Development of an $8 \times 8$ array of LaBr$_3$(Ce) pixels with a multi-anode PMT for a gaseous Compton gamma-ray camera

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Compton gamma camera

This Camera is for Astronomy, medical imaging.

- **gaseous TPC**
  - (time projection chamber):
  - [containing $\mu$-PIC(MPGD), GEM]
  - --- energy and 3-D track of a recoil electron

- **Scintillation camera**:
  - [GSO (Ce) pixel array]
  - --- energy and position of a scattered gamma ray

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

Reconstruct an incident gamma ray event by event
**Scintillator array camera**

8 × 8 multi-anode PMT (MAPMT) HPK H8500

- **size:** 52 × 52 mm²
- **effective area:** 49 × 49 mm²
- **anode pitch:** 6.1 mm

GSO array (8 × 8 pixels)

- **effective area:** 49 × 49 mm²
- **pixel size:** 5.8 × 5.8 × 13 mm²
- **anode pitch:** 6.1 mm
- **reflector:** ESR© (3M)

(GSO has a strong radiation hardness)

4ch readout with a resister chain

- preAMP.
- Resistor chain All 100Ω
- 64 anodes of PMT
- 4 ch output

Charge-division method

- X, Y position
- Sum

Energy resolution (FWHM)

10.7 ± 1.0 % @ 662 keV
Improvement of Angular Resolution

Now: Angular resolution (FWHM): 6.4° @ 662keV

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

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

Sci. Ener. Res. @662keV
Com. Angular Res. @662keV
- 10.5%: 4.2°
- 7%: 3.1°
- 5%: 2.3°
- 3%: 2.1°

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

Calculation assuming
1, no error of position of Compton point
2, energy Res. of TPC: 30% @ 22 keV
LaBr₃(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: φ38×38mm³

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

\[
E^{-0.501 \pm 0.002}
\]

\[
3.3 \pm 0.1 \%
\]

@ 662 keV
Assembly of LaBr₃(Ce) array

We cut $5.8 \times 5.8 \times 15.0 \text{mm}^3$ pixels out of two $\phi 38 \times 38 \text{ mm}^3$ LaBr₃ crystals and assembled an $8 \times 8$ array by our technique.

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

1/2 attenuation length
@662keV
LaBr₃ (Ce): 18 mm

Effective area: $49 \times 49 \text{ mm}^2$
 (=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 MAPMT (H8500)

irradiation of collimated gamma rays to a pixel one by one

Energy resolution (FWHM) @ 356 keV
Ave. ± RMS = 5.5 ± 0.7 %
4ch readout with H8500

LaBr$_3$ array  MAPMT HPK H8500

Reading system is the one for the GSO array
Image and energy spectrum

- Flood field irradiation image by Charge-division method

\[ \begin{array}{c}
\text{Energy spectrum} \\
(\text{sum of all pixels})
\end{array} \]

\[ \begin{array}{c}
\phi_{38 \times 38 \text{mm}^3} \\
\text{monolithic crystal}
\end{array} \]

8x8 pixel array
(sum of all pixels)
Energy resolution (FWHM) of each pixel @ 662 keV (137Cs)

GSO
6×6×13 mm³ 8×8 array
Ave. ± RMS :
10.8 ± 1.0%

LaBr₃
6×6×15 mm³ 8×8 array
Ave. ± RMS :
5.8 ± 0.9%
Energy Resolution (2)

Improved by factor ~2

Worsened by factor ~2

LaBr₃ array

GSO array

LaBr₃ crystal

LaBr₃

6×6×13 mm³ 8×8 array:

FWHM(%) = (10.4±0.3) × (E/662keV)⁻⁰.⁵¹±₀.⁰¹

LaBr₃

6×6×15 mm³ 8×8 array:

FWHM(%) = (5.7±0.4) × (E/662keV)⁻⁰.⁵₃±₀.⁰₁
Setup of Compton camera

(8 × 8 LaBr₃ pixels) 2 × 2

110mm

LaBr₃ TPC source

50mm 200mm

Gaseous TPC containing Ar+C₂H₆ 1atm

Drift cage

GEM μ-PIC

10cm

3-D electron tracking

10cm

500keV
Performance of Compton camera

LaBr₃ TPC source

Source $^{131}$I (364keV)

3cm cube

with LaBr₃ array

with GSO array
Improvement of the angular resolution

Angular resolution (FWHM) @662 keV [degree]

With GSO array: 6.4 ± 0.2 (GSO)
With LaBr₃ array: improved 4.2 ± 0.3 (LaBr₃)
• We assembled an $8 \times 8$ LaBr$_3$ pixel array in order to improve the angular resolution of Compton Camera.
  – Pixel size: $5.8 \times 5.8 \times 15$ mm$^3$
  – Pixel pitch: 6.1 mm (the same as that of MAPMT H8500)
  – Package size: $54 \times 54 \times 20$ mm$^3$ (compact)
• Dynamic range: 80 – 1000 keV
• Energy resolution of the array with MAPMT (FWHM, @662keV)
  – GSO array 10.7 ± 1.0 %
  – LaBr$_3$ array 5.8 ± 0.9 %
• Angular resolution of gamma camera (FWHM, @ 662 keV)
  – With GSO array 6.4±0.2 deg.
  – With LaBr$_3$ array 4.2±0.3 deg. (improved)
• Future works
  – We assemble more LaBr$_3$ arrays for expanding the effective area of Compton camera.
  – Individual readout system of all anode channels.
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