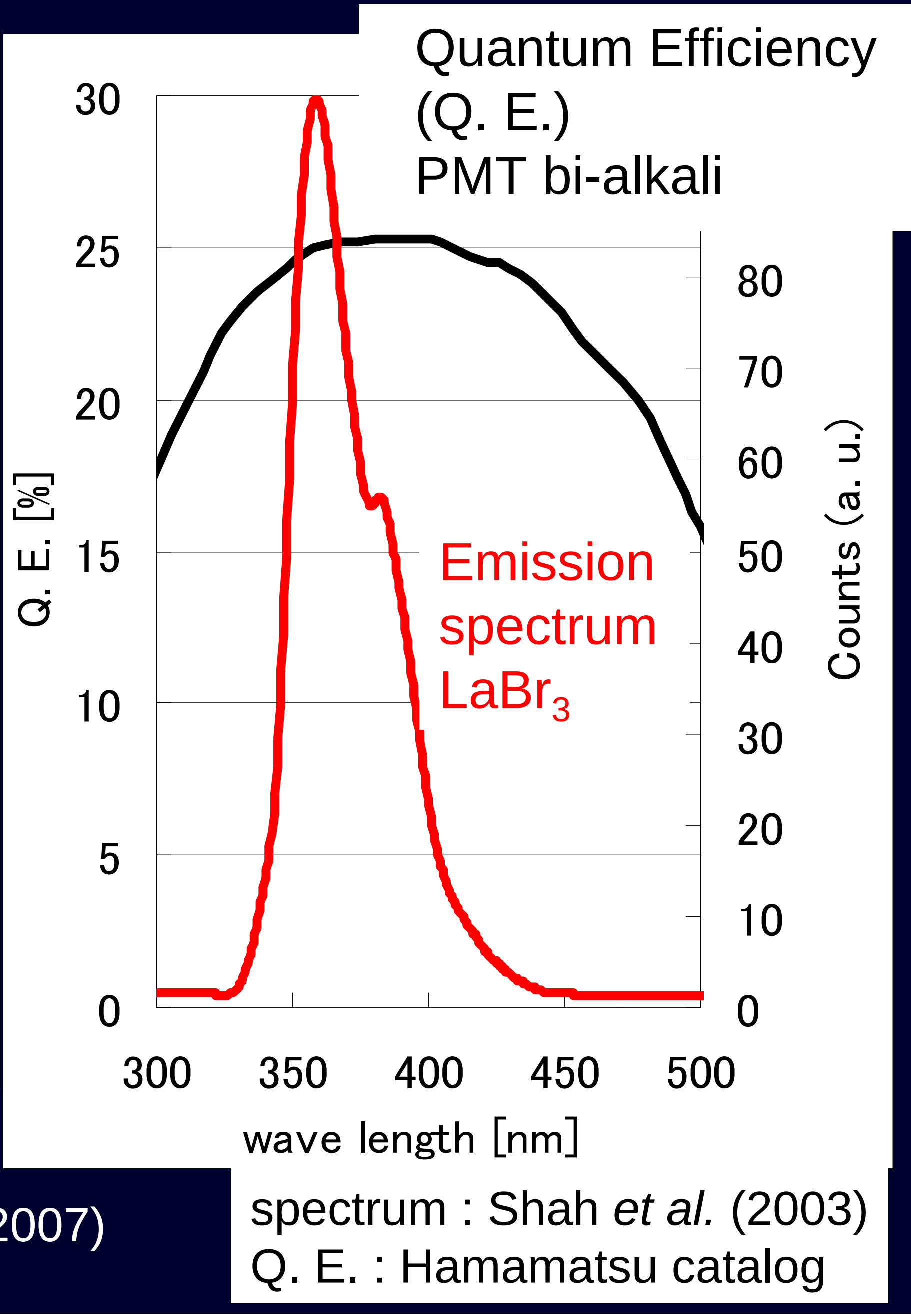
Calculated assuming
1, no error in position of Compton point
2, energy Res. of TPC : 30 % @ 22 keV

Property of scintillators

	Density (g/cm^3)	Decay time constant (ns)	Light output (Relative)	Hydroscopic	Radiation Hardness
NaI(Tl)	3.67	230	100	Strong	very weak
CsI(Tl)	4.53	1050	85	Weak	very weak
BGO	7.13	300	7-12	No	weak
LSO	7.4	40	40-75	No	strong
YSO	4.45	40	30-45	No	strong
PWO	8.2	~3/<40	26/4	No	strong
GSO(Ce)	6.71	30~60	18	No	strong
$LaBr_3$(Ce)	5.3	20	160	strong	strong

$LaBr_3(Ce)$ scintillator

- **Excellent energy resolution**
  : ~3% @ 662keV (FWHM)
  : ~1.5% @ 2615keV (FWHM)
- **High light yield**
  : 160 NaI% @ Ce 5%mol
  [cf. GSO(Ce) : 20 NaI%]
  temp. dependency: 0.01%/deg.
- **Fast decay time**
  : ~20 nsec @ Ce 5%mol
  temp. dependency: 0.04 nsec/deg.
- **Radiation hardness**
  pulse height:
  drop ~ 8% (1kGy ^{60}Co)
- **Internal radioactivity**
  rate < 5 Hz /cc (30 – 3000 keV)
- **Hygroscopic**

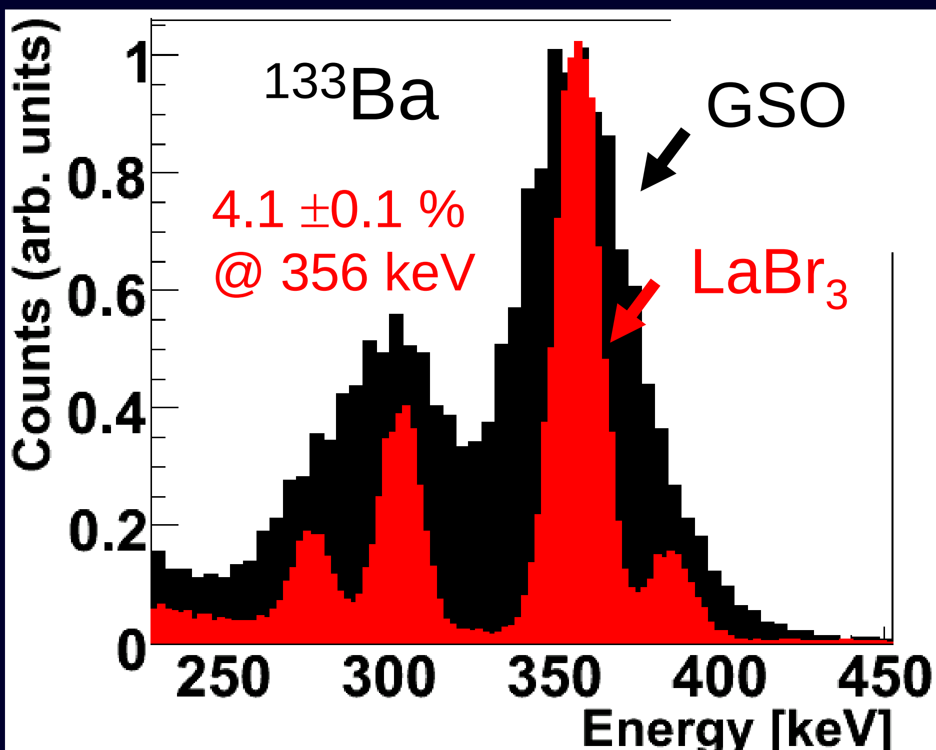


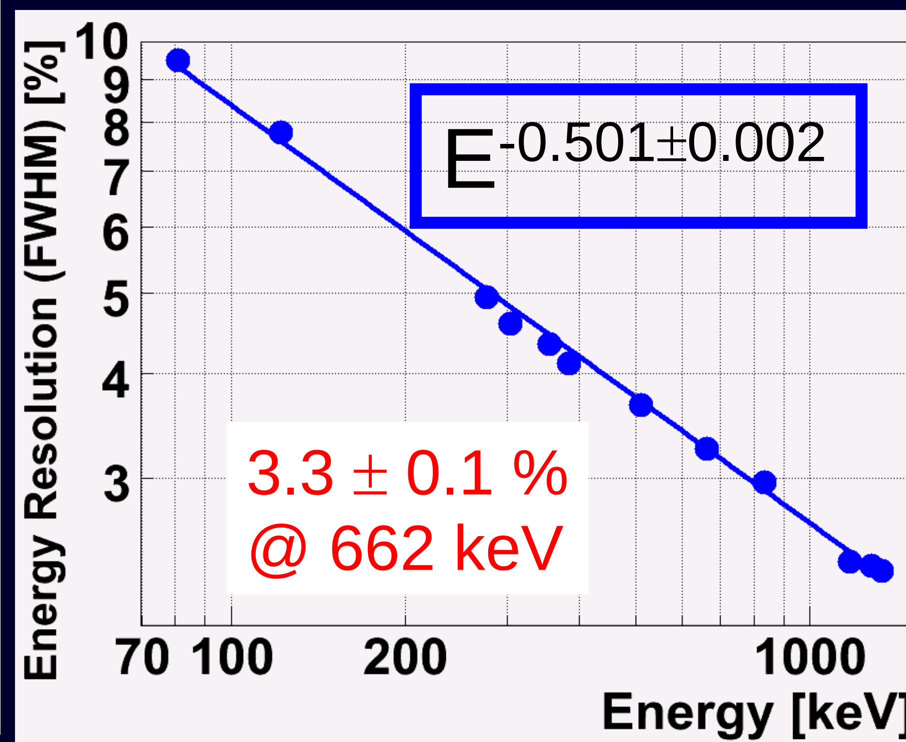
Loef *et al.*, (2000), Drozdowski *et al.* (2007)
M. Moszyńsk *et al.* (2006)

$LaBr_3$(Ce) scintillator

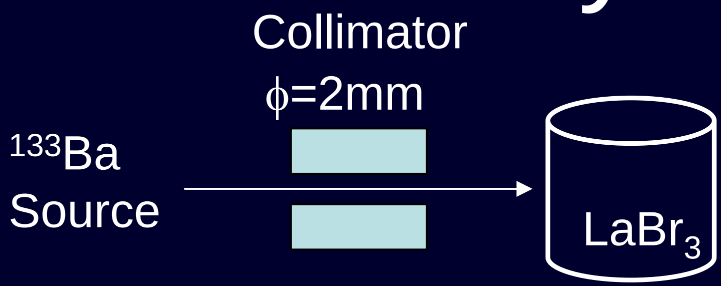
Saint-Gobain
BrilLanCe380
Size:$\phi 38\times 38mm^3$

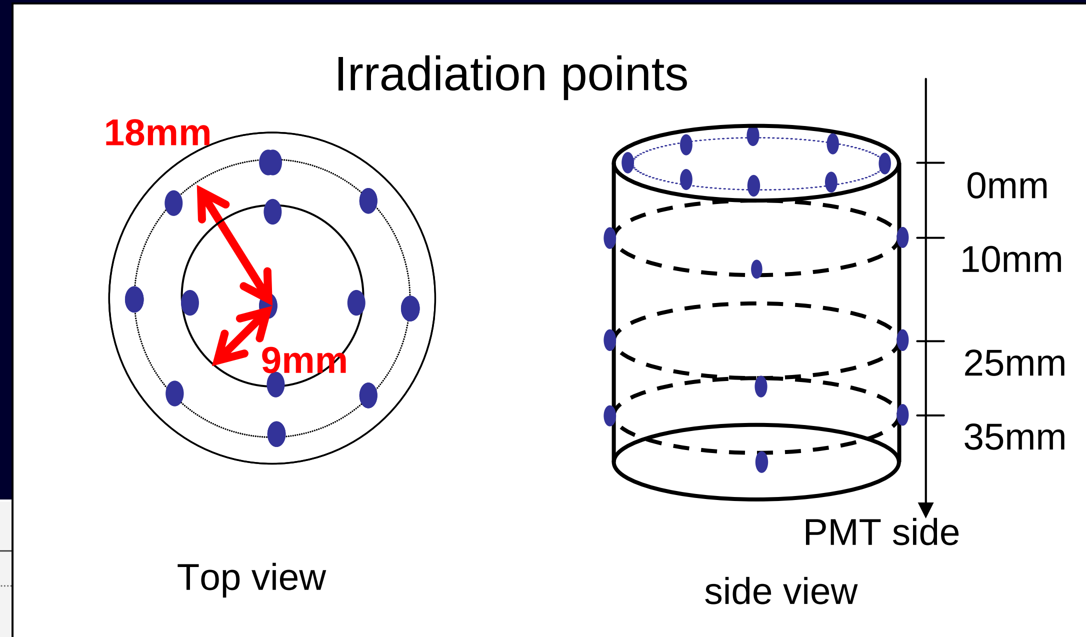
Energy resolution measured with a single-anode PMT (SAPMT) (HPK R6231)

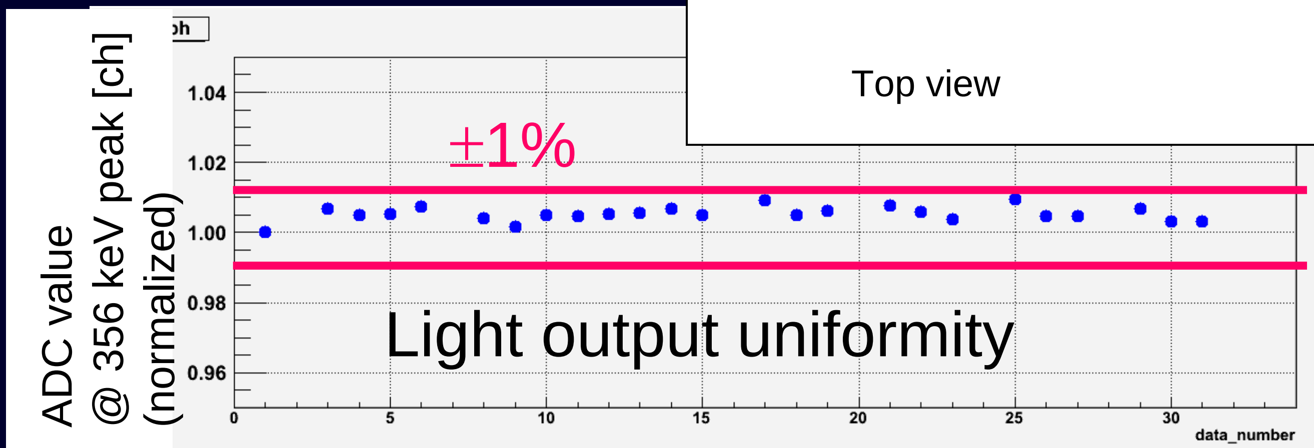




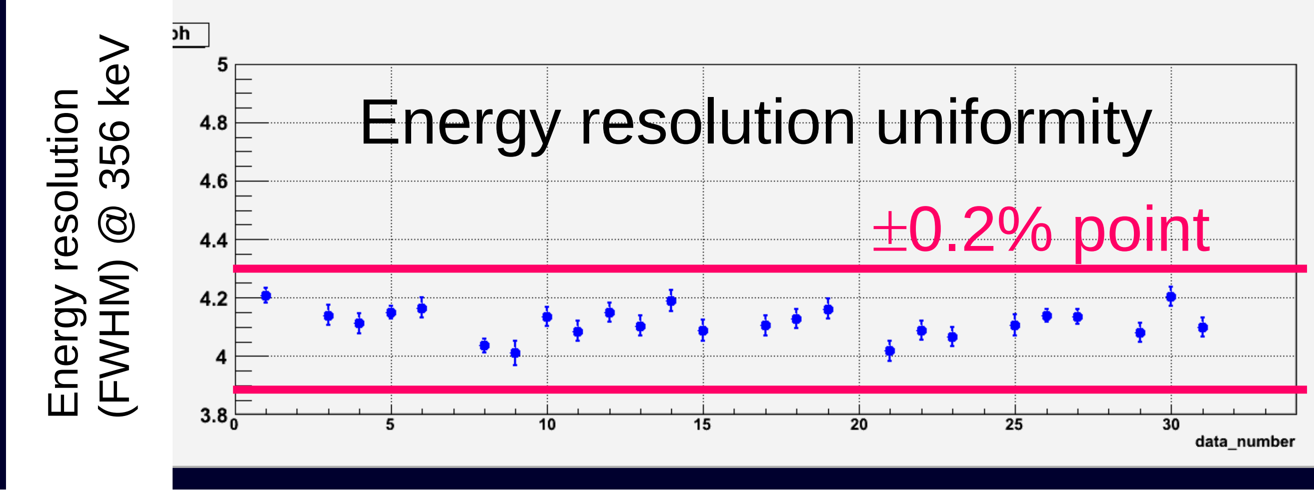
Uniformity







Ave. ± σ
1.005±0.002

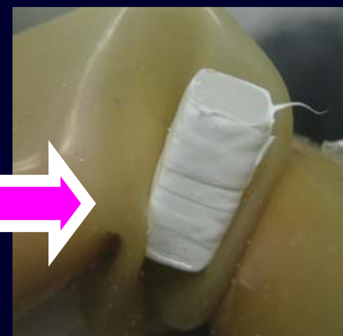


Ave. ± σ
4.11±0.05 %

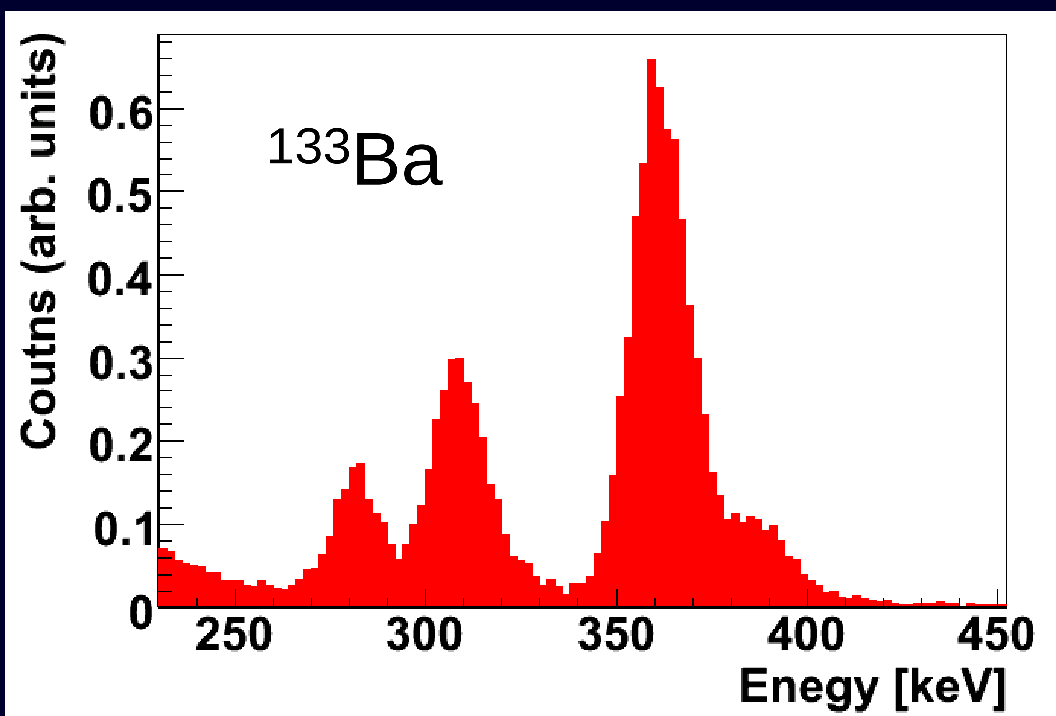
Naked $LaBr_3$ pixel

Test of our cutting & polishing technique

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



Size: $6\times 5\times 14mm^3$ pixel
glass window : none
Hermetic package : none



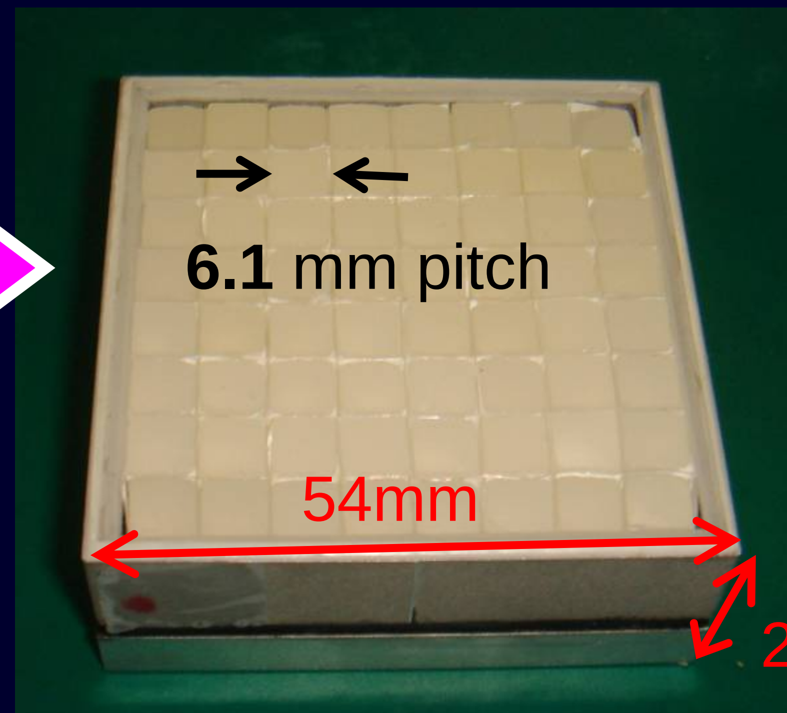
Put the crystal on
single anode PMT (R6231)
directly under the dry condition

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



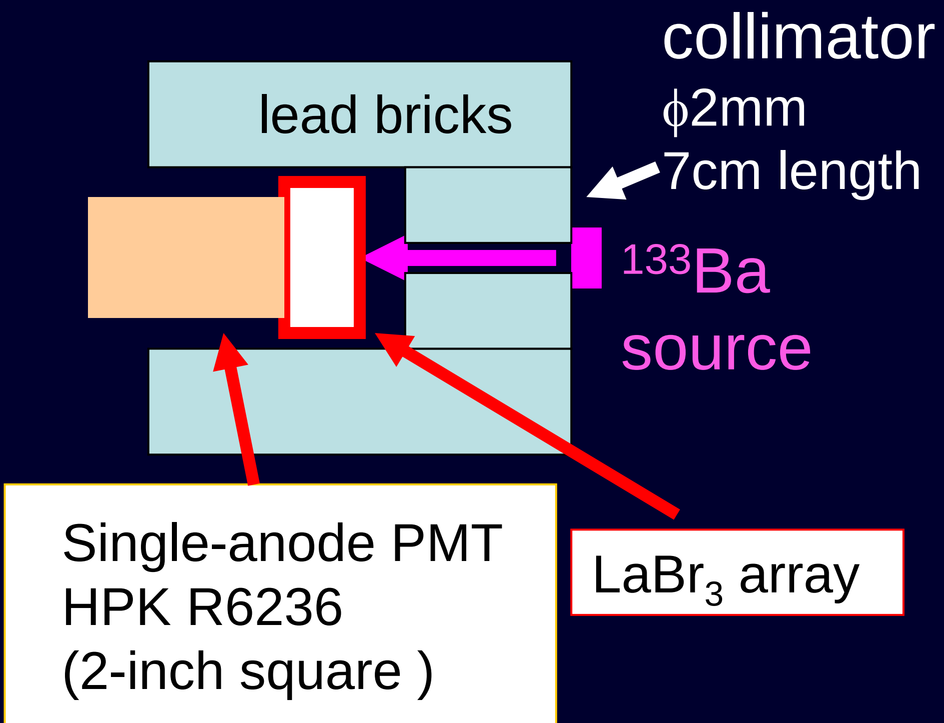
1/2 attenuation length
@662keV
$LaBr_3$ (Ce): 18 mm

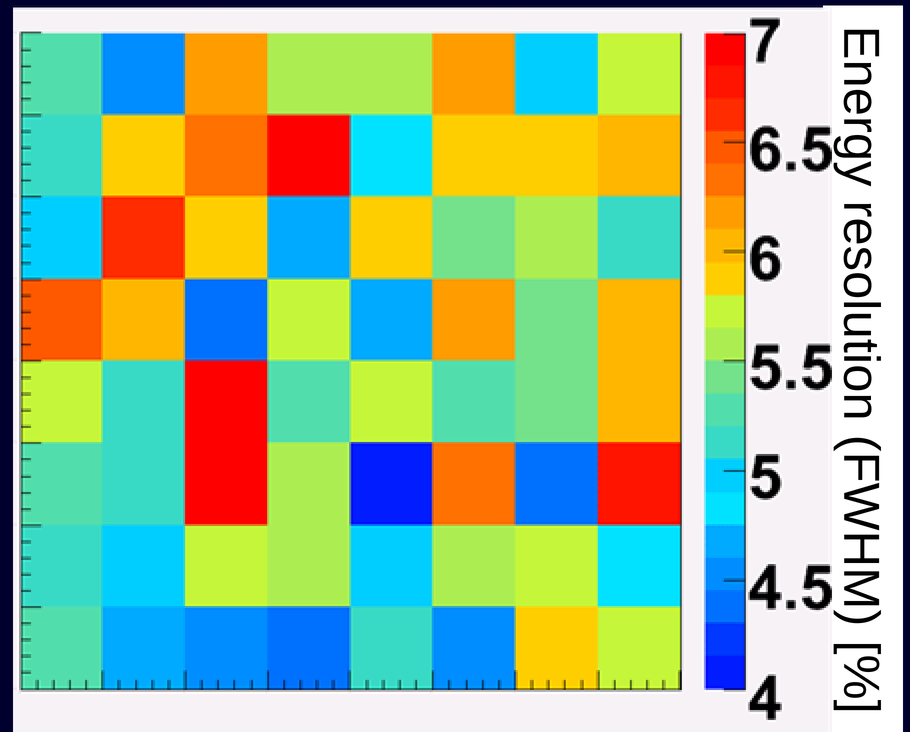
Effective area : 49 × 49 mm^2
(=PMT photocathode)
Glass window : Quartz (t 2.3 mm)
Hermetic package : Aluminum (t 0.5 mm)

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



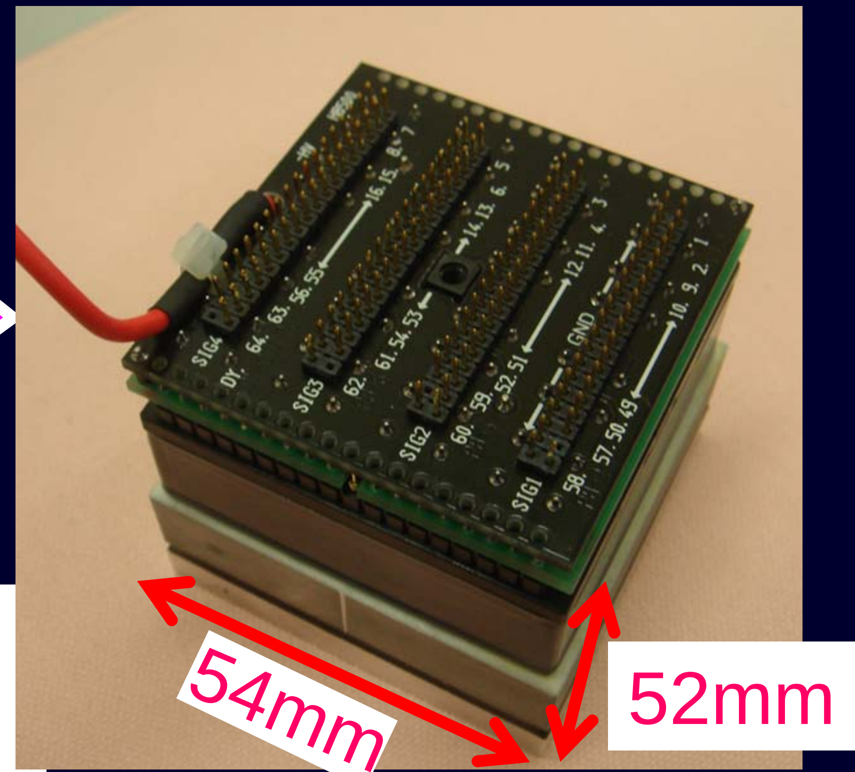


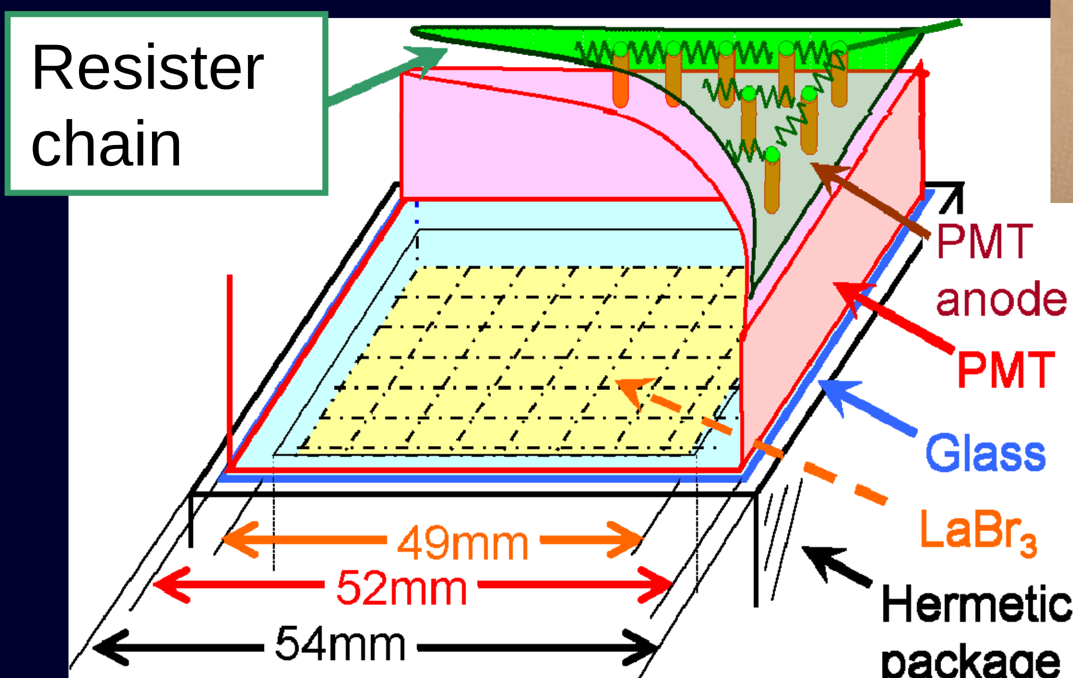
Map of energy Res. of 8 × 8 pixels

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

Readout with H8500

LaBr$_3$ array   MAPMT HPK H8500





H8500

Anode size: 6.08mm × 6.08mm

Number of Anode: 8 × 8

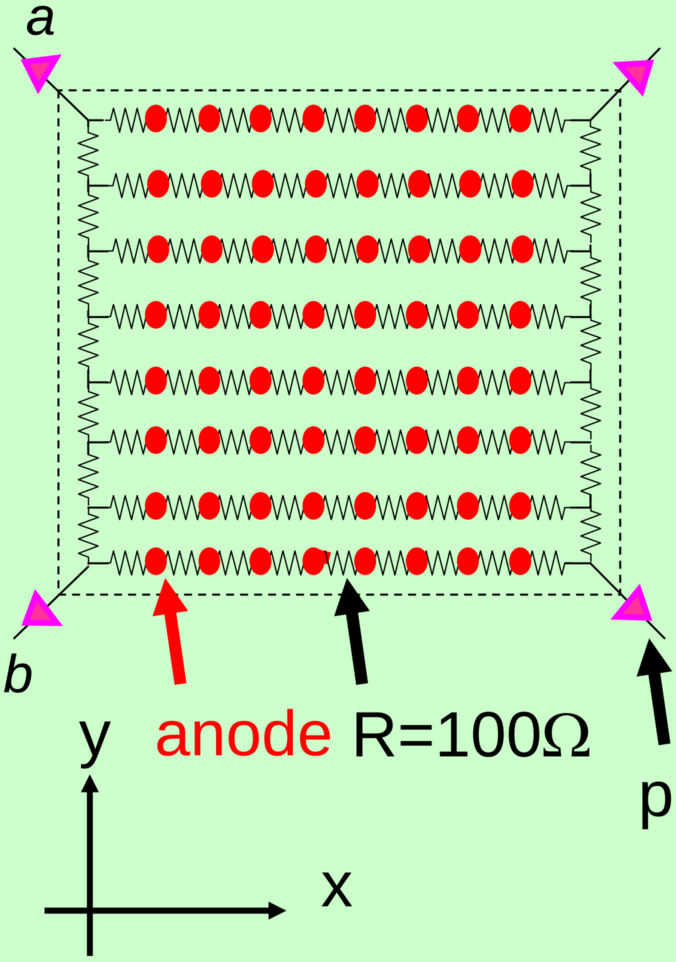
Photocathode: Bialkali

Window: Borosilicate (thickness:1.5mm)

HV: ~-800V

Readout of an array camera

4ch readout with a resister chain



64 anodes of PMT

↓

4 ch output (a, b, c, d)

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

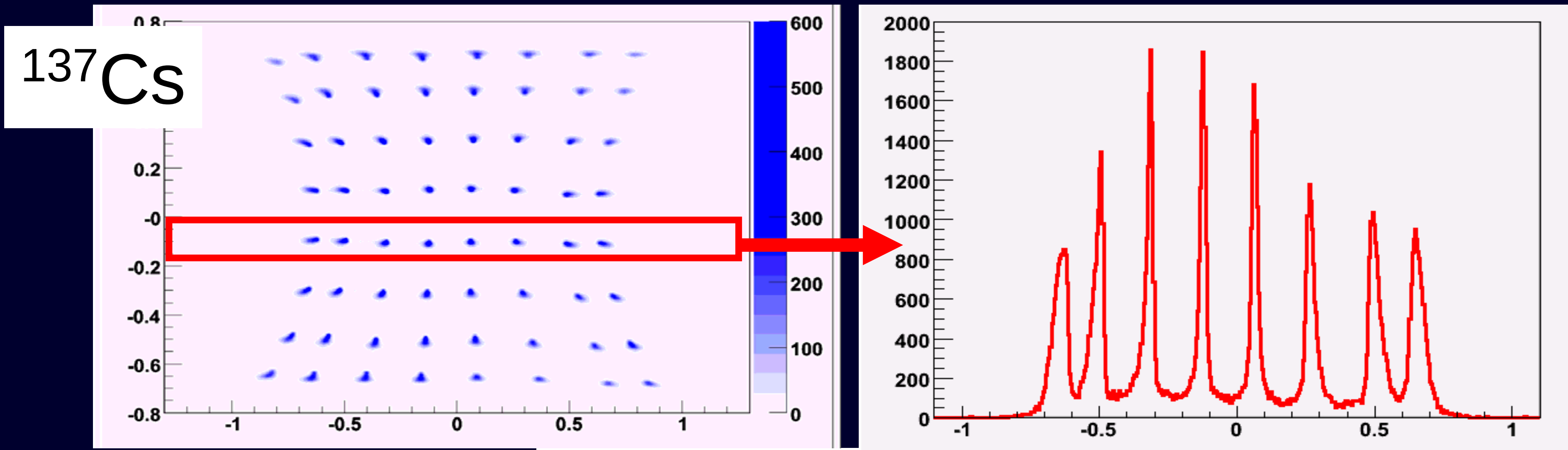
Sum

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

→ Energy

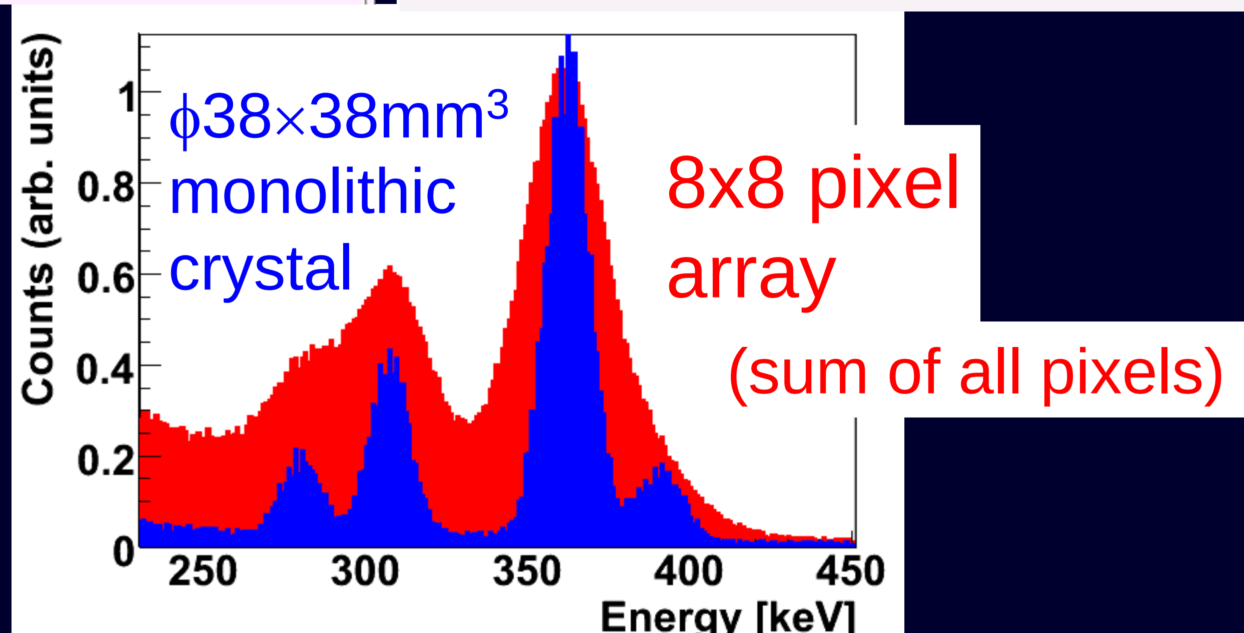
Image and energy spectrum

- ➢Flood field irradiation image

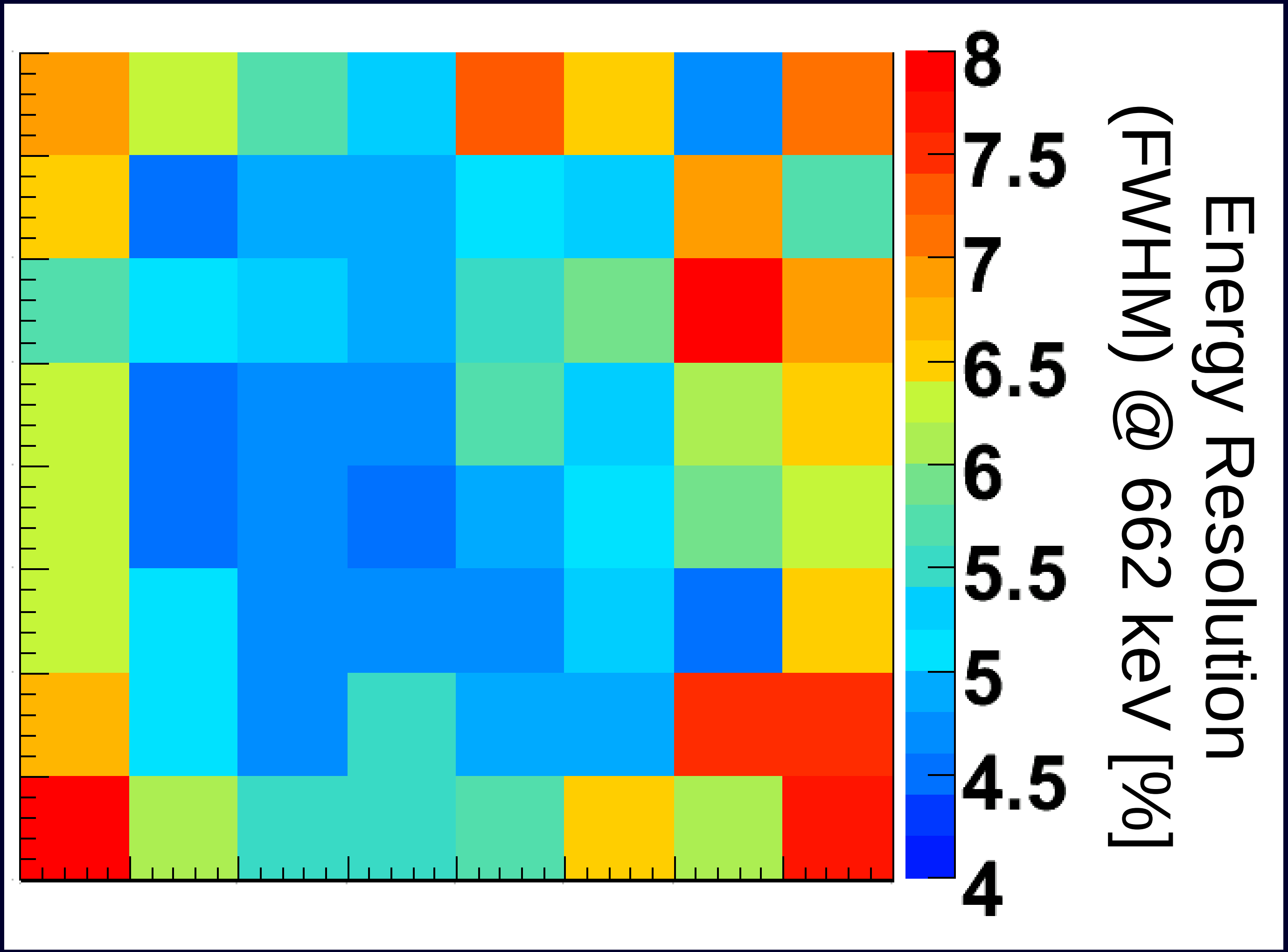


- ➢Energy spectrum (^{133}Ba)

Energy resolution of Array, (FWHM)
7.6 ± 0.4% @ 356 keV
5.7 ± 0.1% @ 662 keV



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

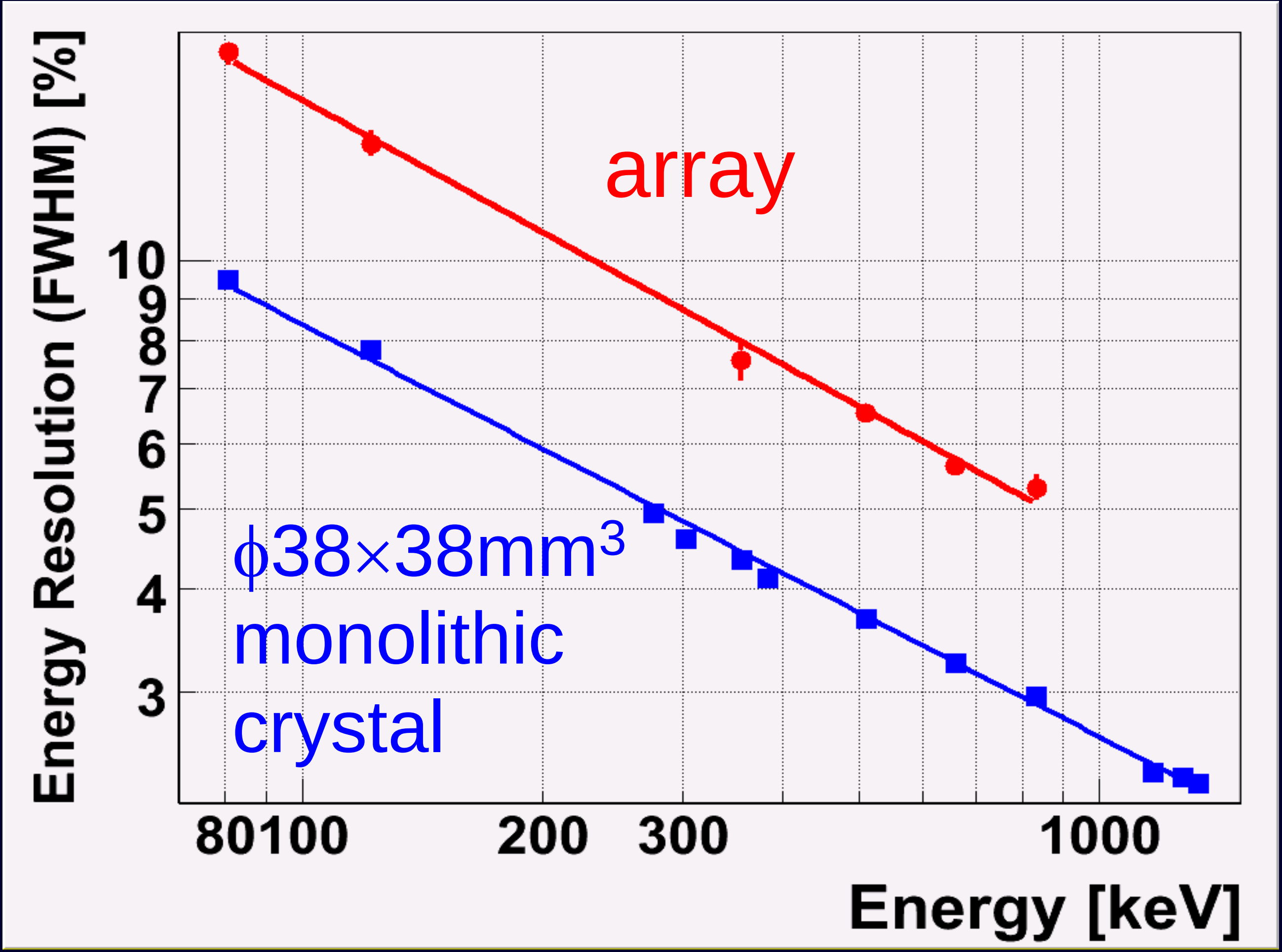


Using MAPMT H8500

Ave. ± σ : 5.8 ± 0.9%

cf.
GSO array
10.8 ± 1.0%

Energy resolution vs. energy



array:

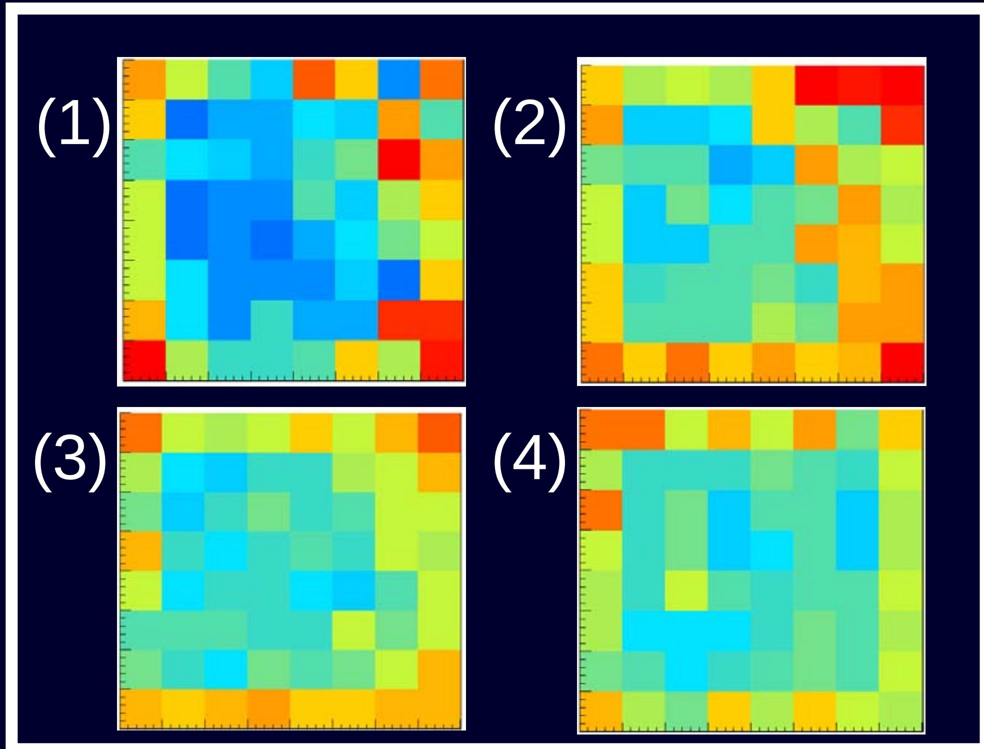
FWHM(%)=(5.7±0.4) ×(E/662keV)$^{-0.52\pm0.01}$

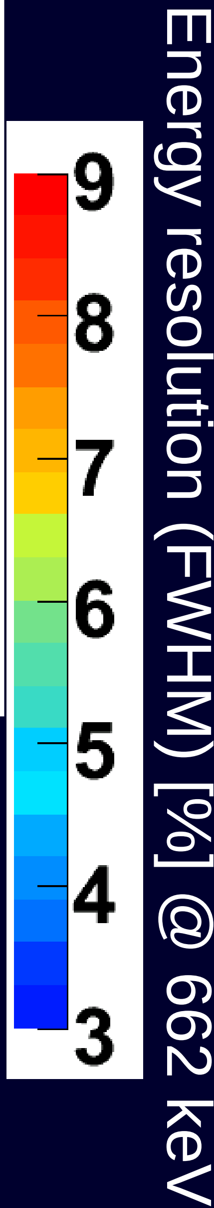
$LaBr_3$ arrays

Energy Resolution (FWHM) @ 662keV

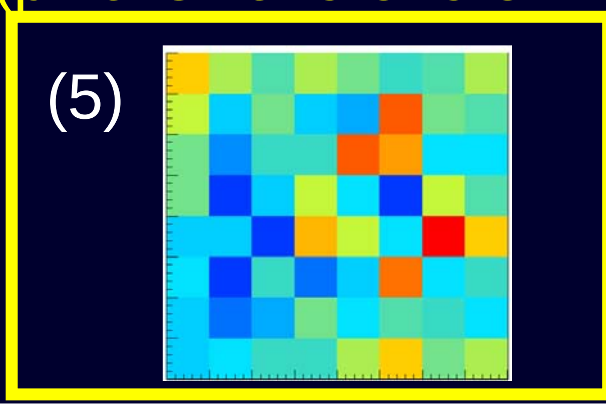
(1) 5.8 ±0.9 %
(2) 6.4 ±1.2 %
(3) 6.0 ±0.8 %
(4) 5.8 ±0.8 %
(5) 5.5 ±0.8 %

15mm-thickness array



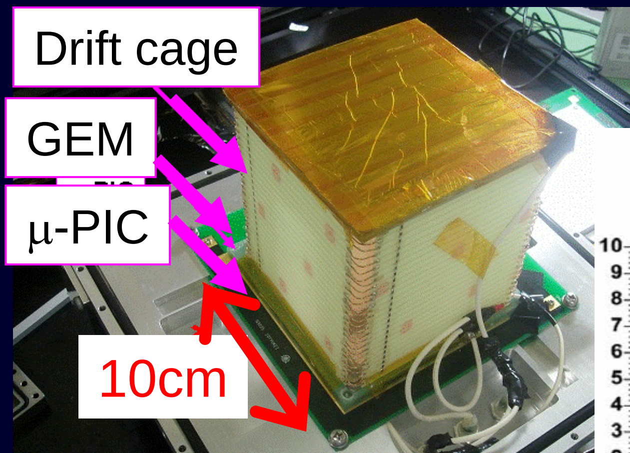


20mm-thickness array
(pixel size: 5.8×5.8×20.0mm^3)

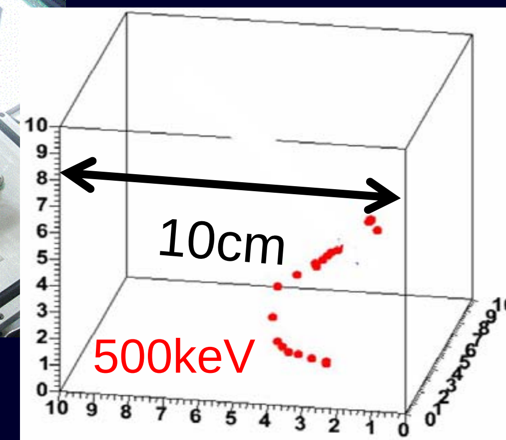


Gaseous TPC

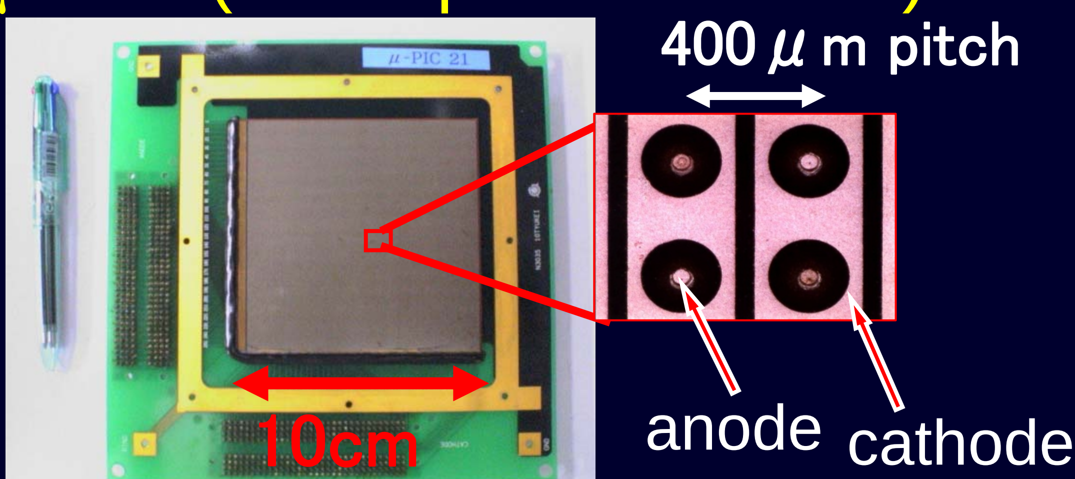
Size: 10 × 10 × 10 cm^3
Gas : Ar+C_2H_6 1atm
Drift: FPGA 100MHz clock
Gain: ~30,000 (GEM gain : ~10)
Position Resolution (FWHM):
drift direction ~ 0.6 mm
horizontal plane ~ 0.4 mm



3-D electron tracking

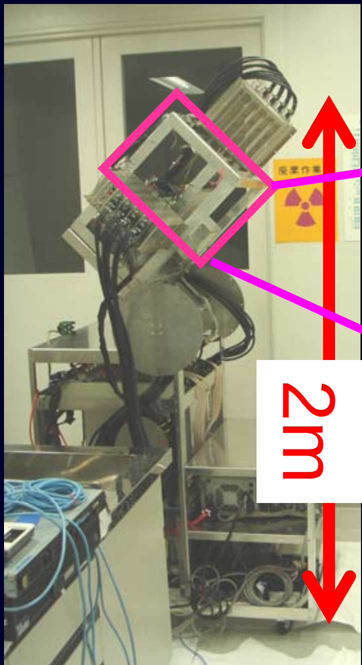


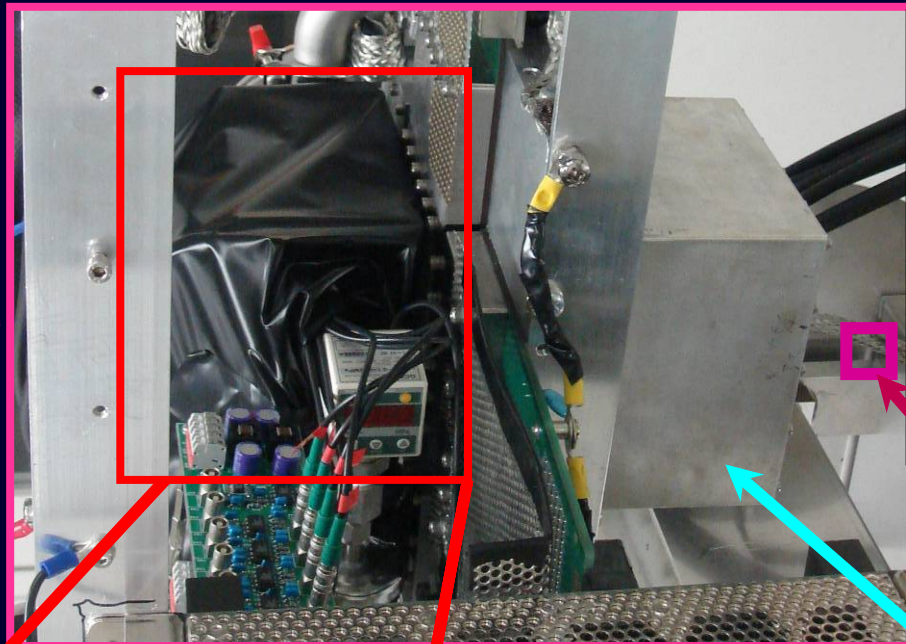
μ-PIC (micro pixel chamber)

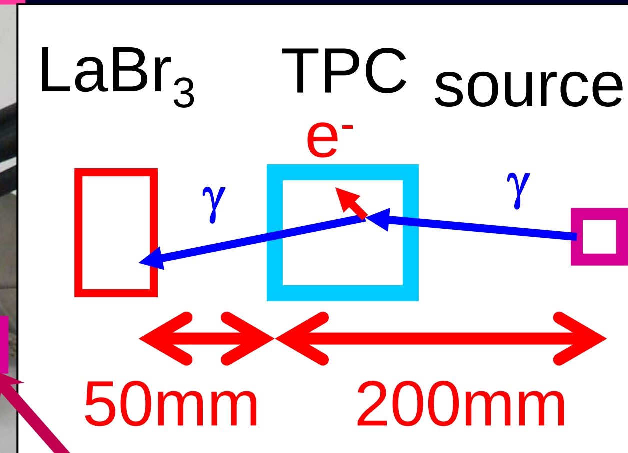


- 2-D gaseous detector
- Size: 10 cm x 10 cm
  ~ 65,000 pixels
- Gas gain: < ~6,000
  (stable driving
  more than 1 month)

Setup of a Compton camera

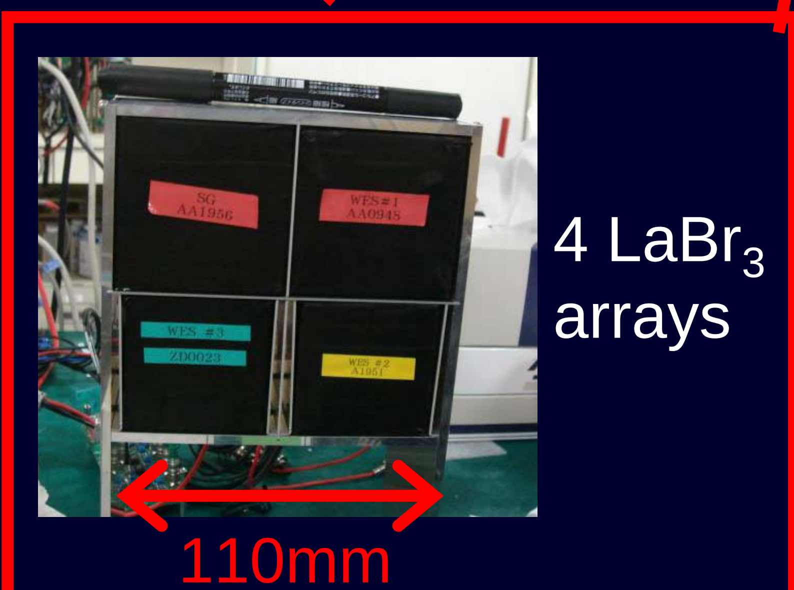






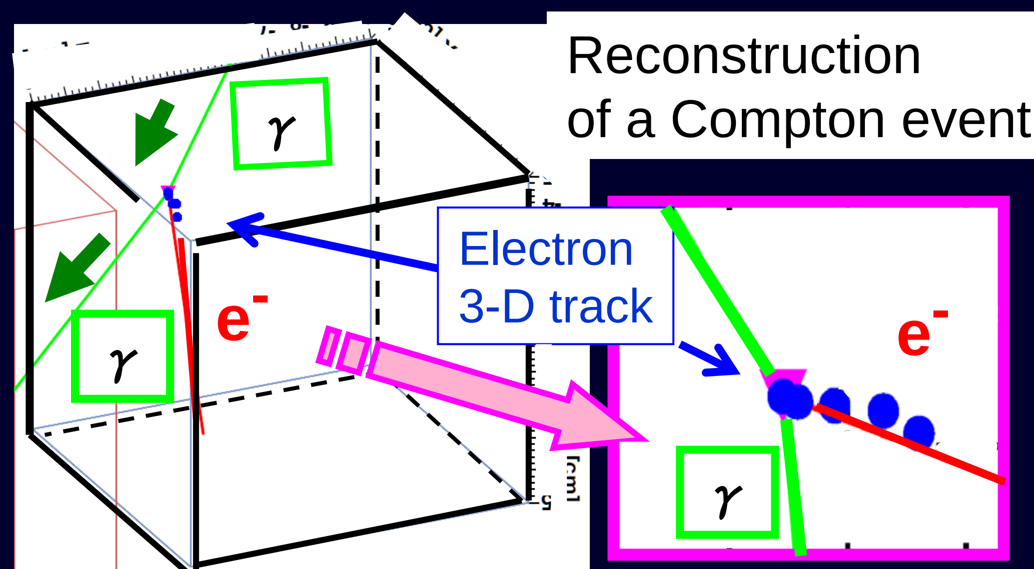
Source

Gaseous TPC



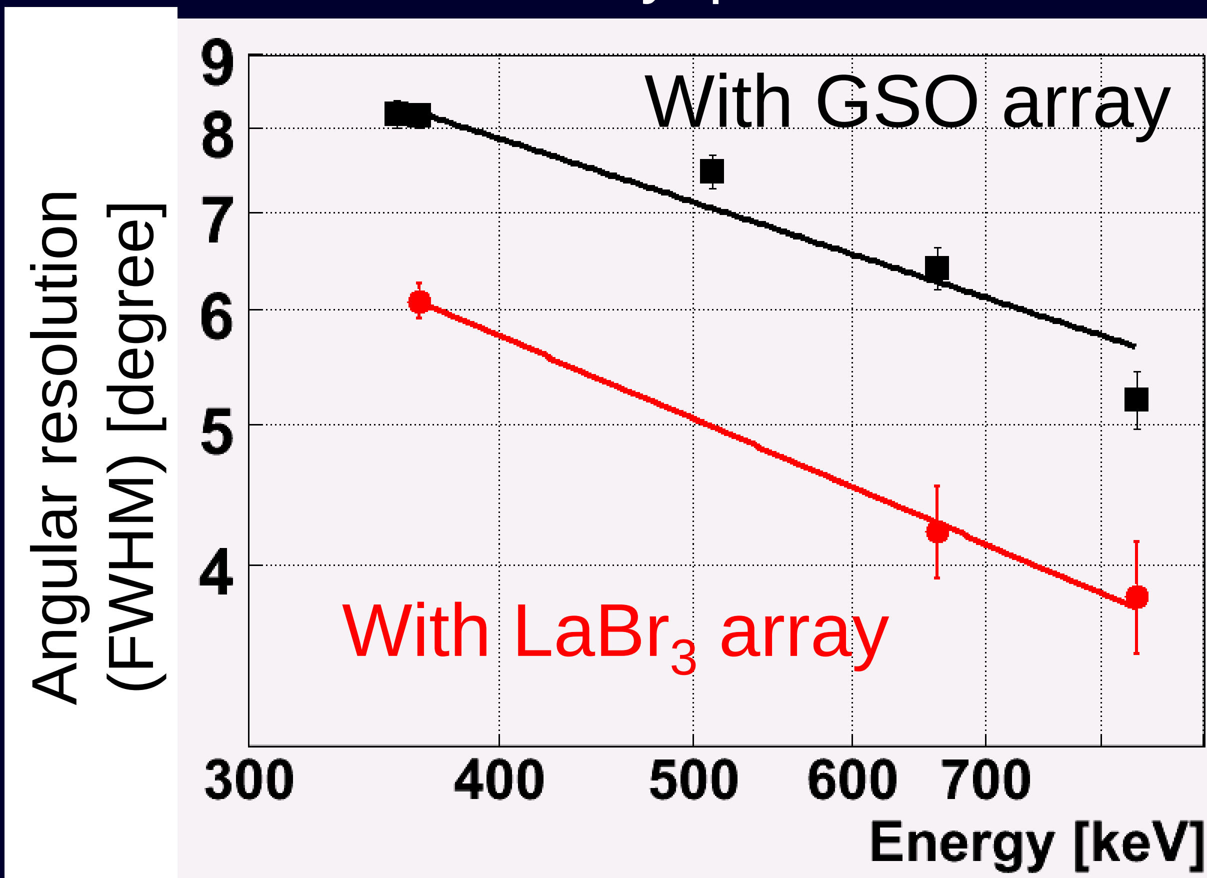
4 $LaBr_3$ arrays

Reconstruction of a Compton event



Angular resolution

Measured by point sources

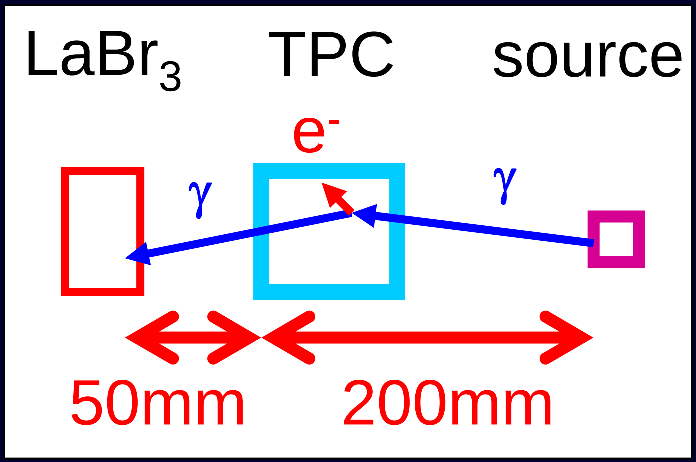


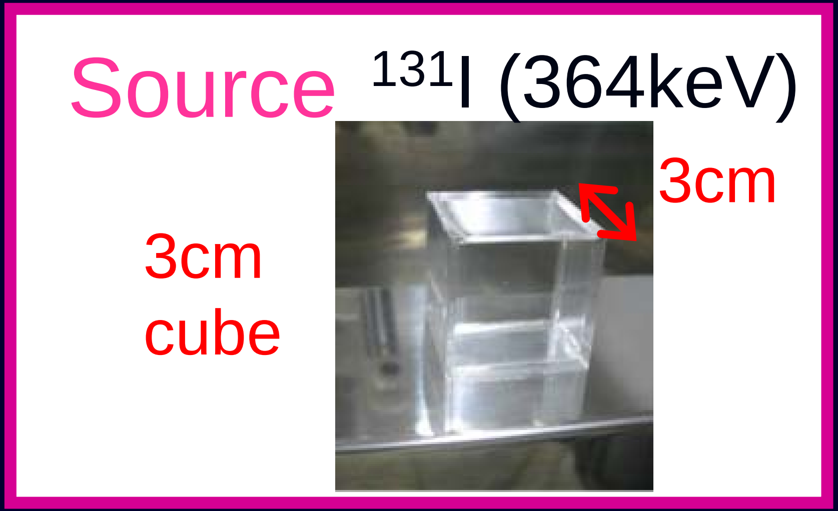
Angular resolution (FWHM) @662 keV

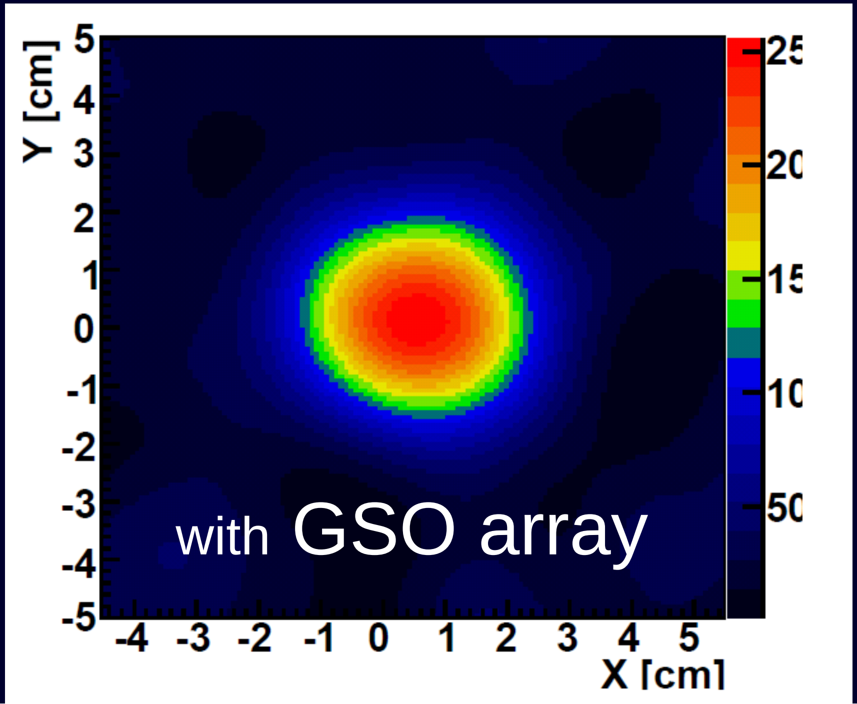
4.2±0.3° (LaBr$_3$)

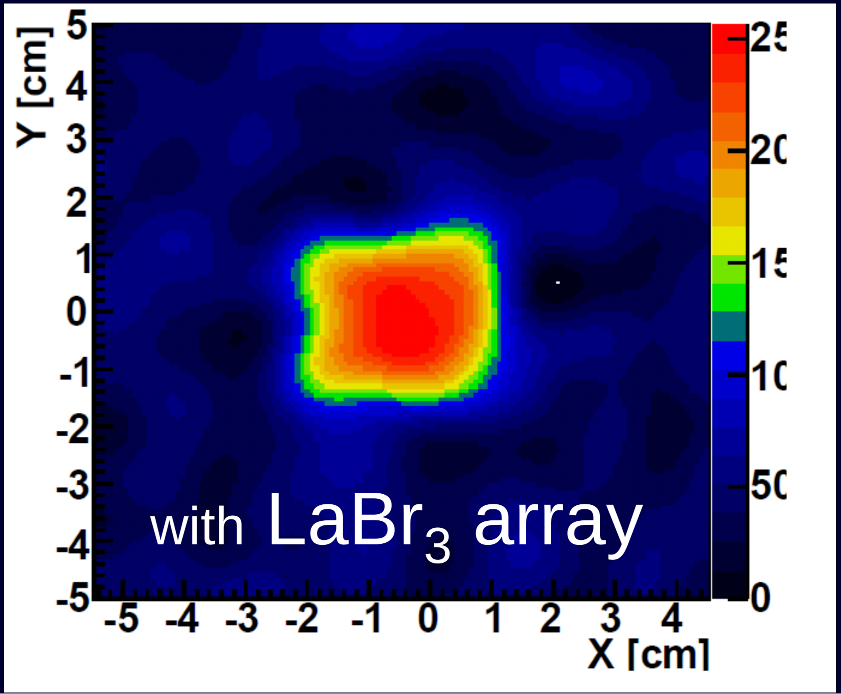
6.4 ± 0.2° (GSO)

Performance of a Compton camera









summary

- In order to improve the angular resolution of Compton Camera, we assembled an 8×8 $LaBr_3$ pixel array.
  - Pixel size : 5.8 ×5.8 ×15 mm^3
  - Pixel pitch: 6.1mm (the same as that of MAPMT H8500)
  - Package size : 54 ×54 ×20 mm^3
- Dynamic range: 80 – 1000 keV
- 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 gamma camera (FWHM, @ 662 keV)
  - With $LaBr_3$ array 4.2±0.3 deg.
  - With GSO array 6.4±0.2 deg.
- Future work
  - $LaBr_3$ array: Individual readout system for each anode channel.
  - TPC: Improve accuracy of electron tracking (cf. Hattori's poster id=85)


Thank you
for your attention